PRESENTATION OUTLINE

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Devon Saunders

MECHANICAL
Daniel McGee
Brittany Notor

LIGHTING / ELECTRICAL
Kyle Houser
Keith McMullen

CONSTRUCTION
Brian Blenner
Matthew Hoerner

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High-Performance Elementary School

Reading, Pennsylvania

Team Mission Statement

"Building to Unite Us"

Project Mission Statement

"To build a stronger sense of community"

April 10, 2013

The Pennsylvania State University
Department of Architectural Engineering

ASCE Charles Pankow Foundation Student Competition

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Project Overview

Project Owner: Reading School District
Project Name: Reading Elementary School
Project Location: Intersection of 13th Street and Union Street
Reading, Pennsylvania

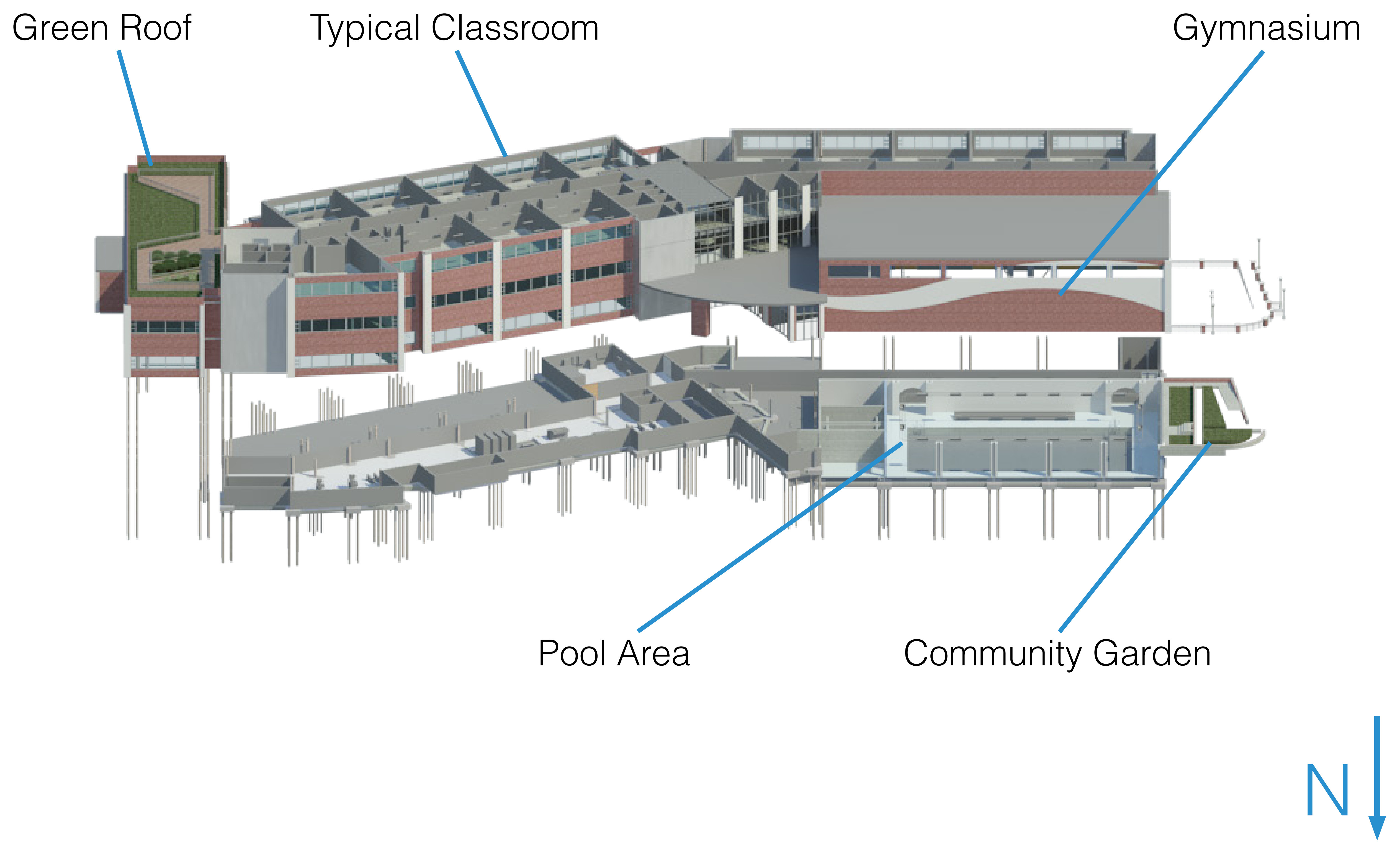
Floor Area: 108,000 SF

Overall Cost: $21,344,312
Cost per SF: $203.15

3 stories above grade, half-footprint basement level open to public

Gymnasium, health clinic and meeting room

6-lane, competition size swimming pool beneath gymnasium



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Competition Guidelines

Teams should address:

"Construction and design issues related to a high performance building that meets the needs of both the school district and community"

Charles Pankow Foundation Mission

"to advance innovations in building design and construction, so as to provide the public with buildings of improved quality, efficiency, and value"

State of the Reading Community

In 2011, *The New York Times* ranked Reading, Pennsylvania as the poorest city in the United States.

"In the middle of every difficulty lies opportunity."
Vaughn D. Spencer, Mayor of Reading

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Project Goals

1. Build a better Reading community through construction and implementation of the school program

2. Design and construct the elementary school to high-performance standards

3. Utilize an integrated design approach to maximize quality, efficiency, and value of the final built product

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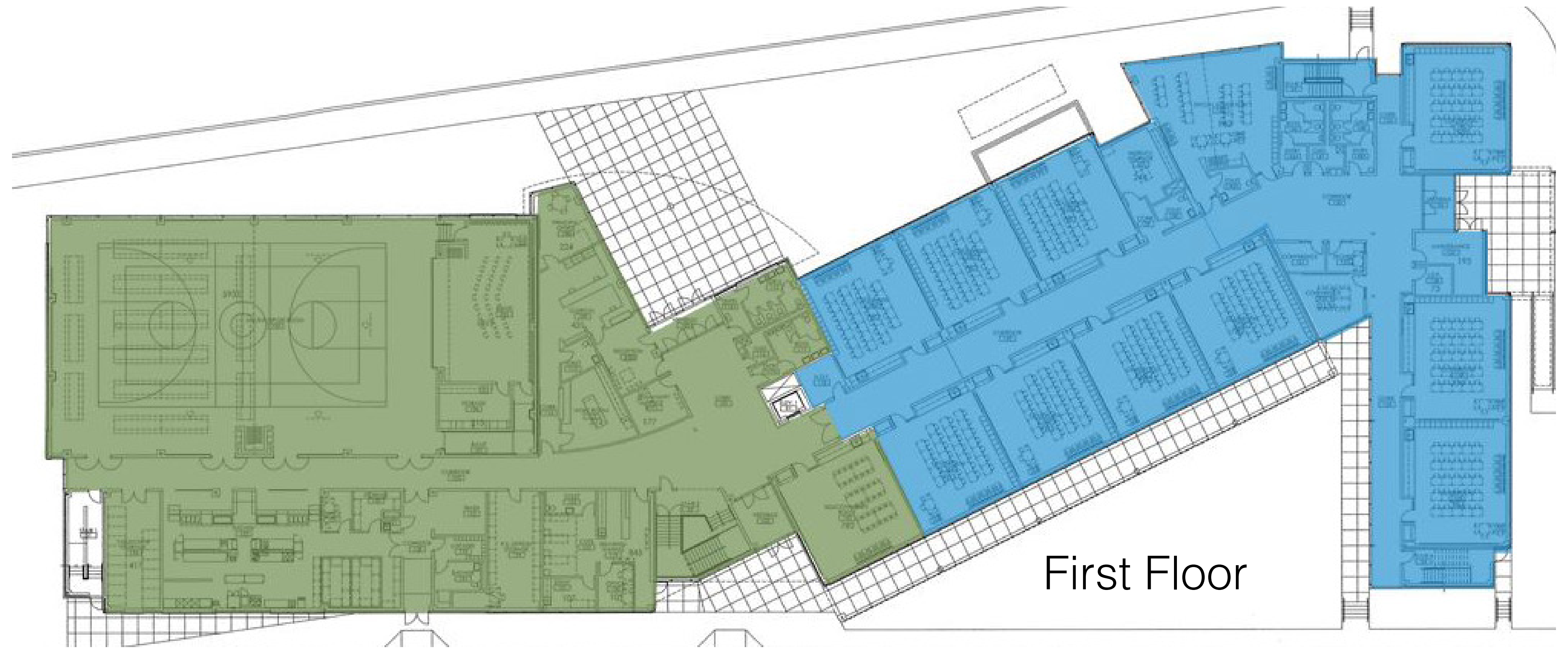
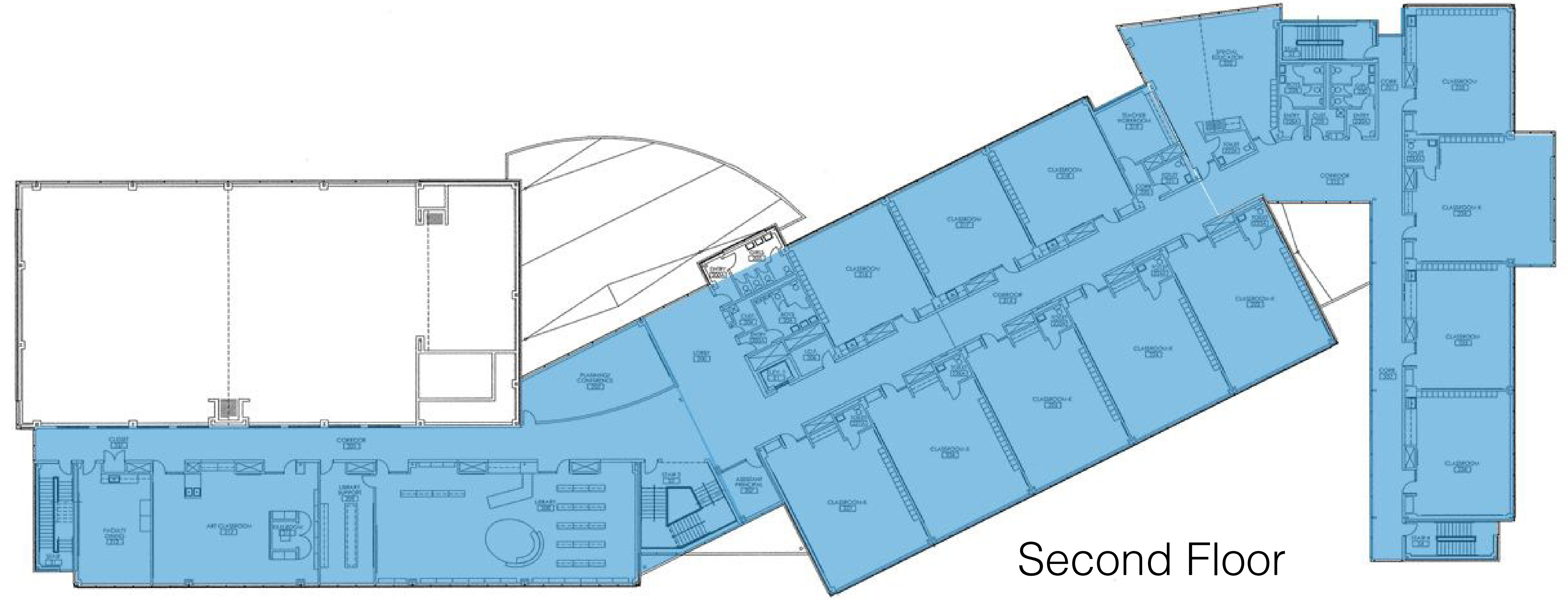




System Separation

Schedule of operations

School Year – September to June		Summer Break – July to August (And weekends during school year)	
12:00AM – 4:00AM	Health clinic only	12:00AM – 9:00AM	Health clinic only
4:00AM – 7:00AM	Use of pool for swim practice	9:00AM – 6:00PM	Pool open to public Gymnasium use for sport events PTA room use for meetings Health clinic Few summer activity camps School offices open
7:00AM – 3:00PM	Normal school hours		
3:00PM – 9:00PM	Extended "after-school" programs Pool open to public Gymnasium use for sport events Health clinic PTA room use for meetings		
9:00PM – 12:00AM	Health clinic only	6:00PM – 12:00AM	Health clinic only

