AUDAIN ART MUSEUM | a case study

48-798 HVAC & Power Supply in Low Carbon Buildings

Jamie Ho

Outline

1 Basic Info

Audain Art Museum

Two-story **Class AA** museum showcasing Canadian art

4750 m^2 (51,130 ft^2)

Completed in June 2016

Designed to reach gold in LEED Canada

(New Construction & Major Renovations ‘09)

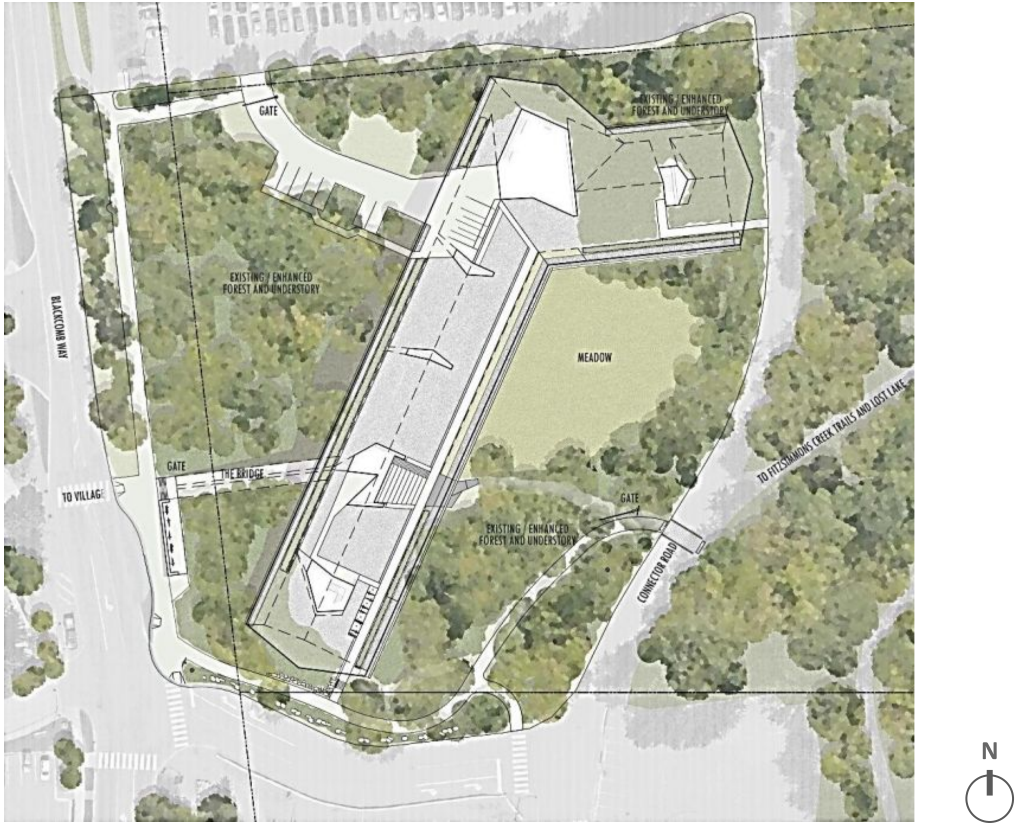
Programme:

“Permanent and temporary exhibit galleries, workshops,

a public lobby, a gift shop, education space, offices,

and a suite for a live-in building manager”

Site Plan



From: https://dailyhive.com/vancouver/audain-art-museum-whistler

Whistler Blackcomb, Whistler, BC, Canada

From: Google Maps

Climate

Humid continental climate (Dfb)

