2012

Technical report 3

American Art Museum

Mechanical Systems Existing Conditions Evaluation

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11/11/2012

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Executive Summary

In this technical report, the objective is to finalize both pervious technical reports and understand the operation of the HVAC system. Afterward, the end of this technical report is to discuss objectives that may be considered in the new HVAC design.

This report can be divided into four parts of analysis.

1) Design objectives with the design factors and influences

   The HVAC design of American Art Museum (AAM) should be based on the protection of art collections and the comfort of occupants. Moreover, the cost factor that might affect the HVAC system heavily is the district steam heating system provided by a local company with different operation cost. If the HVAC system is a steam system, it significantly changes the characteristics and functions of the HVAC system.

2) A summary of ventilation rate and energy load

   The summary can help to understand the characteristics of the HVAC systems and figure out what part of the system is/are needed improvement. In the analysis, it shows that the design ventilation rate doesn't match with the calculated rate. Also, the energy load of heating and cooling system is that the heating system is relatively high.

3) Operation of the HVAC system

   In this report, the flow diagrams of water-sided and air-side HVAC system, the list of HVAC equipment, and the description of system operation, etc., are created to provide better understanding of the HVAC system operation.

4) Rate the mechanical system with LEED Rating System

   On the mechanical side, many LEED points are gained. Reading the LEED documents, the document is written very clear and precisely. Therefore, AAM is more likely to gain all the potential points after the construction.

In the end of the report, the HVAC system is evaluated in five criteria, such as the owner's perspective, the relationship between advanced control system and maintainability and the potential problem of indoor air quality.

In conclusion, this report provides a basic idea of how the HVAC system operates in AAM, the construction cost of the mechanical system, and potential problems of HVAC system.

Project Background

Name	American Art Museum
Location	New York, NY
Occupancy Type	Group A-3 Museum
Size	195000 sq. ft.
Function	Gallery, Classroom, Office, Auditorium, Restaurant
Floors	9 levels with cellar mezzanine and cellar level underground
Construction	Start in February 2012, End in later 2014
Main Architectural Feature(s)	1. Cantilevered entrance 2. The Biggest column-free gallery in New York 3. Ground floor restaurant and top floor café 4. Rooftops on Multiple levels for outdoor exhibition 5. Glazing system, pre-cast concrete, and stud wall as façade
Sustainability	Goal: LEED Gold Certification

Figure 1 Courtesy of the owner

Figure 2 Courtesy of the owner

Figure 3 Courtesy of the owner

Mechanical overview

Cooling System	2 branches of air conditioning system: <u>3 air conditioning systems as cooling systems</u> • Located on the cellar Level (-1) • Handle 1/3 of the load • Manage the air in floors C through 7. <u>Another AC system</u> • Located in Level 8 • Manages the air condition in 8th floor. The main refrigeration plant • 3 electrically driven centrifugal refrigeration machines 5 cooling towers • On the roof • Hold 200 ton cross-flow or counter-flow typed cells Cold water fluiding roofing and greenroofs
Heating System	A hot water heating boiler plant • Located on cellar level • 5 condensing water fire-tubed boilers • Built-in water treatment • A combustion chamber with gas filters Finned tube convector along the exterior walls Unit heaters and fan coil type heaters • Provide heat on all mechanical rooms, exit and entrances. Fan coil units along the glass façade walls • Heat and cool the lobby area
Ventilation	Several main zones with different ventilation distribution: • Galleries with VAV system • Lobbies with VAV system • Restaurant with constant air volume (CAV) system • Auditorium with CAV system. Both branches of AC system • Fogged type humidifier systems. • Flirtation with 95% efficient filters
Control System	Direct Digital Control (DDC) Modes of setting: • Unoccupied Mode • "Summer" Occupied Mode • "Winter" Occupied Mode • "Auto" Mode

Design Objectives and Requirements

The HVAC system of American Art Museum (AAM) is to provide a highly comfort to the occupants and the suitable storage environment of art collections.

Artwork Collections

AAM will hold about 18,000 works, which are 20th – 21st century American art (American Art Museum, 2011). AAM also announced that there will be permanent art collection exhibits on the fourth and fifth floors and long term projects kept on the top floor. Therefore, the HVAC system will be required to maintain the indoor environment to avoid any artwork degradation.

LEED

The design of AAM is requested to obtain at least Gold LEED Certification by the owner. According to the mechanical system in AAM, the potential points of LEED are:

Table 1 Potential LEED points with Mechanical focus

Credits	
Energy and atmosphere	• Minimum energy performance • Refrigerant management • Optimize energy performance • Green power
Indoor environmental quality	• Outdoor delivery monitor • Low emitting material • Controllability of systems thermal comfort

Occupant Comfort

In general, a goal of HVAC system is to minimize the energy use but also maintain the occupants' comfort. However, AAM will consist of galleries, offices, a 170-seat theater, a café, a restaurant and a study center. It is difficult to keep the indoor air environment and 'optimize energy performance', especially AAM is required to have a flexible schedule for different activities and exhibitions, and there will be constant amount of visitor entering and exiting from the building to outside or the rooftop terraces on different floors.

Therefore, AAM needs an advanced HVAC system to achieve these objectives, since these are three extreme objectives: Comfort, art protection, and high performance of HVAC system.

Energy Sources and Rates for the Site

In New York City, there are many utility companies that can provide energy to the consumers. The following five companies are the major utility companies in New York. These companies provide simplified average utility rates of electricity and natural gas. And, ConEdison also provides the rate of steam, because it offers district heating system.

Table 2 Different average energy supply rate of utility companies in NY (NYS Department of Public Service Electronic Tariff System, 2012)

Utility Company	Natural Gas Supply Charge ($/per 100 ft^3)	Electric Supply Charge ($/kWh)	Steam Supply Rate ($/Mlb)
Central Hudson	0.45459	0.06414	--
Long Island Power Authority	--	0.09575	--
Orange & Rockland	0.65417	0.09871	--
National Grid	0.38454	0.04821	--
ConEdison	0.342914	0.0866	39.480

District Heating System

The district heating system operated by ConEdison is under the streets in Manhattan to heat, cool, and supply power to high rise buildings and commercial buildings. The steam also can be used for different applications other than heating and cooling, such as cleaning and disinfection.

Heating and Cooling

The steam heating district system of ConEdison is the largest commercial steam system in the world. (Con Edison, 2012). There are 6 steam plants in this system producing steam and electricity. After generating electricity with steam and an excitation cycle, the waste steam is also sent to the customers of the steam service. The simplified process is shown in the figure from the website of ConEdison (ConEdison, 2012).

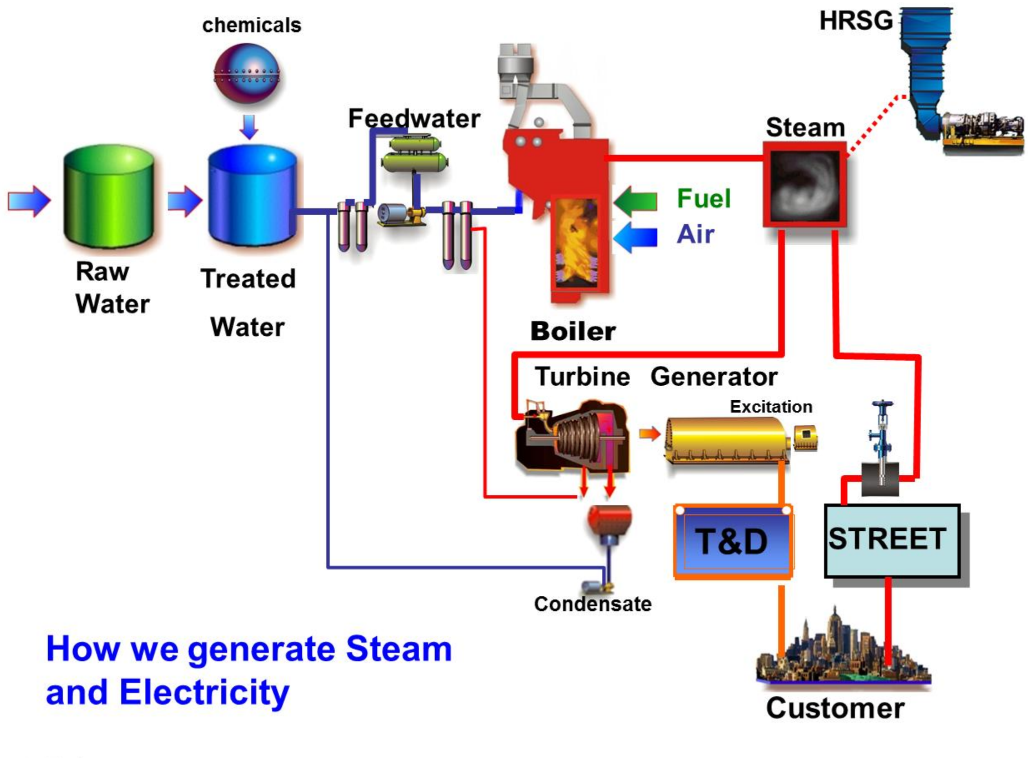


Figure 4 ConEdison's Steam District System Operation

The plants boil water to 1000 °F before sending steam to buildings in New York. Therefore, ConEdison doesn't only highly suggest the clients to use steam for heating, but also applies steam on air conditioning. There are two recommended methods of air conditioning:

1. Adding vapor compression

   In the compression cycle in a chiller, a steam turbine can replace the electric motor.

2. Absorption cycle

   Steam can be used as heating water in the absorption cycle, and a salt solution is used for cooling water. The advantage of an absorption cycle is that the absorption chiller does not use chemicals that may damage the ozone layer.

Other Application(s)

The steam can be used for cleaning, climate control and disinfection service. It is because ConEdison ensures that in water treatment, all chemicals are approved by the FDA regulation, 21 CFR 173.310. ConEdison particularly mentions that because the chemical of steam doesn't damage the art collection.

Factors that Influence Design

Since AAM is located next to a well-designed public park, there are tax rebate and incentive programs offered by the New York government and design limitation. The design limitation is not to inference the view of the public park.

Site Factor – the View of Waterfront and Public Park

AAM is located in M1-5, Zone 8 of New York shown in Figure 5. It also is next to a New York river and an elevated public park.

The elevated public park is a government waterfront landscape project for the memorial of the New York City's maritime history. This landscape project enhances access to the waterfront and a public park. So, it is encouraged to integrate the building project with the public park.

In the zoning code of New York, it states that in M1-5 district, the maximum building height is 135 ft. So, the sizes of 5 cooling towers located on the roof of AAM are on the edge of acceptable range of building height.

