TOWN OF BROOKLINE

Driscoll School

School Building Advisory Committee
Design Subcommittee
March 18, 2020

Jonathan Levi Architects

Design Development Workshop 4

- HVAC Systems Overview
- Custodial/Storage
- Cafeteria/Lobbies
- Community Access
- Elevations
- Entry Environs

HVAC Systems Overview

The Driscoll School
Brookline, MA

March 18, 2020

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Consulting Engineers Inc.
375 Faunce Corner Road, Suite D, Dartmouth, MA 02747-1258

What are Fossil Fuel Free HVAC Systems?

- **Fossil Fuel Free HVAC Systems do not negatively impact the quality of HVAC System distribution.**
- **A very high level of thermal comfort and indoor air quality can be achieved.**
- **HVAC Distribution Systems can be like those of Non-Fossil Fuel Free System**
- **Fossil Fuel Free HVAC systems do not use Gas or Oil for Heating**
- **Heating is provided by Electricity, and there are several Options, which include:**
    - **Air Source Heat Pumps (Including Variable Refrigerant Flow "VRF")**
    - **Water Source Heat Pumps (uses a Cooling Tower or Fluid Cooler)**
    - **Geothermal (Ground-Source) Heat Pumps**
    - **Electric Hot Water Boilers**
    - **Electric Infrared and Resistance Heating**
- **Several of these Options were studied during the Schematic Design HVAC System LCCA.**

Life Cycle Cost Analysis - HVAC System Options (Fossil Fuel Free)

- **Baseline: Electric heating/chilled water cooling Overhead VAV (Variable air Volume)** air handling units with Energy recovery and terminal VAV boxes with Electric reheat coils and supplemental Electric Heating. Code efficiency water cooled chiller plant with cooling tower
- **Option 1: Water Source Heat Pump Heating & Cooling** Displacement VAV System with Energy Recovery and Radiant Heating Panels. High efficiency water source heat pump chillers with Fluid Cooler and Supplemental Electric Hot Water Boiler.
- **Option 2 –**Air-Source VRF (Variable Refrigerant Flow) System with Air Source Heat Pump Dedicated Outdoor Air Handling Units with Energy Recovery and Supplemental Electric Heating
- **Option 3 -** Geothermal Water-Source Version of Option 1 Displacement System - Geothermal wells are used instead of Dry Coolers and Electric Boilers would be provided only for Back-up heating. Hot water Heating and Chilled water provided by High Efficiency Ground-source Hat Recovery Heat Pumps.
- **Option 4 – Higher Efficiency version of Baseline Option System.** Electric reheat coils and supplemental electric heating are replaced with Hot Water provided from Water Source Heat Pump and Electric Hot Water Boiler System.

Mechanical System LCCA Results

Driscoll School - Mechanical System Payback Summary

Baseline	System	Gross Capital Investment*	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Annual CO2 Emissions Reduction (kg)	Annual Maint. Cost	Combined Annual Expense	Combined Expense Savings**	Total Life-Cycle Savings***	Discounted Payback (Years)****	LEED EAc2 Points
-	1. Electric heating/chilled water cooling VAV air handling units with energy recovery wheels with terminal fan-powered VAV boxes with electric reheat coils 2. High efficiency (code) water-cooled chiller plant with cooling tower	$9,701,980	1,423,400	$224,748	$1.45	31.3	876,598.8	-	$32,125	$256,873	-	-	-	-