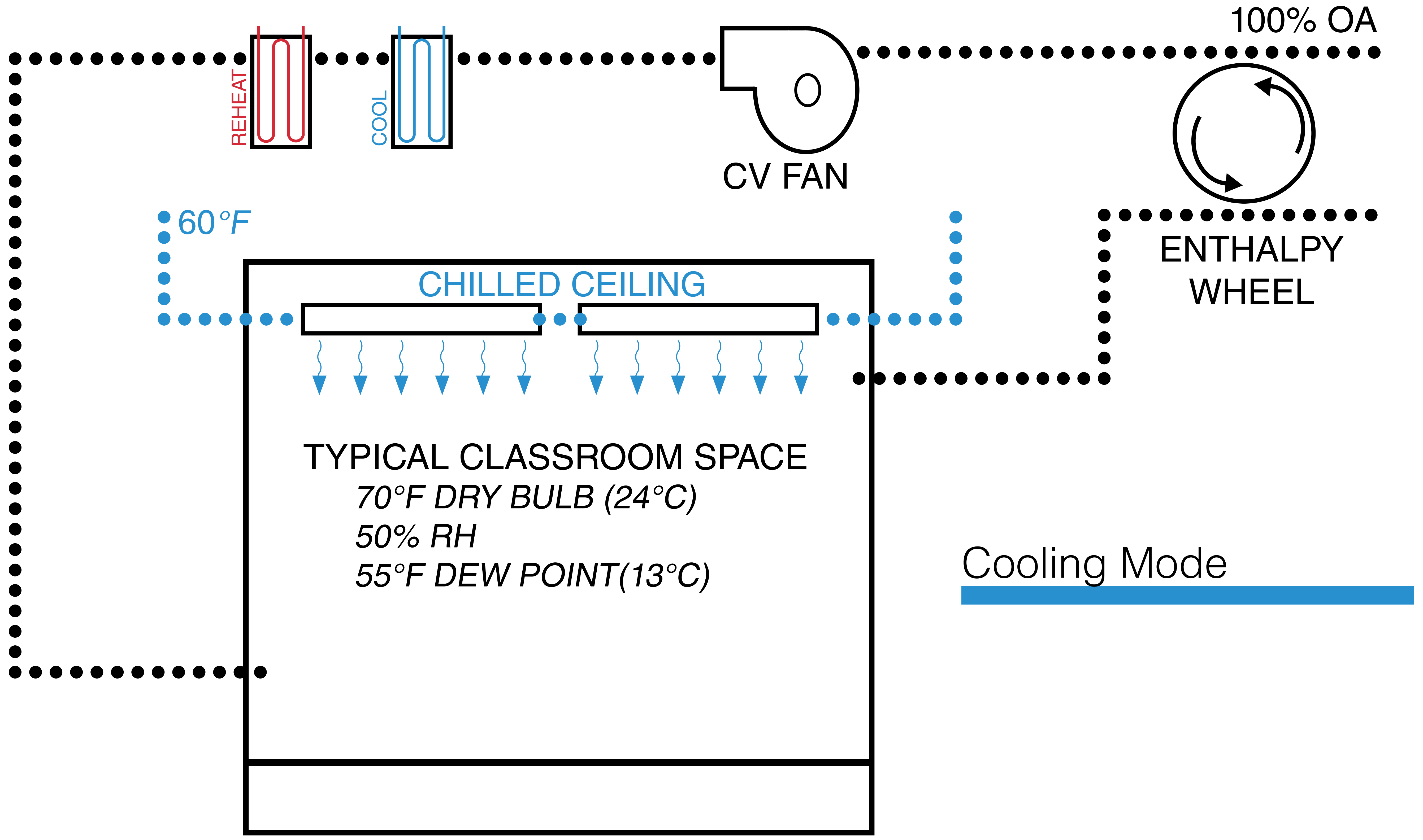
Community Section

Learning Areas / Classroom Spaces

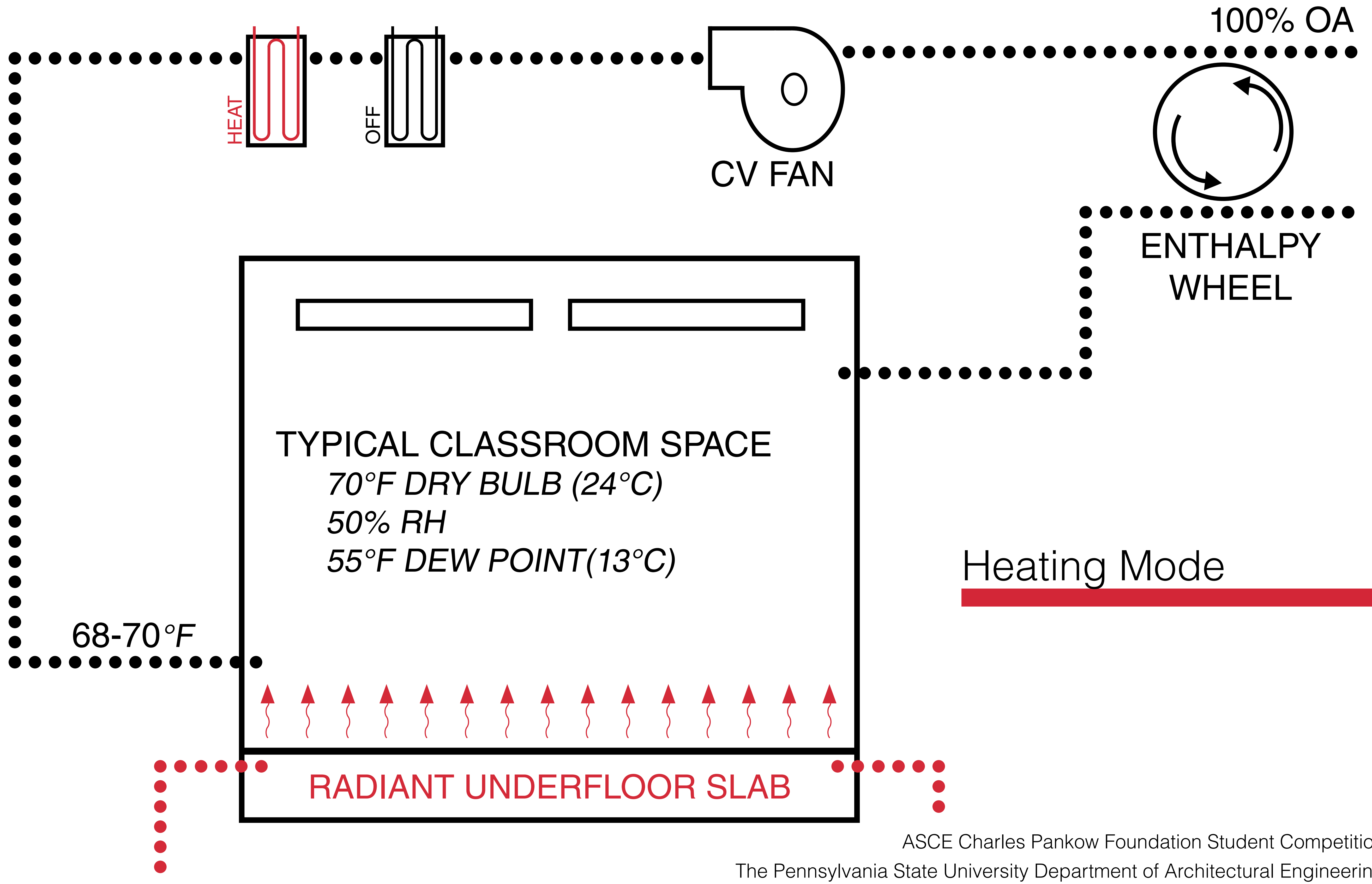
Pool

Green Roof

HVAC System Selection

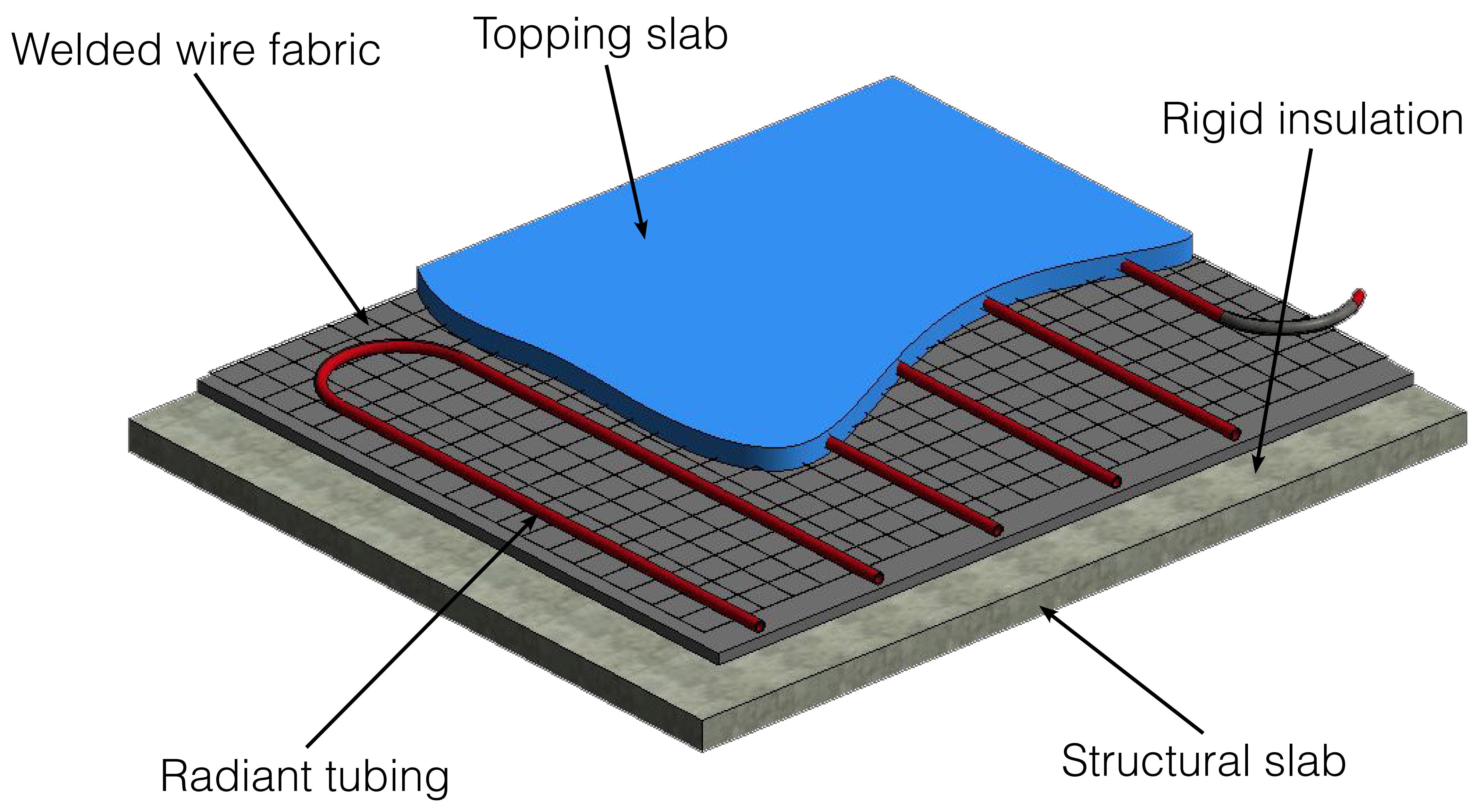


Cooling Mode

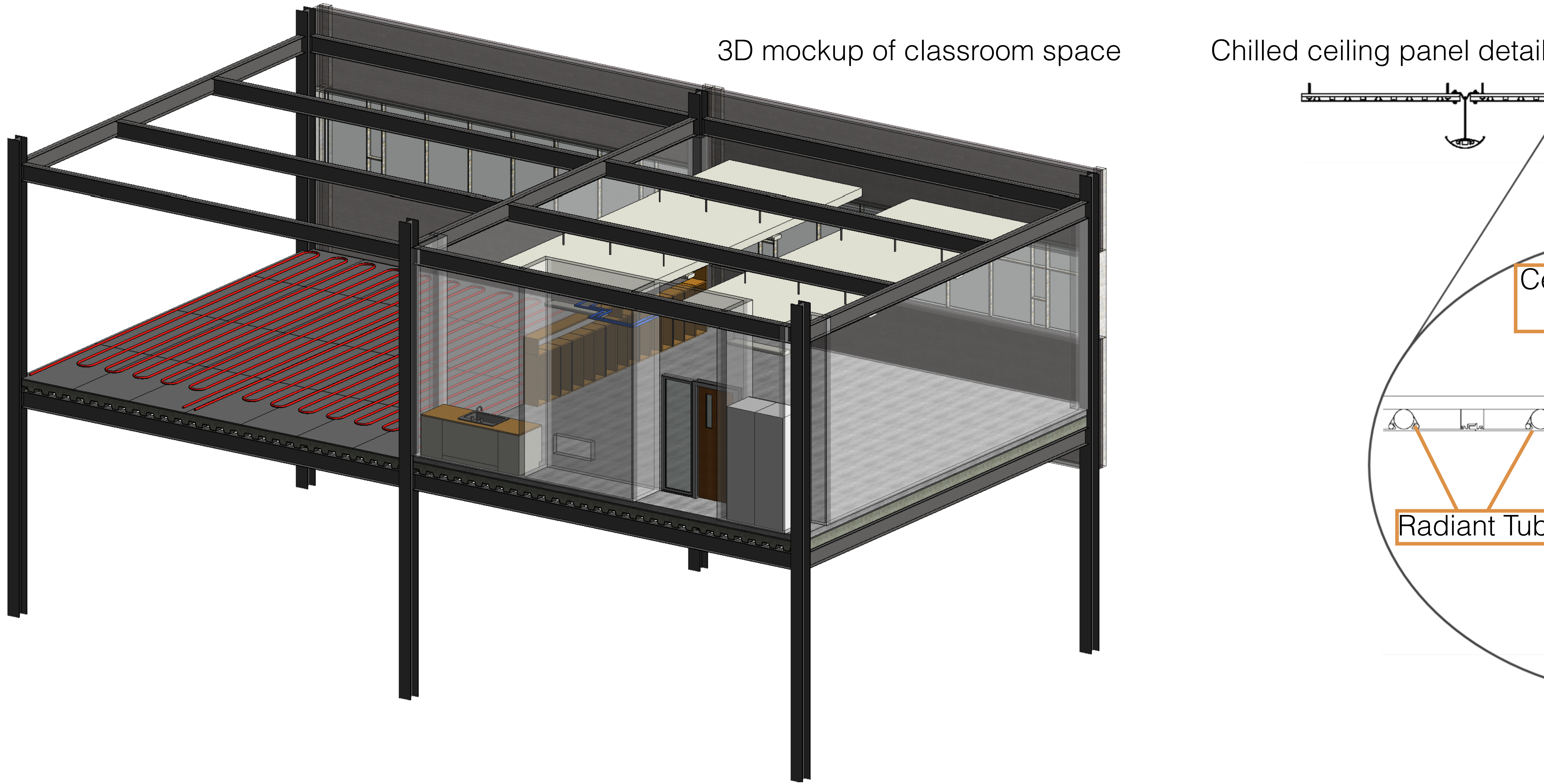


Heating Mode

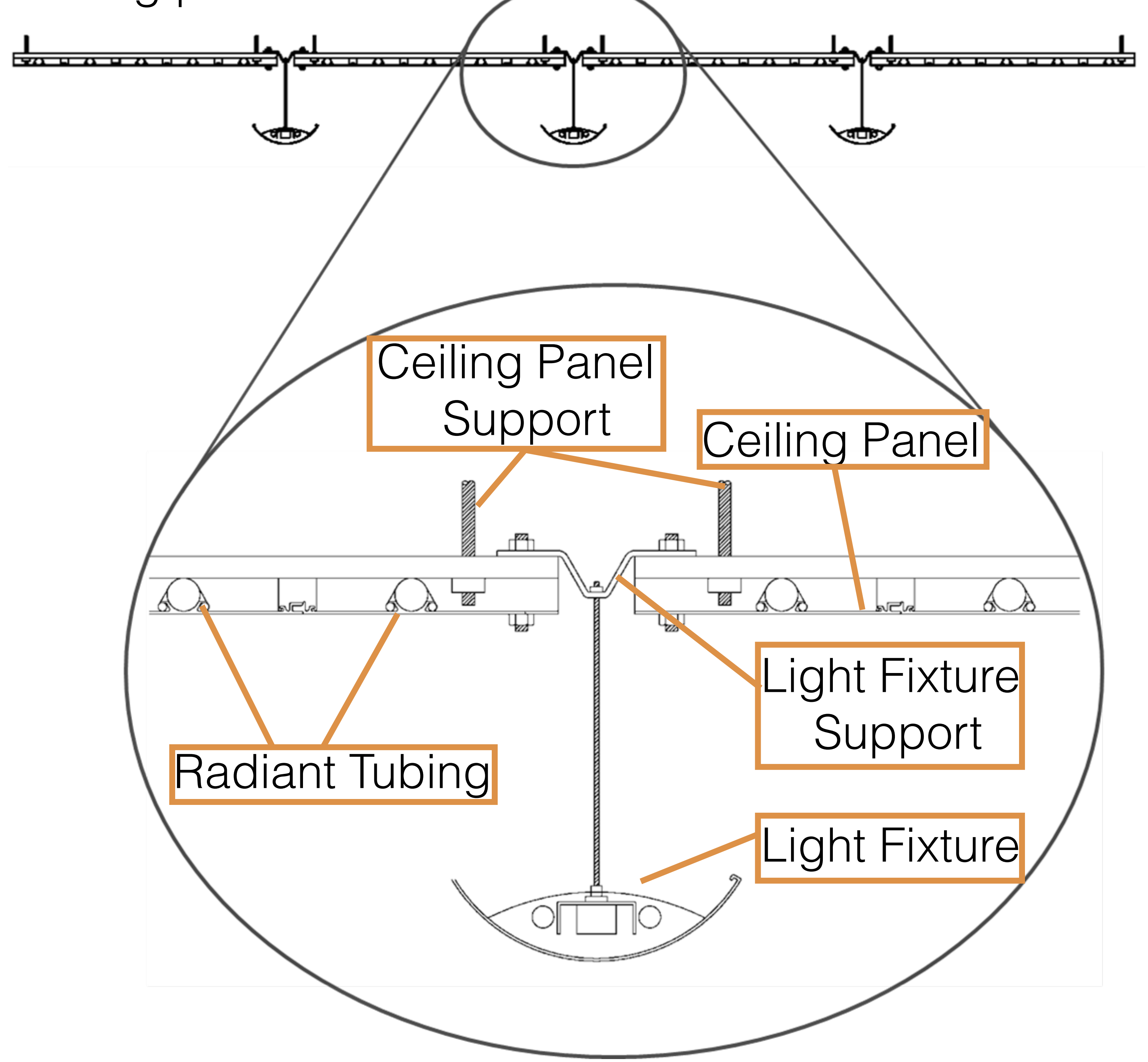
Radiant flooring constructability mockup



3D mockup of classroom space



Chilled ceiling panel detail



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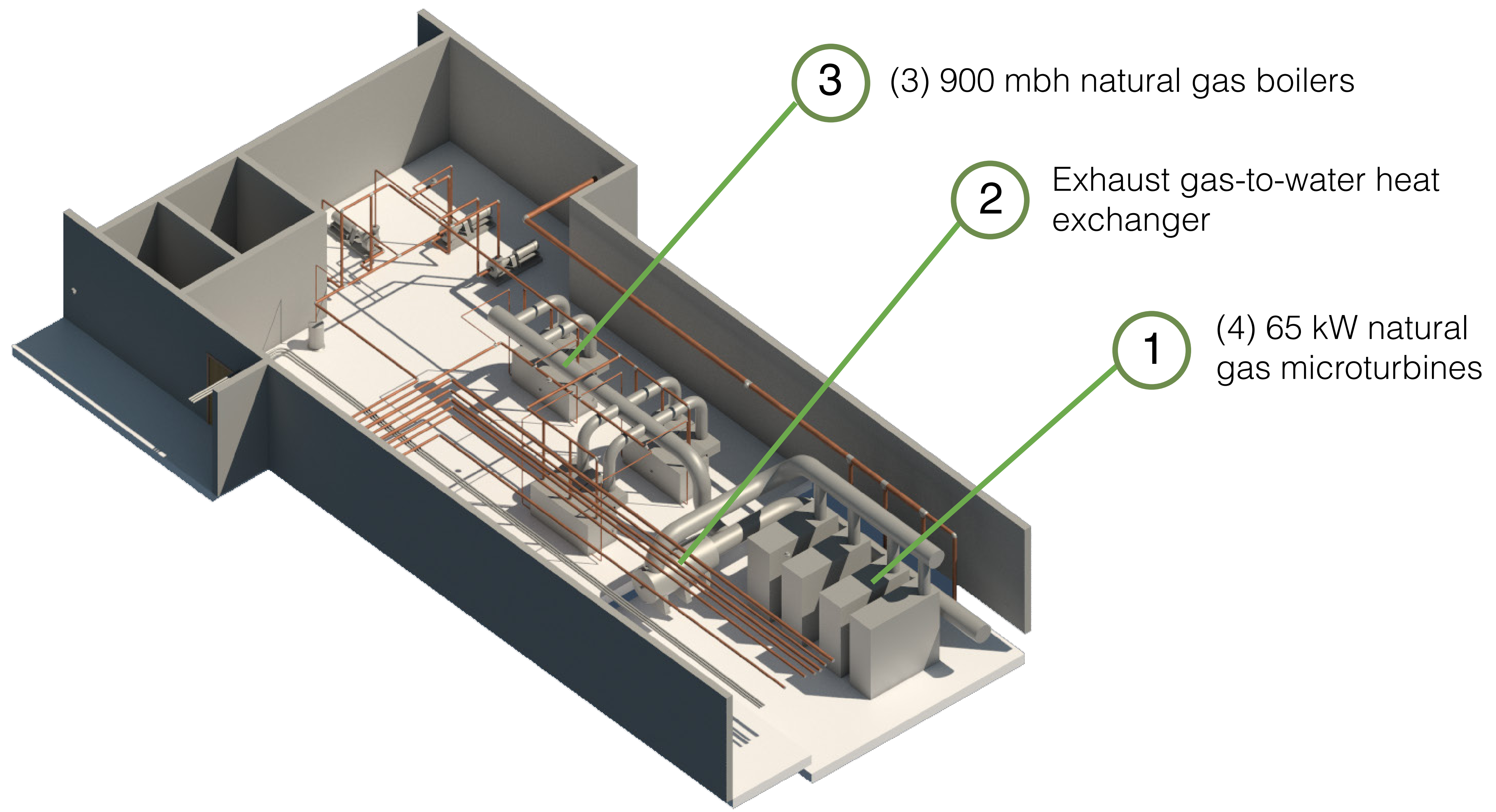
Cogeneration

(4) - 65 kW Capstone Microturbines

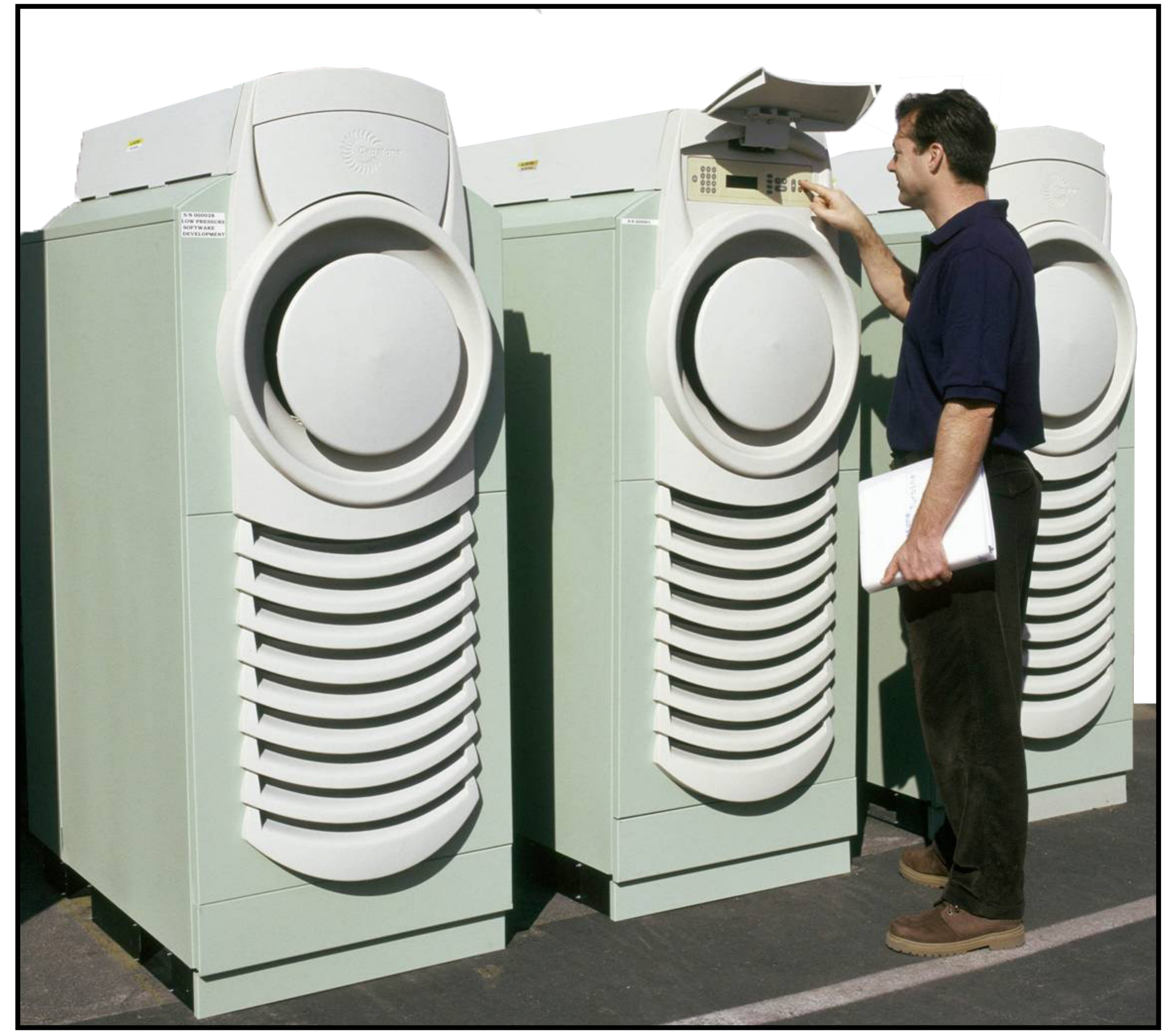
- Natural gas with on-site propane back-up
- 260 kW peak off-grid power generation
- 1200 MBH peak energy from exhaust heat
- 65% total system efficiency (at worst conditions)



Constructability

Logistics:
- Moderate size
- Lead times

Operations Requirements
- Natural gas
- Noise dampening



Maintenance

Requirements:
- Technician maintenance every 6,500 hours of operation

Education:
- Involve staff during design and construction
- Maintenance scheduling
- No risk of losing power

Manufacturer Involvement:
- Monitor equipment status
- Active operation assistance

Life-Cycle Cost Analysis

Category	Cost
Micro turbine Installed Cost	$467,250
Avoided Generator Cost	-$200,000
Energy Grant*	-$250,000
Total Initial Cost	**$17,250**
Yearly Maintenance (kWh)	$10,500
Avoided Generator Maintenance	-$2,000
For 20 Year Life	$170,000
System Life Cycle Cost	$187,250
Yearly Energy Savings	$56,125
Payback Period (years)	**3.34**
Replacement Cost	$378,000