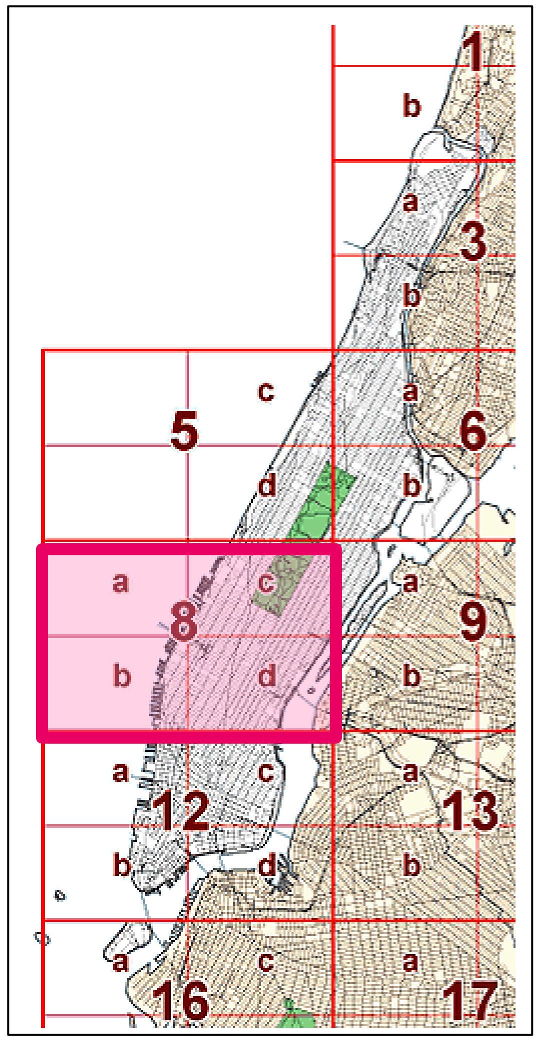


Figure 5 the Zoning Index Map of New York City Department of City Planning

Figure 6 the image from the waterfront project in New York

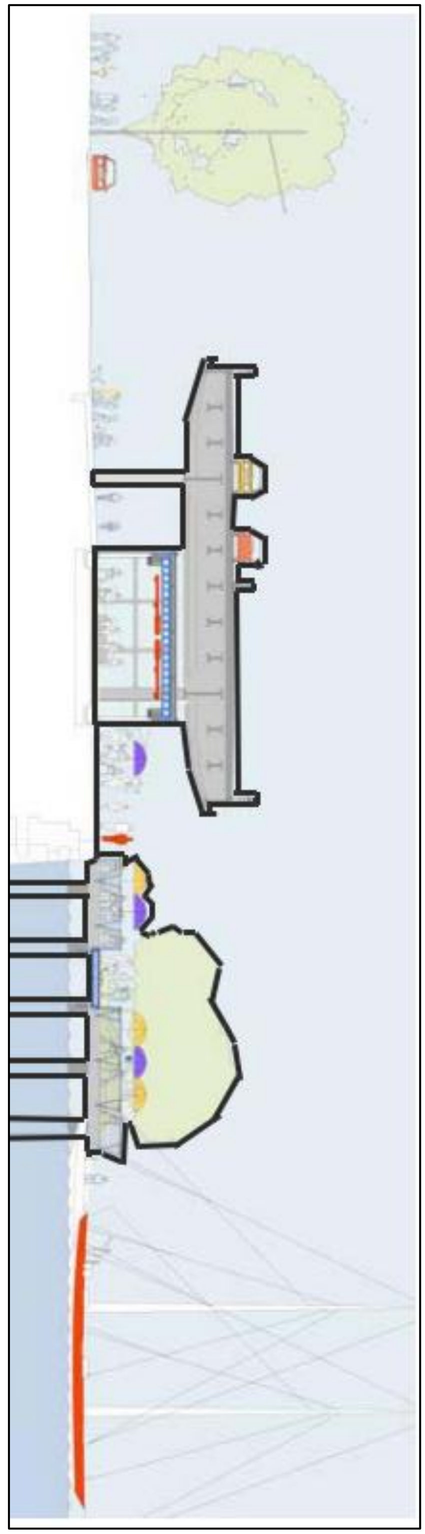


Figure 7 the image from the waterfront project in New York

Cost

In New York, a lot of incentive and rebate program and tax exemption related to energy consumption and performance. Many government programs are focus on solar energy. It is good to integrate the building envelope with the requirements. The list of rebate program provided by utility companies and New York government is provided in below (the Database of State Incentives for Renewables and Efficiency (DSIRE) , 2012):

The Available incentives/Policies of Renewables and Efficiency	
Technology	The corresponding programs
General renewable energy	1. Fuel cell rebate and performance incentive
Biogas	1. RPS customer-sited tier regional program 2. Anaerobic digester gas-to-electricity rebates and performance incentive
Solar energy	1. Solar sales tax exemption 2. RPS customer-sited tier regional program 3. PV incentive program 4. Solar thermal incentive program
Wind	1. On-site small wind incentive program
Energy performance	1. Energy smart new construction program 2. Central Hudson Gas & Electric: Commercial lighting rebate program 3. NYSEG (Gas): Commercial and industrial efficiency program 4. RG&E (Electric): Commercial and industrial efficiency program 5. Orange and Rockland Utilities (Electric): Commercial efficiency program 6. RG&E (Gas): Commercial and industrial efficiency program 7. Central Hudson Gas & Electric (Electric): Commercial lighting rebate program 8. Central Hudson Gas & Electric (Gas): Commercial energy rebate program 9. ConEd (Electric): Commercial and industrial energy efficiency program 10. ConEd (Gas): Commercial and industrial energy efficiency program 11. National Fuel(Gas): Large non-residential conservation program 12. Nation Grid (Electric): Non-residential energy efficiency program

Outdoor and Indoor Design Conditions

By understanding the outdoor and indoor design condition, it helps to develop a new design of the HVAC system. The outdoor design condition is unique due to the building type of AAM. And, the indoor design is different in each zone due to the variation of occupants in each zone.

Indoor

As the pervious section, Design Objectives, mentions that the HVAC system of AAM is required to maintain a suitable environment to keep the art collection from degradation and high performance of the HVAC system.

Air contaminants, temperature and humidity

The level of air contaminants, temperature and humidity are required to be considered. In Environmental Control for Museums, Libraries and Archival Storage Areas by Purfil Inc., it suggests the following standards of the indoor environment in a museum with mixed collections:

Table 3 indoor environmental standard suggested by Purafil, Inc.

Criteria	Suggested level
Temperature	66° to 77 °F
Relative humidity	55 %RH with maximum fluctuation of 12%
Contaminants	Sulfur dioxide: ≤0.35 ~ ≤3.8 ppb Nitrogen dioxide: ≤2.65 ~ ≤5.3 ppb Carbon dioxide: ≤2.5 ppb

So, in the building specification of AAM, it states that there will be CO_2, NO_2, and CO detection system, de/humidification system and high efficiency filters. The filters are listed in the table of air distribution system in The Table of Major Equipment.

Energy Saving and Occupants' comfort

Since different types of occupants are in AAM, it is important to provide different ventilations to the corresponding zones with the consideration of energy consumption. Also, the schedule of AAM is changed more rapidly than other types of buildings. For example, there is a night ceremony in AAM. The engineering consultant is required to install a manual control with an override function, so the control system of HVAC can have the correct respond in short period of time. In addition, it is necessary to offer the HVAC operators and occupants in AAM a lesson of the benefits and penalties of unnecessary overrides to the HVAC systems.

Outdoor

In the ASHRAE Handbook of Fundamental, it provides the design outdoor condition, which is shown in Appendix. A (ANSI/ASHRAE/IESNA, 2007). Using this data, it helps for sizing equipment and the estimation of heating and cooling loads. Especially, the sizing of the cooling towers is strongly depended on the outdoor weather condition. Also, the outdoor weather cannot only affect the heating and cooling load and the infiltration of AAM.

Design Ventilation Requirements

There are essential criteria of ventilation requirements in order to ensure if the indoor environment is suitable to the occupant and art collections. The criteria are the following:

Ventilation Rate

In the Technical Report 1, there is a calculation of ventilation rate based on the number of occupants, their activities, and the area of a room. The following table is a list of the comparison between the calculated minimum ventilation rate in Technical Report 1 and design ventilation rate. It shows there are zones that are NOT complied with the Standard 62.5 of ASHRAE.

Table 4 comparison of ventilation rate

Floor	Zone	Minimum OA	Design OA intake	Comply?	Minimum ventilation rate	Design ventilation rate	comply?
Cellar level	Mechanical room	2378.84	7500	yes	15859	10700	no
	Kitchen	366	6150	yes	3590	5000	yes
Cellar mezzanine	Office	97.16	725	yes	647.7	1250	yes
	Mechanical room	392.7	900	yes	2618	1000	no
	Lobby	78			520		
First floor	Lobby	15500	6000	no	103333.3	16500	no
	Office	97.16	--	yes	647.7	--	yes
	Gallery	357.06	725	yes	2380.4	1900	no
	Mechanical room	2047.4	--	--	13649.3	--	--
	Restaurant	1694.1	6300	yes	11294	11300	yes
Second floor	Mechanical room	807.6	0	no	5384	900	no
	Office	1130.82			7538.8		
Third floor	Classrom	339.36	0	no	2262.4	17955	yes
	Storage	490.2			3268		
	Lobby	145.56			970.4		
	Theater	2186.88	5000	yes	14579.2	11000	no
	Projector room	195	1860	yes	1300	3680	yes
Fourth floor	Office	2103.58	0	no	14023.9	17155	no
	Conference room	85			566.7		
	Art Handling	903			6020		
Fifth floor	Gallery	4923.9	11160	yes	32826	32480	no
	Auditorium	886.24			5908.3		
	Office	47.96			319.7		
Sixth floor	Conservatory	291.1	7360	yes	1940.7	18340	no
	Study Center	206.82			1378.8		
	Gallery	3120.54			20803.6		
	Library	211.76			1411.7		
Seventh floor	Curatorial	424.08	5500	yes	2827.2	17520	no
	Gallery	2496			16640		
	Office	126.12			840.8		
Eighth floor	Conference room	477.9	6500	yes	3186	20500	yes
	Kitchen	174			1160		
	Gallery	2040.9			13606		
Ninth floor	Mechanical room	1645.8	4085	yes	13272	2200	no

Temperature and Humidity

As occupants' comfort, it mentions in ASHRAE Handbook that the acceptable ranges of temperature and humidity during summer and winter are:

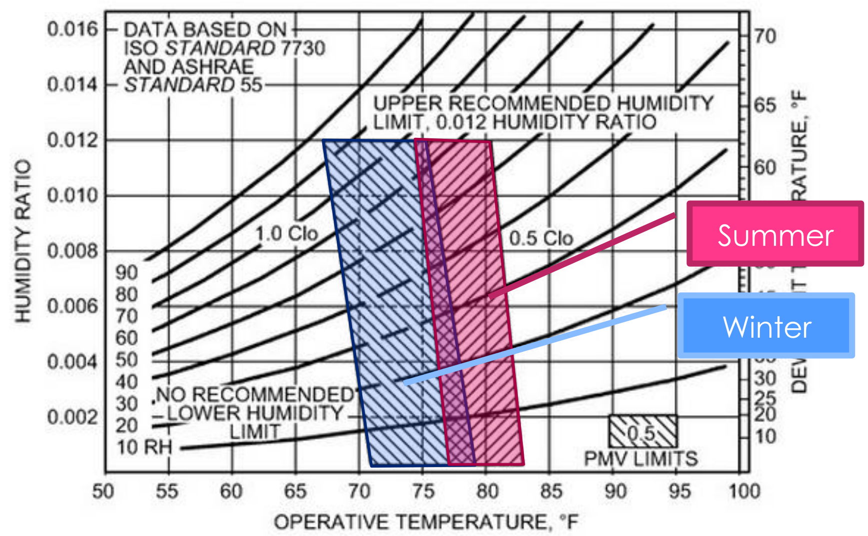


Figure 5. ASHRAE Summer and Winter Comfort Zones [Acceptable ranges of operative temperature and humidity with air speed ≤ 40 fpm for people wearing 1.0 and 0.5 clo clothing during primarily sedentary activity (≤1.1 met).]

Figure 8 ASHREA Handbook: Summer and Winter Comfort Zones

And, for galleries and art handling storage, the temperature and humidity should be fit with the information in Table 3 indoor environmental standard suggested by Purafil, Inc.

Air Contaminants

The mechanical consultant states in the mechanical specification that a pre-occupancy indoor air will be required after the construction. The procedure is to test the air every 25,000 square feet with the air testing equipment specified by ASHRAE. And, the standards in the specification are:

Table 5 Maximum concentration of air contaminant

Air Contaminants	Concentration	
	In Specification	Suggested by Purafil, Inc.
Carbon dioxide (CO_2)	≤5 ppb	≤2.5 ppb
Nitrogen dioxide (NO_2)	--	≤2.65 ~ 5.3 ppb
Sulfur dioxide	--	≤0.35 ppb
Carbon Monoxide (CO)	9 ppm (≤ outdoor concentrations + 2 ppb)	--
Formaldehyde	27 ppb	--
TVOC	500 mg/m^3	--
4-PCH	6.5 mg/m^3	--

Annual Energy Consumption of HVAC System

The design load of the HVAC system in AAM is based the energy model created in the Technical Report 2 with Trace700. In the report, it mentions that the accuracy of design load is acceptable.