Cold & wet winters

Drier & warm summers

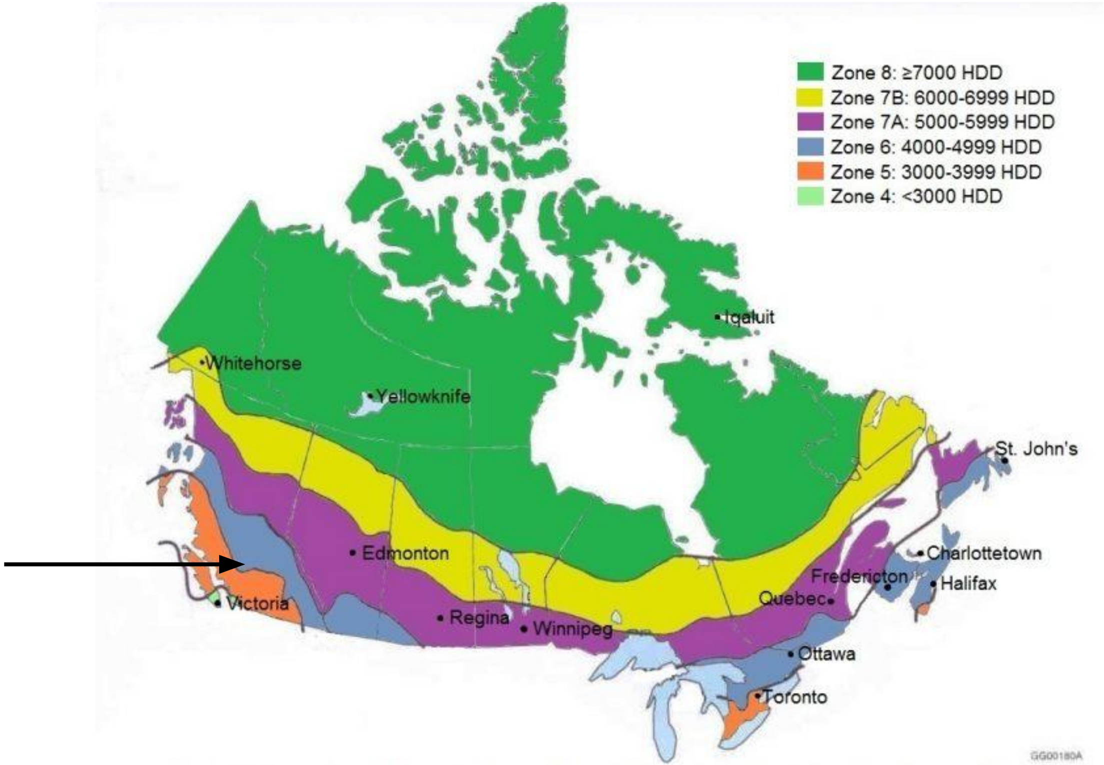
4,180 heating degree-days below 18°C (64°F)

Average 11 days over 30°C (86°F)

Average 24 days under -10°C (14°F)

From: https://en.wikipedia.org/wiki/Whistler,_British_Columbia

Climate



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From: https://guides.co/g/code-booklet/154377

Classes of Control for Museums

Table 1. How to Describe Your Collection

Maximum fluctuations and gradients in controlled spaces		Class of control
Short-term[*] fluctuations and space gradients	**Seasonal adjustments in system set point**	
±5% RH ±2°C	RH no change. Up 5°C and down 5°C.	AA Precision control, minimal seasonal changes to temperature only.
±5% RH ±2°C	Up 10% RH and down 10% RH. Up 5°C and down 10°C.	A Good control, some gradients or seasonal changes.
±10% RH ±2°C	RH no change. Up 5°C and down 10°C.	A Good control, seasonal change to temperature only.
±10% RH ±5°C	Up 10% RH and down 10% RH. Up 10°C (but not above 30°C) and down as low as necessary to maintain RH control.	B Control, some gradients plus winter temperature setback.
Within range 25–75% RH year-round. Rarely over 30°C, usually below 25°C.		C Prevent all high risk extremes.
Reliably below 75% RH.		D Prevent damp.
[*] Short-term fluctuations are any fluctuations less than the seasonal adjustment; however, some fluctuations are too short to affect some less-sensitive artifacts and those that are enclosed.		

From: https://www.canada.ca/en/conservation-institute/services/preventive-conservation/environmental-guidelines-museums/general-care-preventive-conservation.html

Class AA Museum

Table 1. How to Describe Your Collection

Maximum fluctuations and gradients in controlled spaces		
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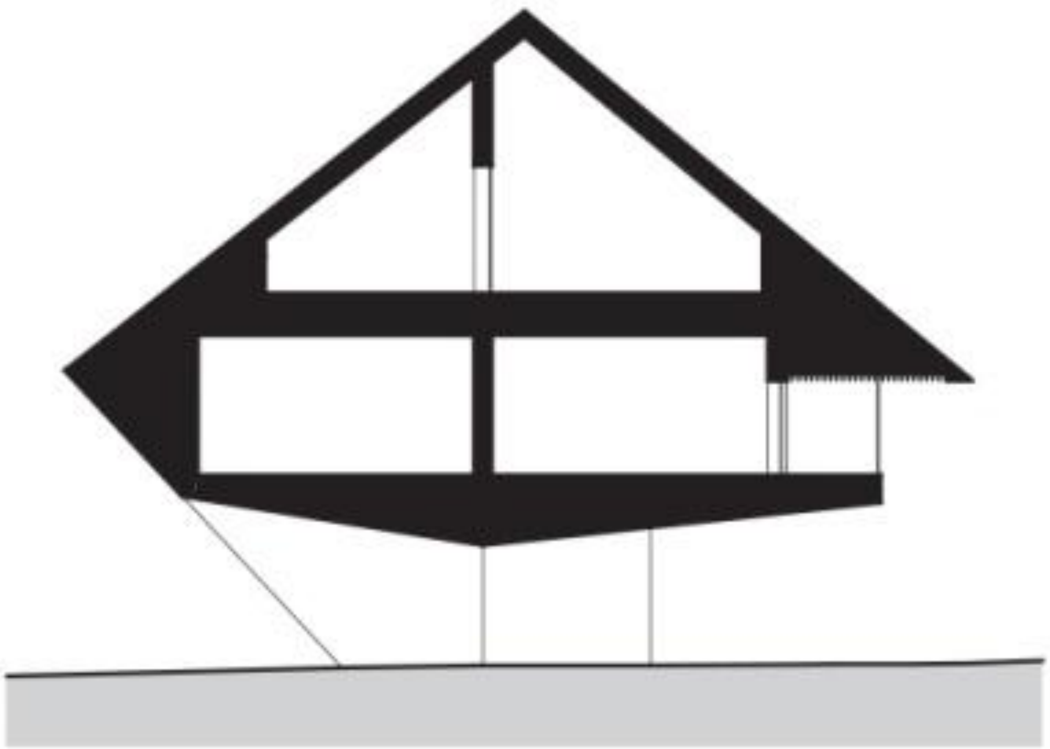
From:

2 Envelope Design

Transverse Section



From: https://www.architectural-review.com/buildings/shaped-by-the-forces-of-nature-audain-art-museum-by-patkau-architects

Envelope R-Values

Wall

R-23.3 (RSI-4.1)

Conduction is 32% lower than baseline

Roof

R-55 (RSI-9.7)

Conduction is 62% lower than baseline

Windows

Triple-glazed

Conduction is 53% lower than baseline

From: https://archello.com/story/48123/attachments/photos-videos

3

Ventilation System

Two Systems

Exhibit Gallery Spaces

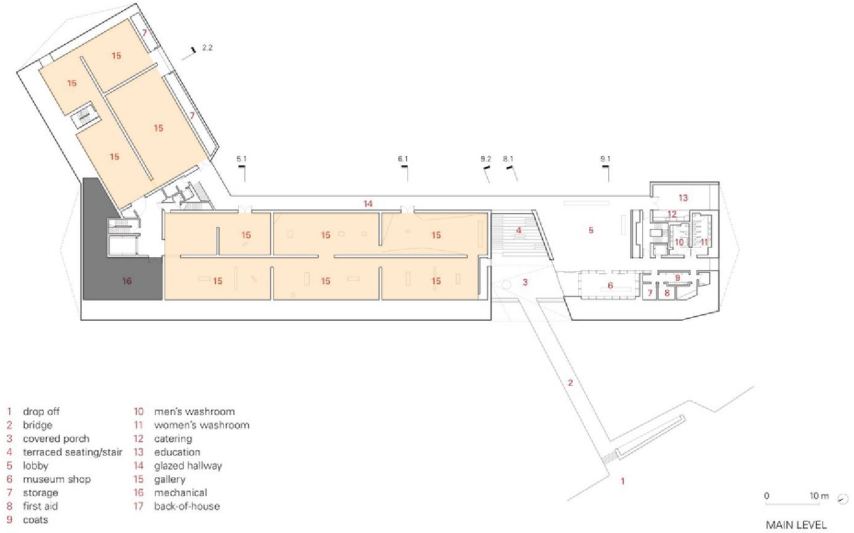
Class AA Requirements

Non-Gallery Spaces

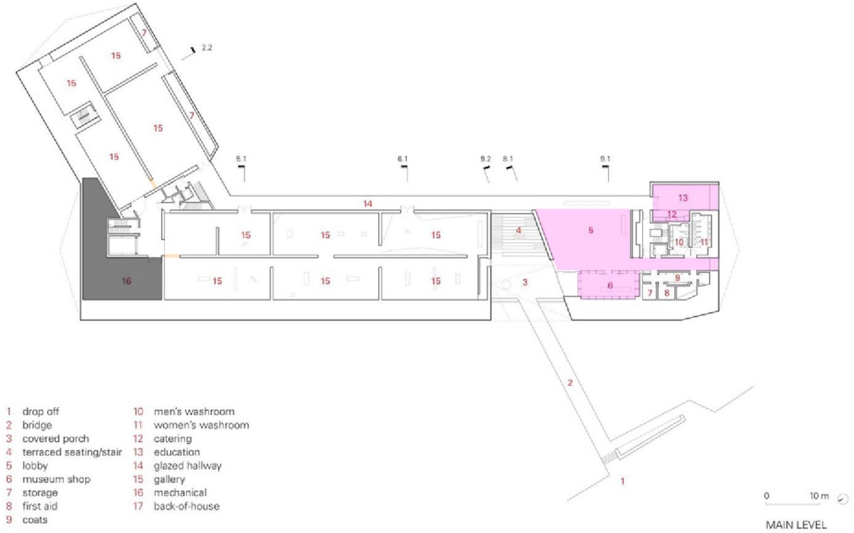
General Requirements

From: https://twitter.com/AudainArtMuseum/

Exhibit Gallery Spaces



Non-Gallery Spaces

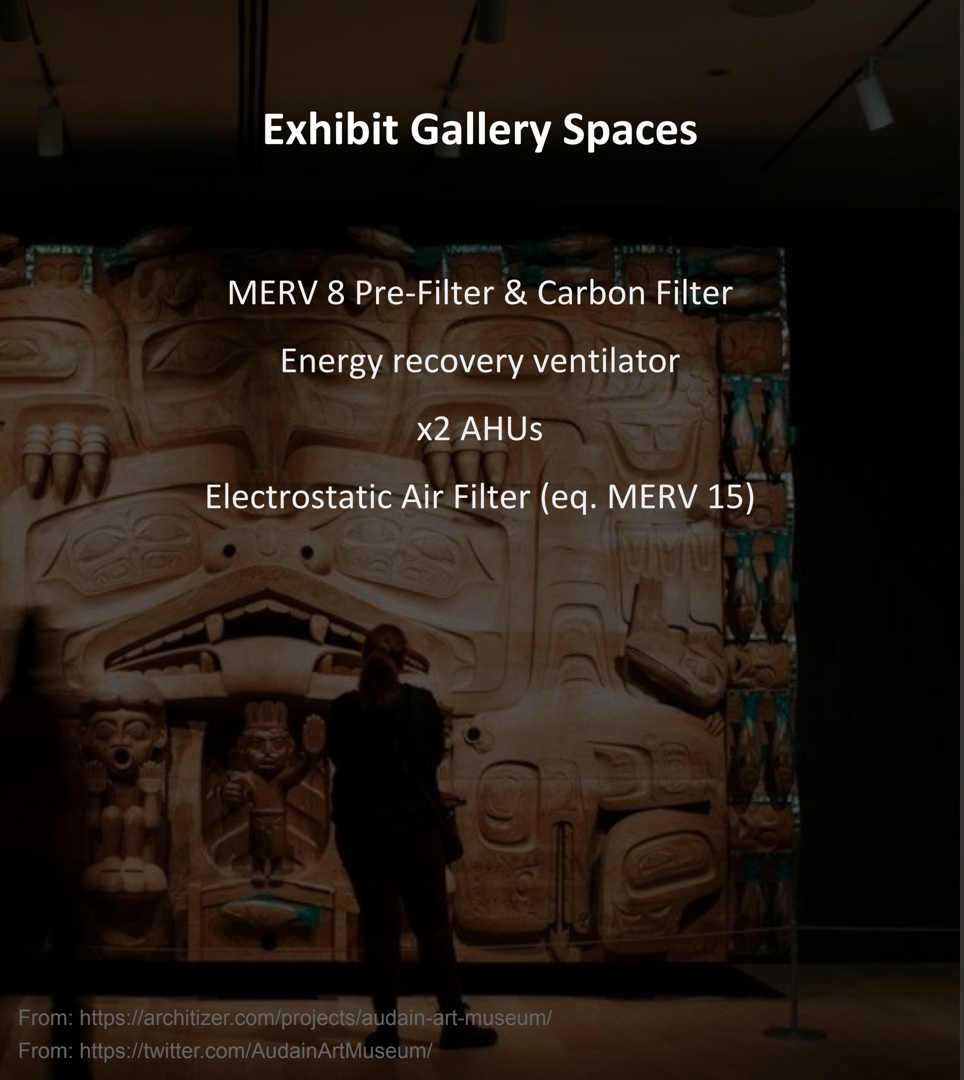


From: https://www.archdaily.com/873187/audain-art-museum-patkau-architects

Exhibit Gallery Spaces

Non-Gallery Spaces