*Without Energy Grant 7.8 Years

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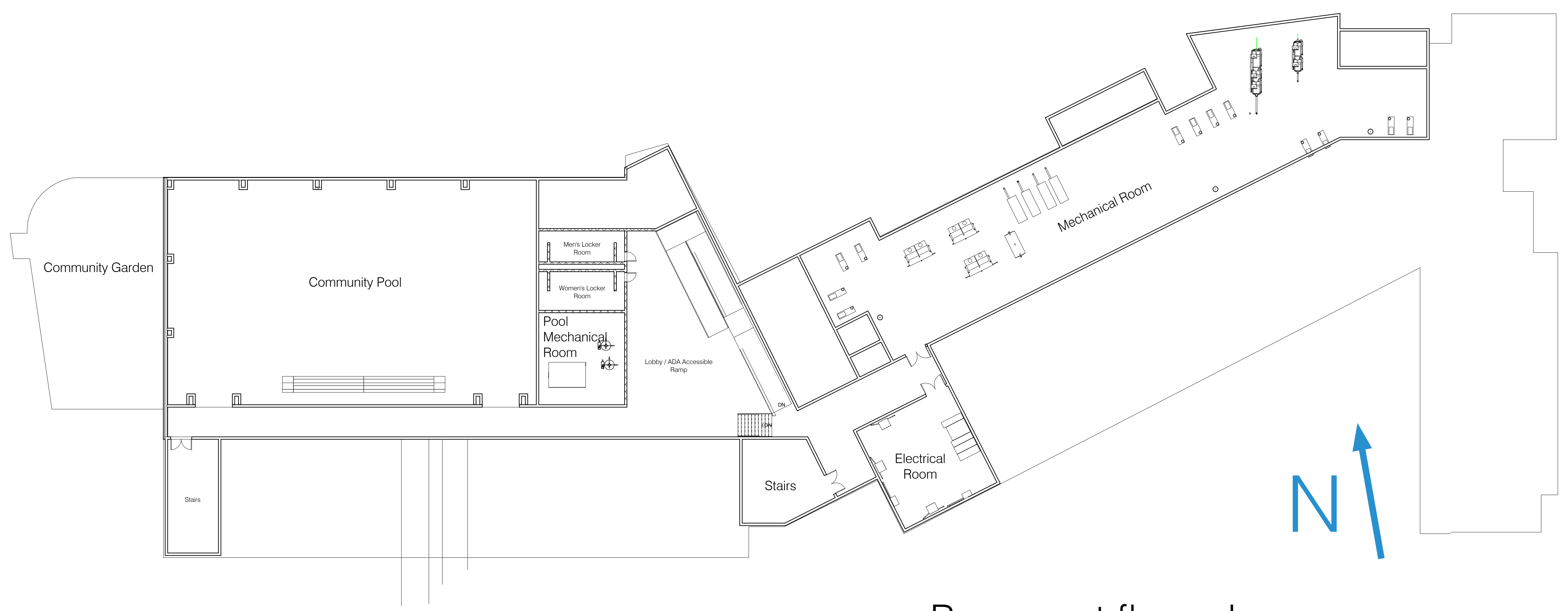
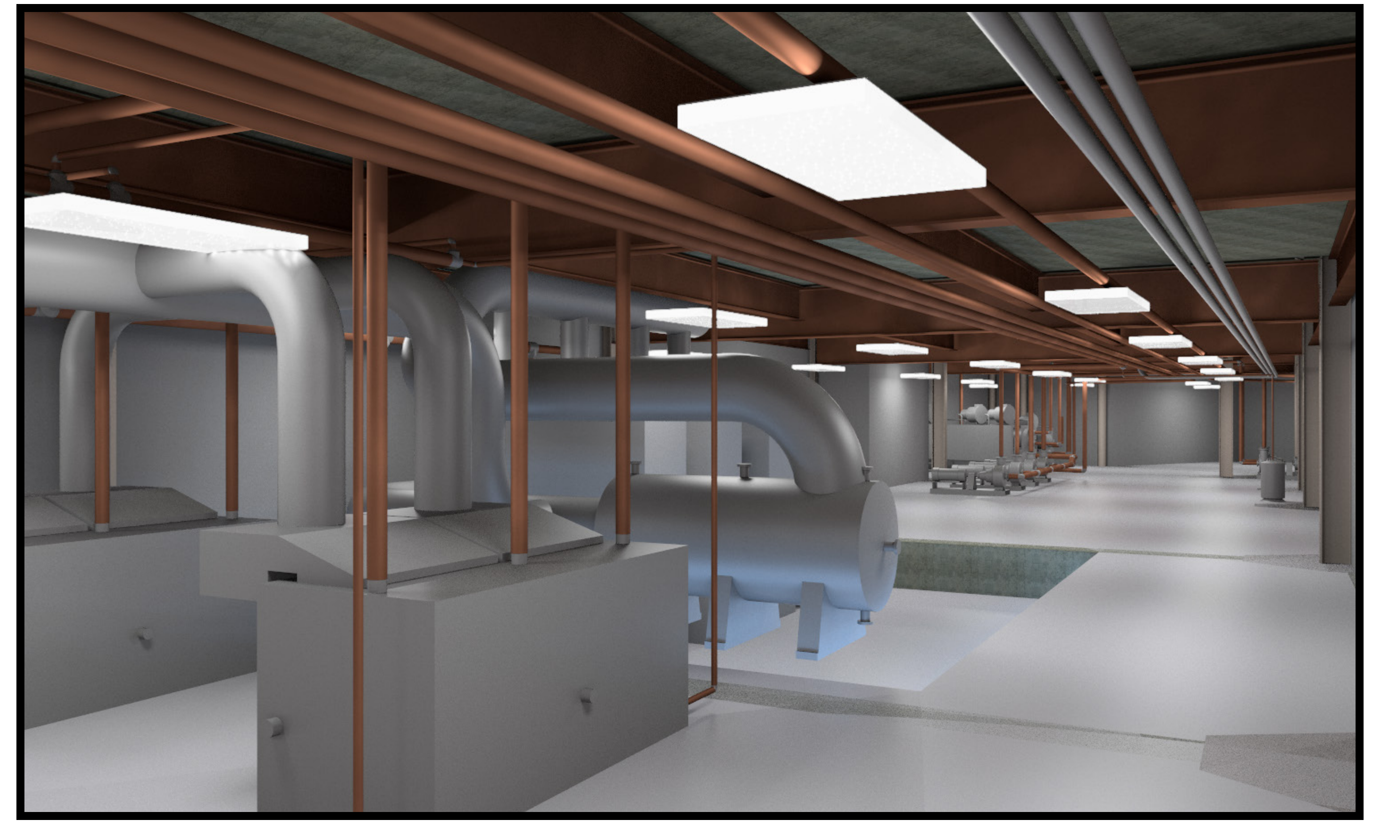
Basement Integration

Pool space - integration with structural cellular beams



Basement floor plan



Mechanical room renderings

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Energy Performance

ASHRAE 90.1 Appendix G Baseline Comparison (Corrected)

Usage Type	Energy Type	90.1 Baseline VAV	Design DV/Radiant	% Design Better than Baseline
		Energy (10^6 Btu/Yr)	Energy (10^6 Btu/Yr)	
Lighting	Electricity	872.2	872.2	
Space Heating	Natural Gas	4543.4	3907.3	
Space Cooling	Electricity	996.0	698.4	
Pumps	Electricity	22.8	71.1	
Heat Rejection	Electricity	56.3	29.6	
Fans	Electricity	766.1	725.9	
Receptacles	Electricity	991.3	991.3	
Pool Heating	Natural Gas	253.4	253.4	
Yearly Electric Cost*		$ 130,697	$ 72,039	
Yearly Natural Gas Cost*		$ 42,920	$ 51,208	
Total Annual Cost		$ 173,617	$ 123,247	29.0 %

Energy Cost Budget / PRM Summary

By ACADEMIC

Project Name: High-Performance Elementary School	Date: February 04, 2013
City: Reading, Pennsylvania	Weather Data: Reading, Pennsylvania

Note: The percentage displayed for the "Proposed/ Base %" column of the base case is actually the percentage of the total energy consumption.

* Denotes the base alternative for the ECB study.

		* Alt-1 Baseline VAV			Alt-2 UNITUS Design		
		Energy 10^6 Btu/yr	Proposed / Base %	Peak kBtuh	Energy 10^6 Btu/yr	Proposed / Base %	Peak kBtuh
Lighting - Conditioned	Electricity	869.8	11	323	872.2	100	324
Space Heating	Electricity	14.9	0	2	26.3	176	3
	Gas	4,038.6	50	1,999	2,513.9	62	1,474
Space Cooling	Electricity	996.0	12	1,226	698.4	70	529
Pumps	Electricity	22.8	0	42	71.1	311	23
Heat Rejection	Electricity	56.3	1	76	29.6	53	43
Fans - Conditioned	Electricity	766.1	10	292	725.9	95	142
Receptacles - Conditioned	Electricity	991.3	12	361	991.3	100	361
	Gas	253.4	3	170	253.4	100	170
Total Building Consumption		**8,009.3**			**6,182.2**		

		* Alt-1 Baseline VAV	Alt-2 UNITUS Design
Total	**Number of hours heating load not met**	0	104
	Number of hours cooling load not met	0	0

	* Alt-1 Baseline VAV		Alt-2 UNITUS Design	
	Energy 10^6 Btu/yr	Cost/yr $/yr	Energy 10^6 Btu/yr	Cost/yr $/yr
Electricity	3,717.2	130,697	3,414.9	120,066
Gas	4,292.0	42,920	2,767.3	27,673
Total	**8,009**	**173,617**	**6,182**	**147,739**

Project Name: High-Performance Elementary School
Dataset Name: SCHEMATIC MODEL.TRC

TRACE® 700 v6.2.8 calculated at 09:25 PM on 02/04/2013
Energy Cost Budget Report Page 1 of 1

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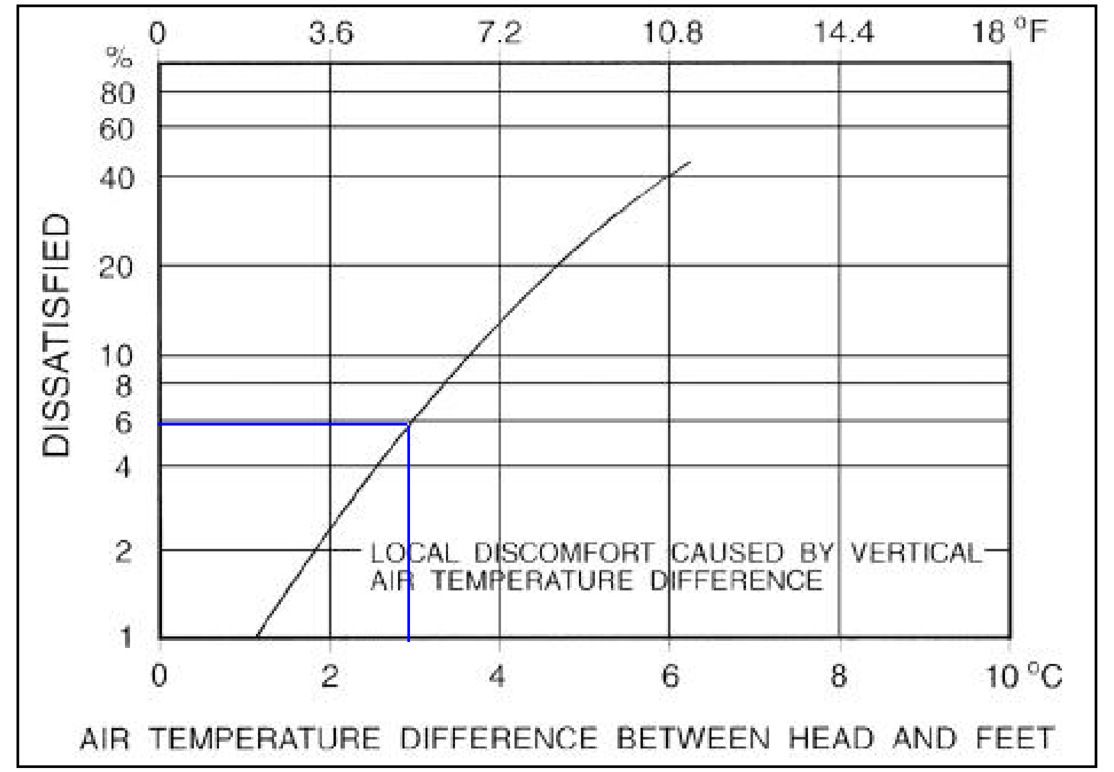
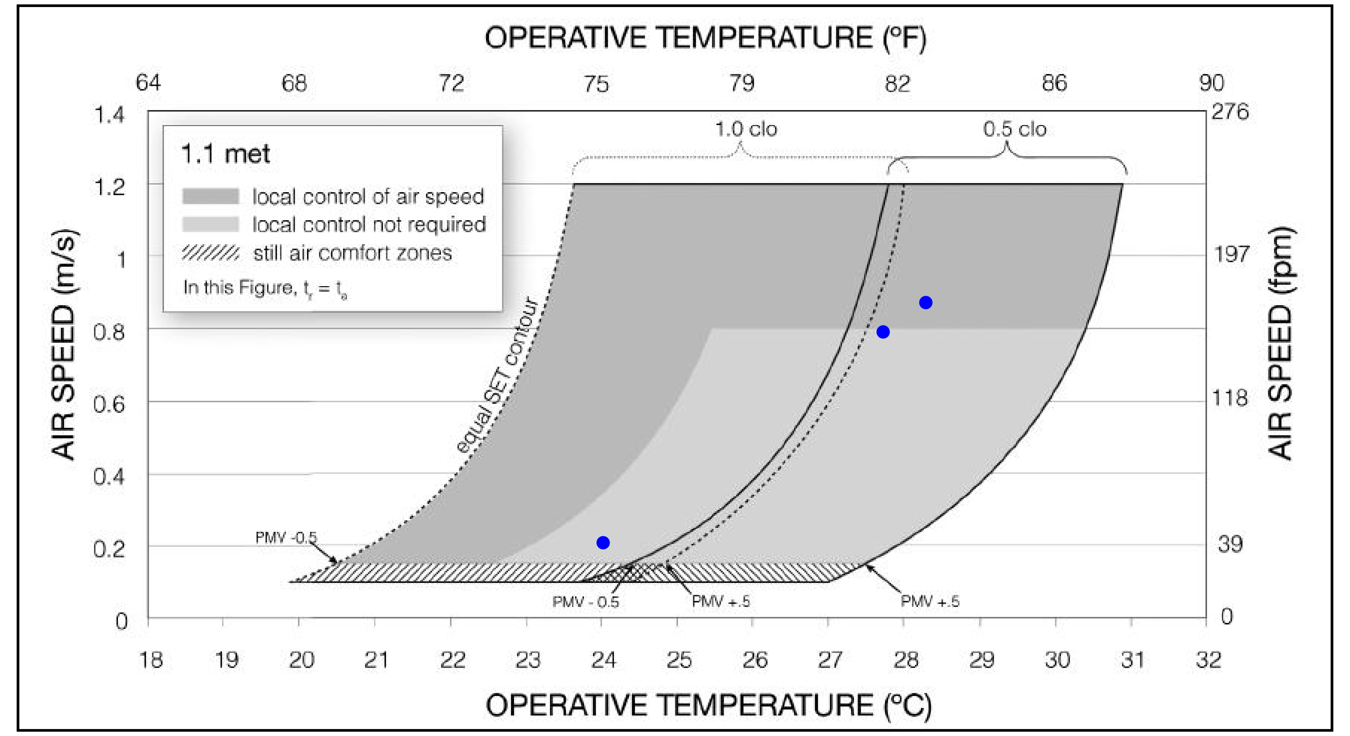
ASHRAE Standard 55