Table 6 the accuracy of calculated vs design system in Tech 2 Report

Heating plant: Building Peak Load				
Calculated	17068.2	Mbh	75.962	Btuh/ft^2
Designed	13500	Mbh	60.081	Btuh/ft^2
			Difference :	-20.91%

Cooling plant: Building Peak Load				
Calculated	811.8	ton	276.786	ft^2/ton
Designed	900	ton	249.661	ft^2/ton
			Difference :	11%

And, the reason is that the secondary system of heating system is not added into the energy model, such as certain fan coil units (which heats the façade of AAM), the cogeneration system, fog-typed humidifiers, and fin tubed heat exchangers. Therefore, this energy model is only considered the primary heating and cooling system.

Annual Design Heating and Cooling Load

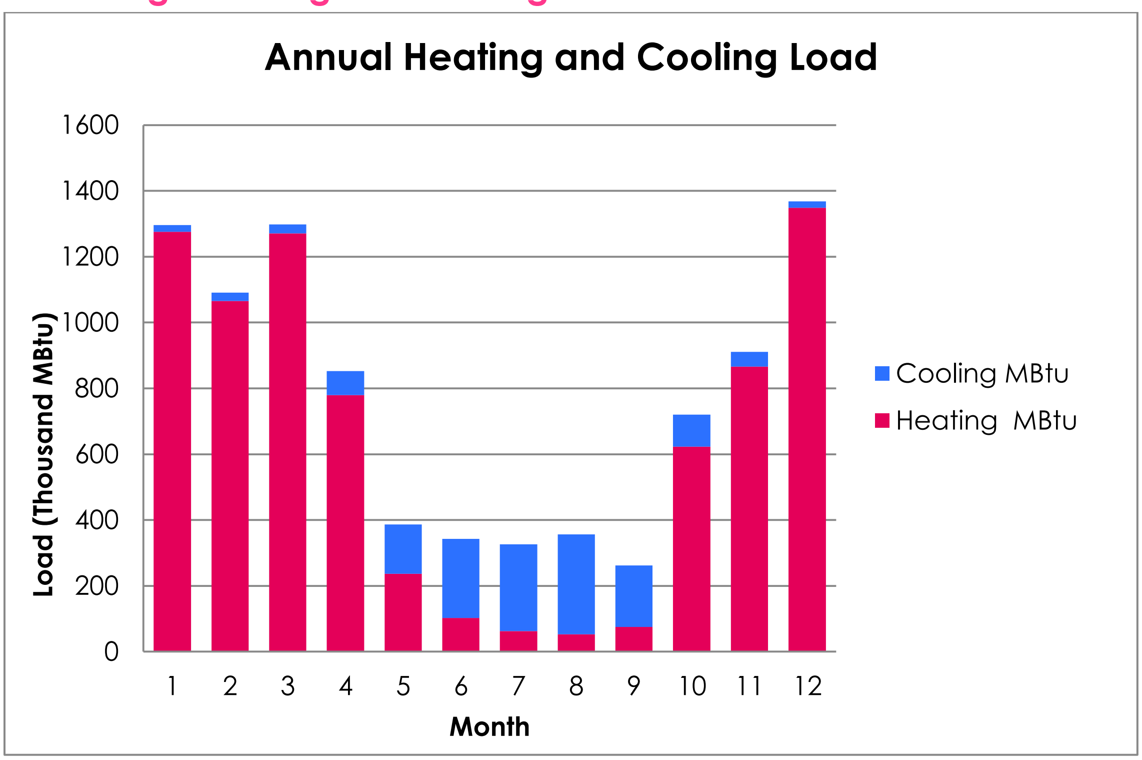


Figure 9 Annual Heating and Cooling Load with the data from Tech 2 Report

In the plot, the major heating loads are at highest during December and February, and the cooling load is at highest during summer. It also shows that the heating loads take a big part of energy consumptions. In order to lower the energy consumption of heating load, it is either lowering the comfort in a zone or adding another optimal component into the HVAC system.

Schematic Drawings

The schematic drawings of the HVAC in AAM are simplified based on the standard of Flow Diagrams (in Y:/AE 481 Mechanical), after analyzing the mechanical specifications and the riser diagram. The simplified flow diagrams of this HVAC system help to design the HVAC system in the future projects.

Due to complexity of the HVAC system, the flow diagrams of the water-sided HVAC system are divided into 4 diagrams, which are Overall HVAC System, Cogeneration, Heating System, and Cooling System. On the other side, the diagrams of air-sided HVAC system are focused on the main zones that are described in the HVAC general specifications, because other zones don't contain full description in the specifications. Secondly, because of the complexity and size of the HVAC system, the components of the control system and labels are not shown in the flow diagram of water-sided HVAC system.

Water-sided HVAC System of AAM

In the water-sided HVAC system, there are several energy saving components in both heating and cooling system.

In the mechanical system every load will has a BTU meter[1] attached with the return and supply piping. And, the pumps, which serve for sending the water to load and to chillers, will be in parallel and with variable speed drive.

[1] BTU meter means a group of sensor including flow meter, flow transmitter, and temperature sensor.

The cooling system will consist of five cooling towers and free cooling heat exchanger.

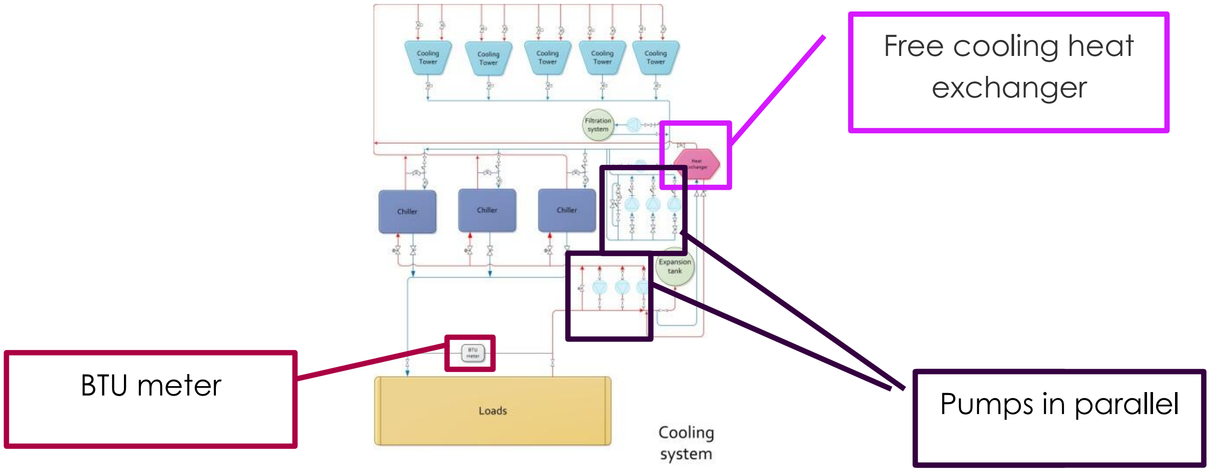


Figure 10 The location of cooling components

The heating system will include isolated service water heating system a bottoming cogeneration system. The cogeneration system will collect waste heat and generate electricity to serve the building. It will also connect with the emergency fuel system, which the equipment is a fuel tank and heat sink.

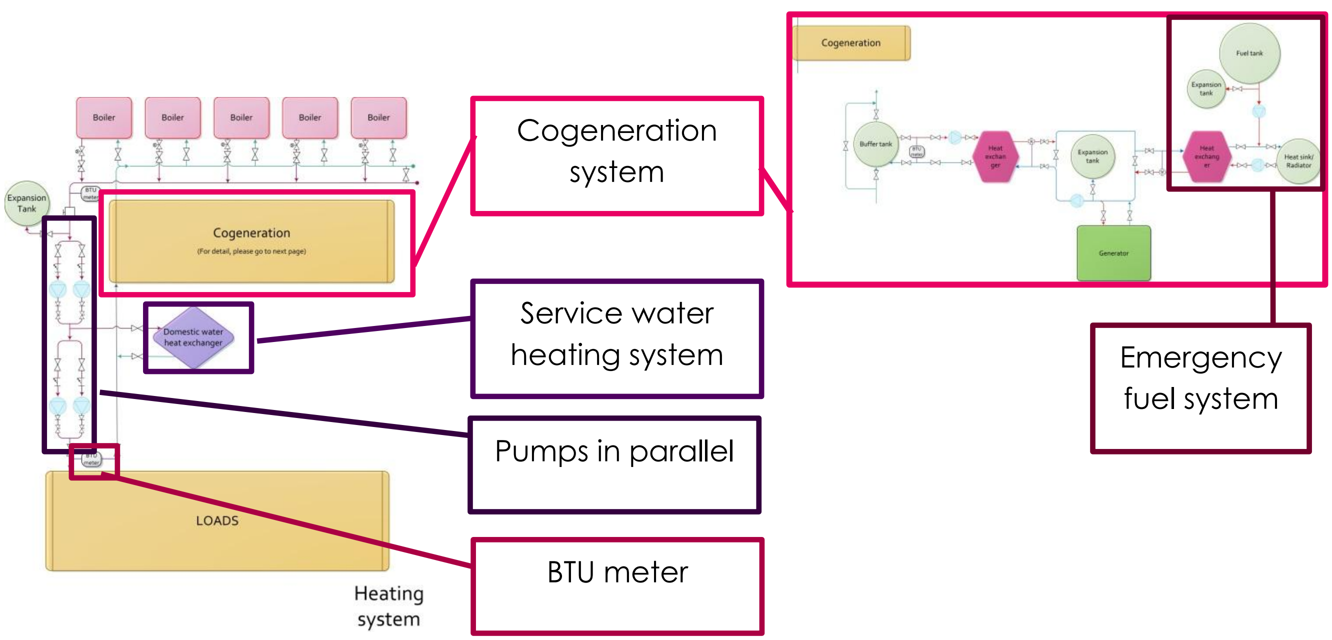


Figure 11 The location of heating components

Table 7Legal of Water-sided HVAC System

Legend			
Symbol	Description	**Symbol**	Description
	2 way valves		Strainer with blow off valve
	Automatic control valve		Check valve
	Balancing valve		Solenoid valve
	3 way valve		Air separator
	Shut-off motorized valve	BTU meter	BTU meter (Flow meter, flow transmitter, temperature sensor)

