Future of HVAC Systems

Design Team 137

Meet the Design Team

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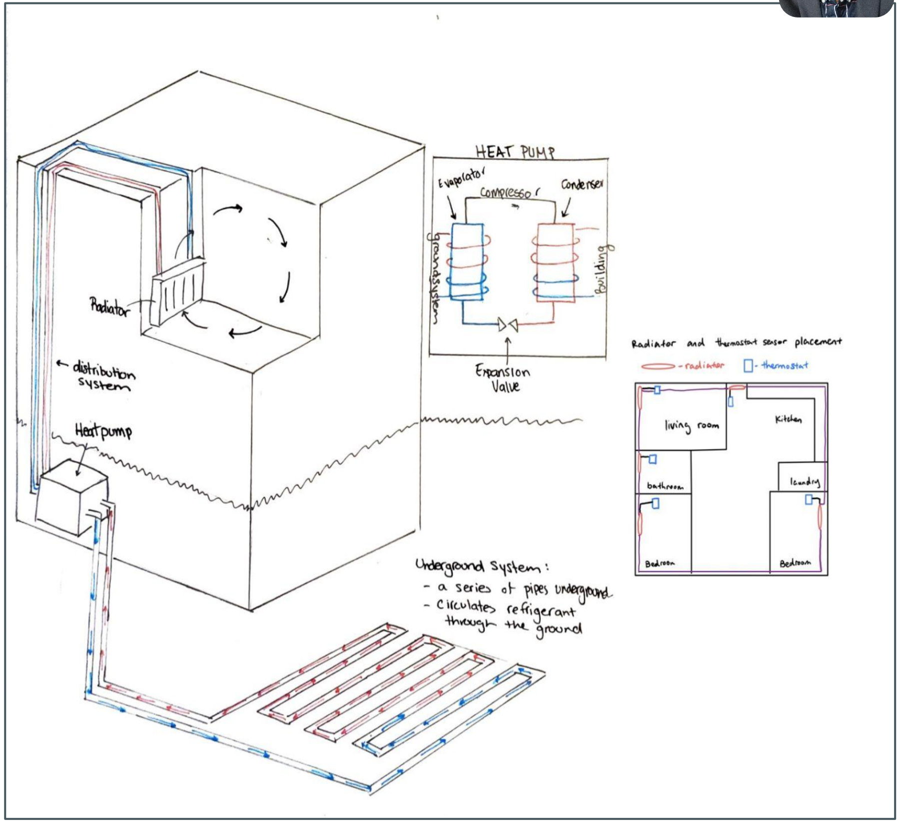
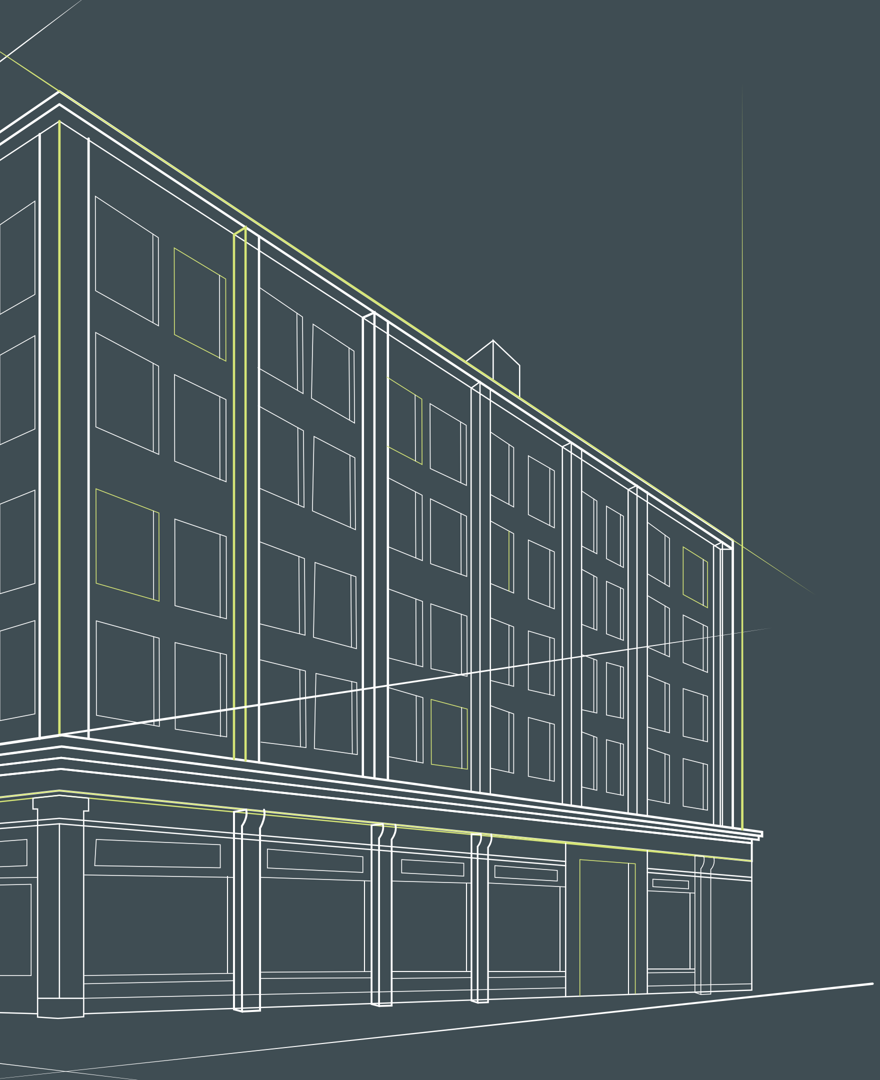
Presenter:
Bob-Yiqiu Chen