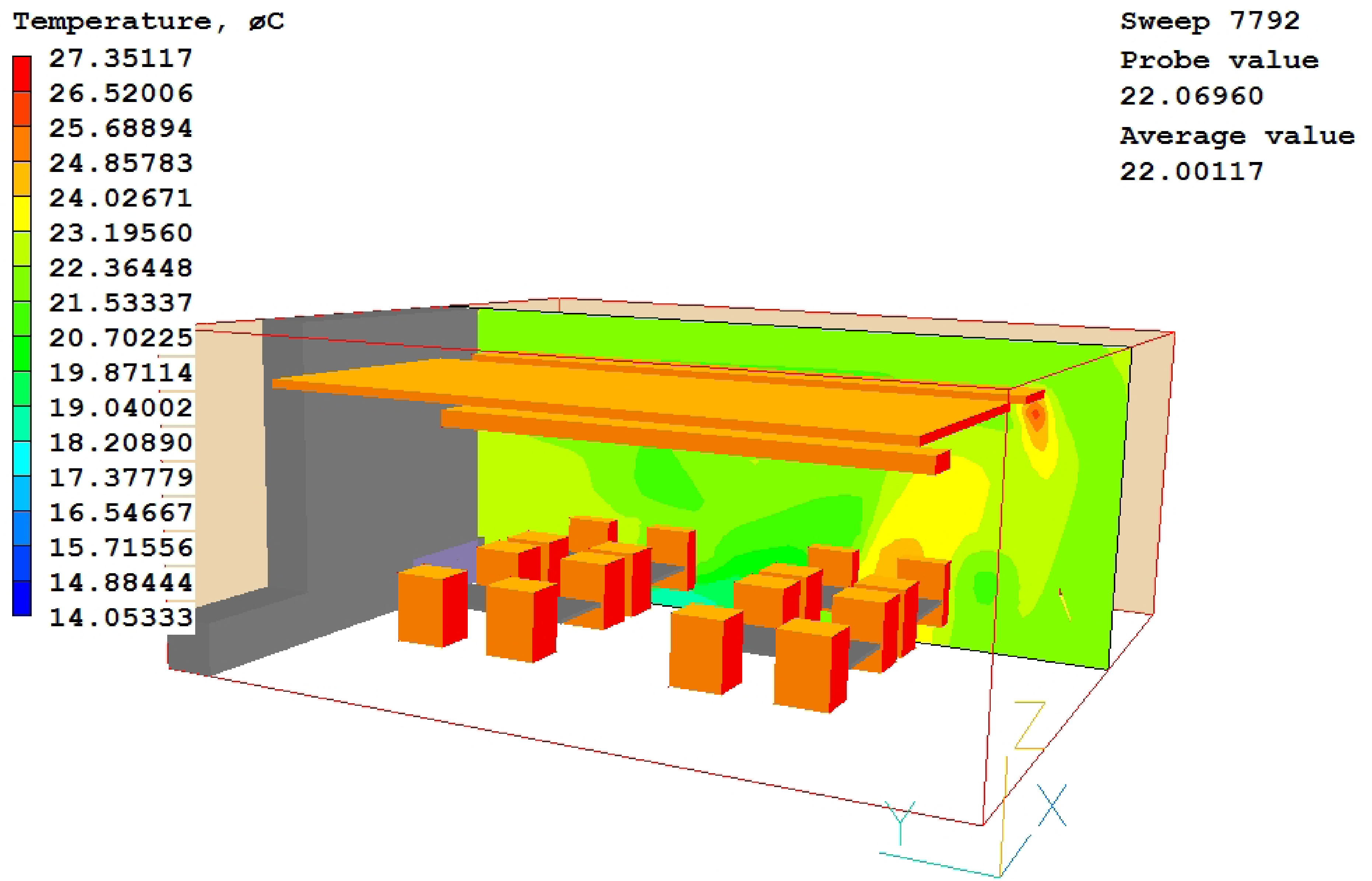
CFD Modeling

Maximum vertical temperature difference = 2.75°C

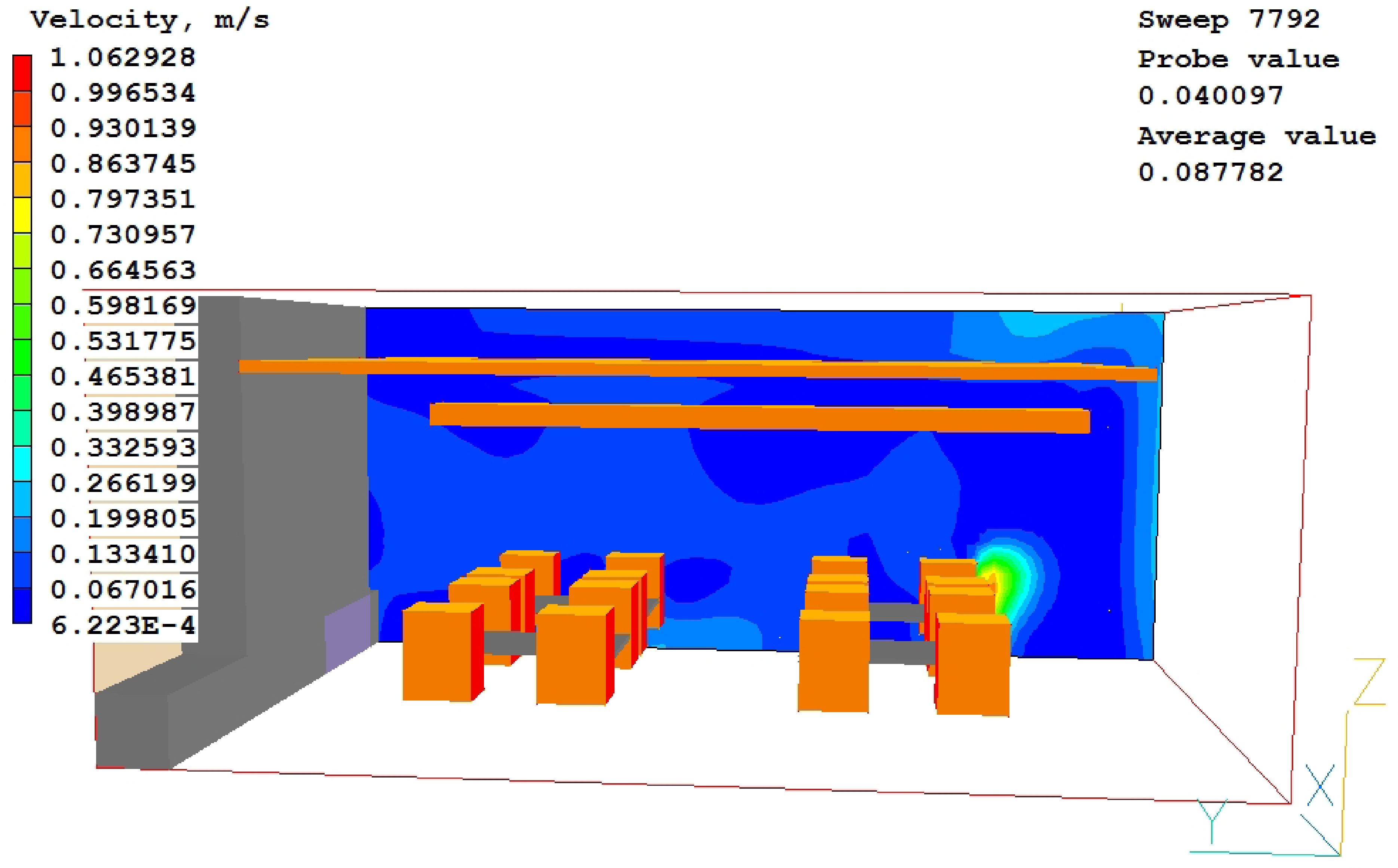


Range of operative temperatures and air speeds





Temperature contour from CFD model



Velocity contour from CFD model

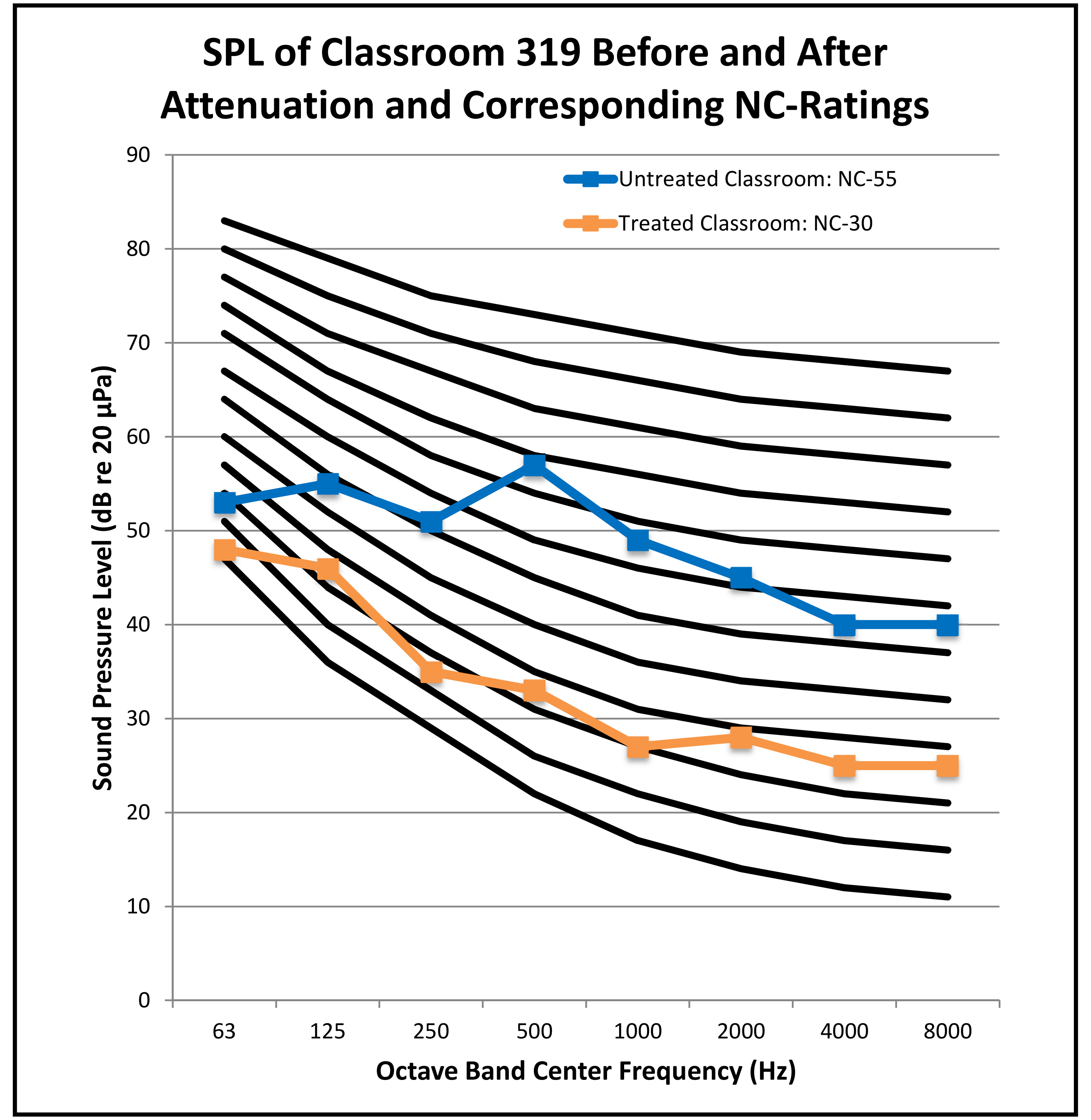
Acoustics

Reverberation time calculations

Surface Description	Surface Area, S (ft^2)	Material Description	Sound Absorption Coefficient, α					
			Frequency (Hz)					
			125	250	500	1000	2000	4000
Interior Walls	1100.00	1/2" gypsum board	0.29	0.10	0.05	0.04	0.07	0.09
Exterior Wall	210.00	1/2" gypsum board	0.29	0.10	0.05	0.04	0.07	0.09
Floor	840.00	Concrete	0.01	0.01	0.02	0.02	0.02	0.02
Windows	140.00	Ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
Exposed Ceiling	840.00	Acoustical metal decking	0.60	0.99	0.92	0.79	0.43	0.23
		Calculated RT (s)	0.46	0.42	0.47	0.50	0.65	0.79

Critical acoustical design areas

N



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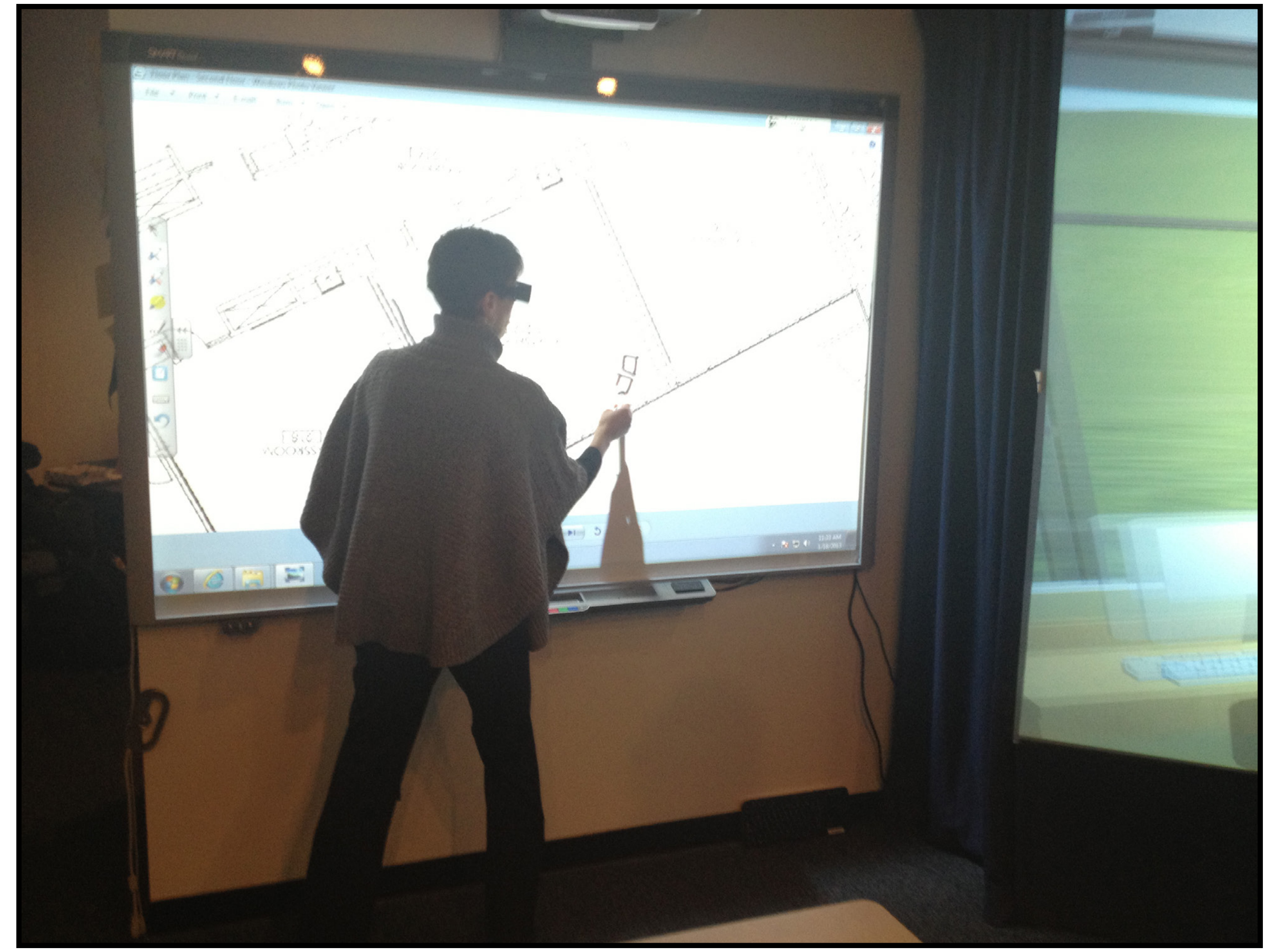
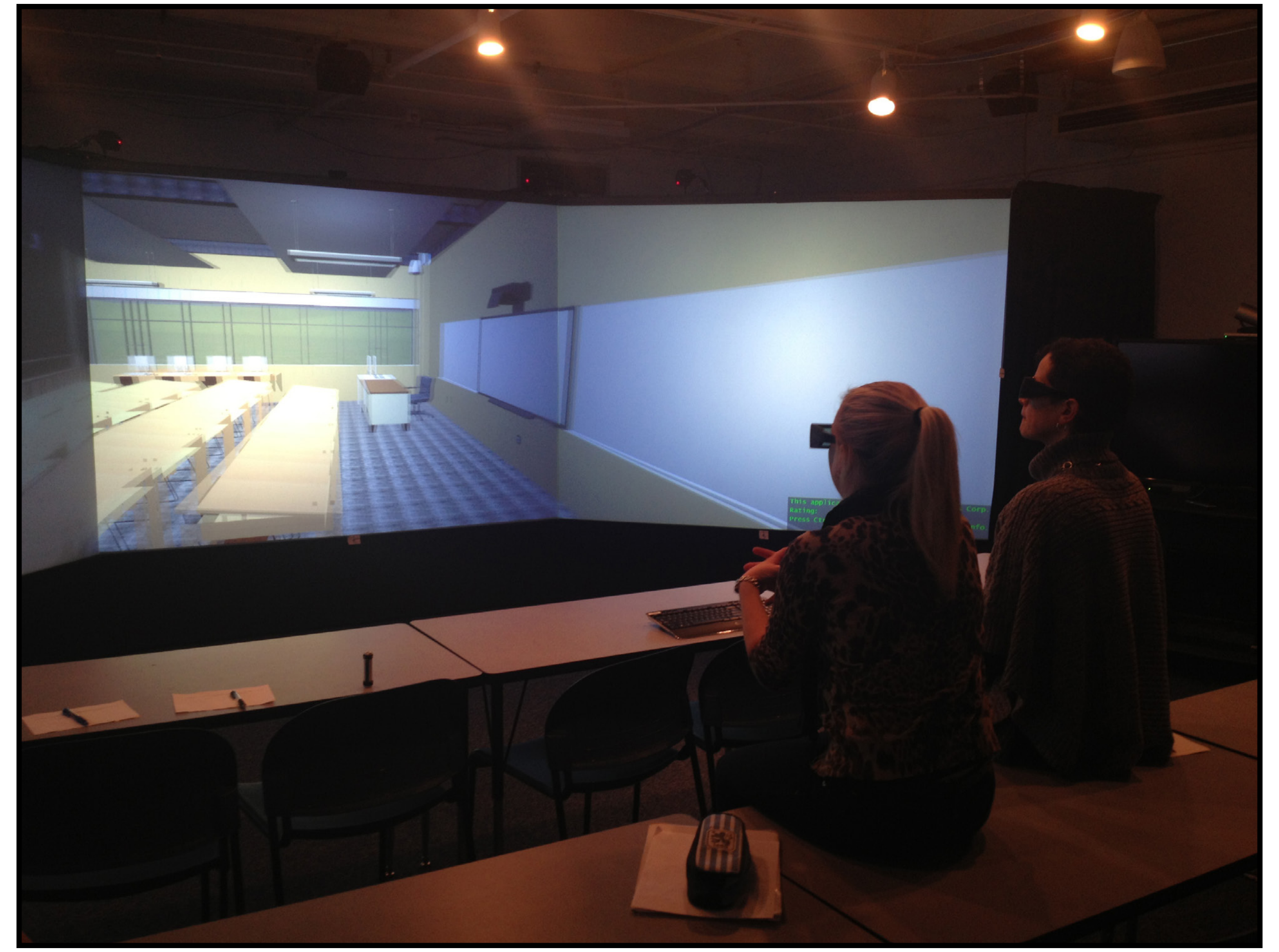
Translation to Industry

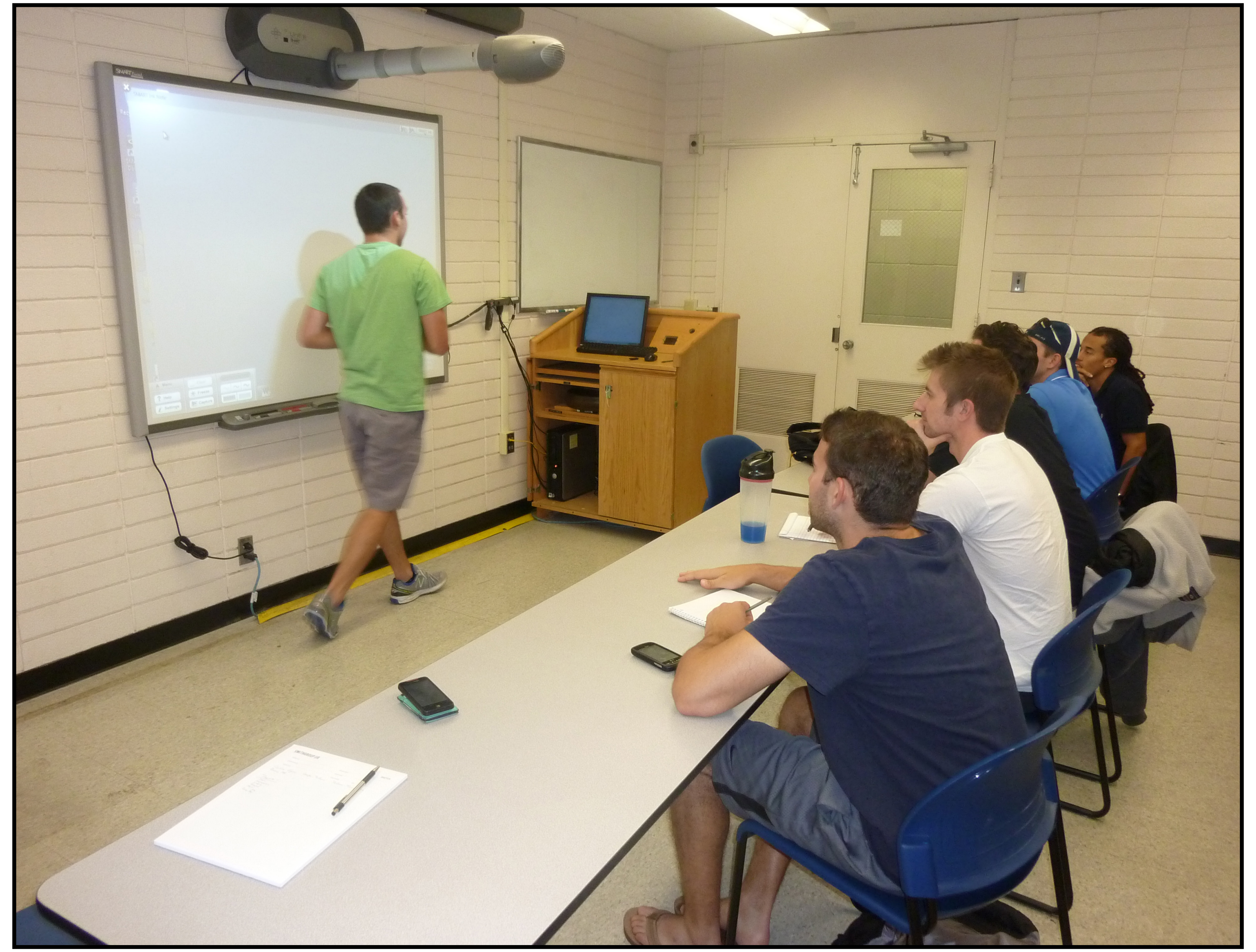
Lead/lag issues
Coordination meetings

Software communication
Energy modeling
REVIT
CFD modeling

Design review
Visual thinking
Virtual mock-up

Virtual mock-up design review



Team coordination meeting

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The Pennsylvania State University
Department of Architectural Engineering
AE 481/482 Senior Capstone Project - BIM Option

April 10, 2013

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Executive Summary

This report details the mechanical system of our team's elementary school design for submission in the 2013 ASCE Charles Pankow Foundation Architectural Engineering Student Competition.

The team goals, which were selected to align with the Reading community, competition guidelines, and Charles Pankow Foundation mission, focused on creating a better community through integrated building design according to high performance standards. This translated mechanically to improved indoor environmental quality and reduced energy consumption.

The overarching theme of community established the backbone of the mechanical system design. The mechanical system was designed to allow the greatest ease of operation in multiple modes to match the varied functionality of the community facility. These modes were made possible through separation of heating, cooling, and air distribution systems into three activity-specific areas. The HVAC system was selected and designed through an integrated approach, which allowed factors affecting the mechanical system to be addressed by the entire project team. Likewise, early analysis of the overall building loads allowed for the collaboration of the mechanical and electrical systems, leading to an energy efficient and cost-effective design.

The process described above resulted in a mechanical design that can be summarized by the following statements:

- Building is separated mechanically to allow multiple operational modes that match the varied school and community based programs.
- Classrooms / Learning Areas are ventilated by a 100% outdoor air displacement ventilation (DV) system. Space heating and cooling is decoupled from ventilation loads, and is served through radiant heating floor slabs and radiant chilled ceiling panels, respectively.
- Community Areas and Pool Area are ventilated by an overhead mixing VAV system. The VAV system also handles all heating and cooling in those areas.
- Peak cooling load is 320 tons. Two chillers are installed in the building, supplying 45°F chilled water to air-handling unit cooling coils and 60°F chilled water to radiant chilled ceiling panels, respectively. Peak heating load is 2700 MBH. Three equally-sized boilers at 900 MBH each are installed to allow staging of part-load conditions.
- Combined heat and power (CHP) is utilized with four (4) 65 kW on-site natural gas microturbines, totaling 260 kW peak electric power and 1,100 MBH of peak collectable waste heat. The combined heat and power system will save the Reading School District approximately $50,000 per year with the assumed schedule of operation. The lifecycle cost resulted in a 3.4-year discounted payback period assuming the design receives a federal or state energy grant.
- School is designed to apply for LEED Gold under LEED 2009 for Schools New Construction and Major Renovations. Design is applying for 61 LEED points, 32 of which are directly related to the mechanical system. Energy models predict that the building uses 29% less energy than the ASHRAE 90.1 2007 Appendix G Baseline model and is anticipated to receive an EnergyStar Rating of 85.