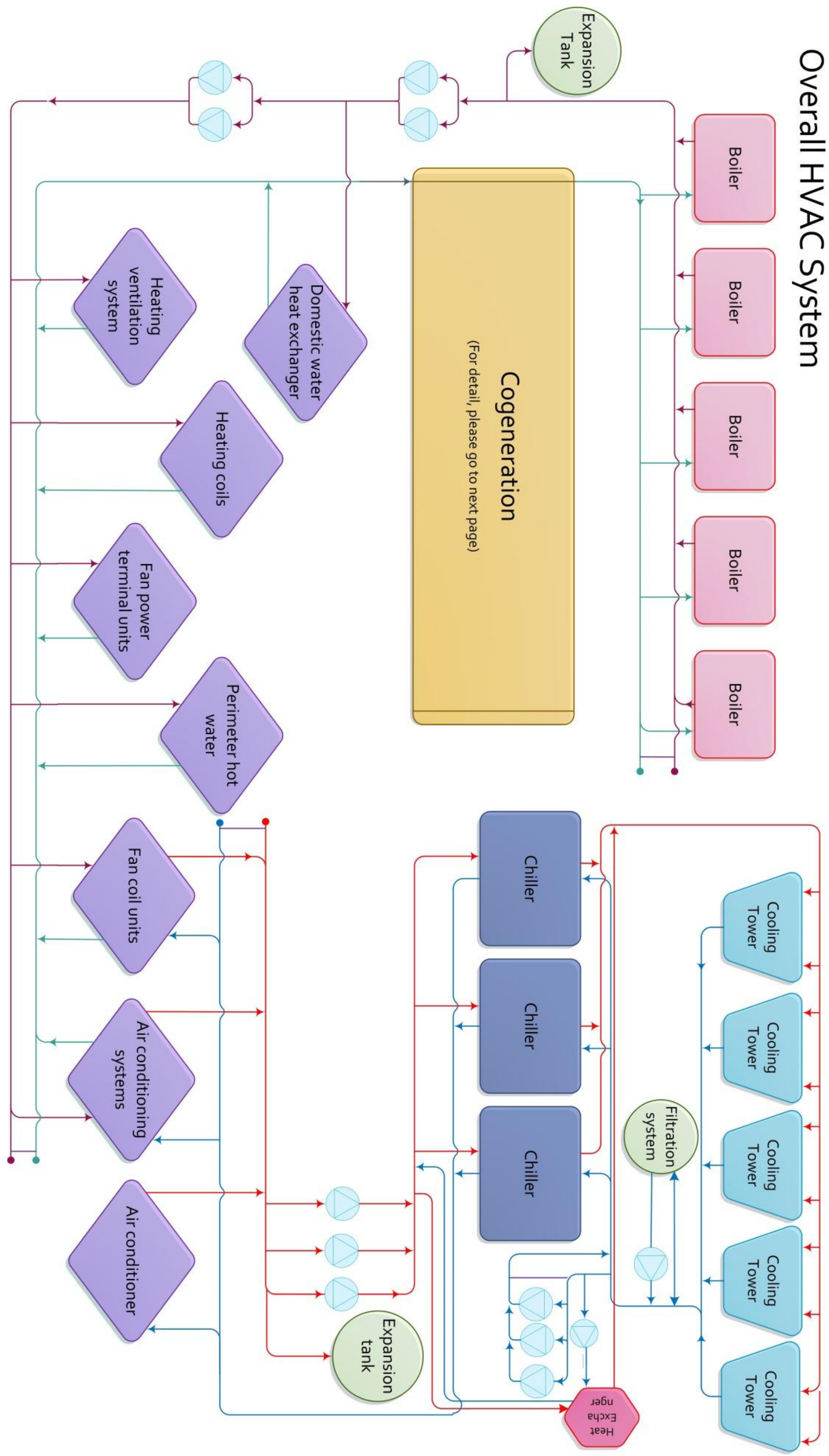


Figure 12 Overall HVAC System of AAM

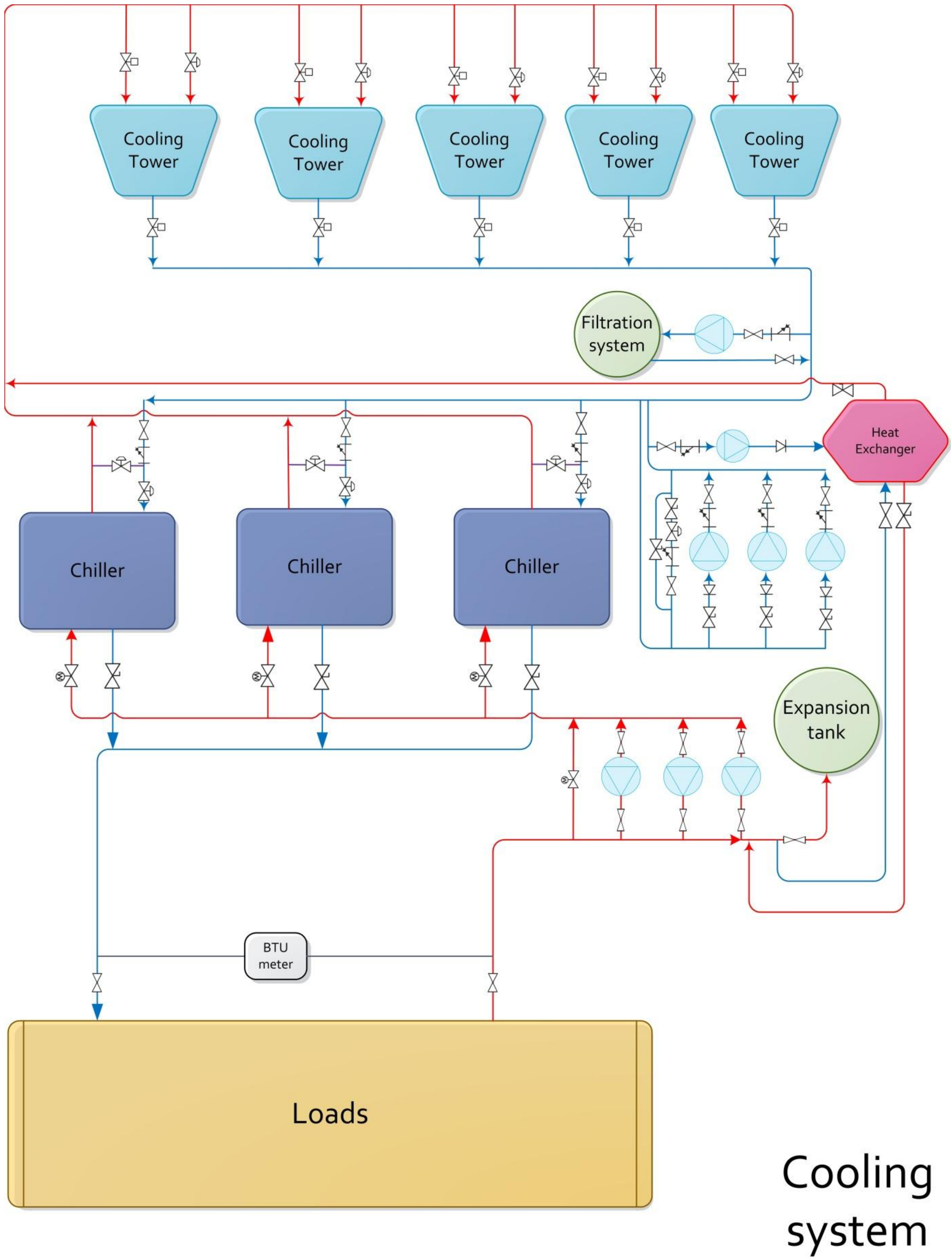


Figure 13 Cooling system of AAM

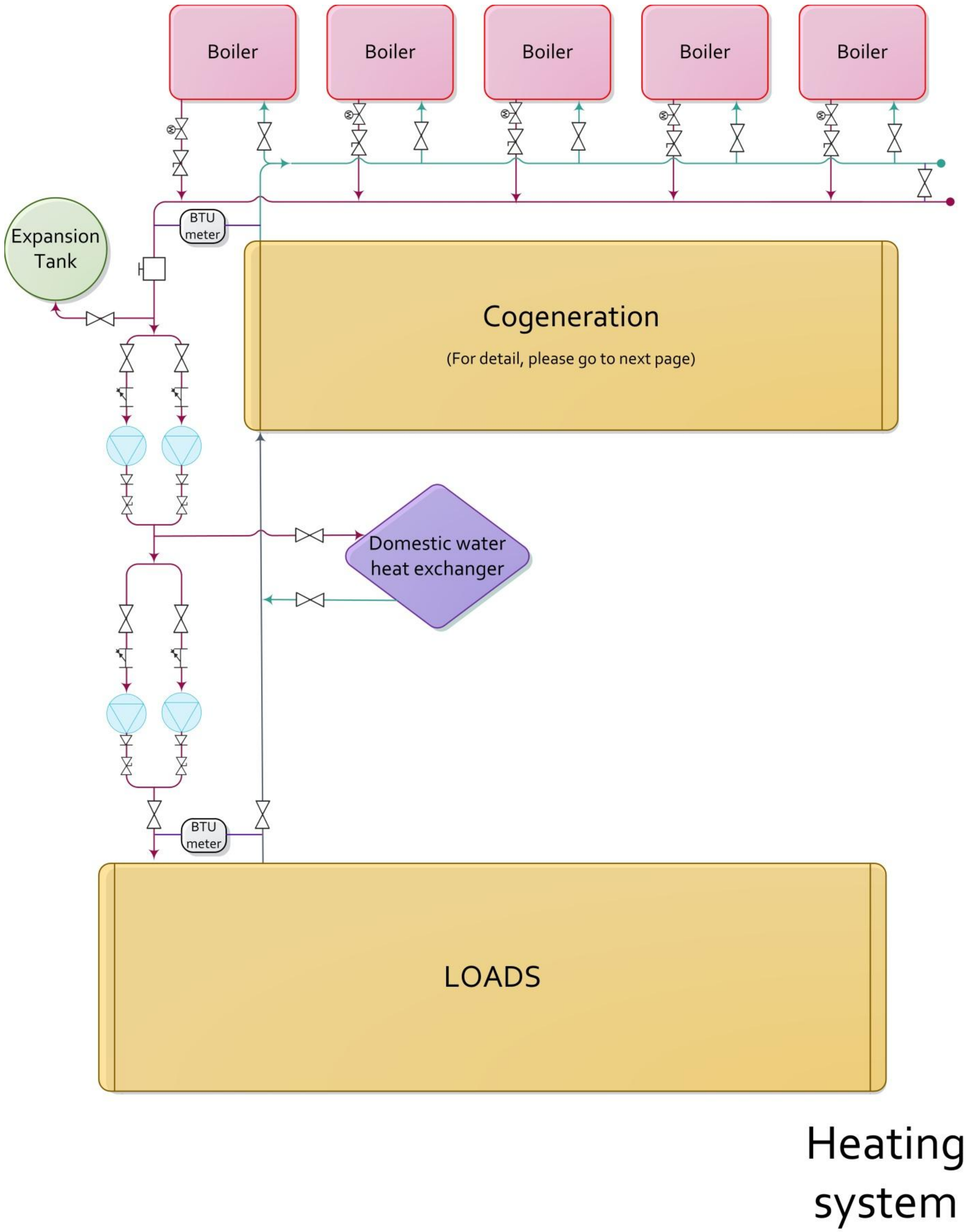


Figure 14 Heating system of AAM

Cogeneration

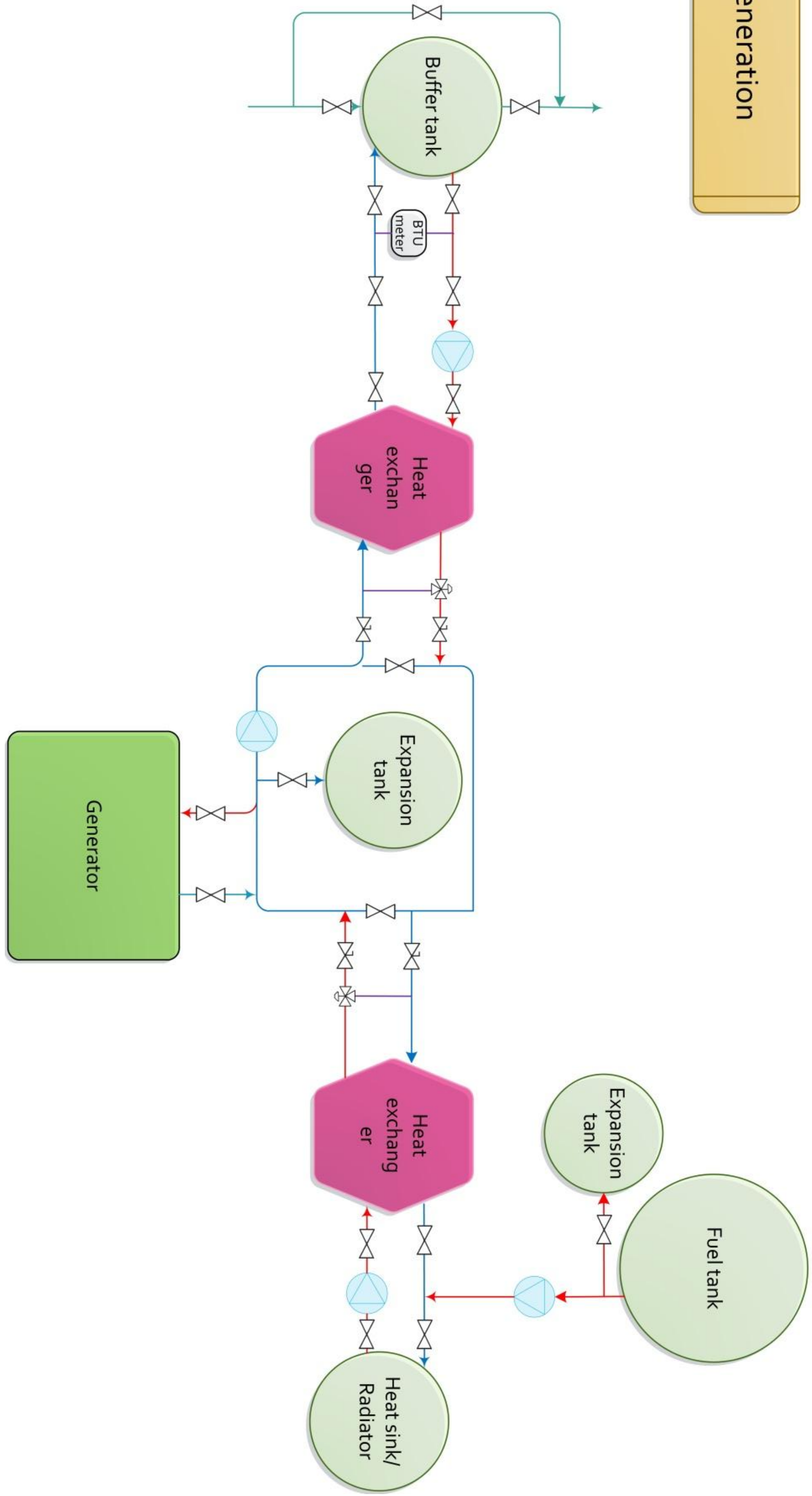
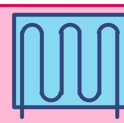
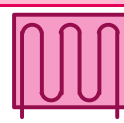
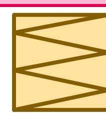
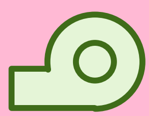


Figure 15 the cogeneration of AAM

Air-sided HVAC System of AAM

The engineering consultants of AAM focus on gallery/office, restaurant, lobby, and fume hood exhaust system, because of the occupant types and the needed quality of indoor environment