From: https://www.archdaily.com/873187/audain-art-museum-patkau-architects



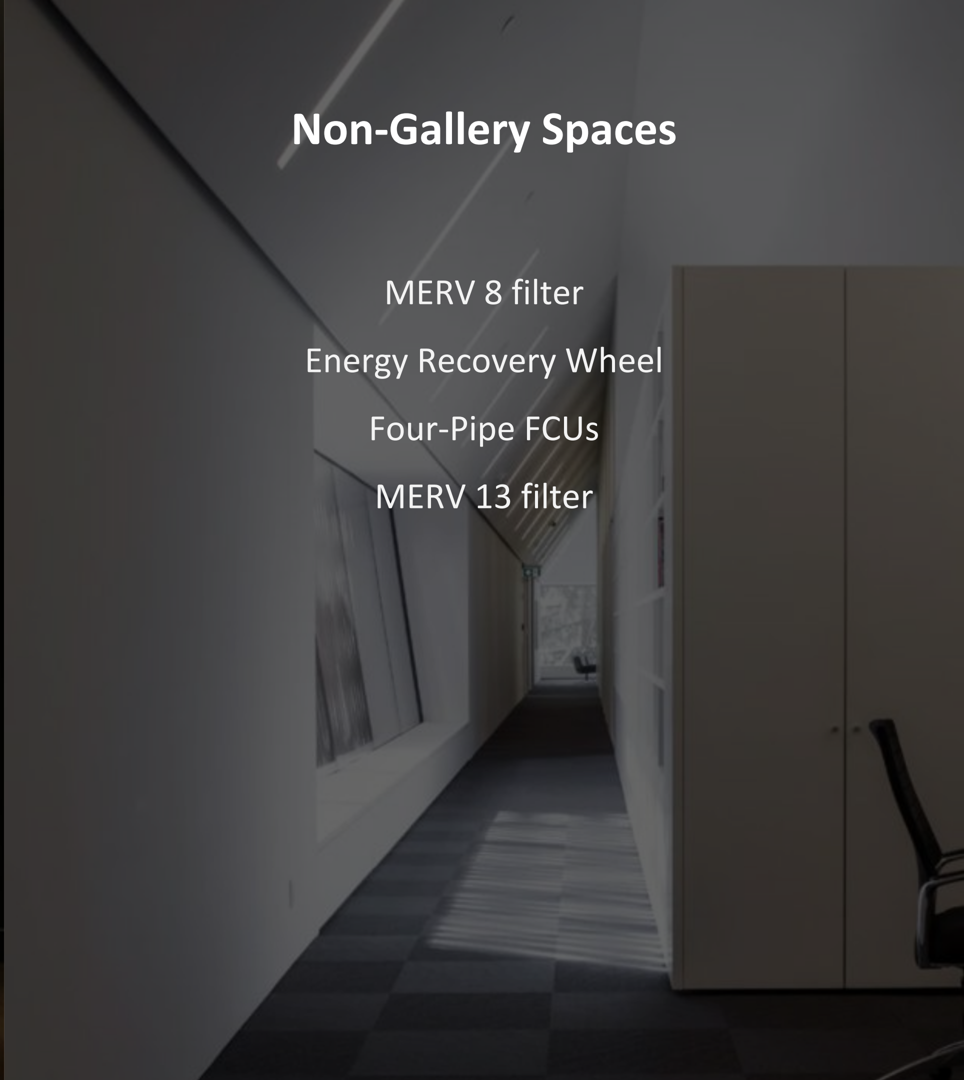


Exhibit Gallery Spaces

MERV 8 Pre-Filter & Carbon Filter

Energy recovery ventilator

x2 AHUs

Electrostatic Air Filter (eq. MERV 15)

Non-Gallery Spaces

MERV 8 filter

Energy Recovery Wheel

Four-Pipe FCUs

MERV 13 filter

From: https://architizer.com/projects/audain-art-museum/

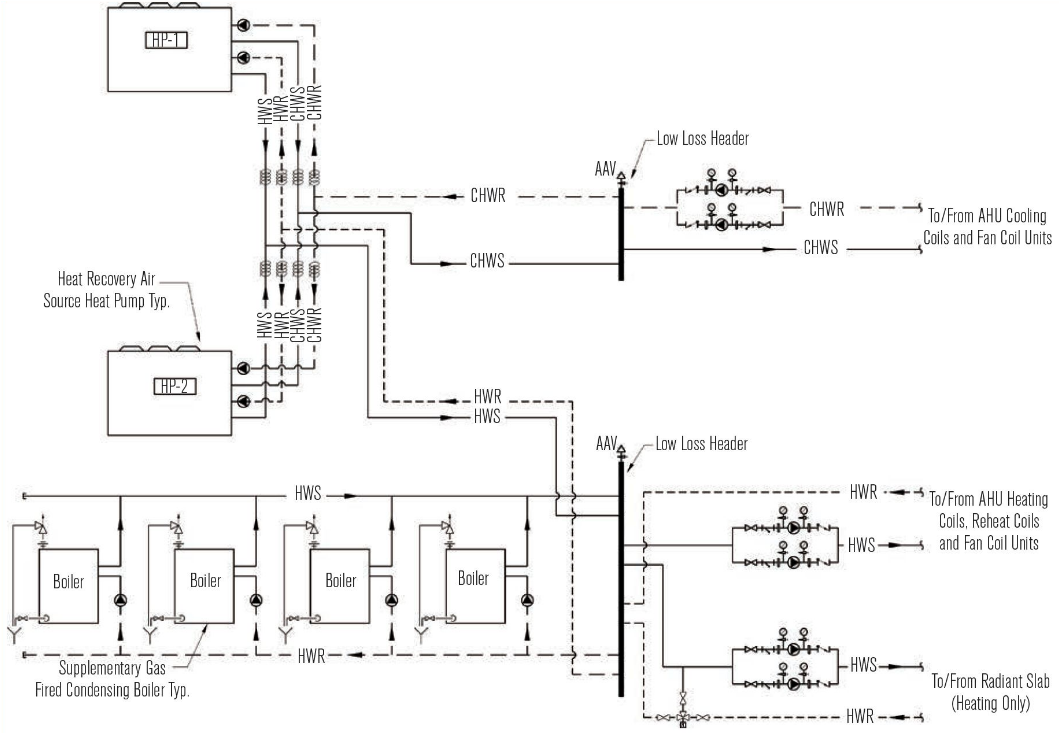
From: https://twitter.com/AudainArtMuseum/