Main Claim:

GSHP+thermostat satisfies the client's needs of reducing GHG emissions





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Background

Presenter:
Bob-Yiqiu Chen

Background information

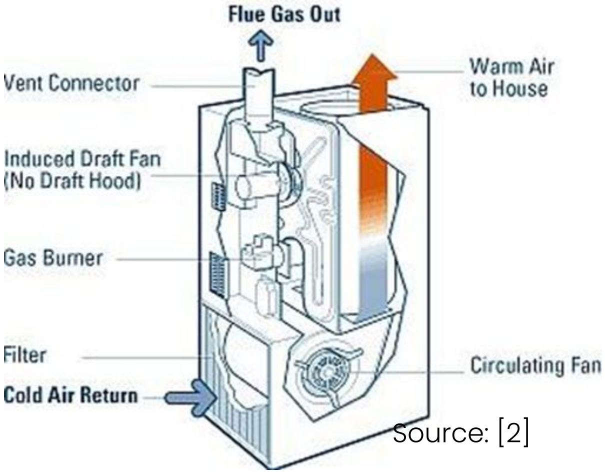
Client Name: Brototi Das(she/her)

Affiliated Company: Emerson Electric Co

Source: [1]

Basis of the project
Reducing GHG (Greenhouse Gas) emission in City 'X'

Why we care?
Protecting environment



Source: [2]