in these zones. Each of the zones has different small component change(s) of air distribution system, such as humidifier and fan coil unit. However, in the Sequence of Operator, these changes bring a significant effect on control system and the adjustment of indoor air environment.

Table 8 Legend of Air-sided HVAC System

Legend			
Symbol	**Description**	**Symbol**	**Description**
M	Motorize		Humidifier
S	Smoke sensor		Cooling coil
T	Temperature sensor		Heating coil
	Actuator		Damper
CT	Control transmitter		Filter
VFD	Variable speed drive		Fan

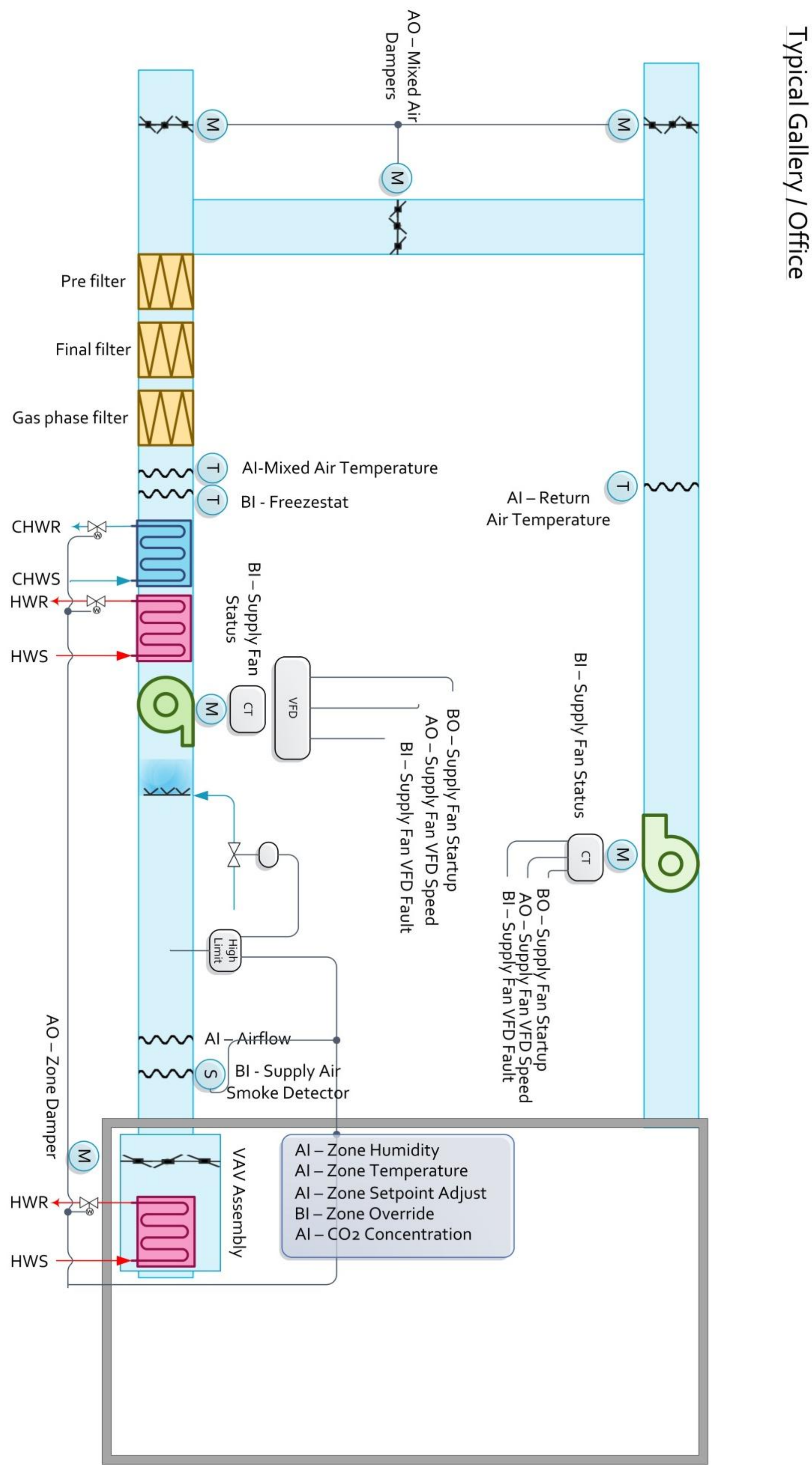


Figure 16 Typical Gallery

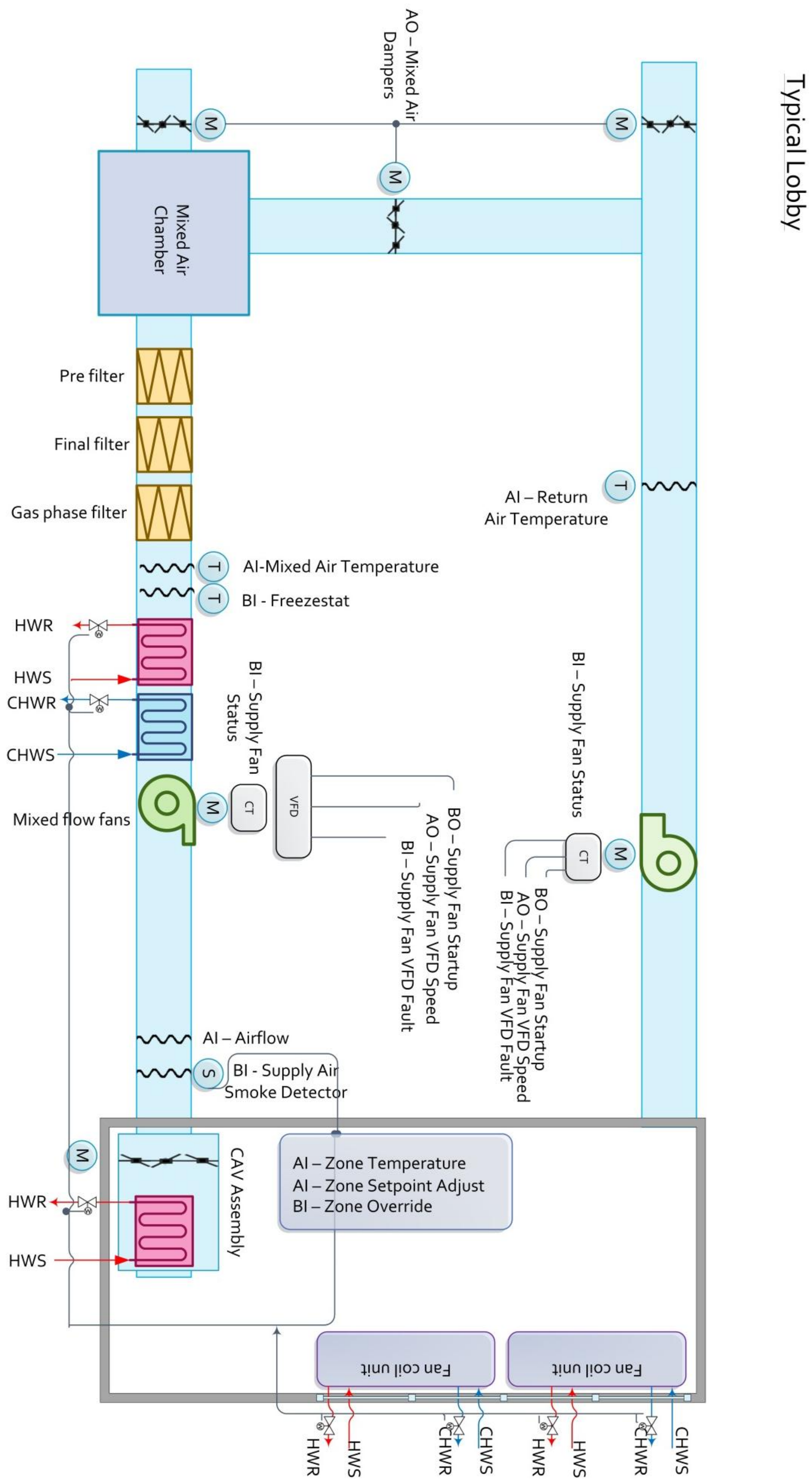
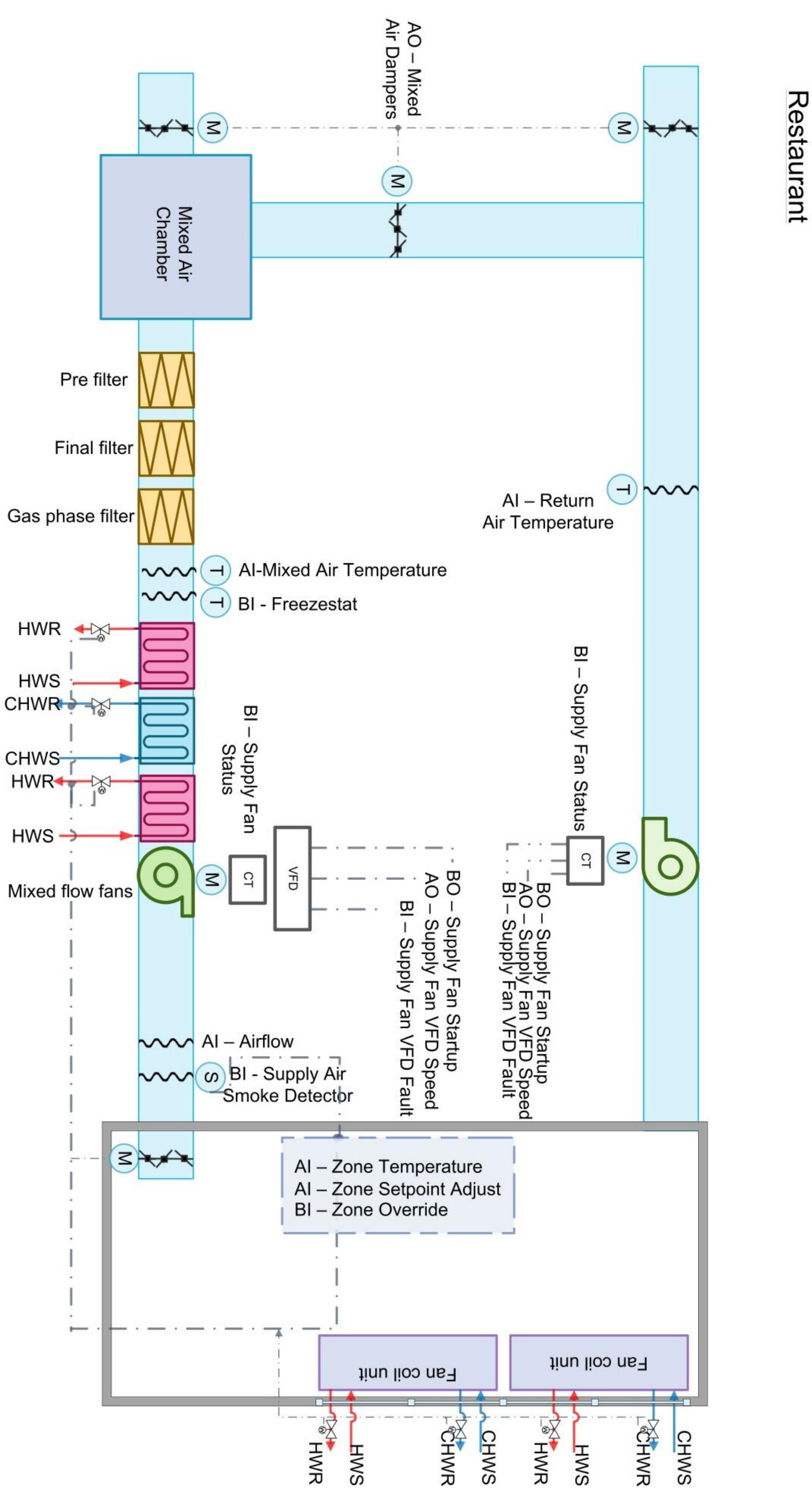