Option	System	Gross Capital Investment*	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Annual CO2 Emissions Reduction (kg)	Annual Maint. Cost	Combined Annual Expense	Combined Expense Savings**	Total Life-Cycle Savings***	Discounted Payback (Years)****	LEED EAc2 Points
1	1. Full air-conditioning displacement ventilation diffusers with passive heating radiation 2. Hot water coil heating/chilled water cooling VAV air handling units with energy recovery with terminal VAV boxes with CO2 controls providing displacement ventilation 3. High efficiency water-to-water source heat pump chiller plant with fluid cooler 4. Supplemental electric hot water boiler plant	$7,818,915	1,122,100	$177,176	$1.14	24.7	690,980.5	185,618.3	$23,150	$200,326	$56,547	$3,182,845	Instant*****	14
2	1. Variable refrigerant flow (VRF) terminal evaporator units with air-cooled condensing units serving the administration, classroom media center, and support areas 2. Split system air-cooled heat pump heating/cooling VAV dedicated outside air handling units with energy recovery with terminal VAV boxes with CO2 controls providing ventilation to the VRF units 3. Full air-conditioning displacement ventilation diffusers with passive heating radiation 4. Split system air-cooled heat pump heating/cooling VAV air handling units with energy recovery with terminal VAV boxes with CO2 controls providing displacement ventilation to the dining, gymnasium, multi-purpose/stage, and small gymnasium areas	$8,334,430	1,222,000	$192,959	$1.24	26.9	752,498.2	124,100.6	$50,750	$243,709	$13,164	$1,744,635	Instant*****	12
3	1. Full air-conditioning displacement ventilation diffusers with passive heating radiation 2. Hot water coil heating/chilled water cooling VAV air handling units with Tempeff energy recovery with terminal VAV boxes with CO2 controls providing displacement ventilation 3. High efficiency water-to-water source heat pump chiller plant with closed-loop geothermal wells	$10,044,815	949,250	$149,887	$0.97	20.9	593,291.3	283,307.6	$18,150	$168,037	$88,836	$1,922,366	5	16
4	1. Hot water heating/chilled water cooling coil VAV air handling units with energy recovery wheels with terminal fan-powered VAV boxes with hot water reheat coils 2. High efficiency (code) water-cooled chiller plant with cooling tower 3. Electric hot water boiler plant	$9,745,335	1,435,000	$226,588	$1.46	31.6	883,662.0	-7,063.1	$33,125	$259,713	-$2,840	-$107,059	N/A******	7

* Gross capital investment based upon in-house cost estimate utilizing cost data from similar past projects and industry standard estimating references. Costs have been estimated for system comparison purposes only and do not incorporate all supplemental/independent HVAC system costs which would be required for all systems studied (i.e. kitchen exhaust, supplemental cooling systems for tel/data rooms, radiation heating for unoccupied areas, overhead and profit, etc.).
** Combined expense savings is the difference between the combined annual expense of the baseline and system in comparison.
*** Total life-cycle savings is based on a 30 year study period.
**** Discounted payback years is based upon BLCC5 Life Cycle Analysis.
***** Discounted payback never reached because system is more efficient and/or less expensive than baseline system.
****** Discounted payback never reached within 30 year study period.

LEED Energy Savings Summary
(LEED v4 ASHRAE 90.1-2010 Baseline
Option 1a & 3a factor in Photo-Voltaic System Impact)

Baseline	System	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Annual CO2 Emissions Reduction (kg)	Combined Expense Savings*	Energy Cost Savings Percentage	LEED EAc2 Points
LEED Baseline	1. ASHRAE Standard 90.1-2010 Envelope (Wall Insulation R-13 + R-7.5 c.i., Roof Insulation R-20 c.i., Windows 0.55 U-Value/0.40 SHGC, Curtainwall 0.45 U-Value/0.40 SHGC) 2. ASHRAE Standard 90.1-2010 Mechanical Systems (System 8 - Electric Heating/Chilled Water Cooling VAV System with Terminal Fan-Powered VAV Boxes w/ Electric Reheat Coils with Water-Cooled Chiller Plant) 3. ASHRAE Standard 90.1-2010 Lighting Systems (0.99 w/s.f.) 4. ASHRAE Standard 90.1-2010 Electric Domestic Hot Water Systems	1,780,900	$281,207	$1.81	39.17	1,096,664.5	-	-	-	-

Option	System	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Annual CO2 Emissions Reduction (kg)	Combined Expense Savings*	Energy Cost Savings Percentage	LEED EAc2 Points
Option 1	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (Option 1 - VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant w/ Fluid Cooler and Supplemental Electric Boiler Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems	1,122,100	$177,180	$1.14	24.7	690,980.5	405,684.0	$104,027	**37.0%**	14
Option 1a	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (Option 1 - VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant w/ Fluid Cooler and Supplemental Electric Boiler Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems 5. 192 kW Photovoltaic System	901,531	$142,352	$0.92	19.8	555,155.9	541,508.7	$138,855	**49.4%**	17
Option 3	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems	949,250	$149,887	$0.97	20.9	593,291.3	503,373.3	$131,320	**46.7%**	16
Option 3a	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems 5. 192 kW Photovoltaic System	728,681	$115,059	$0.74	16.0	448,716.2	647,948.4	$166,148	**59.1%**	18

*Combined expense savings is the difference between the combined annual expense of the baseline and building in comparison.