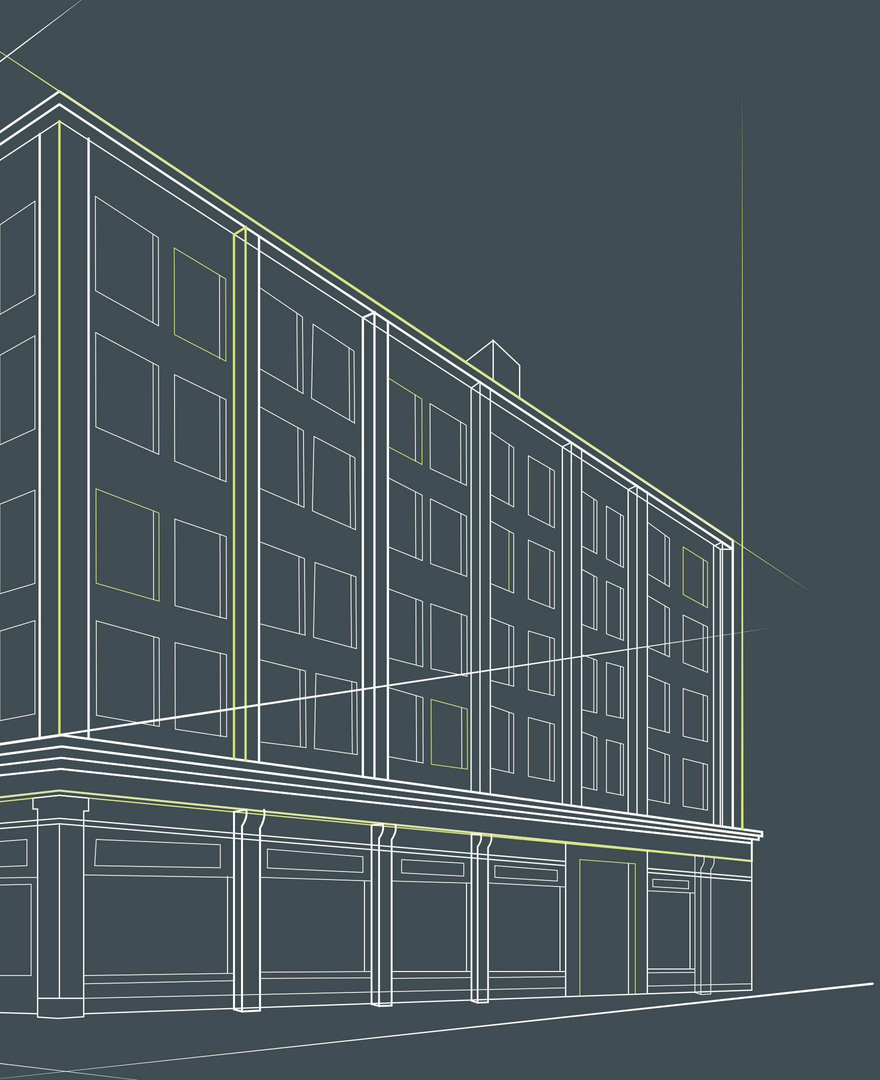
Presenter:
Bob-Yiqiu Chen

Gap, Need, Scope

Gap: Lack of a cost-effective, zero-emission centralized HVAC system

Scope: Future high-rise buildings (> 5 floors) in Toronto

Need: An integrated system to generate heat and circulate air without using natural gas



Presenter:
Keli Chen

01

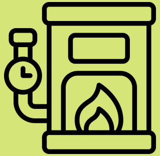
Claim A

The chosen design does not rely on combustion of fossil fuels, thus reducing GHG emissions