Figure 17 Typical lobby

Figure 18 Restaurant



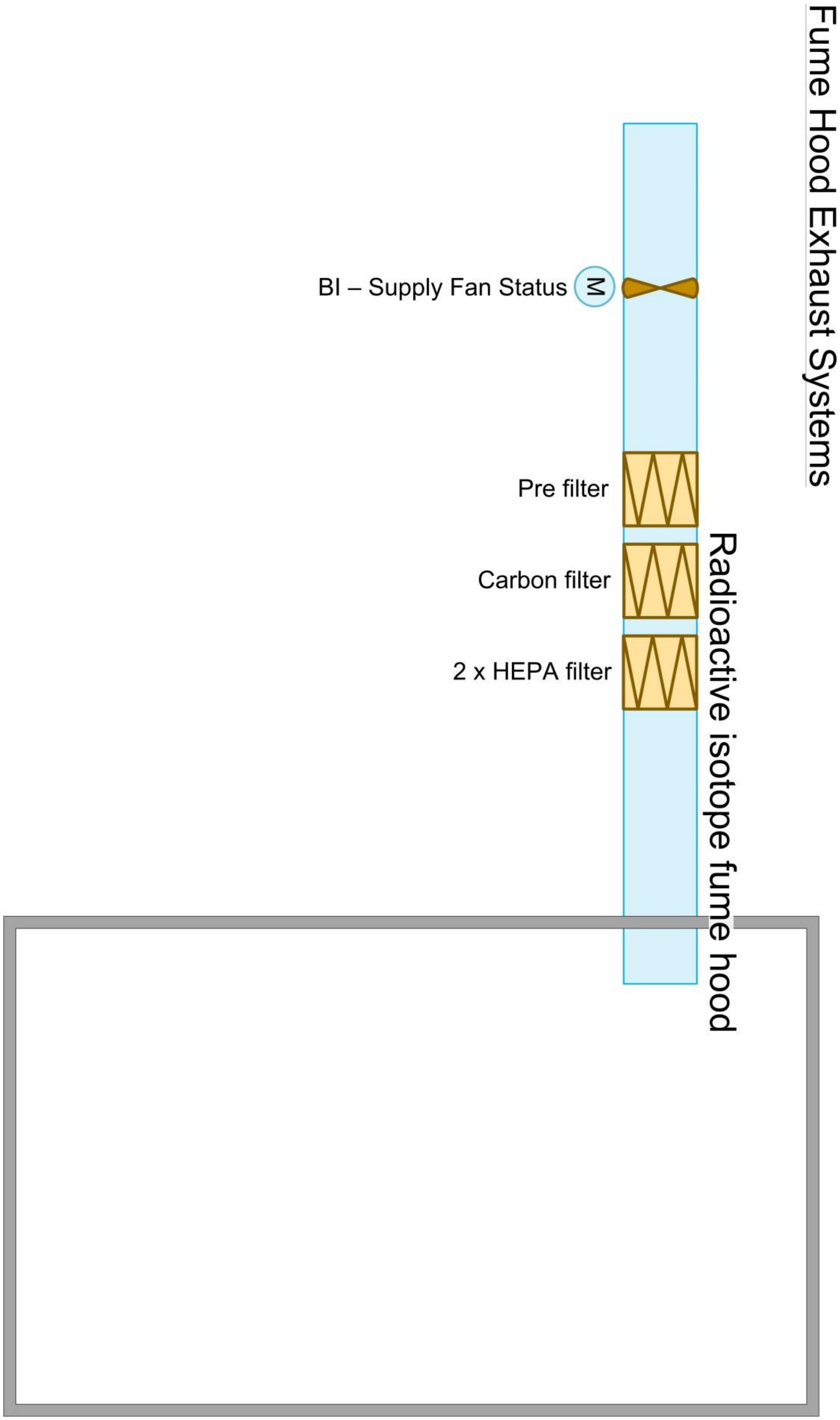


Figure 19 Fume Hood Exhaust System

Tables of Major Equipment

In this section, it introduces a list of major HVAC equipment. This list will be very helpful during the design process of a new HVAC system.

This equipment is classified into 2 criteria: ventilation system and the equipment of heating and cooling plants. Although this list of equipment is simplified, the equipment is divided into small tables, because the ranges of equipment types and sizes are very wide. It only lists the amount and type of equipment.

By looking into the model of some equipment, it shows that the owner focus more on the efficiency and performance of an equipment than the cost of equipment.

Equipment of Ventilation System

Type of typical system	Service	Type of air	Filter type		Cooling	Heating		Humidifier	Supply fan
					Cooling Coil	Reheating Coil	Preheat coil		
Air conditioning system	Kitchen, lobby, restaurant, auditorium, galleries, 8th floor.	Mixed air	Prefilter: Final filter Gas phase:	Panel: 35% MERV 8 Rigid: 95% MERV 16 Activated carbon filter	✓	x	(only provided in Lobby, Restaurant, Gallery, and auditorium	✓	EPQN
Heating + ventilation system	Mechanical rooms, kitchen	100% Outdoor air	2 filters:	Panel: 35% + Rigid: 95%	x	x	✓	x	EPQN
Chilled water packaged air conditioning unit	Switchboard room, IT room	Return air	30% filter		✓	x	✓	✓	x
Constant/variable volume boxes	Gallery and lobby, etc.	Mixed air	--	--	x	✓	x	x	x
Fan powered terminal units (with Variable volume regulators)	Gallery, offices, and theater	Mixed air	--	--	x	✓	x	x	x
Fan coil units	Lobby	Return air	1" Thick, throw-away (lobby only)		✓	✓	x	x	x
Unit heater	Stair, mechanical room, entrance, toilet, and terracce door	Return air	--	--	x	✓	x	x	x

Table 10 Equipment of Ventilation System

Equipment of Heating and Cooling System

Chillers and Boilers

Type of equipment	Amount	Model No.	Capacity (ton)	Refrigerant	Condenser		
					Flow rate (gpm)	Temperature (F)	
						Inlet water	Outlet water
Chiller	3	19xR3	300	R134-A	900	85	95

Type of equipment	Amount	Model No.	Type of boiler	Capacity (BHP)	Water			Fuel	
					Flow rate (gpm)		Outlet temperature	Fuel type	Gas input (ft^3/hr)
					Min	Max			
Boiler	5	BMK-3.0LN	Condensing firetube	86	0	350	150	Natural gas	3000

Table 9 Chillers and Boilers

Pumps

Type of equipment	Service	Type	Variable speed drive	Constant speed
Hot water pump	Boiler plant	Vertical in-line	✓	x
Chilled water pump	Chiller plant	Vertical in-line	✓	x
Pump	Coil freeze protection	Vertical in-line	x	✓
Pump	Coil freeze protection	Circulating	x	✓
Pump	Co-generation	End-line	--	--
Hot water pump	Co-generation, demestic hot water	In-line	--	--
Chilled water pump	Expansion tank	Duplex	x	✓
Hot water pump	Expansion tank	Duplex	x	✓
Cold Condensate Pump	Chilled water cooled Air conditiong unit, fan coil unit	Simplex	x	x

Table 13 Pumps

Expansion Tanks

Type of equipment	Service	Type	With a pump?
Expansion tank	Fan coil unit, kitchen equipment, co-generation heat sink	Diaphram	x
Expansion tank	Chiller water, hot water	Diaphram	✓

Table 12 Expansion Tanks

Cooling Towers

Type of equipment	Location	No. # of fuels	Flow rate (GPM/cell)	Temperature		range	Features
				Inlet water	Outlet water		
Cooling tower	Roof	5	600	95	85	10	Non-corrosive stainless steel, induced draft, and crossflow design with vertical air discharge

Table 11 Cooling Towers

Fans

Type of equipment	Service	Type of fan	Total amount	Amount of fan with variable speed drive
Exhaust fan	Mechanical room	TCVX	6	6
		TCLB	4	0
		TCVS	1	0
		TL	2	0
		BSI	2	2
		QSL	2	1
Supply fan	Mechanical room	TCLB	2	0
		TCVX	2	1
Exhaust fan	Roof exhaust	BAV	1	1
		BAE-SW	1	1
Exhaust fan	Toilet exhaust	TCLB	3	0
		T	1	0
		QSL	1	1
Supply fan	Stair pressurization	QSL	2	2
		TCVX	2	2
Exhaust fan	Kitchen	BAE-SW	3	0
Exhaust Fan	Electrical closet	Ceiling	4	4
Return fan	Gallery	QSL	4	4
		BAE-SW	1	1
Return fan	Lobby	QSL	1	1
Return fan	Restaurant	QSL	1	1
Return fan	Auditorium	QSL	1	1

Table 14 Fans

The Abbreviation of Fans

Fan abbreviation	Name
BAE-SW	Airfoil centrifugal fan
BAV	Backward inclined fan with an airfoil wheel
BSI	Belt driven square inlined fan
EPQN	Non-overloading centrifugal fans
QSL	Quiet mixed flow fan
T	Tubeaxial fan with belt driven
TCLB	Tubular and backward inline centrifugal fan
TCVS	Vaneaxial fan steel wheel
TCVX	Vaneaxial fan adjustable pitch blades
TL	Torque limiting fan

Table 15 The Abbreviation of Fans

Description of System Operation on a Conceptual Level

The HVAC system of AAM is a very sensitive system, due to the amount of sensor and the variation of the schedule of a museum. Although there are many modes in the control system of HVAC, only the conceptual modes are considered in this section. The conceptual modes are 'Winter' mode, 'Summer' Mode, dehumidification, humidification and an economizer cycle in the zone 'Gallery', where is the biggest zone in AAM.