Code Energy Savings Summary (IECC 2018 Baseline)

Option 1a & 3a factor in Photo-Voltaic System Impact)

Baseline	System	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Greenhouse Gas Equivalence (× 10-4 metric tons	Annual CO2 Emissions Reduction (kg)	Combined Expense Savings*	Energy Cost Savings Percentage
IECC 2018 Baseline	1. IECC 2018 Envelope (Wall Insulation R-13 + R-7.5 c.i., Roof Insulation R-30 c.i., Windows 0.45 U-Value/0.38 SHGC, Curtainwall 0.38 U-Value/0.38 SHGC) 2. IECC 2018 Mechanical Systems (System 1 - Electric Heating/Chilled Water Cooling VAV System with Terminal Fan-Powered VAV Boxes w/ Electric Reheat Coils with 0.660 kW/ton Water-Cooled Chillers) 3. IECC 2018 Lighting System (0.81 w/s.f.) 4. Electric Domestic Hot Water Systems	1,605,700	$253,534	$1.63	35.31	988,777.7	9.9	-	-	-

Option	System	Annual Elec. Cons. (kWh)	Annual Electric Cost	Annual Utility $/s.f.	Annual kBTU/s.f. (EUI)	Annual CO2 Emissions (kg)	Greenhouse Gas Equivalence (× 10-4 metric tons	Annual CO2 Emissions Reduction (kg)	Combined Expense Savings*	Energy Cost Savings Percentage
Option 1	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (Option 1 - VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant w/ Fluid Cooler and Supplemental Electric Boiler Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems	1,122,100	$177,180	$1.14	24.7	690,980.5	6.9	297,797.2	$76,354	30.1%
Option 1a	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (Option 1 - VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant w/ Fluid Cooler and Supplemental Electric Boiler Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems 5. 192 kW Photovoltaic System	901,531	$142,352	$0.92	19.8	555,155.9	5.6	433,621.8	$111,182	43.9%
Option 3	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems	949,250	$149,887	$0.97	20.9	593,291.3	5.9	395,486.4	$103,647	40.9%
Option 3a	1. Design Envelope (Wall Insulation R-18 c.i., Roof Insulation R-42 c.i., Windows 0.30 U-Value/0.27 SHGC, Curtainwall 0.30 U-Value/0.27 SHGC) 2. Design Mechanical Systems (VAV Displacement Ventilation Systems with High-Efficiency Water-to-Water Source Heat Pump Chiller Plant) 3. Design High-Efficiency Lighting Systems (0.4 w/s.f.) 4. Electric Domestic Hot Water Systems 5. 192 kW Photovoltaic System	728,681	$115,059	$0.74	16.0	448,716.2	4.5	540,061.5	$138,475	54.6%

Life Cycle Cost Analysis - Summary

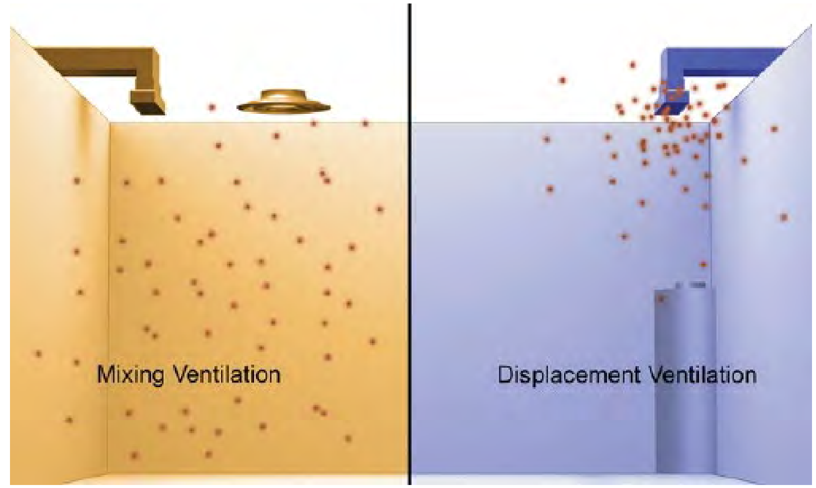
- **Option 3: – Geothermal Heat Heat Pump Displacement System was chosen as the Preferred option for Design Development due to:**
  - **Benefits of Displacement Air Ventilation**
  - **High Efficiency of Geothermal Plant**
  - **Lower Maintenance Costs**
  - **Lowest EUI (Energy Use Intensity)**
- **Option 1: Water Source Heat Pump Displacement VAV System is also being considered due to:**
  - **Lower First Cost**
  - **Maintains Benefit of Displacement Ventilation System**
  - **Second Lowest EUI**
- **HVAC Distribution Systems are Similar for these Options**
- **Differences: Option 1 uses Cooling Tower(Dry Cooler) and Supplemental Boiler Plant for Heat Rejection & Absorption whereas Option 3 used the Geothermal Wells. Electric Boilers for Option 3 would only be for Emergency Back up use.**