Building a Better Community

The community of Reading, Pennsylvania is in a concerning state. In 2011, *The New York Times* ranked Reading as the poorest city in the United States on the basis of having the largest percentage of its population living in poverty. The Reading School district is in a comparable condition. The school district is in "Corrective Action II" as defined by the No Child Left Behind Law, and has lately achieved mixed results in national and state standardized test scores.

The ASCE Charles Pankow Foundation Student Competition provided our design team the opportunity to shape the future of the Reading community. With an innovative, high-performance elementary school, our design team hopes to educate and inspire the next generation of Reading.

A theme of community was inherited by our design team for this project. The mechanical system of the school can help build a better community by improving learning conditions through better indoor air quality and thermal comfort. The efficient design minimizes energy costs so as not to burden the stagnating Reading community.

Project Goals

Project goals were selected to align with the state of the Reading community, the Reading School District Strategic Plan, competition guidelines, and the mission of the Charles Pankow Foundation. The goals listed below are uniform across all disciplines of our team, and were expanded on to better relate to the mechanical system design. A complete, visual list of how our team met the competition guidelines and the mission of the Charles Pankow Foundation can be found on Page 2 of the Integration Supporting Documentation.

1. Build a better Reading community through construction and implementation of the school program
   - Select mechanical systems on the basis of building a better community and learning conditions
   - Reduce environmental impact to encourage fiscally- and environmentally-responsible life decisions
   - Model building as a learning tool through the use of visible environmental features
   - Use enhanced indoor environmental quality to improve learning conditions
2. Design the elementary school to high-performance standards
   - Enhance indoor air quality and thermal comfort standards
   - Reduce energy consumption by 20% compared to the ASHRAE Standard 90.1baseline model
   - Provide individual environmental control to each classroom
   - Achieve an NC-30 acoustical rating in all classroom spaces
3. Utilize an integrated design approach to maximize quality, efficiency, and value of the final built product
   - Design an unobtrusive mechanical system that allows school and community activities to occur without interference from the mechanical system
   - Use mechanical system as a base for integration with other systems
   - Create a system that is flexible to future changes to the building and elementary school program

Environmental Conditions

The designed elementary school will be located at the intersection of 13th Street and Union Street in Reading, Pennsylvania. The location is in ASHRAE Climate Zone 5A. The design heating and cooling weather conditions were collected from ASHRAE Fundamentals 2009 for Reading Spaatz Field and are shown in Table 1 below [1].

Table 1: Design Heating and Cooling Environmental Conditions from ASHRAE Fundamentals 2009

Design Condition	Extreme Month	99.6% DB (.4% Cooling)	MCWB
Heating	January	9.4°F	-
Cooling	July	92.4°F	74.1°F

Schedule of Operation

Expected operating hours of the building are shown in Table 2. Operation of the school was predicted based on the school schedules reported on the Reading School District website, but was modified to match the added community functions that the design offers.

Table 2: Predicted operating hours of the designed High-Performance Elementary School

School Year – September to June		Summer Break – July to August (And weekends during school year)	
12:00AM – 4:00AM	Health clinic only	12:00AM – 9:00AM	Health clinic only
4:00AM – 7:00AM	Use of pool for swim practice	9:00AM – 6:00PM	Pool open to public Gymnasium use for sport events PTA room use for meetings Health clinic Few summer activity camps School offices open
7:00AM – 3:00PM	Normal school hours		
3:00PM – 9:00PM	Extended "after-school" programs Pool open to public Gymnasium use for sport events Health clinic PTA room use for meetings		
9:00PM – 12:00AM	Health clinic only	6:00PM – 12:00AM	Health clinic only

Even though the main function of the building is an elementary school, the building is also used for many community activities. The pool, gymnasium, and PTA room are open to the public at times when the school is not in operation. Operating and conditioning the entire school during these extended community hours would be inefficient. Thus, the building was separated mechanically to allow the community functions to occur without having to condition the entire building.

Mechanically, the building is separated into the following areas, which are illustrated in Figure 1 on the following page.

- **Classrooms / Learning Areas** – This area comprises the majority of the building: half of the ground level, as well as all of the 2nd and 3rd floors. This area will be operated during normal school hours, and not operated when school is not in session. Loads are served through a 100% outdoor air displacement ventilation system, radiant chilled ceiling, and heated floor slab.
- **Community Areas** – Gymnasium, pool, health clinic, offices, and PTA room are operated during school hours and in extended hours and weekends when school is not in session. Loads are served through an overhead mixing VAV system.
- **Pool Area** – Due to the strict temperature and moisture setpoints for natatoriums stated in ASHRAE Applications Chapter 5, the pool will be operated and conditioned on its own system [2]. Pool loads will be handled through an overhead mixing VAV system.

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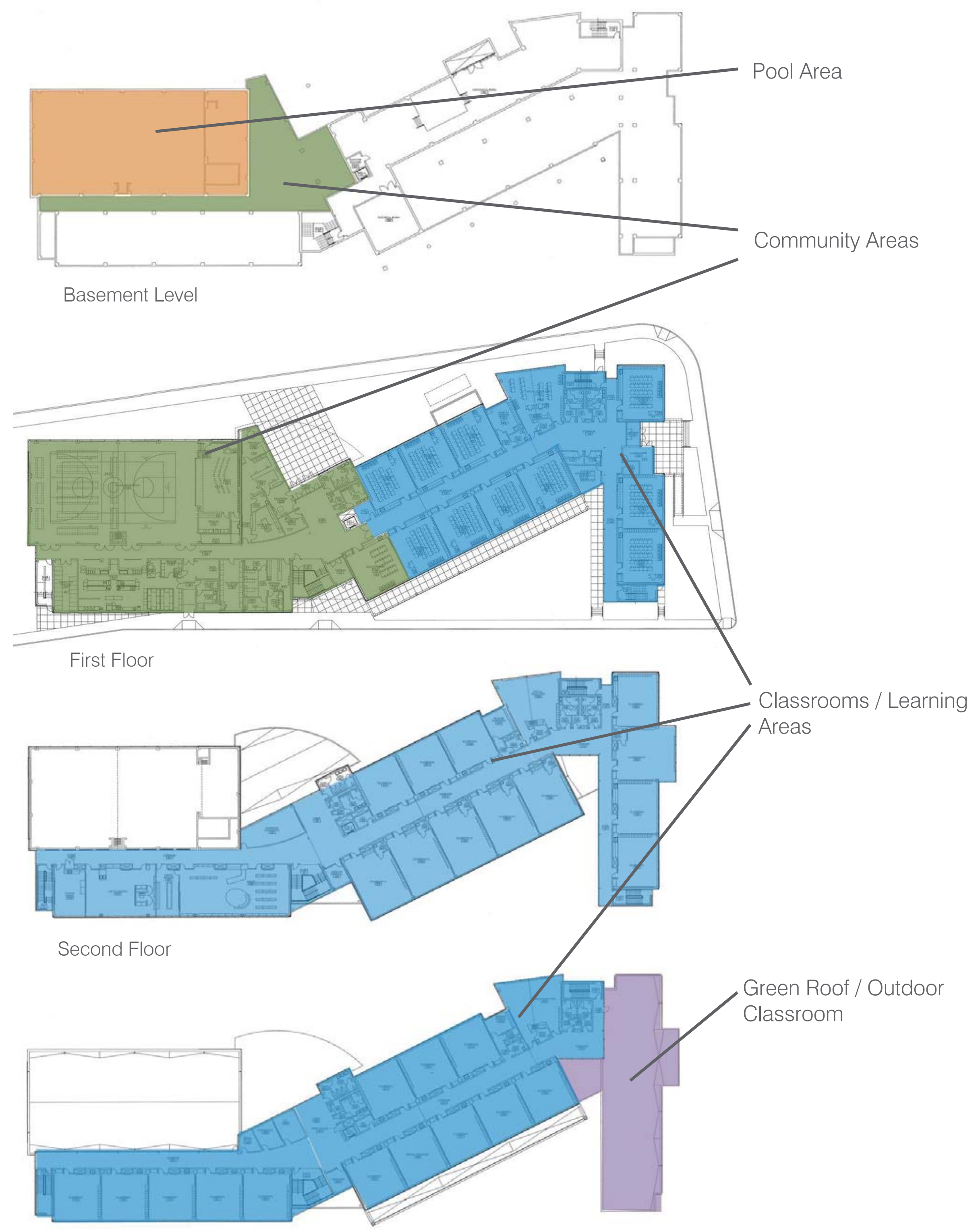
Figure 1: Mechanical System Separation in Plan View



Space Heating, Cooling, and Ventilation Loads

This section of the report highlights some of the design building loads. Building loads were calculated with Trane TRACE700, and were verified by some hand calculations. Full building loads can be found in the TRACE systems reports on pages 16-17 of the Mechanical Supporting Documentation.

Classroom Cooling Loads

Full occupancy loads in a typical classroom were calculated for both the warmest and coldest months of the year. It was found that the building is driven by internal loads, meaning that cooling will occur year-round under full occupancy conditions. Loads for a typical classroom space are shown below in Table 3.

Table 3: Typical Classroom Loads Under Full Occupancy

January (Coldest Month)			July (Warmest Month)		
Internal Loads			Internal Loads		
	Sensible Load (Btu/hr)	Latent Load (Btu/hr)		Sensible Load (Btu/hr)	Latent Load (Btu/hr)
30 Students	7500	3000	30 Students	7500	3000
1 Teacher	250	100	1 Teacher	250	100
2 Computers	3400	0	2 Computers	3400	0
Lighting (1.1 W/SF)	3000	0	Lighting (1.1 W/SF)	3000	0
Miscellaneous	2000	0	Miscellaneous	2000	0
External Loads			External Loads		
	Sensible Load (Btu/hr)	Latent Load (Btu/hr)		Sensible Load (Btu/hr)	Latent Load (Btu/hr)
Wall Assembly R-25	-1000	0	Wall Assembly R-25	650	0
Solar	2550	0	Solar	2550	0
Roof	-1500	0	Roof	1350	0
Net Load	16200	3100	Net Load	20700	3100

Ventilation Requirements

Ventilation requirements were calculated through the prescriptive method of ASHRAE Standard 62.1 2007. The ventilation design was also targeted to achieve the LEED credit for 30% increased ventilation. ASHRAE 62.1 calculations can be found in the Mechanical Supporting Documentation Pages 3-6, and summary of the ventilation requirements is shown in Table 4 below.

Table 4: ASHRAE 62.1 2007 Minimum Ventilation Requirements by Air-Handling Unit

Name	Ventilation Type (See next page)	E_Z	Minimum Outdoor Intake (CFM)
Classrooms / Learning Areas	Displacement Ventilation	1.2	18,550
Community Areas	Overhead Mixing VAV	0.8	14,150
Pool Area	Overhead Mixing VAV	0.8	2,900

Pool Area

ASHRAE Applications Chapter 5 offers natatorium design pool water and ambient air conditions that help manage the evaporation losses from the pool surface [2]. These design conditions for our competition swimming pool are shown in Table 5.

Table 5: ASHRAE Applications Typical Natatorium Design Conditions

Type of Pool	Air Temperature °F	Water Temperature °F	Relative Humidity %
Competition	78 to 85	76 to 82	50 to 60

Even complying with these conditions, evaporation losses from the pool surface are a significant heating load on the mechanical system: 250 Million Btu per year. Refer to Page 10 of the Mechanical Supporting Documentation for pool calculations. Strategies for heating the pool in an efficient manner are described in the "Combined Heat and Power" section of this report starting on Page 12 of this Mechanical Narrative.

HVAC System Selection

This section details the HVAC system selection and reasoning of the elementary school. The HVAC system was ultimately chosen to align system advantages with our stated project goals. As previously stated, the mechanical system was separated to match the multiple operating modes of the school. Likewise, each area of the building was matched with an HVAC system that most effectively conditioned the spaces for the functions listed in the schedule of operation.

Classrooms / Learning Areas

In the classroom areas, the team found a match between system benefits and project goals for a 100% outdoor air displacement ventilation (DV) system combined with passive radiant chilled ceiling panels and a heated floor slab. Our reasoning for this system selection is described below, and shown in bullet points in Figure 2 on the next page.

- 100% outdoor air DV system was chosen because of air quality benefits stated in many reports [3]. The floor-to-ceiling height in each classroom (12') was deemed sufficient to allow temperature stratification.
- Heated floor slab will be very comfortable for the elementary school children, who typically spend a lot of time playing and sitting directly on the floor. The kindergarten children, who in particular spend the most time on the floor, will receive the highest thermal comfort benefits.
- Passive radiant cooling was selected for its thermal comfort benefits, and also desired by the whole design team for its integration possibilities. The passive chilled ceiling panels will replace a drop-ceiling, while achieving the same sense of plane. Indirect lighting and sprinkler systems will be integrated into the panels' structural system, as detailed on Page 2 of the Integration Supporting Documentation.

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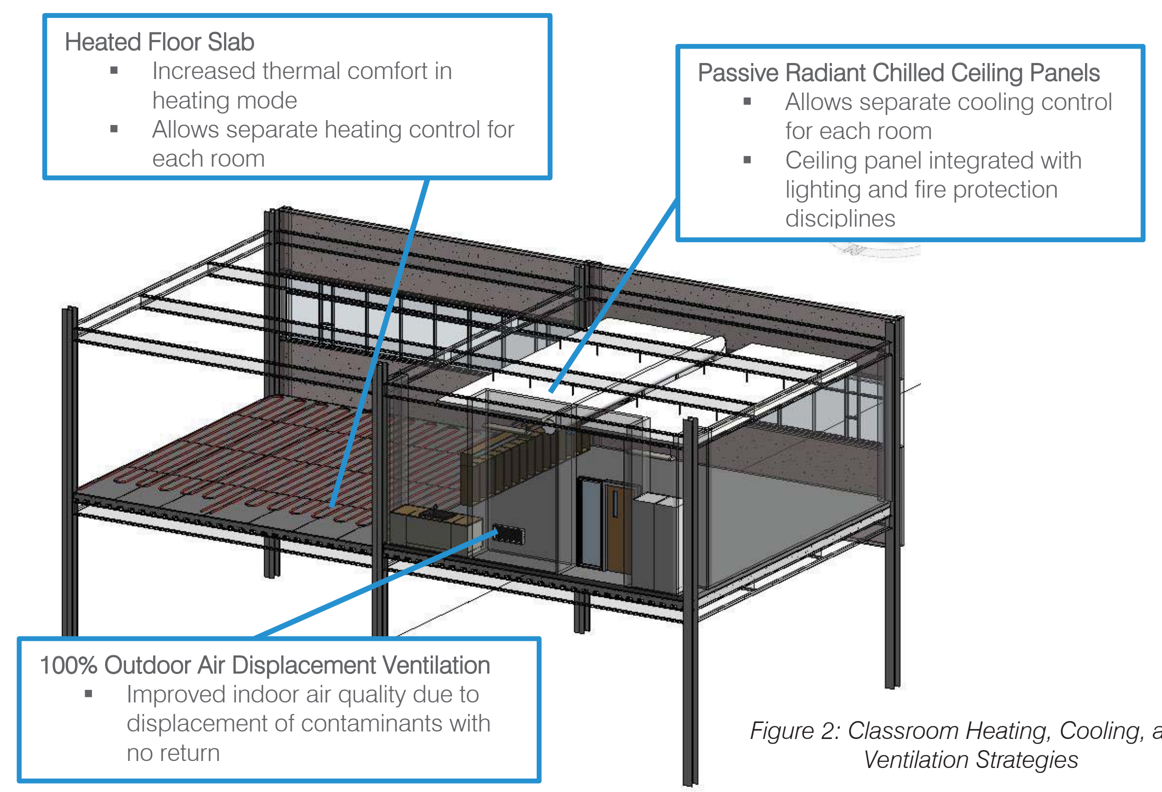

Figure 2: Classroom Heating, Cooling, and Ventilation Strategies

Community Areas

Some of the functions in the community areas, particularly the gymnasium and kitchen, result in high space latent loads, making the combined DV/CC system selected for the classrooms inappropriate for the community area. The community area will also experience a sporadic loading schedule, as large functions and events in the gymnasium will take place randomly. Ultimately, an overhead mixing VAV system was selected for the community area. The VAV can be designed to handle the large range of functions that take place in the community areas.

The community area VAV system will be zoned as shown in Table 6 and its corresponding diagram.

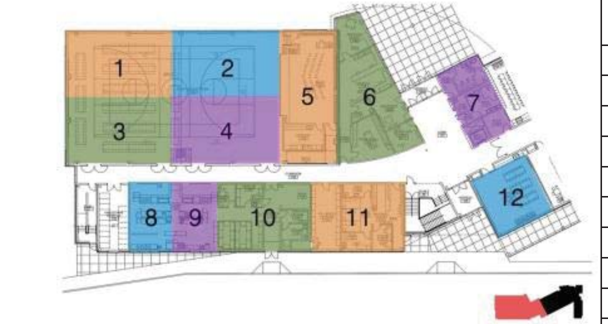

Table 6 Community Area VAV Zones

Zone	Room Name	Maximum Airflow (CFM)	Min. Airflow (CFM)
1	Gymnasium	1000	600
2	Gymnasium	1000	600
3	Gymnasium	1000	600
4	Gymnasium	1000	600
5	Stage	1000	600
6	Offices	1550	930
7	Bathrooms	200	120
8	Kitchen	1250	750
9	Kitchen	1250	750
10	Kitchen and P.E.	600	360
11	Health Clinic	600	360
12	PTA Room	800	480

Acoustical Performance

According to Part 1 of the American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for schools, the maximum permitted reverberation time for a core learning space with an enclosed volume between 10,000 ft^3 and 20,000 ft^3 should be 0.7 seconds in octave bands with mid-band frequencies of 500, 1000, and 2000 Hz [10]. The High Performance Elementary School's typical classroom surface materials included interior gypsum walls, concrete flooring, acoustical metal decking, and ordinary window glass. A summary of the materials and their absorption coefficients is organized below in Table 14.

Table 14: Classroom Material Absorption Summary

Surface Description	Surface Area, S (ft^2)	Material Description	Sound Absorption Coefficient, α					
			Frequency (Hz)					
			125	250	500	1000	2000	4000
Interior Walls	1100.00	1/2" gypsum board	0.29	0.10	0.05	0.04	0.07	0.09
Exterior Wall	210.00	1/2" gypsum board	0.29	0.10	0.05	0.04	0.07	0.09
Floor	840.00	Concrete	0.01	0.01	0.02	0.02	0.02	0.02
Windows	140.00	Ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
Exposed Ceiling	840.00	Acoustical metal decking	0.60	0.99	0.92	0.79	0.43	0.23
		Calculated RT (s)	0.46	0.42	0.47	0.50	0.65	0.79

Reverberation calculations proved that the T_{60} under the aforementioned conditions at 1000 Hz totals to 1.00 seconds. In order to decrease the reverberation time to provide a most acoustically comfortable learning environment, 40 percent of the floor area was substituted with heavy carpet on concrete block. This design modification brought the reverberation time within the limits of the standard.

The core layout of the building is arranged to be sensitive to the acoustical demands of critical spaces. Ducts are run throughout the corridors to minimize crosstalk and loud mechanical/electrical rooms are buffered by storage space. Mechanical equipment located on the roof, however, threatens the acoustics of classrooms below. In order to ensure an NC-30 rating for the classrooms, an acoustical analysis of the duct route between the Central Air Handling Unit and Classroom 319 was performed using the Dynasonics AIM software. Before acoustical attenuation, the classroom was experiencing an NC-55. This is due to the short branch of duct that leads to the classroom, as well as the high frequency noise of the air handling unit. Table 15 is extracted from manufacturer's data of the air handling unit [11]:

Table 15: Central AHU Acoustical Data

42 ton AHU Acoustics								
	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2kHz	4 kHz	8 kHz
Discharge Duct	87 dB	87 dB	84 dB	86 dB	80 dB	76 dB	72 dB	68 dB

By adding a 36" duct silencer to the Central AHU's main supply duct, the NC rating was brought down to NC-30. Table 16 organizes the sound power level data of Classroom 319 before and after the duct silencer was included in the design.