There are also advanced settings in DDC system. For example, the Normal Operation 'Auto' Mode is that the system will select the 'Winter' Mode or 'Summer' Mode by calculating the outdoor air enthalpy based on outdoor temperature and humidity; 'Warm-up/Cool-down' Mode is to give a time offset from 5 to 10 minutes before the DDC sends out command.

These control modes help to minimize the energy consumption by setting an adjustment constraint on heating and cooling system.

'Winter' Mode

Heating: Outdoor Temperature < Set Point Temperature

Air-sided HVAC System

When the outdoor temperature is lower than the set point temperature, the temperature sensor sends signal to the following component of HVAC system:

- Control valves

  The control valve of cooling coil gets closed and minimizes the flow in coil, and the control valves of heating coil and the preheat coil get opened and increases the mixed air temperature in order to maintain the comfort in 'Gallery'. When the supply temperature reaches back to the set point, the control valve of preheat coil gradually closes and the control valve of cooling coil also gradually open in order to avoid simultaneous heating.

- Dampers

  The exhaust damper and outdoor air damper are partially closed to increase the portion of return air and reduce the portion of cool outdoor air, after receiving the feedback from the temperature sensor. Then, the exhaust damper and supply damper gradually open.

Water-sided HVAC System

During winter, the load of chillers decreases due to low demand of cooling, the cooling towers and free-cooling heat exchangers. The chillers are running with low part load. On the other hand, the load of boilers increases, because of the demand of heating. According to the energy saving, the waste heat produced by the boilers is sent to the cogeneration system by heat exchangers.

Humidification: Outdoor RH < Set Point RH

Air-sided HVAC System

When the zone is with low relative humidity, the humidity sensor sends the feedback to the humidifier and request for humidification. The fog-typed humidifier starts operation until the relative humidity reaches to the set point level.

'Summer' Mode

Cooling: Outdoor Temperature > Set Point Temperature

Air-sided HVAC System

The operation is similar to the heating mode. The temperature sensor sends signal(s) to dampers and control valve. So that, the damper of exhaust air and the supply air are closed, and the damper of return air is opened. Also, the control valves of heating coils are closed to stop heating the supply air, and the control valve of cooling coil is opened to lower the temperature. After the room temperature reaches the set point temperature, the dampers and the control valves get back to the original states to maintain the zone temperature.

Water-sided HVAC System

The operation also is similar to the cooling mode. The supply water of chillers first goes through the rooftop cooling towers and then the free-cooling heat exchanger to cool down the exhausted water from the loads. It is finally sent to the chillers, and the chillers cool down the water and pump the chilled water back to loads.

Dehumidification: Outdoor RH > Set Point RH

Air-sided HVAC System

During summer, outdoor relative humidity is sometimes higher than the set point humidity.

- Cooling coils

  The cooling coil cools the air until the temperature of air hit the dew point temperature, then the water inside air becomes condensates and drains to the drain pan of the cooling coil.

- Heating coils

After the air passes through the cooling coil, the air temperature is lower than the set point temperature. The heating coil heats the air to the wanted temperature. Then, the fan in the supply air side sends the air to the 'Gallery'.

Water-sided HVAC System

Since the cooling and heating coils are used in this process, the loads of chillers and boilers increase. According to the energy saving, the benefit of cooling tower is less. It is because the concept of cooling towel is to take out the latent and sensible heat from the water to the air. Since the weather is humid, the air is less likely to evaporate, which also less likely to take out the latent heat of the water in the system.

Economizer Cycle: Outdoor Temperature = Set Point Temperature

Air-sided HVAC System

When the outdoor air temperature is the same with the set point temperature, a global software enthalpy program calculates the enthalpy of outdoor air. If the enthalpy of outdoor temperature is fit the following standards,

- Winter: The outdoor air enthalpy is less than the return air enthalpy.
- Summer: The outdoor air enthalpy is greater than the return air enthalpy.

The supply air is supplied with 100% volume and no mixing with return air. Therefore, the mixing air damper, the heating and cooling coils are closed.

Water-sided HVAC System

Since the cooling and heating coils are not operating, the loads of chillers and boilers are lowered significantly.

Breakdown of the Lost Usable Space Associated with the Mechanical System

The mechanical space is taken from AAM is about 35%. This percentage is a large number. In order to have a good arrangement of rooms, the main mechanical rooms are located on cellar level, mezzanine level and 9th level.

Table 16 Mechanical room and shaft area take off

	Total Area	Mechanical Room Area	Mechanical Shaft Area	% Mechanical use area
Cellar Level	25802	16554	140	65%
Cellar Mezzanine	3645	0	2774.2	76%
First Floor	13793	0	1707.31	12%
Second Floor	2692	2444	0	91%
Third Floor	17636	0	1854.88	11%
Fourth Floor	17543	0	1653.18	9%
Fifth Floor	22252	0	1458.92	7%
Sixth Floor	19795	0	1284.43	6%
Seven Floor	15258	0	788.82	5%
Eighth Floor	10857	0	937.54	9%
Ninth Floor	5486	4454	851.9	97%
			Overall % area	35%

Mechanical System Cost

The estimated cost of the mechanical system in AAM is taken from the draft estimation from Turner Construction Company. The cost is relatively high, because the owner plans to operate in this museum for at least 50 years, since the original museum was built in 1929, and it still is operating.

Table 17 Estimated Cost of Mechanical System

Name:	American Art Museum	
Area:	222,952 sf	
Building Cost w/o fee:	$215,041,873	$964.52/sf
Mechanical Cost:		
HVAC System Work	$2,890,000	$12.96/sf
HVAC System Control	$215,041,873	$964.52/sf

LEED Rating System for New Construction of HVAC

The potential LEED credits obtained by the AAM are 110 points (Platinum certified), and the more likely LEED credits are 52 points (Sliver certified). In this section, the focused LEED criteria are only related to mechanical system, which are Energy and Atmosphere and Indoor Air Quality (U.S. Green Building Council, 2012). The following criteria are considered by the building consultants of AAM.

Energy and Atmosphere

EA Prerequisite 1 Fundamental Commissioning

In order to obtain LEED point of Energy Atmosphere, some commission process activities must be completed. First, the owner should hire a commissioning authority to review the construction documents and commissioning plans. Second, the owner must have the documentation of the project requirements.

In this project, a commissioning authority is allowed to request any needed information for the final commissioning documentations and assistance in any verification and integral system tests. In addition, the owner will have the documentations of the project requirements after the construction.

EA Prerequisite 2 Minimum Energy Performances

The standard in this prerequisite is to satisfy the Mandatory Provision Standard in ASHRAE Standard 90.1-2007. In Technical Report 1, the design documents were checked with ASHRAE Standard 90.1-2007. And, the energy performance of AAM complies with the Mandatory Provision Standard.

EA Prerequisite 3 Fundamental Refrigerant Management

This prerequisite suggests that one of the options is zero use of a certain refrigerant, CFC. The HVAC system of AAM complies with the prerequisite, because the refrigerant used in AAM is HFC-134a.

EA Credit 1: Optimize Energy Performance

The maximum LEED point of new building energy simulation are 19 points depended on the percentage of energy cost saving based on the baseline building performance rating in ASHRAE Standard 90.1-2007.

Table 18 The list of potential LEED point(s) in EA Credit 1

New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2
16%	12%	3
18%	14%	4
20%	16%	5
22%	18%	6
24%	20%	7
26%	22%	8
28%	24%	9
30%	26%	10
32%	28%	11
34%	30%	12
36%	32%	13
38%	34%	14
40%	36%	15
42%	38%	16
44%	40%	17
46%	42%	18
48%	44%	19

And, the consultants of AAM planned to obtain at least 2 LEED points in this section and maximum at 4 points.

EA Credit 3: Enhanced Commissioning (2 points gained)

This section requires the commissioning process to start in the early design process and continue additional activities after the performance verification is completed. In the LEED section of the construction specifications, it states that there are:

- Monthly LEED Certification Meetings at Pre-bid, Pre-construction
- Regular job site meetings, LEED Orientation Program for the workers in the project sites before the construction
- LEED Training Program on the Project Site before and during the construction.

EA Credit 4: Enhanced Refrigerant Management (2 points gained)

This section of LEEF rating system provides three equations:

$$LCGWP + LCODP\ x\ 10^5 \leq 100$$

$$LCGWP\ = [GWPr\ *\ (Lr\ *\ Life + Mr)\ *\ Rc/Life$$

$$LCODP\ = [ODPr * Lr * (Life + Mr * Rc)]/Life$$

The following input data is based on The Treatment by LEED of Environmental Impact of HVAC Refrigerants (TSAC HCFC TASK GROUP, 2004).

Table 19 The input data of EA Credit 4

Refrigerant	R-134a / HCF-134a		
ODP	1.50E-05	lb CFC-11 quiv	
GWP	1320	lb CO2, equiv	
	Min	Max	
Leakage per yr (Lr)	0.50%	2%	
End-of-life leakage (Mr)	2%	10%	
Life	20	35	yr
Charge (Rc)	1.4	3.3	lb/ton
Chiller			
No.#	3		
Capacity	300	ton	

The calculated result is:

Table 20 Calculated result of EA Credit 4

LEED requirement		
	Min	Max
LCGWP	11.088	99.56571429
LCODP	7.5105E-08	3.02829E-07
∑(LCGWP+LCODP*1e5)	11.0955105	99.59599714

In conclusion, the calculated result satisfies the standard of EA Credit 4.

EA Credit 5: Measurement & Verification (1 point gained)

The control system is required to be flexible to the occupants and lower the energy consumption in this section. And, the HVAC design of AAM satisfies the following requirements, which are:

1. Leakage valve in the cooling and heating coils within air handling unit must be under control over time.

   The HVAC design of AAM: In final acceptance test, the flow rates of cooling and heating coil will be measured at the maximum load to ensure the coil performance.

2. Software and manual override must allow the equipment to operate regularly. And, the HVAC equipment is operated stably.

   The HVAC design of AAM: In the construction specification of commissioning for HVAC, the Field Performance and Test will be executed. This test is to check the ability of overriding or operating the external control systems in AAM and operating the air handling unit continuously.

   The HVAC operator of AAM will also go through a training of understand the operation and maintenance of the HVAC system after the construction. And, the owner will be offered operation and maintenance manuals. So, the HVAC system will be operated correctly, when AAM is being occupied.

3. There is no missed economizer opportunity.

   The HVAC design of AAM: The Digital Direct Control (DDC) controllers will provide many energy management routines.

   - Temporary schedule overrides
   - Optimal start
   - Optimal Stop
   - Night setback
   - Enthalpy switchover – economizer control
   - Peak demand limiting
   - VAV fan matching and supply fan control

EA Credit 6: Green Power (2 points gained)

It engages a building is provided at least 35% of the building's electricity from renewable sources. However, in the specifications of AAM, it doesn't indicate any renewable energy will be applied.

Indoor Environmental Quality

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance

The HVAC system is required to satisfy ASHREA Standard 62.1-2007. In the Technical Report 1, the HVAC system design of AAM complies with the standard.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

This prerequisite is to prevent exposure of building occupants and HVAC systems to tobacco smoke. And, AAM will prohibit smoking.