Displacement System

- Ventilation air is provided from air handling units and supply air is delivered at low velocity and at low levels within the space
- The system uses naturally occurring buoyant forces within the space to create a vertical rise of the air throughout the space.
- Supply air rises when heat source is contacted which displaces room air upward causing pollutants to be exhausted at ceiling returns.

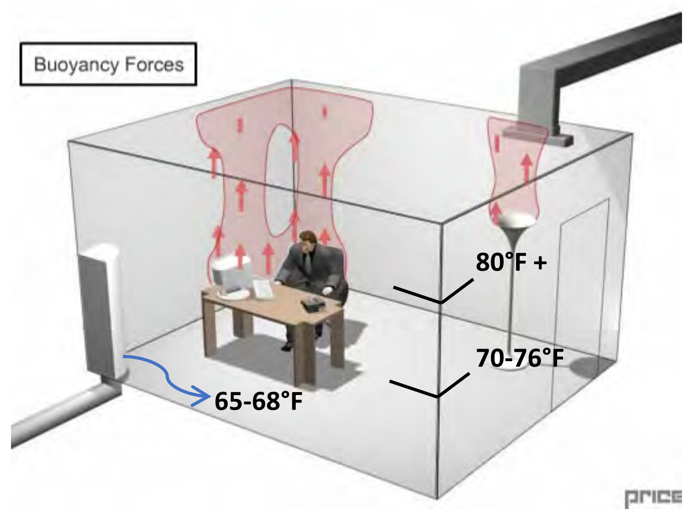
Pros:

- **Excellent pollution removal**
- **Low Velocity & Low Noise**
- **Reduced cooling loads**
- **High ventilation effectiveness**
- **Excellent Thermal Comfort**



Mixed Systems | DV Systems

$E_c = 0.8$ | $E_c = 1.2 - 1.4$



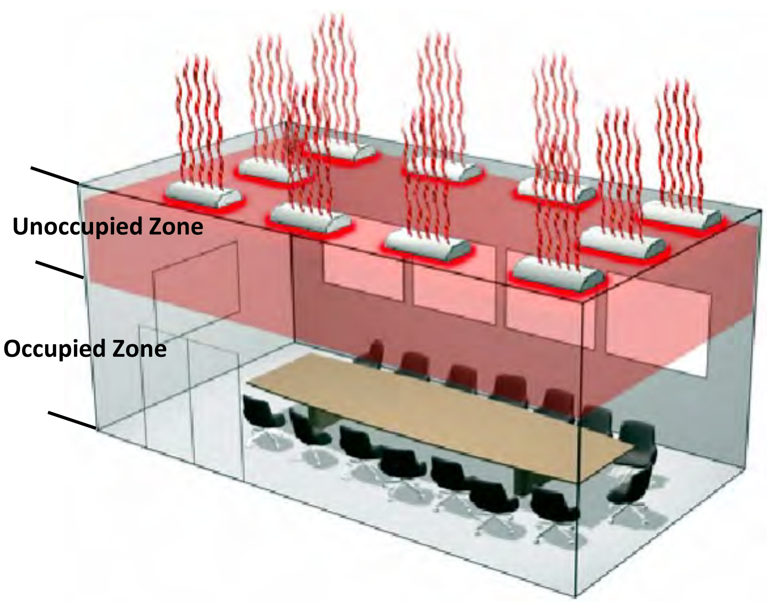
Displacement System – Energy Conservation