Table 16: Classroom 319 Sound Attenuation Summary

	Frequency (Hz)								NC-Rating
	63	125	250	500	1000	2000	4000	8000	
Lp Classroom 319 Untreated (dB re: 20 μPa)	53	55	51	57	49	45	40	40	55
Approximate NC Rating	25	40	45	55	50	50	45	45	
Lp Classroom 319 Treated (dB re: 20 μPa)	48	46	35	33	27	28	25	25	30
Approximate NC Rating	20	30	25	30	25	30	30	30	

System Sizing

This section of the report details the sizing of the critical aspects of the mechanical systems and equipment. First, the design method for sizing the combined displacement ventilation and chilled ceiling system (DV/CC) in the classrooms is described. Next, the chiller and boiler sizing for the entire building is discussed.

Combined DV/CC System in Learning Areas

The combined DV/CC system in the classroom presented a challenge to the design due to the unconventional system combination. Standardized design calculations for this system combination do not yet exist, so the process our team undertook to design this system was created from information taken from multiple research documents, notably "Designing a Dedicated Outdoor Air System…" by Jeong and Mumma, and "A Critical Review on the Performance…" by Novoselac and Srebric [4,5].

The combined DV/CC system required strict design setpoint conditions to avoid condensation and uncomfortable thermal plumes from the downward buoyancy effects of the chilled ceiling panels. Careful attention was paid to the latent load in the classrooms and relative humidity of supply air. Since radiant chilled ceiling panels were selected for the classrooms, the classrooms must have inoperable windows. The design team found this reasonable, however, since the mechanical system is supplying 100% fresh outdoor air.

Displacement Ventilation Boundary Conditions

Since displacement ventilation supplies unmixed air at the occupied level, the supply air temperature must be warmer than supply air in mixing conditions to maintain thermal comfort. Bauman and Daly suggest that air supply from UFAD or DV systems stay between 63°F – 68°F [6]. Since the elementary school students that will occupy this space form a lower occupied zone than adults, our design team was unwilling to drop the supply air temperature to 63°F, and will keep the supply temperature in the range of 65°F – 68°F.

Supply air velocity is also a limiting factor for the displacement ventilation system. To avoid drafts in the occupied level, our design limited the face velocity of the supply air to 40 fpm. In a typical 800 SF classroom with a 2' x 6' DV diffuser, this resulted in 480 CFM, or 0.6 CFM/SF. This 0.6 CFM/SF value was transferred to the all of the spaces for cooling calculations.

Set Target Space Conditions and Chilled Ceiling Temperature

Conventional cooling setpoints are 75°F and 50%RH in the occupied space. This setpoint coincides with a dew point temperature of around 55°F. So, the chilled ceiling temperature could go as low as 60°F. This ceiling temperature was assumed and checked with the following calculation. For a conservative design, the latent load calculated for a typical classroom on Page 5 was roughly doubled.

Supply conditions:
Supply Air: 480 CFM at 65°F DB, 50 grains/lb
Latent load: 6000 btu/hr. (Roughly doubled from calculation on Page 5 for conservative design)

$$6000\frac{Btu}{hr} = 0.68 \times 480CFM \times \Delta W$$

$$\Delta W = 18.4 \text{ grains/lb}$$

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Applying this ΔW on a psychrometric chart, the dew point of the air with doubled latent load conditions comes to around 57°F – 58°F. Thus, a 60°F chilled ceiling temperature will work for the space, especially for normally expected latent loads.

Determine DV Cooling Capacity, CC Cooling Requirement

From the displacement ventilation boundary conditions, air-side cooling can be calculated:

$$\dot{q} = 1.08\,(480\text{CFM})(75°\text{F}-65°\text{F}) = 5184 \text{ btu/hr}$$

Air-side cooling represents 25% of the peak sensible cooling required in the typical classroom. The rest of the sensible cooling – 15,516 btu/hr – must be handled by the chilled ceiling panels.

Calculate Required Chilled Ceiling Capacity

Temperature stratification is expected to occur from the DV system. While the occupied setpoint temperature is 75°F, the air temperature near the chilled ceiling panel is expected to be around 78°F. The chilled ceiling panel temperature is set at 60°F, giving a ΔT of 18°F. Manufacturer's data from the Price HVAC RPLA Radiant Panels lists a performance of 36 btu/hr*square foot of panel for that temperature difference [7]. The size of the radiant chilled ceiling panels can then be sized from the stated capacity and required cooling load:

$$15516\frac{\text{btu}}{\text{hr}} = \frac{36\frac{\text{btu}}{\text{hr}}}{\text{SF}} \times \text{CHILLED CEILING AREA}$$

CHILLED CEILING AREA = 431 SF (Between 50-60% of ceiling area)

This equation was applied to all spaces with the combined DV/CC system as shown on Pages 7-9 in the Mechanical Supporting Documents. Additional ceiling panel area was added to make a more conservative design, and it was decided that the ceiling panels would cover 70% of the ceiling area.

Combined DV/CC Design Summary:

In short, our classroom cooling and ventilating design can be summarized by the following bullet points:

- 100% outdoor air is supplied to the classrooms at floor level between the range of 65°-68°F at a rate of 0.6 CFM/SF.
- Displacement air handles 25% of the cooling load, while the chilled ceiling handles 75% of cooling load.
- Passive chilled ceiling panels are set at 60°F and cover 70% of the ceiling area.

The designed ventilation/cooling strategy resulted in a 29% decrease in annual cooling consumption compared to the ASHRAE 90.1 2007 baseline model because cooling is applied directly to the classroom spaces and less air is passed through the cooling coils. Refer to page 14 of this Mechanical Narrative for a full description of the 90.1 energy model baseline comparison.

Chiller Sizing

Chilled water will be handled by two electric chillers of differing sizes and chilled supply temperatures, detailed in Tables 7 and 8. Heat will be rejected from the chillers from air-cooled condensers on the roof of the school. Total peak cooling load for the school design is 320 tons.

Chiller 1

Table 7: Chiller 1 supplies 45°F water to cooling coils in air handling units

Load Description	Cooling Load (Tons)
AHU 1-West Cooling Coil	50
AHU 2-Central Cooling Coil	60
AHU 3-East Cooling Coil	40
AHU 4-Community Cooling Coil	50
AHU 5-Pool Cooling Coil	20
Misc. Refrig. Applications	20
Total	240

Chiller 2

Table 8: Chiller 2 supplies 60°F water to radiant chilled ceiling panels

Load Description	Cooling Load (Tons)	Basis of Design
Radiant Chilled Ceiling Panels	80	Price HVAC Radiant Panels Series RPLA

Boiler Sizing

Heating will be handled by three natural gas hot water boilers of 900 MBH each. Staging will occur based on heating demand load. Hot water return will be preheated by exhaust heat from the cogeneration sources in the school design (discussed immediately following this section). Peak building heating loads are listed in Table 9.

Table 9: Peak building heating loads

Load Description	Heating Load (MBH)
AHU 1-West Heating Coil	350
AHU 2-Central Heating Coil	430
AHU 3-East Heating Coil	310
AHU 4-Community Heating Coil	285
Pool Heating from Evaporation Losses	170
Radiant Heated Floor Slab	700
Misc. Heating Applications	400
Total	2700 (Approx.)

Coil sizes reported in the TRACE energy model were verified by the McQuay Psychrometric Analyzer, shown in Figure 4.

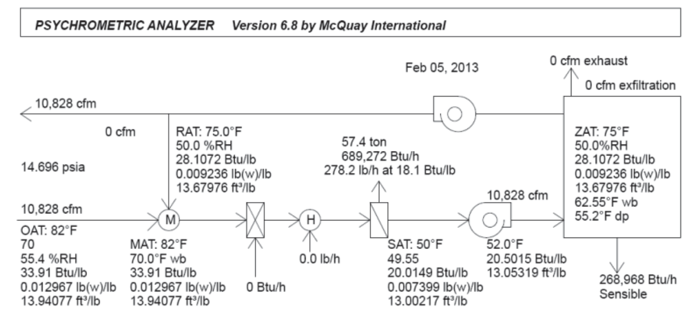

Figure 4: Central cooling coil sizing calculated with the McQuay Psychrometric Analyzer

Combined Heat and Power

The design team is presenting a combined heat and power design as an innovative way to meet the pool heating requirements. The design is detailed below through the following page. The Reading School District has the alternative to waive the pool and/or combined heat and power system from the design if the district does not have the funding for either of these programs.

The school will employ the use of four natural gas microturbines each rated at 65kW to reduce the amount of electricity consumed from the Reading electric grid. The exhaust heat from those microturbines will be utilized for building heating loads, including the pool. Combined heat and power is viable in our school design because the school has significant year-round heating loads, as shown in Table 10.

Table 10: Design Heating Loads Met by Combined Heat and Power

Heating Load	Peak Energy Requirement (MBH)	Seasonal Period
AHU Main Heating Coils	2134	Winter (heating mode)
AHU Reheat Coils	640	Summer (Cooling mode)
Pool Reheat	170	Year-Round

Apart from the school heating demands, CHP is made even more viable with the existence of the present office building on-site and another Reading School District elementary school across the street from the school site. Thermal or electric energy could be generated in the designed CHP plant and transported to those two other locations in a district energy system.

Microturbine Efficiency and Capacity

Manufacturer catalogs claim each microturbine can reach 85% efficiency with the collection of exhaust heat [8]. However, this efficiency seems rather high for typical conditions. Our design team calculated our own assumed microturbine efficiency for determining energy savings, shown in Table 11.

Table 11: Assumed Microturbine Efficiency. Basis of design for the microturbine model is Capstone Model C65.

Process	Efficiency (% of Energy Input)	Notes
Electric Production	29%	Per Capstone Microturbine product sheet
Collectable Exhaust Heat	36%	After electric conversion, our design team estimates we will be able to recover half of the heat from the exhaust gas (without installing a very large heat exchanger)
Total	65%	Assumed efficiency for energy savings calculations

Assumption of this overall microturbine efficiency results in the following CHP plant capacity.

Natural Gas Input: 3,068 MBH
Electric Power Generation: 260 kW
Collectible Exhaust Heat: 1,100MBH

Operation and Cost-Savings

The team created an hourly demand load model for a typical day in every month of the year, modeling both building electric demand and heating demand. From that model, microturbine operation was assessed to determine a preliminary schedule and run times for each of the four microturbines in the plant. Graphical representation of the model is sampled in Figure 5 on the next page.

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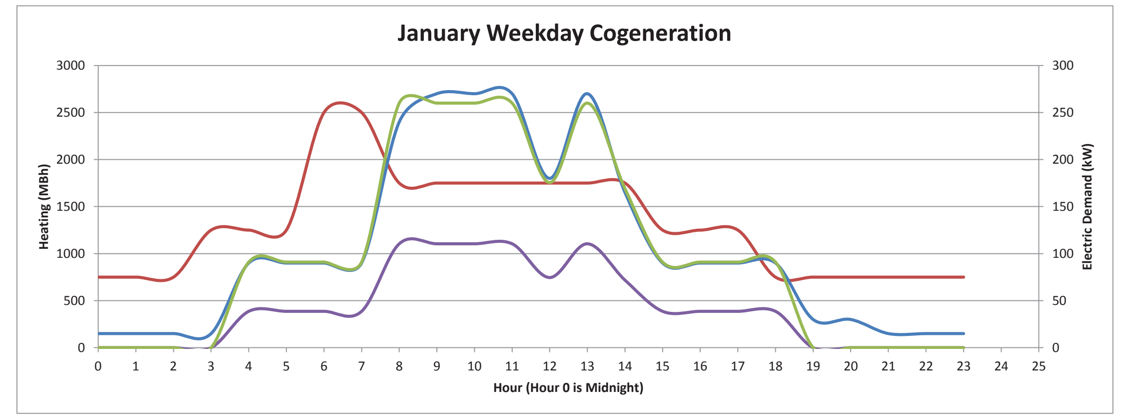

Figure 5: January Weekday Daily Load Profile Matched with Cogeneration

Legend:
Blue = Electric demand
Red = Building heating demand
Green = Electric generation from microturbine
Purple = Waste heat from microturbine

Use of this program was beneficial in realizing the limitations of our CHP use. It was decided to operate the microturbines only when both electric and heat demand are higher than microturbine output. Microturbines can then be staged as building loads increase and decrease. It was found that electricity was the limiting factor for microturbine operation during winter months, and heat was the limiting factor for summer months.

From these building load profiles and microturbine operation times, cost-savings of $50,000/year were predicted. These gross savings were then analyzed in a 25-year life cycle cost comparison to the same mechanical system with no CHP system. Refer to Page 19 of the Mechanical Supporting Documentation for information regarding the cost-savings calculation and life-cycle cost. The results of the life-cycle cost are summarized below in Table 12, with the CHP system resulting in a 10-year payback period assuming no governmental loans or grants are awarded to the system (Grants and loans have been awarded to very similar CHP designs in the past) [9].

Table 12: CHP System Payback Period Analysis

Year	Baseline NPV	Design NPV	Design Savings
0	$202,000.00	$530,500.00	-$328,500.00
1	$402,145.06	$688,613.21	-$286,468.15
2	$590,813.00	$837,743.00	-$246,929.99
3	$768,643.05	$978,386.38	-$209,743.33
4	$938,005.00	$1,112,332.46	-$174,327.46
5	$1,099,302.10	$1,239,900.16	-$140,598.06
6	$1,254,519.69	$1,362,589.60	-$108,069.91
7	$1,403,871.01	$1,480,576.11	-$76,705.10
8	$1,549,015.22	$1,595,114.55	-$46,099.33
9	$1,688,631.08	$1,705,232.28	-$16,601.20
10	$1,824,233.35	$1,812,074.86	$12,158.48
11	$1,954,633.03	$1,914,767.11	$39,865.92
12	$2,081,213.04	$2,014,354.80	$66,858.24
13	$2,202,903.45	$2,110,050.47	$92,852.98
14	$2,319,882.90	$2,201,998.97	$117,883.93
15	$2,433,356.33	$2,291,111.39	$142,244.94
16	$2,542,409.32	$2,376,714.85	$165,694.48
17	$2,647,205.57	$2,458,941.46	$188,264.11
18	$2,748,794.85	$2,538,584.91	$210,209.94
19	$2,846,395.75	$2,615,070.30	$231,325.45
20	$2,940,157.75	$2,688,517.78	$251,639.97
21	$3,030,225.15	$2,759,043.26	$271,181.90
22	$3,116,737.21	$2,826,758.46	$289,978.75
23	$3,199,828.28	$2,891,771.11	$308,057.17
24	$3,279,628.02	$2,954,185.05	$325,442.97
25	$3,356,895.44	$3,014,574.10	$342,321.33

Payback of CHP system WITHOUT government grants or loans (shown left):

10 years

Payback of CHP system WITH government grant (see page 9 of Construction Narrative):

3.4 years

Fuel escalation factors for lifecycle cost were collected from NIST "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2011".

Energy Performance

Energy performance of our overall building design was modeled in Trane TRACE700. A baseline energy model was constructed using Appendix G of ASHRAE Standard 90.1-2007 for comparison to our design. However, due to the complexity of our system design, our team was not comfortable with some of the reported energy use values that came from the software. Thus, the TRACE model was supplemented with some calculations performed outside the software. The values that came from those outside calculations were replaced in the energy cost budget shown below in Table 13 (in red).

Table 13: Energy Performance Comparison to ASHRAE Standard 90.1-2007 Baseline

Usage Type	Energy Type	90.1 Baseline VAV Energy (10^6 Btu/Yr)	Design DV/Radiant Energy (10^6 Btu/Yr)	% Design Better than Baseline
Lighting	Electricity	872.2	872.2	
Space Heating	Natural Gas	4543.4	3907.3	
Space Cooling	Electricity	996.0	698.4	
Pumps	Electricity	22.8	71.1	
Heat Rejection	Electricity	56.3	29.6	
Fans	Electricity	766.1	725.9	
Receptacles	Electricity	991.3	991.3	
Pool Heating	Natural Gas	253.4	253.4	
Yearly Electric Cost*		$ 130,697	$ 72,039	
Yearly Natural Gas Cost*		$ 42,920	$ 51,208	
Total Annual Cost		$ 173,617	$ 123,247	29.0 %

*Electricity priced at $0.12/kWh. Natural gas priced at $1.00/therm. Cogeneration savings based on schedule and efficiencies described later.

Space Heating Correction

The annual heating energy use value from the TRACE model was overly optimistic compared to the baseline model. After hand calculation analysis of enthalpy changes across the heating coils and radiant slabs (of both design and baseline case), it was found that our design was 14% more efficient than the baseline case.

Yearly Electric Cost Correction

The designed CHP system is predicted to save $50,000 annually in electric costs. Effects of the CHP system were not modeled in TRACE, so the savings were deducted from the annual electric cost calculated in the energy model.

$$\text{Yearly Electric Cost} = \$122{,}039 - \$50{,}000 = \$72{,}039$$

Yearly Natural Gas Cost Correction

While electricity costs were decreased from the CHP system, the natural gas consumption of our design is more than the TRACE energy model prediction. The TRACE model assumed a boiler of 80% efficiency. Energy will be collected from the natural gas microturbines at 65% efficiency. So, the natural gas consumption was multiplied by the following factor:

$$\text{Yearly Natural Gas Cost} = \$41{,}607 \times \frac{0.8 \text{ Boiler Efficiency}}{0.65 \text{ Microturbine Efficiency}} = \$51{,}208$$

h-Performance Elementary School
Reading, Pennsylvania

Conclusions

The ASCE Charles Pankow Foundation Architectural Engineering Student Competition provided our design team the opportunity to shape the future of the Reading community. By creating a learning space that is inviting, safe, and efficient, our design team hopes to inspire the next generation of the Reading community.

The mechanical system enhanced the learning and community spaces by adhering to the project goals:

1. Build a better Reading community through construction and implementation of the school program
2. Design the elementary school to high-performance standards
3. Utilize an integrated design approach to maximize quality, efficiency, and value of the final built product

To match the varied functions that the facility offers, the mechanical system is separated into activity-specific areas: Classrooms / Learning Areas, Community Areas, and Pool Area. This separation aligned with the various expected occupancies of the facility, allowing efficient operation of the system. The Community Areas and Pool Area are ventilated, heated, and cooled by an overhead mixing VAV system, while the Classrooms / Learning Areas are ventilated by a 100% outdoor air displacement ventilation (DV) system. Space heating and cooling for the Classrooms / Learning Areas is decoupled from ventilation loads, and is served through radiant heating floor slabs and radiant chilled ceiling panels, respectively.

The displacement ventilation provides indoor air quality improvements. According to research by the EPA, improved IAQ can positively affect academic performance, thus accomplishing a standard set by the first project goal. The low-velocity displacement ventilation, as well as some additional acoustical attenuation will provide an NC-30 rating or lower to all classroom spaces. These acoustical considerations are sensitive to the initiatives of the Collaborative for High Performance Schools, which suggest that students are negatively affected by high background noise levels, and therefore also meet the high performance standards set by the team in our second project goal [13].

The school will utilize three hot water boilers for heating demands, two chillers for cooling loads, and a combined heat and power system run by four natural gas microturbines. The combined heat and power system was a result of integration among all disciplines of the design team, and would not have been possible without transparency of building loads and cost data early in the design stage. The overall mechanical system will be 29% more energy efficient compared to the ASHRAE Standard 90.1 Baseline model, beating our third project goal of 20%.

References

[1] "Weather BIN Data." *ASHRAE Fundamentals*. Atlanta: ASHRAE, 2009.
[2] "Natatoriums". ASHRAE Applications. Atlanta: ASHRAE, 2011.
[3] http://doas.psu.edu/papers.html
[4] Jeong, Jae-Woen, and Mumma, Stan. "Designing a Dedicated Outdoor Air System with Ceiling Radiant Cooling Panels". ASHRAE Journal. October 2006.
[5] Novoselac, Atila, and Srebric, Jelena. "A Critical Review on the Performance and Design of Combined Cooled Ceiling and Displacement Ventilation Systems". Energy and Buildings. 2002.
[6] Bauman, Fred S., and Allan Daly. *Underfloor Air Distribution Design Guide*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2003.
[7] Price HVAC. "Radiant Panels RP Series Product Information". 2011.
[8] Capstone Turbine Corporation. "Capstone Product Catalog". Chatsworth, CA. 2010.
[9] Database of State Incentives for Renewables & Efficiency (DSIRE). "Pennsylvania State Incentives/Policies". http://www.dsireusa.org/incentives/index.cfm?re=0&ee=0&spv=0&st=0&srp=1&state=PA. 2012.
[10] ANSI/ASA S12.60-2010/Part 1
[11] Carrier Corporation. "Product Data for 39MN,MW03-110 Indoor and Weathertight Outdoor Air Handlers". 2012.
[12] http://www.epa.gov/iaq/schools/benefits.html
[13] "Planning." The Collaborative for High Performance Schools Best Practices Manual. Volume I. Sacramento, CA: 2006.