4 Heating & Cooling System

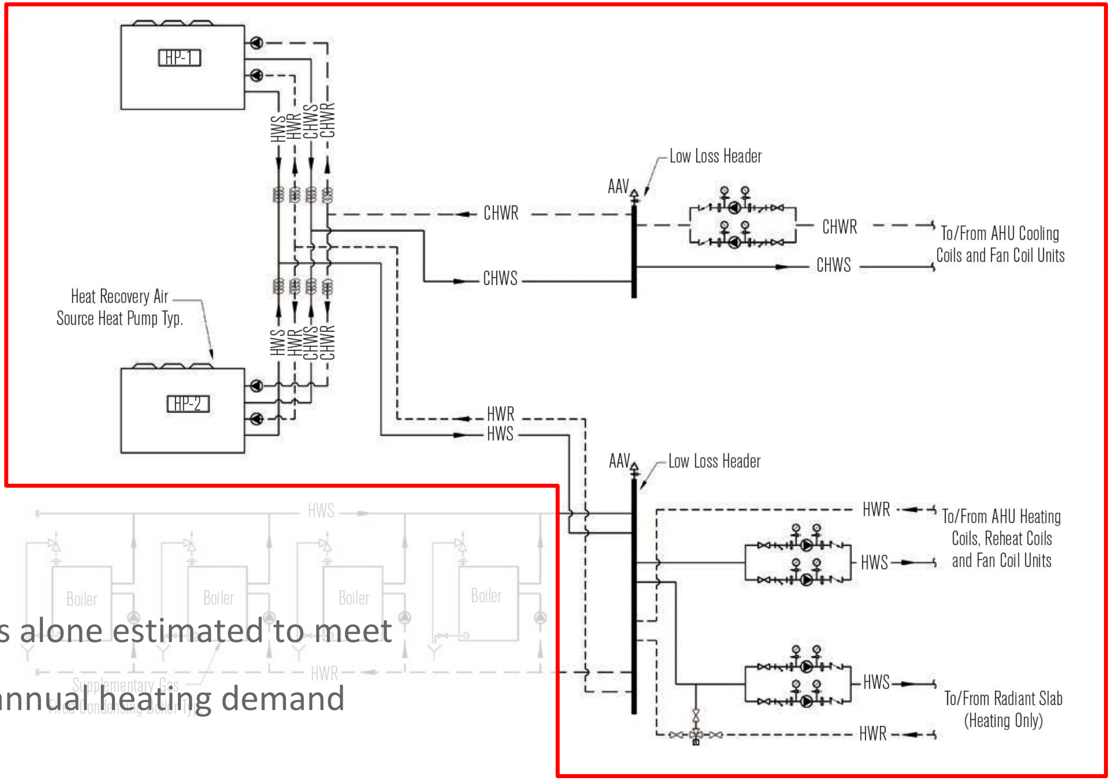
Requirements

	GALLERY SPACES	NON-GALLERY SPACES	
	Year-Round (Class AA)	Summer	Winter
Temperature	21°C / 70°F	23°C / 73°F	21°C / 70°F
Allowed Temp Change	± 1°C / ± 2°F		
Relative Humidity	50%	< 60%	40%
Allowed RH Change	± 5%	-	± 10%
Terminal Air Velocity	0.1 m/s	0.8 m/s	
Controls	Temp, Humidity, CO_2 sensors in each gallery	Temp, Humidity, CO_2 sensors in each fan-coil zone	