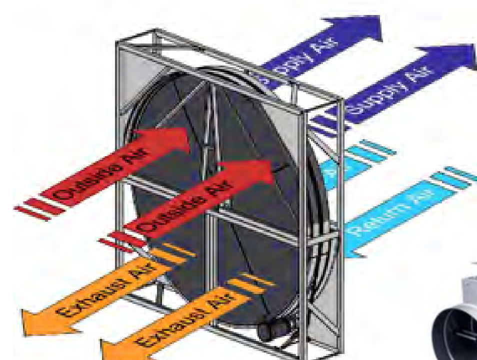
Load Calculation Reductions

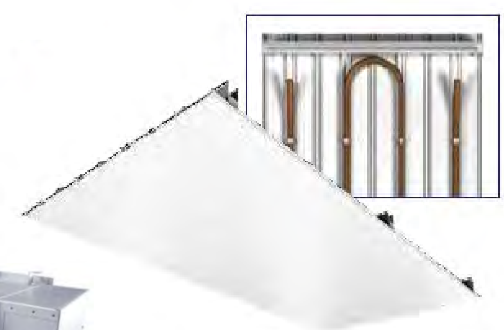
- Conventional System: All heat generated in room is included in air flow calculation since all airflow is mixed.
- Displacement System: Only loads which occur in the Occupied Zone are factored
- Results in: Smaller equipment & systems and lower installed and operating costs for Displacement Systems

Additional Energy Efficiency Measures

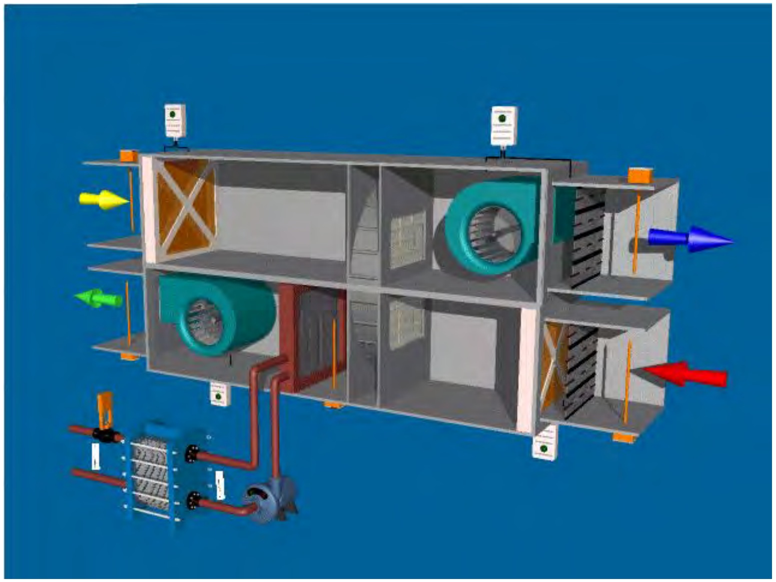
- Energy Recovery: Transfers energy from the return air stream to the supply air stream to pre-heat or pre-cool the outside air.
- Variable Air Volume w/ CO2 Demand Control Ventilation: Modulates the airflow to large single zone areas in accordance to space mounted thermostat and CO2 sensors reducing energy consumption due to reduced air changes.
- Perimeter Radiation Heating – Allows use of Hot Water Heating system for Night Setback and Supplemental Heating