IEQ Credit 1: Outdoor Air Delivery Monitoring (2 points gained)

In order to obtain the LEED points of this section, it is to monitor CO_2 concentrations in the zone with high occupant density. In AAM, there will be CO_2 sensors/transmitter in galleries and a theater, etc. The location of wall-mounted CO_2 transmitter in the design documents is the same with the requirement of LEED rating system, which is 'between 3 feet and 6 feet above the finished floor'.

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan – During Construction (1 point gained)

The following standards must be achieved in order to gain this LEED point, which are:

- During a construction, the control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings Under Construction must be met or exceed.

  The HVAC design of AAM: In the specification, Construction Indoor Quality, it requires that the construction IAQ management must meet the pervious control measures.

- The on-site and installed absorptive materials must be protected from moisture damage.

  The HVAC design of AAM: During the construction, the on-site and installed absorptive materials are protected by controlling water penetration, dampness, and humidity. If a material is defected by visible formation, the non-absorbent materials will be cleaned with low hazard cleaners, or the materials will be removed and replaced.

- The filtration media in the return air grille must meet any of the three standards:
  1. Filtration media with a Minimum Efficiency Reporting Value (MERV) of 8
  2. Filtration media is Class F5 or higher
  3. Filtration media with a minimum dust spot efficiency of 30% or higher and greater than 90% arrestance

The HVAC design of AAM: In Table 10 Equipment of Ventilation System, every system with mixed air will include filter(s) with a MERV of 8.

IEQ Credit 3.2: Construction Indoor Air Quality Management Plan – Before Occupancy (1 point gained)

The air testing must be conducted after the construction and before the building getting occupied. The maximum contaminant level provided by USGBC must not be exceeded. The construction specification states the exactly same standards of Pre-occupancy air testing with IEQ Credit 3.2.

IEQ Credits 4.1- 4.4: Low Emitting Materials (4 points gained)

The suggested low emitting materials in LEED rating system will be used in the construction of AAM. If any product is in conflicted with the requirements of this section, the contractors or the construction manager must provide notification(s).

IEQ Credit 6.1: controllability of System – Lighting (1 point gained)

The lighting should be applied with lighting control, so the occupants can adjust the lighting to suit their needs. The Lighting Specification describes the lighting control system includes occupancy and vacancy sensors, local control, and web-based personal control software in order to provide the best lighting comfort to the occupants.

IEQ Credit 7.1: Thermal Comfort – Design (1 point gained)

The LEED rating system requires the HVAC system to meet the requirements of ASHRAE Standard 55-2004. However, due to the limitation of reference source, it is unable to check if the HVAC system complies with the requirements.

IEQ Credit 7.2: Thermal Comfort – Verification (1point gained)

6-18 months after the construction, a thermal comfort survey of AAM is required to be conducted in order to obtain this LEED point. And, it is unable to verify if the HVAC system satisfies the standard, since the construction of AAM is not completed.

Conclusion

Overall, the construction team and the design teams have written a clear document on LEED rating. And, the design teams don't only satisfy the LEED requirement, but also bring the building technology to an advanced level, such as having regular LEED meeting between the construction team and contractor and a flexible and an user-friendly lighting control system.

Overall evaluation

In the final evaluation, there are five criteria that are important to be concerned, such as the consideration of the owner, the amount of mechanical space, and the providing the education of HVAC control system to the staffs or/and the owner. Although the following ideas might not look related, it provides a new perspective of this HVAC system.

Construction Cost vs. Preformance

The construction cost of this mechanical system is $ 12.96/sf and the control system is $ 964.52/sf. The cost is relatively high. But, the owner of AAM concerns more on long term payback period, because the original museum started operation from 1929 to now. Therefore, the objective of the owner is high performance and quality with long payback period, which the HVAC system should be last longing and highly performed.

Space Requirements vs. Material Cost

The ratio of mechanical rooms and shafts to the total floor area is 35%, which is a high number. In order to solve the space problem, the architect and the engineering consultant divided the mechanical system into 3 groups and located them on Cellar level, mezzanine level and 9th level. However, it might bring up a problem of increasing the length of ductworks and piping.

Maintainability vs. DDC

The museum will be required high maintenance, because of the advanced control system of HVAC and lightings. First, there will be many types of sensor, such as photosensors, carbon dioxide transmitters, occupancy sensors and humidity sensor, which are required to be calibrated from time to time. Second, the DDC system is complex, because it has about 4 control modes of each zone, which are 'Summer' Mode, 'Winter' Mode, Normal Operation 'Auto' Mode, and 'Occupied' Mode. The other control modes in particular zones are Life Safety Shutdown and Smoke Purge Mode, and Warm-up/Cool-down Mode, etc. It is difficult to understand or edit the mode setting without any training. Also, this control system will need to be calibrated more often than a typical control system.

Indoor Air Quality Issues vs. Architectural Design

Due to the nature of a museum, the indoor air quality is required to be monitored and well-controlled. But, the problem is that the museum visitors may enter from outside or exit from indoor and bring unconditioned outdoor air flow through the doors, especially there will be outdoor exhibitions in terraces. The possible solutions are to limit the number of door and relocate the entrance and exit.

Potential of District Steam Heating System

The district steam heating system is a good option of shortening the payback period. It is because ConEdison provides incentive programs for installing and having a steam system. Second, using steam can reduce the amount of pumps, which is an opportunity to increase the usable space.

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Appendix. A Weather Data

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NEW YORK LAGUARDIA ARPT, NY, USA

WMO#: 725030

Lat: 40.78N Long: 73.88W Elev: 30 StdP: 14.68 Time Zone: -5.00 (NAE) Period: 82-06 WBAN: 14732

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	12.6	17.3	-4.1	4.4	15.2	-0.4	5.4	19.6	32.3	32.0	28.9	28.1	16.8	320

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	13.9	92.2	74.4	89.3	73.0	86.6	71.9	77.2	87.2	75.9	84.6	74.7	82.6	12.4	270

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
74.3	128.5	81.0	73.2	123.3	80.1	72.0	118.5	79.5	40.5	87.5	39.2	84.8	38.1	82.4	741

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
27.3	24.7	21.7	83.1	7.4	97.3	5.8	2.7	3.3	99.2	-0.1	100.8	-3.4	102.3	-7.6	104.3

Monthly Climatic Design Conditions

			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg		55.7	33.4	35.8	42.3	52.6	62.4	72.1	77.3	76.4	69.2	58.3	48.6	38.8
	Sd			9.70	8.47	8.50	7.56	7.04	6.59	5.33	5.29	6.47	7.25	7.84	9.07
	HDD50		1731	517	403	267	53	1	0	0	0	0	12	117	361
	HDD65		4603	979	818	705	380	137	16	0	1	31	230	493	813
	CDD50		3812	3	5	28	130	385	664	847	817	576	269	75	13
	CDD65		1210	0	0	1	7	56	229	382	353	158	23	1	0
	CDH74		9251	0	0	9	80	463	1729	3324	2745	821	77	3	0
	CDH80		3025	0	0	1	21	141	584	1215	866	189	8	0	0
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		60.0	63.1	73.3	83.3	89.5	93.7	96.6	95.0	90.3	80.6	72.2	64.7
		MCWB		53.3	51.1	58.9	65.6	70.2	74.2	76.0	76.0	73.3	67.4	61.4	57.5
	2%	DB		54.9	56.0	64.6	74.5	84.0	89.9	92.6	90.7	84.9	75.7	66.6	58.9
		MCWB		51.0	47.8	52.8	59.0	67.8	72.1	74.8	74.6	70.4	65.5	59.2	54.0
	5%	DB		50.1	51.1	58.7	68.9	79.3	86.5	89.5	87.6	81.4	72.3	63.2	54.7
		MCWB		45.4	45.0	49.9	56.1	65.7	71.0	73.5	73.4	69.8	64.1	56.8	50.0
	10%	DB		46.0	47.5	54.1	64.0	74.5	83.1	86.5	84.7	78.6	69.2	60.6	51.1
		MCWB		40.9	41.8	46.6	52.8	62.5	69.3	72.3	72.1	68.7	61.7	55.4	46.0
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		56.1	55.4	61.8	66.7	73.2	76.9	78.8	79.1	76.5	71.6	64.6	59.5
		MCDB		58.4	58.4	72.6	81.1	83.3	88.5	90.8	90.1	84.2	75.1	68.9	62.3
	2%	WB		51.7	50.2	55.3	61.8	69.9	74.9	77.3	77.1	74.7	68.5	61.4	55.0
		MCDB		54.2	54.3	60.7	71.6	80.1	85.7	87.7	86.5	80.2	73.2	64.5	58.1
	5%	WB		46.0	45.9	51.2	58.2	67.2	73.1	76.0	75.8	73.1	65.9	59.0	51.1
		MCDB		49.8	50.5	57.2	65.2	77.2	82.7	85.4	83.5	78.0	71.1	62.2	54.2
	10%	WB		41.6	42.2	47.8	55.0	64.3	71.3	74.7	74.6	71.2	63.0	55.9	46.5
		MCDB		45.2	46.8	53.7	61.5	72.8	79.9	83.2	81.7	76.5	67.9	59.9	50.0
Mean Daily Temperature Range		MDBR		11.1	12.2	13.5	14.7	15.4	14.8	13.9	13.0	12.7	12.6	11.6	10.8
	5% DB	MCDBR		15.7	17.4	20.0	22.0	22.4	18.8	17.3	15.7	15.3	15.8	14.7	14.9
		MCWBR		14.1	14.1	13.2	11.7	10.7	8.5	7.1	6.8	7.4	9.4	12.0	13.8
	5% WB	MCDBR		15.8	16.7	18.7	20.1	20.5	17.1	15.4	13.8	13.2	14.1	13.9	14.7
		MCWBR		15.8	15.0	14.4	12.8	11.3	9.1	7.5	7.0	9.1	11.0	13.5	15.3
Clear Sky Solar Irradiance	taub			0.329	0.364	0.400	0.431	0.467	0.525	0.532	0.518	0.415	0.377	0.353	0.326
	taud			2.304	2.126	2.035	1.979	1.918	1.806	1.821	1.844	2.182	2.241	2.264	2.370
	Ebn,noon			259	264	267	267	259	244	241	239	260	257	247	251
	Edh,noon			32	42	50	55	60	67	66	62	42	37	32	28

CDD*n* Cooling degree-days base n°F, °F-day
CDH*n* Cooling degree-hours base n°F, °F-hour
DB Dry bulb temperature, °F
DP Dew point temperature, °F
Ebn,noon } Clear sky beam normal and diffuse hori-
Edh,noon } zontal irradiances at solar noon, Btu/h/ft2
Elev Elevation, ft
Enth Enthalpy, Btu/lb
HDD*n* Heating degree-days base n°F, °F-day
Hours 8/4 & 55/69 Number of hours between 8 a.m. and 4 p.m with DB between 55 and 69 °F
HR Humidity ratio, grains of moisture per lb of dry air

Lat Latitude, °
Long Longitude, °
MCDB Mean coincident dry bulb temperature, °F
MCDBR Mean coincident dry bulb temp. range, °F
MCDP Mean coincident dew point temperature, °F
MCWB Mean coincident wet bulb temperature, °F
MCWBR Mean coincident wet bulb temp. range, °F
MCWS Mean coincident wind speed, mph
MDBR Mean dry bulb temp. range, °F
PCWD Prevailing coincident wind direction, °, 0 = North, 90 = East

Period Years used to calculate the design conditions
Sd Standard deviation of daily average temperature, °F
StdP Standard pressure at station elevation, psi
taub Clear sky optical depth for beam irradiance
taud Clear sky optical depth for diffuse irradiance
Tavg Average temperature, °F
Time Zone Hours ahead or behind UTC, and time zone code
WB Wet bulb temperature, °F
WBAN Weather Bureau Army Navy number
WMO# World Meteorological Organization number
WS Wind speed, mph