Hydronic System



Main System



AHUs & FCUs for cooling

AHUs & FCUs for heating

Radiant heating

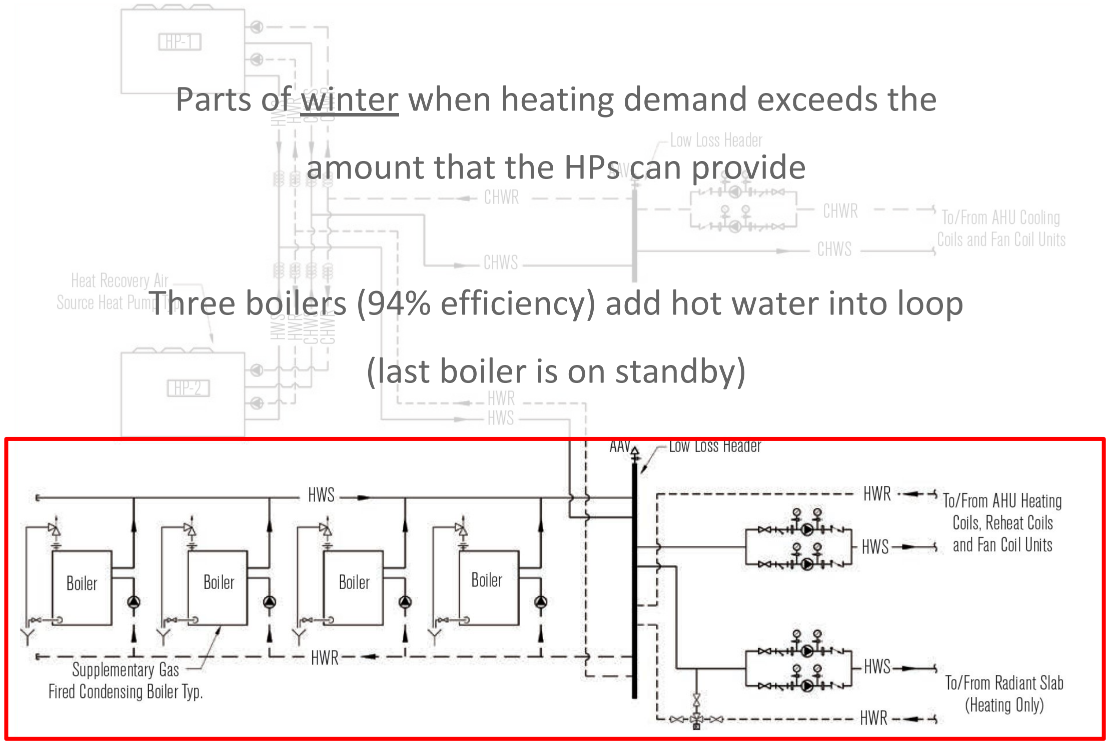
Heat pumps alone estimated to meet

76% of annual heating demand

Supplemental System

Parts of winter when heating demand exceeds the amount that the HPs can provide

Three boilers (94% efficiency) add hot water into loop (last boiler is on standby)



Deconstructing the System

Centralised system

Hydronic heating/cooling system

Ventilation integrated into AHUs

Primary Equipment	Heat Pumps
Fuel	Electricity
Heat Source & Heat Sink	Water loop connected to HPs
Energy Carrier	Water to air
Energy Transfer Medium	Water pipes
Terminal Device/Equipment	Fan coil units to grilles

Deconstructing the System: Gallery Space

Ventilation and heating/cooling is <u>integrated</u>

ERV <u>partially conditions</u> the air passively

AHU <u>fully conditions</u> the air (AHU sized for heating and cooling)

Large ducts <u>distribute</u> the fresh air and conditioned air

↓

Air-based

Deconstructing the System: Non-Gallery Space

Ventilation and heating/cooling is separated

Energy recovery wheel partially conditions the air actively

Ducts supply fresh air

4-pipe FCU uses hot water and chilled water to fully condition the air

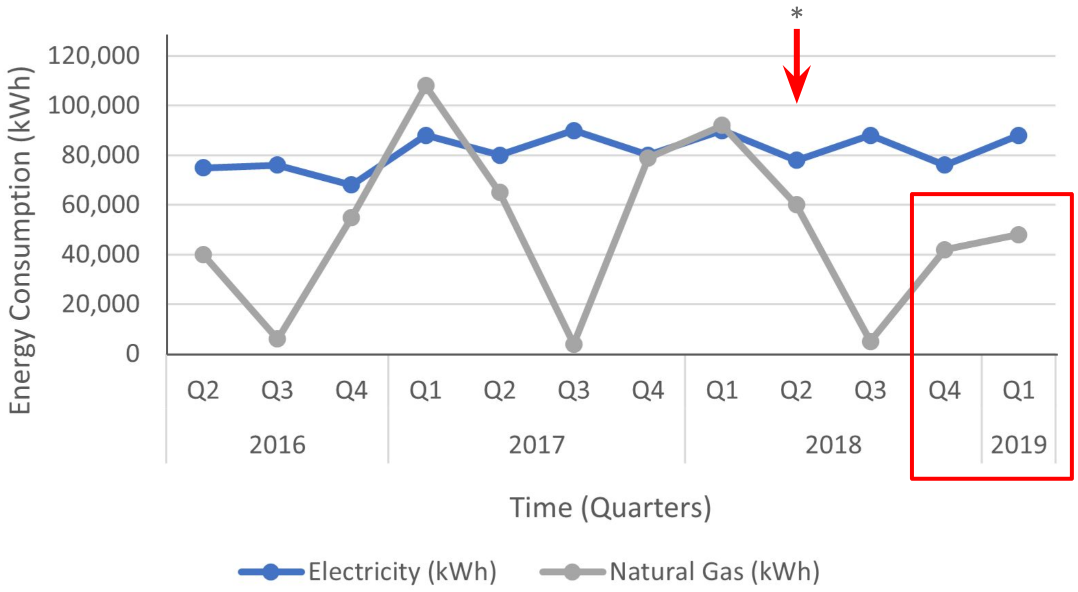
↓

Water-based

5 Performance & Cost Data

Metered Energy Consumption Over Time

*Discovered in March 2018 that "supplementary" boilers were operating even when not needed