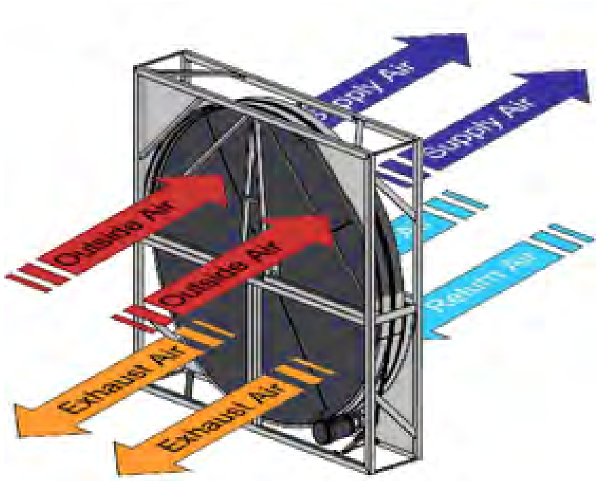






Rooftop Air Handling Units for Displacement Systems



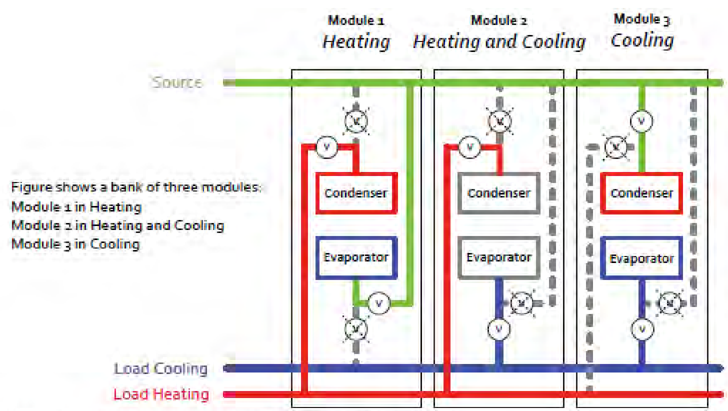


Features:

- **Hot Water Heating & Chilled Water Cooling**
- **Variable Speed Airflow Control**
- **Energy Recovery Ventilation**
- **CO2 demand Ventilation Control**
- **Lower Noise Levels – No Compressors or Condenser Fans**
- **AHUs Zoned per Building Area (8 Units Proposed)**
    - **Classrooms (2 Units), Gym, Small Gym, Multi-Purpose, Cafeteria & Kitchen MUA**

High-Efficiency Water-To-Water Source Simultaneous Heating/Cooling Heat Pump Chillers w/ Heat Recovery Plant

Modular Heat Recovery Heat Pump Chillers



*Simplified single line water circuit shown; V=motorized isolation and control valve

BENEFITS:

- **High-efficiency**
- **Modular design provides level of redundancy & individual module control**
- **Heat recovery provides reheat during cooling season**
- **Maneuverable – All modules fit through 36" door and have low center of gravity with base cutouts for pallet jacks/forklifts**
- **Durability & Reliability**
- **Service friendly with easy access to all major components**
- **Fossil Fuel Free - Zero combustion design**

Geothermal (Option 3)- Closed Loop Geothermal Field

Vertical closed loop wells are used to provide ground source condenser water to heat recovery heat pump chiller plant, which is used to provide hot water heating and chilled water cooling

Pros:

- Lower maintenance costs
- High energy efficiency & Lower operating costs
- Lower replacement costs as pumps located within building and no Cooling Tower or Dry Cooler is required

Cons:

- Test wells required
- Increased permitting
- Higher first cost

Non-Geothermal Option 1
Utilizes Dry Cooler and Supplemental Electric Boilers for Heat Pump Chiller Plant

<u>Closed Cell Dry Coolers (Option 1)</u>

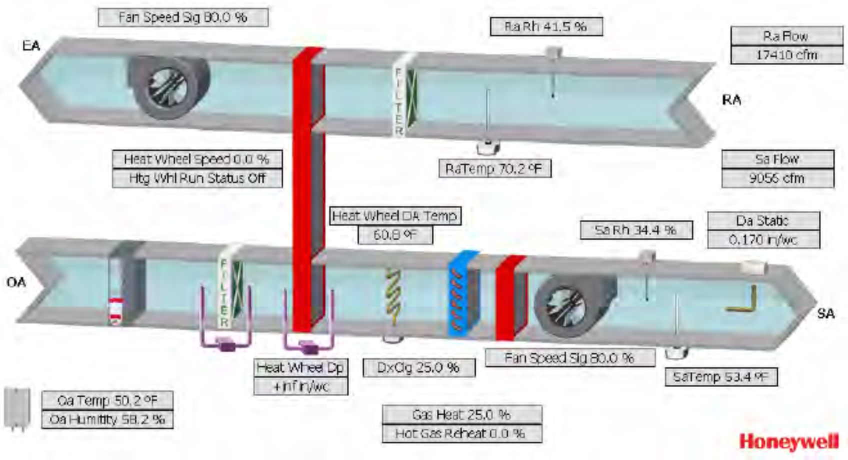
- Higher Efficiency than Open Loop Cooling Tower
- Lower Maintenance than Open Tower
- Lower Make-Up Water and Chemical Treatment Requirements

<u>Supplemental Electric Boilers (Option 1 & 3)</u>

- Boiler temperature reset controls
- Variable speed pumps with VFD's
- Maintain Condenser Water Loop Temperature in Winter Heating Season
- Increased Boiler use in Option 1. Boilers for Backup only in Option 3.