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Kyle Houser
Keith McMullen

CONSTRUCTION

Brian Blenner
Matthew Hoerner

List of Contents

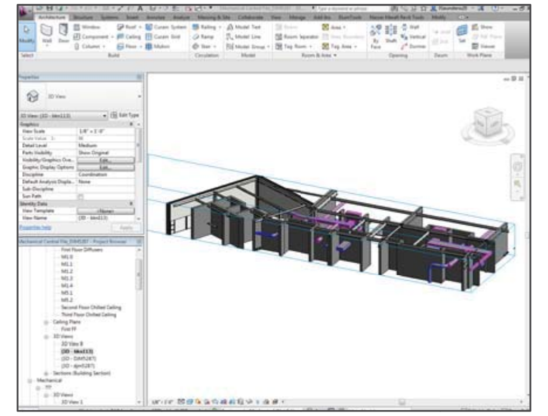
The following is included in the Mechanical Supporting documents.

Design Tools

The following software was used in our mechanical system design. The bullet points underneath each program detail what functions that program was used for.

Autodesk REVIT 2013

- BIM modeling – mechanical equipment, ductwork, and pipes



Trane TRACE700

- Energy modeling
- Load calculations
- ASHRAE 90.1 Appendix G baseline energy model comparison

Taco HVAC Design Solutions

- Hydronic system sizing and schematic visuals

Autodesk Green Building Studio

- Water use
- Energy model check

Trane TOPSS

- Mechanical equipment sizing – chillers, boilers

AIM Dynasonics Software

- Acoustical analysis

ASHRAE 62.1 2010: AHU 1 - WEST

ASHRAE 62.1 Occupancy Category	Area A_z (sf/zone)	People Outdoor Air Rate R_p (cfm/person)	Area Outdoor Air Rate R_a (cfm/sf)	Occupant Density P_z (#people)	Equation 6-1 Breathing Zone Outdoor Air Flow $V_{bz}=R_pP_z+R_aA_z$ (CFM)	Table 6-2 Zone Air Distribution Effectiveness E_z	Equation 6-2 Zone Outdoor Air Flow $V_{oz}=V_{bz}/E_z$ (CFM/unit)	30% Increase Outdoor Air Intake V_{oz} (CFM)	Design Supply Air (CFM)
Lobby	1870.00	5.00	0.06	20.00	212.20	1.2	176.83	229.88	1122
Corridor	975.00	0.00	0.06	0.00	58.50	1.2	48.75	63.38	585
Conference/meeting	540.00	5.00	0.06	15.00	107.40	1.2	89.50	116.35	324
Corridor	170.00	0.00	0.06	0.00	10.20	1.2	8.50	11.05	102
Storage, dry	61.00	5.00	0.06	1.00	8.66	1.2	7.22	9.38	37
Corridor	150.00	0.00	0.06	0.00	9.00	1.2	7.50	9.75	90
Computer (not printing)	100.00	5.00	0.06	1.00	11.00	1.2	9.17	11.92	60
Office space	155.00	5.00	0.06	2.00	19.30	1.2	16.08	20.91	93
Media center	1900.00	10.00	0.12	50.00	728.00	1.2	606.67	788.67	1140
Media center	390.00	10.00	0.12	4.00	86.80	1.2	72.33	94.03	234
Art classroom	40.00	10.00	0.18	1.00	17.20	1.2	14.33	18.63	24
Art classroom	1115.00	10.00	0.18	27.00	470.70	1.2	392.25	509.93	669
Cafeteria/fast-food dining	535.00	7.50	0.18	10.00	171.30	1.2	142.75	185.58	321
Classroom	1000.00	10.00	0.12	20.00	320.00	1.2	266.67	346.67	600
Storage, dry	15.00	5.00	0.06	1.00	5.90	1.2	4.92	6.39	9
Lobby	1850.00	5.00	0.06	20.00	211.00	1.2	175.83	228.58	1110
Corridor	970.00	0.00	0.06	0.00	58.20	1.2	48.50	63.05	582
Office space	100.00	5.00	0.06	2.00	16.00	1.2	13.33	17.33	60
Conference/meeting	185.00	5.00	0.06	6.00	41.10	1.2	34.25	44.53	111
Computer (not printing)	230.00	5.00	0.06	0.00	13.80	1.2	11.50	14.95	138
Corridor	170.00	0.00	0.06	0.00	10.20	1.2	8.50	11.05	102
Storage, dry	60.00	5.00	0.06	1.00	8.60	1.2	7.17	9.32	36
Corridor	150.00	0.00	0.06	0.00	9.00	1.2	7.50	9.75	90
Computer (not printing)	100.00	5.00	0.06	0.00	6.00	1.2	5.00	6.50	60
Office space	155.00	5.00	0.06	2.00	19.30	1.2	16.08	20.91	93
Classroom	830.00	10.00	0.12	27.00	369.60	1.2	308.00	400.40	498
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	480
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	480
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	480
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	480
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	480
Corridor	60.00	0.00	0.06	0.00	3.60	1.2	3.00	3.90	36
Corridor	35.00	0.00	0.06	0.00	2.10	1.2	1.75	2.28	21
Corridor	40.00	0.00	0.06	0.00	2.40	1.2	2.00	2.60	24
Corridor	60.00	0.00	0.06	0.00	3.60	1.2	3.00	3.90	36
Corridor	35.00	0.00	0.06	0.00	2.10	1.2	1.75	2.28	21
	18,046.00			**345.00**	**4,842.76**		**4,035.63**	**5,246.32**	**10,827.60**

UNITUS
designing for people
enhancing environment
BUILDING TO UNITE U

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STRUCTURAL
Eric Co
Devon Saunde

MECHANICAL
Daniel McG
Brittany Not

LIGHTING / ELECTRICAL
Kyle Hous
Keith McMulle

CONSTRUCTION
Brian Blenn
Matthew Hoerner

ASHRAE 62.1 2010: AHU 2 - CENTRAL

ASHRAE 62.1 Occupancy Category	Area A_z (sf/zone)	People Outdoor Air Rate R_p (cfm/person)	Area Outdoor Air Rate R_a (cfm/sf)	Occupant Density P_z (#people)	Equation 6-1 Breathing Zone Outdoor Air Flow $V_{bz}=R_pP_z+R_aA_z$ (CFM)	Table 6-2 Zone Air Distribution Effectiveness E_z	Equation 6-2 Zone Outdoor Air Flow $V_{oz}=V_{bz}/E_z$ (CFM/unit)	30% Increase Uncorrected Outdoor Air Intake V_{oz} (CFM)	Design Supply Air (CFM)
Classroom	814.00	10.00	0.12	33.00	427.68	1.2	356.40	463.32	463
Classroom	815.00	10.00	0.12	33.00	427.80	1.2	356.50	463.45	463
Classroom	817.00	10.00	0.12	33.00	428.04	1.2	356.70	463.71	464
Storage, dry	253.00	5.00	0.06	1.00	20.18	1.2	16.82	21.86	22
Corridor	65.00	0.00	0.06	0.00	3.90	1.2	3.25	4.23	4
Classroom	822.00	10.00	0.12	33.00	428.64	1.2	357.20	464.36	464
Classroom	812.00	10.00	0.12	33.00	427.44	1.2	356.20	463.06	463
Classroom	816.00	10.00	0.12	33.00	427.92	1.2	356.60	463.58	464
Classroom	821.00	10.00	0.12	33.00	428.52	1.2	357.10	464.23	464
Corridor	1575.00	0.00	0.06	0.00	94.50	1.2	78.75	102.38	102
Corridor	650.00	0.00	0.06	0.00	39.00	1.2	32.50	42.25	42
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Office space	240.00	5.00	0.06	6.00	44.40	1.2	37.00	48.10	48
Corridor	50.00	0.00	0.06	0.00	3.00	1.2	2.50	3.25	3
Corridor	70.00	0.00	0.06	0.00	4.20	1.2	3.50	4.55	5
Classroom	1000.00	10.00	0.12	20.00	320.00	1.2	266.67	346.67	347
Corridor	45.00	0.00	0.06	0.00	2.70	1.2	2.25	2.93	3
Classroom	990.00	10.00	0.12	20.00	318.80	1.2	265.67	345.37	345
Corridor	45.00	0.00	0.06	0.00	2.70	1.2	2.25	2.93	3
Classroom	1000.00	10.00	0.12	20.00	320.00	1.2	266.67	346.67	347
Corridor	45.00	0.00	0.06	0.00	2.70	1.2	2.25	2.93	3
Classroom	1000.00	10.00	0.12	20.00	320.00	1.2	266.67	346.67	347
Corridor	40.00	0.00	0.06	0.00	2.40	1.2	2.00	2.60	3
Corridor	500.00	0.00	0.06	0.00	30.00	1.2	25.00	32.50	33
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Storage, dry	240.00	5.00	0.06	1.00	19.40	1.2	16.17	21.02	21
Corridor	70.00	0.00	0.06	0.00	4.20	1.2	3.50	4.55	5
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
Classroom	800.00	10.00	0.12	18.00	276.00	1.2	230.00	299.00	299
	21,595.00			**580.00**	**8,118.12**		**6,765.10**	**8,794.63**	**8,794.63**

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ASHRAE 62.1 2010: AHU 3 - EAST

Room Name	ASHRAE 62.1 Occupancy Category	Area A_z (sf/zone)	People Outdoor Air Rate R_p (cfm/person)	Area Outdoor Air Rate R_a (cfm/sf)	Occupant Density P_z (#people)	Equation 6-1 Breathing Zone Outdoor Air Flow $V_{bz}=R_pP_z+R_aA_z$ (CFM)	Table 6-2 Zone Air Distribution Effectiveness E_z	Equation 6-2 Zone Outdoor Air Flow $V_{oz}=V_{bz}/E_z$ (CFM/unit)	30% Increase Uncorrected Outdoor Air Intake V_{oz} (CFM)	Design Supply Air (CFM)
AL ED	Classroom	988.00	10.00	0.12	25.00	368.56	1.2	307.13	399.27	399
	Corridor	70.00	0.00	0.06	0.00	4.20	1.2	3.50	4.55	5
	Corridor	46.00	0.00	0.06	0.00	2.76	1.2	2.30	2.99	3
	Corridor	114.00	0.00	0.06	0.00	6.84	1.2	5.70	7.41	7
DIAN	Storage, dry	65.00	5.00	0.06	1.00	8.90	1.2	7.42	9.64	10
	Corridor	114.00	0.00	0.06	0.00	6.84	1.2	5.70	7.41	7
	Corridor	51.00	0.00	0.06	0.00	3.06	1.2	2.55	3.32	3
DOR	Corridor	479.00	0.00	0.06	0.00	28.74	1.2	23.95	31.14	31
ERENCE	Conference/meeting	211.00	5.00	0.06	8.00	52.66	1.2	43.88	57.05	57
ITY	Office space	70.00	5.00	0.06	1.00	9.20	1.2	7.67	9.97	10
DOR	Corridor	555.00	0.00	0.06	0.00	33.30	1.2	27.75	36.08	36
DOR	Corridor	561.00	0.00	0.06	0.00	33.66	1.2	28.05	36.47	36
ROOM	Classroom	817.00	10.00	0.12	32.00	418.04	1.2	348.37	452.88	453
TENANCE	Storage, dry	206.00	5.00	0.06	1.00	17.36	1.2	14.47	18.81	19
	Computer (not printing)	67.00	5.00	0.06	0.00	4.02	1.2	3.35	4.36	4
ROOM	Classroom	822.00	10.00	0.12	32.00	418.64	1.2	348.87	453.53	454
ROOM	Classroom	822.00	10.00	0.12	32.00	418.64	1.2	348.87	453.53	454
ERENCE	Conference/meeting	84.00	5.00	0.06	5.00	30.04	1.2	25.03	32.54	33
DOR	Corridor	1060.00	0.00	0.06	0.00	63.60	1.2	53.00	68.90	69
AL EDUCATION	Classroom	987.00	10.00	0.12	18.00	298.44	1.2	248.70	323.31	323
	Corridor	70.00	0.00	0.06	0.00	4.20	1.2	3.50	4.55	5
	Corridor	115.00	0.00	0.06	0.00	6.90	1.2	5.75	7.48	7
	Corridor	45.00	0.00	0.06	0.00	2.70	1.2	2.25	2.93	3
DIAN	Storage, dry	65.00	5.00	0.06	1.00	8.90	1.2	7.42	9.64	10
	Corridor	115.00	0.00	0.06	0.00	6.90	1.2	5.75	7.48	7
	Corridor	50.00	0.00	0.06	0.00	3.00	1.2	2.50	3.25	3
DOR	Corridor	170.00	0.00	0.06	0.00	10.20	1.2	8.50	11.05	11
DOR	Corridor	530.00	0.00	0.06	0.00	31.80	1.2	26.50	34.45	34
ROOM	Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
ROM-K	Classroom	1050.00	10.00	0.12	20.00	326.00	1.2	271.67	353.17	353
	Corridor	50.00	0.00	0.06	1.00	3.00	1.2	2.50	3.25	3
ROOM	Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
ROOM	Classroom	800.00	10.00	0.12	27.00	366.00	1.2	305.00	396.50	397
DOR	Corridor	1000.00	0.00	0.06	0.00	60.00	1.2	50.00	65.00	65
	Corridor	71.00	0.00	0.06	0.00	4.26	1.2	3.55	4.62	5
	Corridor	90.00	0.00	0.06	0.00	5.40	1.2	4.50	5.85	6
	Corridor	40.00	0.00	0.06	0.00	2.40	1.2	2.00	2.60	3
DIAN	Storage, dry	20.00	5.00	0.06	1.00	6.20	1.2	5.17	6.72	7
	Corridor	90.00	0.00	0.06	0.00	5.40	1.2	4.50	5.85	6
	Corridor	40.00	0.00	0.06	0.00	2.40	1.2	2.00	2.60	3
DOR	Corridor	125.00	0.00	0.06	0.00	7.50	1.2	6.25	8.13	8
AL EDUCATION	Classroom	990.00	10.00	0.12	18.00	298.80	1.2	249.00	323.70	324
		15,315.00			**277.00**	**4,121.46**		**3,434.55**	**4,464.92**	**4,464.92**

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ASHRAE 62.1 2010: AHU 4 - COMMUNITY

)	Area Outdoor Air Rate R_a (cfm/sf)	Occupant Density P_z (#people)	Equation 6-1 Breathing Zone Outdoor Air Flow $V_{bz}=R_pP_z+R_aA_z$ (CFM)	Table 6-2 Zone Air Distribution Effectiveness E_z	Equation 6-2 Zone Outdoor Air Flow $V_{oz}=V_{bz}/E_z$ (CFM/unit)	30% Increase Uncorrected Outdoor Air Intake V_{oz} (CFM)	Zone Primary Air Flow V_{pz} (CFM)	Equation 6-5 Primary Outdoor Air Fraction $Z_p=V_{oz}/V_{pz}$	Table 6-3 System Ventilation Efficiency E_v	Estimated Peak Population P_s	Equation 6-6 Uncorrected Outdoor Air Intake V_{ou} (CFM)	Equation 6-8 Outdoor Air Intake $V_{ot}=V_{ou}/E_v$ (CFM/zone)	Minimum Design OA Intake
00	0.06	0.00	44.88	0.8	56.10	72.93	146	0.50	0.6	0.00	56.10	93.50	94
00	0.06	0.00	88.20	0.8	110.25	143.33	287	0.50	0.6	0.00	110.25	183.75	184
50	0.06	30.00	290.94	0.8	363.68	472.78	946	0.50	0.6	30.00	472.78	787.96	788
00	0.06	1.00	17.78	0.8	22.23	28.89	58	0.50	0.6	1.00	28.89	48.15	48
50	0.06	1.00	23.16	0.8	28.95	37.64	75	0.50	0.6	1.00	37.64	62.73	63
00	0.06	2.00	24.34	0.8	30.43	39.55	79	0.50	0.6	2.00	30.43	50.71	51
00	0.06	4.00	40.40	0.8	50.50	65.65	131	0.50	0.6	4.00	50.50	84.17	84
00	0.06	7.00	49.04	0.8	61.30	79.69	159	0.50	0.6	7.00	61.30	102.17	102
00	0.06	8.00	48.94	0.8	61.18	79.53	159	0.50	0.6	8.00	61.18	101.96	102
00	0.06	0.00	4.14	0.8	5.18	6.73	13	0.50	0.6	0.00	5.18	8.63	9
00	0.06	2.00	27.94	0.8	34.93	45.40	91	0.50	0.6	2.00	34.93	58.21	58
00	0.06	0.00	13.92	0.8	17.40	22.62	45	0.50	0.6	0.00	17.40	29.00	29
00	0.06	0.00	10.26	0.8	12.83	16.67	33	0.50	0.6	0.00	12.83	21.38	21
00	0.06	1.00	8.66	0.8	10.83	14.07	28	0.50	0.6	1.00	10.83	18.04	18
00	0.06	0.00	8.76	0.8	10.95	14.24	28	0.50	0.6	0.00	10.95	18.25	18
00	0.06	1.00	11.18	0.8	13.98	18.17	36	0.50	0.6	1.00	13.98	23.29	23
00	0.06	8.00	59.50	0.8	74.38	96.69	193	0.50	0.6	8.00	74.38	123.96	124
00	0.06	1.00	11.00	0.8	13.75	17.88	36	0.50	0.6	1.00	13.75	22.92	23
00	0.18	5.00	69.62	0.8	87.03	113.13	226	0.50	0.6	5.00	87.03	145.04	145
00	0.18	5.00	87.62	0.8	109.53	142.38	285	0.50	0.6	5.00	109.53	182.54	183
00	0.06	0.00	4.98	0.8	6.23	8.09	16	0.50	0.6	0.00	6.23	10.38	10
00	0.06	1.00	29.54	0.8	36.93	48.00	96	0.50	0.6	1.00	36.93	61.54	62
00	0.06	1.00	14.18	0.8	17.73	23.04	46	0.50	0.6	1.00	23.04	38.40	38
00	0.06	0.00	4.68	0.8	5.85	7.61	15	0.50	0.6	0.00	7.61	12.68	13
00	0.06	0.00	6.24	0.8	7.80	10.14	20	0.50	0.6	0.00	10.14	16.90	17
00	0.06	0.00	13.74	0.8	17.18	22.33	45	0.50	0.6	0.00	22.33	37.21	37
00	0.06	1.00	9.56	0.8	11.95	15.54	31	0.50	0.6	1.00	15.54	25.89	26
00	0.06	1.00	12.50	0.8	15.63	20.31	41	0.50	0.6	1.00	20.31	33.85	34
50	0.12	35.00	460.26	0.8	575.33	747.92	1496	0.50	0.6	35.00	747.92	1246.54	1247
00	0.06	1.00	30.38	0.8	37.98	49.37	99	0.50	0.6	1.00	49.37	82.28	82
00	0.06	40.00	250.10	0.8	312.63	406.41	813	0.50	0.6	40.00	312.63	521.04	521
50	0.06	200.00	1679.16	0.8	2098.95	2728.64	5457	0.50	0.6	200.00	2728.64	4547.73	4548
50	0.06	200.00	1679.10	0.8	2098.88	2728.54	5457	0.50	0.6	200.00	2728.54	4547.56	4548
00	0.06	0.00	2.04	0.8	2.55	3.32	7	0.50	0.6	0.00	2.55	4.25	4
00	0.06	0.00	2.04	0.8	2.55	3.32	7	0.50	0.6	0.00	2.55	4.25	4
00	0.06	0.00	216.00	0.8	270.00	351.00	702	0.50	0.6	0.00	351.00	585.00	585
00	0.06	0.00	36.00	0.8	45.00	58.50	117	0.50	0.6	0.00	58.50	97.50	98
00	0.06	0.00	30.00	0.8	37.50	48.75	98	0.50	0.6	0.00	48.75	81.25	81
		556.00	**5,420.78**		**6,775.98**	**8,808.77**	**17,617.54**			**556.00**	**8,472.36**	**14,120.59**	**14,120.59**

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HVAC System Selecti
Combined Heat and Pow
Energy Performan
CFD Modelin
Acousti
Lessons Learn
Conclusio