Site EUI

2017 Q1 - Q4 (before boiler discovery)

Annual Energy Consumption:

[Electricity]	338,000 kWh
[Natural Gas]	256,000 kWh
[Total]	594,000 kWh

Site EUI:

594,000 kWh / 51,130 m^2 = **11.6 kWh/m^2/yr**

2,026,728 kBtu / 550,360 ft2 = **3.7 kBtu/ft^2/yr**

2018 Q2 - 2019 Q1 (after boiler discovery)

Annual Energy Consumption:

[Electricity]	330,000 kWh
[Natural Gas]	155,000 kWh
[Total]	485,000 kWh

Site EUI:

485,000 kWh / 51,130 m^2 = **9.5 kWh/m^2/yr**

1,654,820 kBtu / 550,360 ft2 = **3.0 kBtu/ft^2/yr**

Source EUI

2017 Q1 - Q4 (before boiler discovery)

Source Multiplier:

[Electricity] 338,000 * 3.15 = 1,064,700 kWh

[Natural Gas] 256,000 * 1.09 = 279,040 kWh

[Total] 1,343,740 kWh

Source EUI:

1,343,740 kWh / 51,130 m^2 = **26.3 kWh/m^2/yr**

4,584,840 kBtu / 550,360 ft2 = **8.3 kBtu/ft^2/yr**

2018 Q2 - 2019 Q1 (after boiler discovery)

Source Multiplier:

[Electricity] 330,000 * 3.15 = 1,039,500 kWh

[Natural Gas] 155,000 * 1.09 = 168,950 kWh

[Total] 1,208,450 kWh

Source EUI:

1,208,450 kWh / 51,130 m^2 = **23.6 kWh/m^2/yr**

4,123,231 kBtu / 550,360 ft2 = **7.5 kBtu/ft^2/yr**

Energy Efficiency

Baseline Building

ANSI/ASHRAE/IESNA Standard 90.1-2007 → 2,884,292 kWh (9,833,333 kBth)

Proposed Building

LEED Canada NC 2009 Gold rating → 1,730,575 kWh (5,900,000 kBtu)

Estimated
40% reduction
in annual energy consumption

Achieved primarily through energy savings in **space heating** (70% of savings)

Space heating now makes up 31% of proposed building energy usage

Costs VS Carbon Emissions

Electricity rate ($0.0462/kWh) VS Gas rate ($0.056/kWh)

Hybrid system has annual energy savings of $2,837

BUT...

This system costs $155,000 more than boiler-only system

(ROI is longer than equipment's life expectancy)

BUT!

British Columbia uses hydroelectric power generation!!!

Building estimated to save 216,529 kg (476,364 lb) CO_2e compared to the baseline model

6 Renewable Energy

Hydroelectric Energy Generation

From: http://www.energybc.ca/largehydro.html

Hydroelectric Energy Generation

BC Hydro and Power Authority operates 32 hydroelectric facilities

Hydroelectric energy generation provides 92% of

British Columbia's electricity

Carbon emissions can be greatly reduced by selecting an electric system:

Hydroelectric: 0.09 kg CO_2e/kWh

Natural gas: 0.185 kg CO_2e/kWh

From: https://en.wikipedia.org/wiki/BC_Hydro

7 Lessons Learned

In designing systems for museums, we have to consider not only the occupants, but also the art collections.

Art needs to be housed in a consistent environment to prevent damage from temperature or humidity. Also needs to be undisturbed as much as possible. Therefore, **commissioning** is important and should occur before any of the art collection arrives. (In this project, temperature and RH were recorded for 14 days before any exhibits were allowed to be set up.)

Mechanical systems don't last as long as the building, so at some point, different parts will fail. The failure must not damage the art. (Ex. water services are located as far away from galleries as possible and leak detectors are added to detect and prevent major leaking issues.)

Don’t ignore the data!

Commissioning should be done properly.

It really shouldn’t take 2 winters to realise that the supplementary boilers were operating when not needed AND operating at a higher temperature than designed for. The natural gas consumption in quarter 4 of 2018 was half of the amount in quarter 4 of 2017!

Perhaps performing better than the baseline energy model hid the fact that there were errors that did not align with the designed intent.

Consider how power is generated before selecting the system.

There may be a more environmentally-friendly solution.

Since British Columbia generates power through hydroelectric means, the carbon emissions can be greatly reduced by selecting an electric system.

Hydroelectric:	0.09 kg CO_2e/kWh
Natural gas:	0.185 kg CO_2e/kWh

This would save a lot of carbon emissions by using electric heat pumps, since it is estimated that the heat pumps would consume 75% of the heating energy consumption.

Thank you!

Information and images in this case study presentation was primarily gathered from the July 2020 ASHRAE Journal unless otherwise specified in each slide.

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