Building Automation and Energy Management System

- System (Zone) Scheduling
- Occupied-Unoccupied Control
- Night Setback Operation
- Lighting Control System Integration
- Increased Energy Savings
- Integrate with Preventative Maintenance Scheduling



Custodial/Storage

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Cafeteria/Lobbies

34 TABLES
= 272 SEATS
> 266 REQUIRED

CAFETERIA

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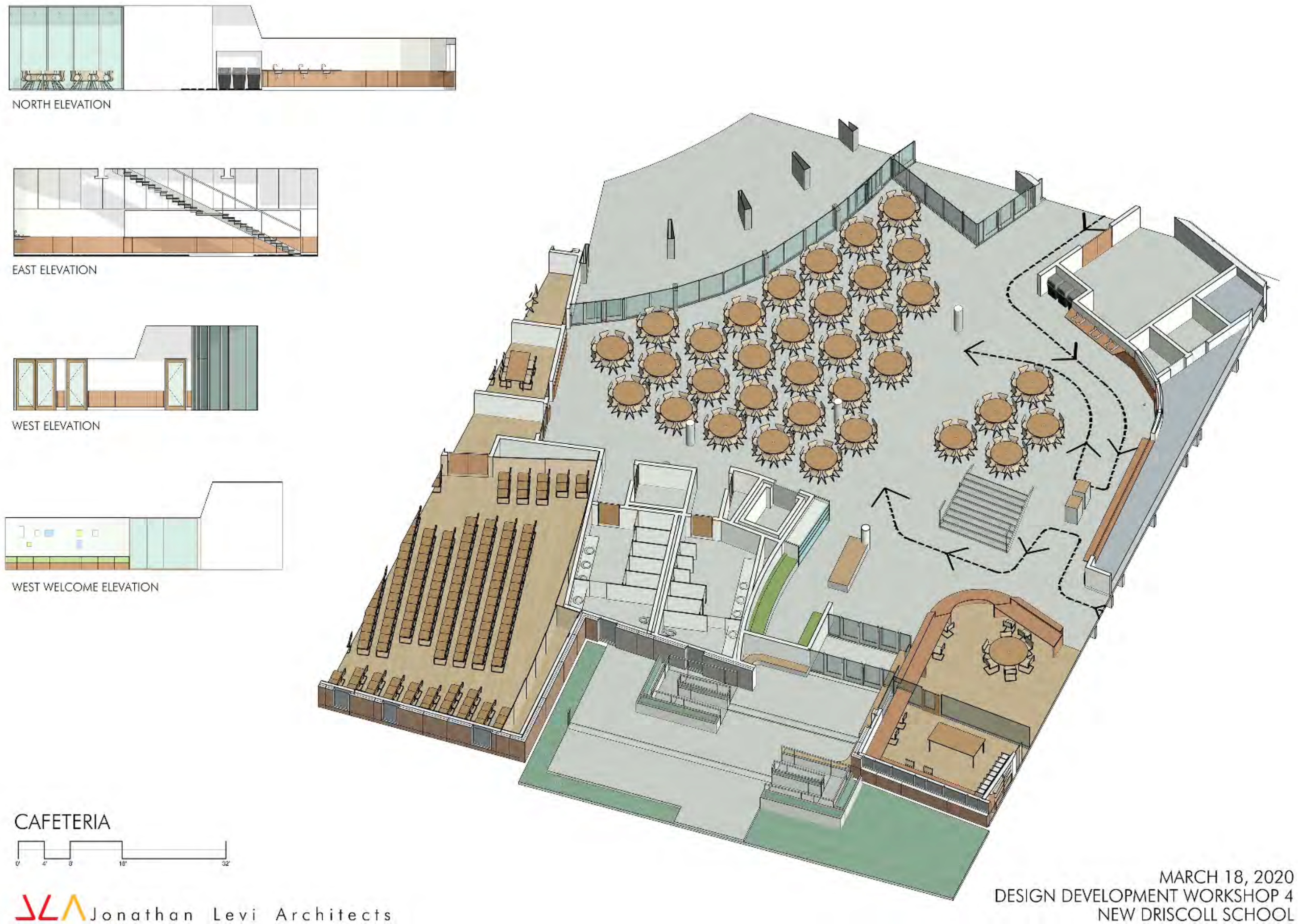
Cafeteria/Lobbies