STRUCTURAL

Eric Co
Devon Saunde

MECHANICAL

Daniel McG
Brittany No

LIGHTING / ELECTRICAL

Kyle Hous
Keith McMulle

CONSTRUCTION

Brian Blenn
Matthew Hoerner

e Cooling			Radiant Ceiling Cooling				
w	Supply Airflow Temperature (F)	Air-side Cooling Capacity (Btu/hr)	Fraction of Ceiling With Radiant Panels	Radiant Ceiling Panel Area (SF)	Cooling Capacity of Ceiling Panels (BTH/HR/SF Panel)	Total Cooling Capacity of Radiant Ceiling (BTU/HR)	Capacity Meets Load?
.00	65.00	12117.6		0.00		0.00	YES
.00	65.00	6318		0.00		0.00	YES
.00	65.00	3499.2	0.70	378.00	38.00	14364.00	YES
.00	65.00	1101.6		0.00		0.00	YES
.60	65.00	395.28		0.00		0.00	YES
.00	65.00	972		0.00		0.00	YES
.00	65.00	648		0.00		0.00	YES
.00	65.00	1004.4	0.70	108.50	38.00	4123.00	YES
.00	65.00	12312	0.70	1330.00	38.00	50540.00	YES
.00	65.00	2527.2	0.70	273.00	38.00	10374.00	YES
.00	65.00	259.2		0.00		0.00	YES
.00	65.00	7225.2	0.70	780.50	38.00	29659.00	YES
.00	65.00	3466.8	0.70	374.50	38.00	14231.00	YES
.00	65.00	6480	0.70	700.00	38.00	26600.00	YES
.00	65.00	97.2		0.00		0.00	YES
.00	65.00	11988		0.00		0.00	YES
.00	65.00	6285.6		0.00		0.00	YES
.00	65.00	648	0.70	70.00	38.00	2660.00	YES
.00	65.00	1198.8	0.70	129.50	38.00	4921.00	YES
.00	65.00	1490.4	0.70	161.00	38.00	6118.00	YES
.00	65.00	1101.6		0.00		0.00	YES
.00	65.00	388.8		0.00		0.00	YES
.00	65.00	972		0.00		0.00	YES
.00	65.00	648		0.00		0.00	YES
.00	65.00	1004.4	0.70	108.50	38.00	4123.00	YES
.00	65.00	5378.4	0.70	581.00	38.00	22078.00	YES
.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	65.00	388.8		0.00		0.00	YES
.00	65.00	226.8		0.00		0.00	YES
.00	65.00	259.2		0.00		0.00	YES
.00	65.00	388.8		0.00		0.00	YES
.00	65.00	226.8		0.00		0.00	YES
60	**2,340.00**		**11.90**	**7,794.50**			**0.00**

ir-Side Cooling			Radiant Ceiling Cooling				
Airflow FM)	Supply Airflow Temperature (F)	Air-side Cooling Capacity (Btu/hr)	Fraction of Ceiling With Radiant Panels	Radiant Ceiling Panel Area (SF)	Cooling Capacity of Ceiling Panels (BTH/HR/SF Panel)	Total Cooling Capacity of Radiant Ceiling (BTU/HR)	Capacity Meets Load?
488.40	65.00	5274.72	0.70	569.80	38.00	21652.40	YES
489.00	65.00	5281.2	0.70	570.50	38.00	21679.00	YES
490.20	65.00	5294.16	0.70	571.90	38.00	21732.20	YES
151.80	65.00	1639.44		0.00		0.00	YES
39.00	65.00	421.2		0.00		0.00	YES
493.20	65.00	5326.56	0.70	575.40	38.00	21865.20	YES
487.20	65.00	5261.76	0.70	568.40	38.00	21599.20	YES
489.60	65.00	5287.68	0.70	571.20	38.00	21705.60	YES
492.60	65.00	5320.08	0.70	574.70	38.00	21838.60	YES
945.00	65.00	10206		0.00		0.00	YES
390.00	65.00	4212		0.00		0.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
144.00	65.00	1555.2	0.70	168.00	38.00	6384.00	YES
30.00	65.00	324		0.00		0.00	YES
42.00	65.00	453.6		0.00		0.00	YES
600.00	65.00	6480	0.70	700.00	38.00	26600.00	YES
27.00	65.00	291.6		0.00		0.00	YES
594.00	65.00	6415.2	0.70	693.00	38.00	26334.00	YES
27.00	65.00	291.6		0.00		0.00	YES
600.00	65.00	6480	0.70	700.00	38.00	26600.00	YES
27.00	65.00	291.6		0.00		0.00	YES
600.00	65.00	6480	0.70	700.00	38.00	26600.00	YES
24.00	65.00	259.2		0.00		0.00	YES
300.00	65.00	3240		0.00		0.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
144.00	65.00	1555.2		0.00		0.00	YES
42.00	65.00	453.6		0.00		0.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
2,957.00	**2,275.00**		**15.40**	**12,562.90**			**0.00**

	Air-Side Cooling				Radiant Ceiling Cooling				
(F)	Airflow per Area (CFM/SF)	Total Airflow (CFM)	Supply Airflow Temperature (F)	Air-side Cooling Capacity (Btu/hr)	Fraction of Ceiling With Radiant Panels	Radiant Ceiling Panel Area (SF)	Cooling Capacity of Ceiling Panels (BTH/HR/SF Panel)	Total Cooling Capacity of Radiant Ceiling (BTU/HR)	Capacity Meets Load?
.00	0.6	592.80	65.00	6402.24	0.70	691.60	38.00	26280.80	YES
.00	0.6	42.00	65.00	453.6		0.00	38.00	0.00	YES
.00	0.6	27.60	65.00	298.08		0.00	38.00	0.00	YES
.00	0.6	68.40	65.00	738.72		0.00	38.00	0.00	YES
.00	0.6	39.00	65.00	421.2		0.00	38.00	0.00	YES
.00	0.6	68.40	65.00	738.72		0.00	38.00	0.00	YES
.00	0.6	30.60	65.00	330.48		0.00	38.00	0.00	YES
.00	0.6	287.40	65.00	3103.92		0.00	38.00	0.00	YES
.00	0.6	126.60	65.00	1367.28	0.70	147.70	38.00	5612.60	YES
.00	0.6	42.00	65.00	453.6	0.70	49.00	38.00	1862.00	YES
.00	0.6	333.00	65.00	3596.4		0.00	38.00	0.00	YES
.00	0.8	448.80	65.00	4847.04		0.00	38.00	0.00	YES
.00	0.6	490.20	65.00	5294.16	0.70	571.90	38.00	21732.20	YES
.00	0.6	123.60	65.00	1334.88		0.00	38.00	0.00	YES
.00	0.6	40.20	65.00	434.16		0.00	38.00	0.00	YES
.00	0.6	493.20	65.00	5326.56	0.70	575.40	38.00	21865.20	YES
.00	0.6	493.20	65.00	5326.56	0.70	575.40	38.00	21865.20	YES
.00	0.6	50.40	65.00	544.32	0.70	58.80	38.00	2234.40	YES
.00	0.6	636.00	65.00	6868.8		0.00	38.00	0.00	YES
.00	0.6	594.00	65.00	6415.2	0.70	693.00	38.00	26334.00	YES
.00	0.6	42.00	65.00	453.6		0.00	38.00	0.00	YES
.00	0.6	69.00	65.00	745.2		0.00	38.00	0.00	YES
.00	0.6	27.00	65.00	291.6		0.00	38.00	0.00	YES
.00	0.6	39.00	65.00	421.2		0.00	38.00	0.00	YES
.00	0.6	69.00	65.00	745.2		0.00	38.00	0.00	YES
.00	0.6	30.00	65.00	324		0.00	38.00	0.00	YES
.00	0.6	102.00	65.00	1101.6		0.00	38.00	0.00	YES
.00	0.6	318.00	65.00	3434.4		0.00	38.00	0.00	YES
.00	0.6	480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	0.6	630.00	65.00	6804	0.70	735.00	38.00	27930.00	YES
.00	0.6	30.00	65.00	324		0.00	38.00	0.00	YES
.00	0.6	480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	0.6	480.00	65.00	5184	0.70	560.00	38.00	21280.00	YES
.00	0.6	600.00	65.00	6480		0.00	38.00	0.00	YES
.00	0.6	42.60	65.00	460.08		0.00	38.00	0.00	YES
.00	0.6	54.00	65.00	583.2		0.00	38.00	0.00	YES
.00	0.6	24.00	65.00	259.2		0.00	38.00	0.00	YES
.00	0.6	12.00	65.00	129.6		0.00	38.00	0.00	YES
.00	0.6	54.00	65.00	583.2		0.00	38.00	0.00	YES
.00	0.6	24.00	65.00	259.2		0.00	38.00	0.00	YES
.00	0.6	75.00	65.00	810		0.00	38.00	0.00	YES
.00	0.6	594.00	65.00	6415.2	0.70	693.00	38.00	26334.00	YES
		9,303.00	**2,730.00**		**9.10**	**6,470.80**			**0.00**

Pool Evaporation

From ASHRAE Applications Chapter 5:

Load Estimation

Loads for a natatorium include heat gains and losses from outdoor air, lighting, walls, roof, and glass. Internal latent loads are generally from people and evaporation. Evaporation loads in pools and spas are significant relative to other load elements and may vary widely depending on pool features, areas of water and wet deck, water temperature, and activity level in the pool.

Evaporation. The rate of evaporation can be estimated from empirical Equation (1). This equation is valid for pools at normal activity levels, allowing for splashing and a limited area of wetted deck. Other pool uses may have more or less evaporation (Smith et al. 1993).

$$w_p = \frac{A}{Y}(p_w - p_a)(95 + 0.425\ V) \qquad (1)$$

where

w_p = evaporation of water, lb/h
A = area of pool surface, ft^2
Y = latent heat required to change water to vapor at surface water temperature, Btu/lb
p_w = saturation vapor pressure taken at surface water temperature, in. Hg
p_a = saturation pressure at room air dew point, in. Hg
V = air velocity over water surface, fpm

Units for the constant 95 are Btu/(h · ft^2 · in. Hg). Units for the constant 0.425 are Btu · min/(h · ft^3 · in. Hg).

For the designed pool:

A = ~4000 SF
Y = 900 btu/lb
P_w = 1.04 inHg
P_a = 0.745 inHg
V = 30 fpm

Substituting into eq (1):

W_p = 141.27 lb/hr

Finally,

$$q = 141.27\frac{lb}{hr} \times 1150\frac{btu}{lb} = 162{,}500\frac{btu}{hr}$$

School Water Consumption

A basic analysis of water consumption was calculated through the use of Green Building Studio. The program can calculate the water consumption based on building square footage or fixtures may be inputted manually. The following fixture schedule is based on the building's current state. The shower count may increase with the demands of the pool.

Fixture Schedule			
Fixture	Total	Male	Female
Toilets	59	15	44
Urinals	9	9	
Sinks	85	42	43
Showers	10	4	6

The next table details the elementary school's water usage assuming standard flow fixtures and typical outdoor irrigation.

Water Usage with Standard Fixtures		
Total	2,531,700 Gal/yr	$15,333/yr
Indoor	2,514,600 Gal/yr	$15,289/yr
Outdoor	17,100 Gal/yr	$44/yr
Net Utility	2,531,700 Gal/yr	$15,333/yr

By introducing low-flow fixtures, water efficiency increases by 16%, totaling to a $2,447 annual cost savings.

Fixture Schedule					Efficiency Savings		
Fixture	Total	Male	Female	Efficiency	% of Indoor Usage	Gal/yr	Annual Cost Savings
Toilets	59	15	44	Low-Flow	9.6%	242,015	$1,471
Urinals	9	9		Low-Flow	4.8%	120,410	$732
Sinks	85	42	43	Low-Flow	1.1%	28,779	$175
Showers	10	4	6	Low-Flow	0.4%	11,230	$68
				Total Efficiency Savings	16%	402,434	$2,447

Water Usage with Low-Flow Fixtures		
Total	2,129,266 Gal/yr	$12,886/yr
Indoor	2,112,166 Gal/yr	$12,842/yr
Outdoor	17,100 Gal/yr	$44/yr
Net Utility	2,129,266 Gal/yr	$12,886/yr

Waterless urinals and hands-free sinks introduce an opportunity for greater efficiencies.

Fixture Schedule					Efficiency Savings		
Fixture	Total	Male	Female	Efficiency	% of Indoor Usage	Gal/yr	Annual Cost Savings
Toilets	59	15	44	Low-Flow	9.6%	242,015	$1,471
Urinals	9	9		Waterless	9.6%	240,820	$1,464
Sinks	85	42	43	Hands-Free	1.2%	29,163	$177
Showers	10	4	6	Low-Flow	0.4%	11,230	$68
				Total Efficiency Savings	20.8%	523,228	$3,181

Water Usage with Hands-Free and Waterless Fixtures		
Total	2,008,472 Gal/yr	$12,152/yr
Indoor	1,991,372 Gal/yr	$12,108/yr
Outdoor	17,100 Gal/yr	$44/yr
Net Utility	2,008,472 Gal/yr	$12,152/yr

A rainwater harvesting system will provide environmental and economic benefits. A preliminary study was conducted to anticipate the annual catchment volume of a rainwater harvesting system with varying surface types. In this particular study, the catchment area is noted to be 7,811 square feet, which is the roof area above the gymnasium. We understand that this area has potential to increase.

Net-Zero Measures			Net-Zero Savings		
	Annual Rainfall	Catchment Area	Surface Type	Gal/yr	Annual Cost Savings
Rainwater Harvesting	44.82 in	7,811	Gravel/Tar	174,578	$454
Rainwater Harvesting	44.82 in	7,811	Concrete/Asphalt	196,400	$511
Rainwater Harvesting	44.82 in	7,811	Metal	207,311	$539

The above tables will provide a competent comparison of systems to organize a cost analysis that will be pertinent in choosing the best fixtures and net-zero systems in terms of water usage.

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enhancing environments
BUILDING TO UNITE US

STRUCTURAL

Eric Cook
Devon Saunders

MECHANICAL

Daniel McGee
Brittany Notor

LIGHTING / ELECTRICAL

Kyle Houser
Keith McMullen

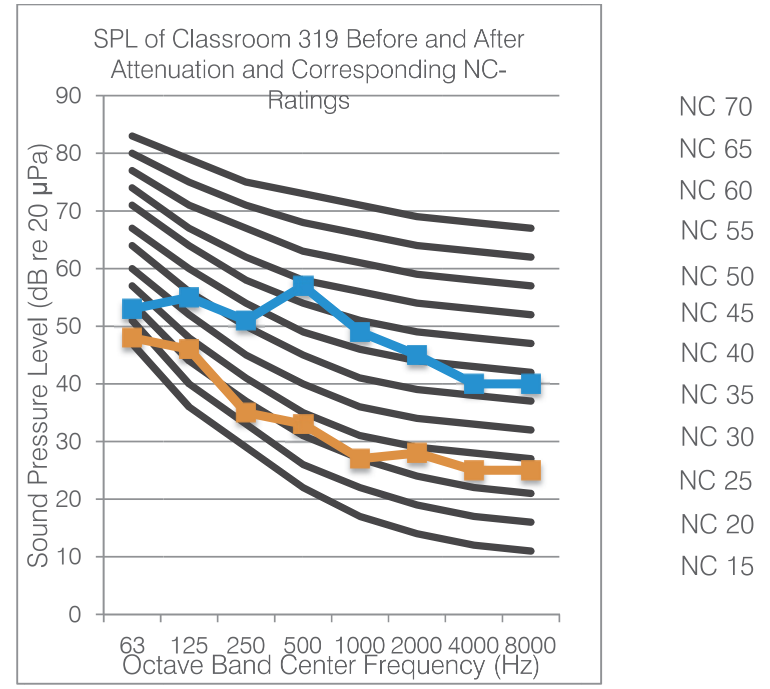
CONSTRUCTION

Brian Blenner
Matthew Hoerner

Acoustics

The Central Air Handling Unit, highlighted in orange, threatens the acoustical integrity of Classroom 319, as explained on Page 16 of the Mechanical Narrative. The figure below summarizes the duct route traced from the Central Air Handling Unit to Classroom 319. The area highlighted in yellow will be the location of the duct silencer, which is necessary to ensure a reasonable classroom NC-rating.

The following graph summarizes the decrease in sound pressure level once the duct run to Classroom 319 was treated with the aforementioned silencer.



LEED Certification

The proposed design is applying for LEED Gold certification under the LEED 2009 for Schools New Construction and Major Renovations.

Sustainable Sites 15 / 24

While the building site posed challenges to our team with respect to construction logistics and security, the urban setting of the site allowed us to claim many of the credits in the Sustainable Sites category. The proposed green roof, rainwater collection, and local vegetation plan also helped us claim credits in this category.

Credit 1	Site Selection	1 Point
Credit 2	Development Density and Community Connectivity	4 Points
Credit 3	Brownfield Redevelopment	1 Point
Credit 4.1	Alternative Transportation – Public Transportation Access	4 Points
Credit 4.2	Alternative Transportation – Bicycle Storage and Changing Rooms	1 Point
Credit 6.1	Stormwater Design – Quantity Control	1 Point
Credit 6.2	Stormwater Design – Quality Control	1 Point
Credit 7.2	Heat Island Effect – Roof	1 Point
Credit 10	Joint Use of Facilities	1 Point

Water Efficiency 8/11

The points claimed in the Water Efficiency section are due to the green roof, rainwater collection, and low-flow plumbing fixtures designed in our school.

Credit 1	Water Efficient Landscaping Option 2	4 Points
Credit 2	Innovative Wastewater Technologies	2 Points
Credit 3	Water Use Reduction – 30% Reduction	2 Points

Energy and Atmosphere 15/33

The majority of the points we are claiming in Energy and Atmosphere stem from the efficiencies of our system and equipment selection and our cogeneration plant. A commissioning plan will also be established to claim the points in Enhanced Commissioning and Measurement and Verification.

Credit 1	Optimize Energy Performance – 30% Improvement	10 Points
Credit 3	Enhanced Commissioning	2 Points
Credit 4	Enhanced Refrigerant Management	1 Point
Credit 5	Measurement and Verification	2 Points

Materials and Resources 5/13

An enhanced construction waste recycling plan and use of recycled and local materials constitute the majority of the points in this category.

Credit 2	Construction Waste Management – 50% Recycled or Salvaged	1 Point
Credit 4	Recycled Content – 10% of Content	1 Point
Credit 5	Regional Materials – 20% of Materials	2 Points
Credit 7	Certified Wood	1 Point

Indoor Environmental Quality 16/19

Indoor Environmental Quality was a large factor in our design. Many of the points in this category are claimed from the increased indoor air and thermal quality of the mechanical system.

Credit 2	Increased Ventilation	1 Point
Credit 3.1	Construction IAQ Management Plan – During Construction	1 Point
Credit 4	Low-Emitting Materials	4 Points
Credit 5	Indoor Chemical and Pollutant Source Control	1 Point
Credit 6.1	Controllability of Systems – Lighting	1 Point
Credit 6.2	Controllability of Systems – Thermal Comfort	1 Point
Credit 7.1	Thermal Comfort – Design	1 Point
Credit 7.2	Thermal Comfort – Verification	1 Point
Credit 8.1	Daylight and Views – Daylight – 90% of Classrooms	2 Points
Credit 9	Enhanced Acoustical Performance	1 Point
Credit 10	Mold Prevention	1 Point

Innovation and Design Process 2/6

Our team will be applying for an innovation in design through use of the cogeneration plant. We are claiming that the waste heat from the cogeneration plant will be able to heat the pool, the largest energy consumer in our building.

Credit 1.1	Innovation in Design: Efficient Pool Heating Strategy	1 Point
Credit 3	The School as a Teaching Tool	1 Point

EnergyStar Performance Rating

The elementary school design will apply for an EnergyStar Performance Rating of 85.

Energy	Design	Median Building
Energy Performance Rating	85	50
Energy Reduction	32%	0%
Source Energy Use Intensity	107 kBtu/SF/year	159 kBtu/SF/year
Site Energy Use Intensity	58 kBtu/SF/year	85 kBtu/SF/year
Total Annual Source Energy	10,745076 kBtu	15,862,880 kBtu
Total Annual Site Energy	5,775,500 kBtu	8,526,330 kBtu
Total Annual Cost	$102,894	$151,902

Pollution Emissions		
CO2 Equivalent Emissions	488 Metric tons/year	721 Metric tons/year
CO2 Equivalent Reduction	32%	0%