Community Access

BASEMENT FLOOR

FIRST FLOOR

COMMUNITY MODE DIAGRAM

0' 4' 8' 16' 32'

ATHLETIC AND PTO COMMUNITY ACCESS

CAFETERIA AND MULTIPURPOSE COMMUNITY ACCESS

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Elevations – SD Recap

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Elevations

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Elevations

Elevations

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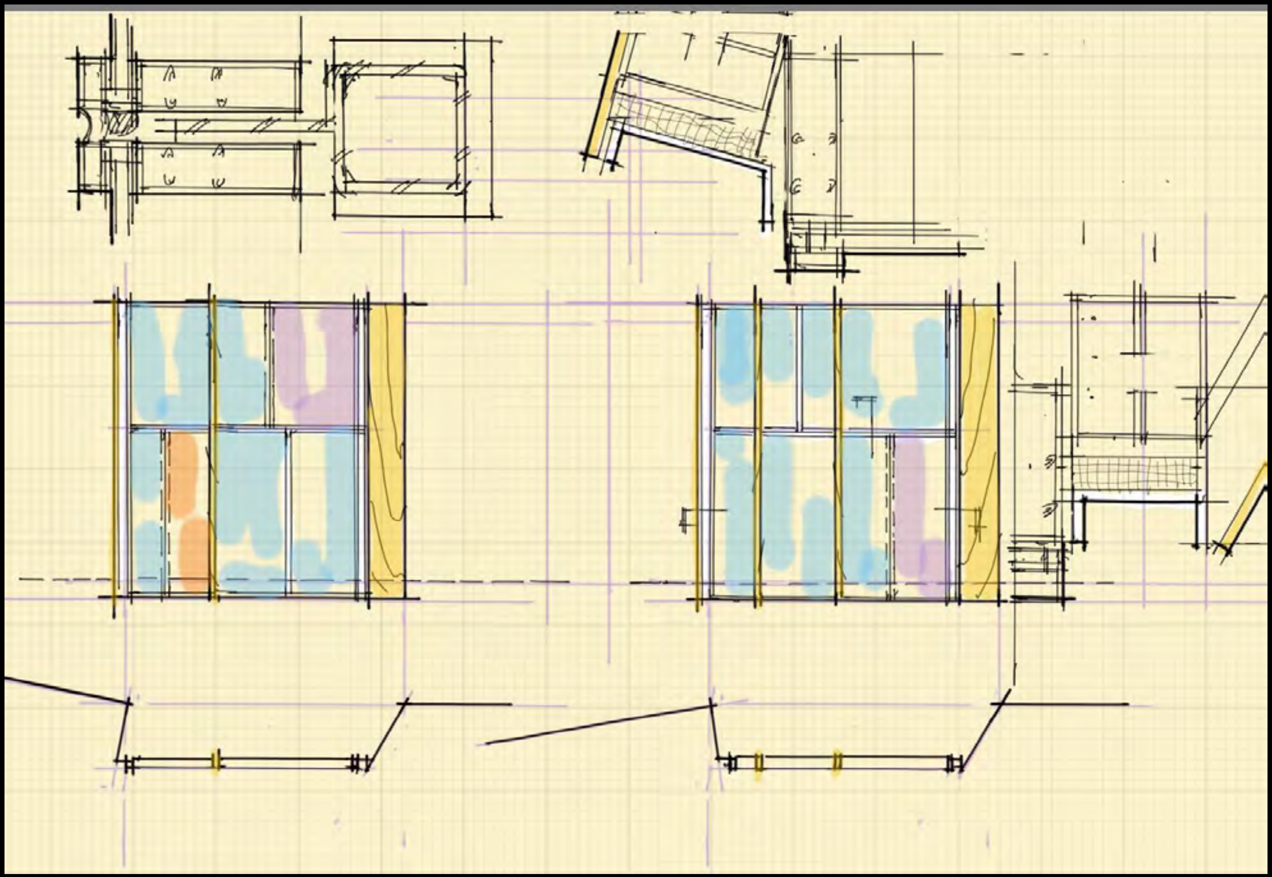
Classroom Window Study



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Elevations

Elevations

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Elevations

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Entry Environs

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