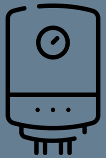
Presenter: Keli Chen

Idea generation: Main Thermal Energy Output Methods

Furnaces



Boilers



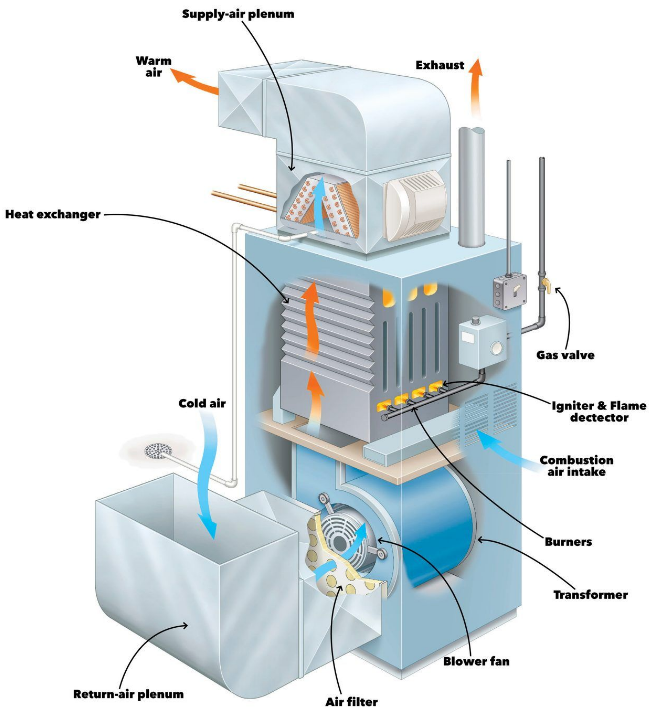
Heat pumps

Thermal storage + fan

Electric baseboard heaters

Presenter: Keli Chen

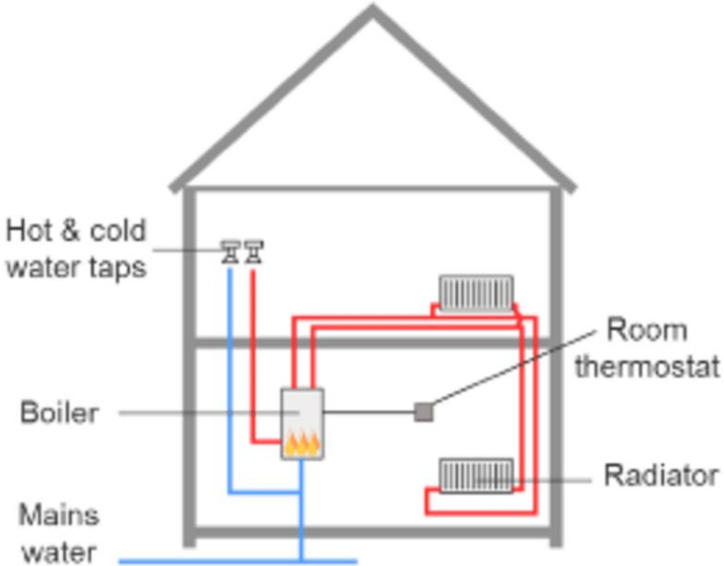
Furnace



- Burns fossil fuels to generate heat in the burner.
- Heat produced passes through a heat exchanger
- A blower distributes the heated air throughout the home.

Advantages	Disadvantages
- Heats home rapidly - Cost-Effective	- Non-renewable - Short lifespan - High Maintenance

Boiler

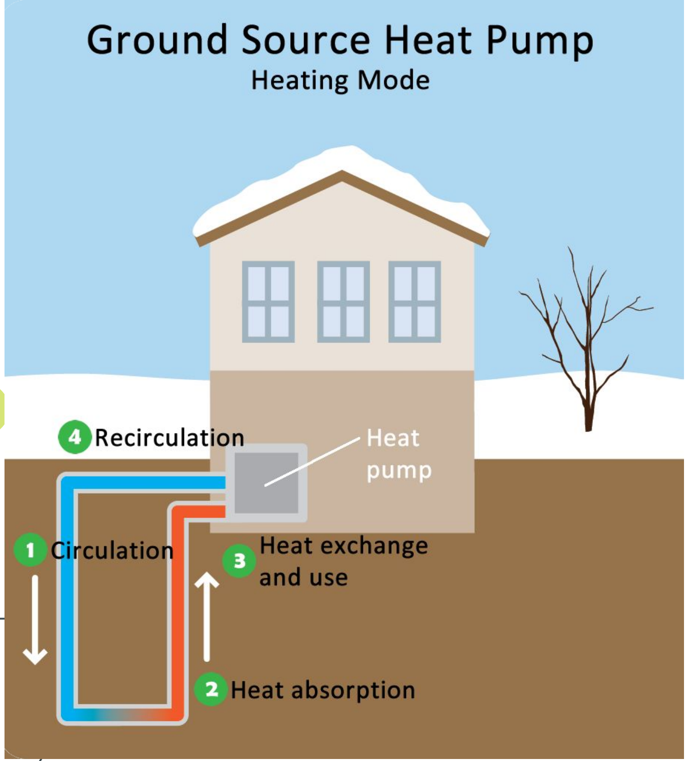


- The boiler heats water by burning fuel (can be either fossil fuels or biomass materials)
- The heated water or steam is sent through a system of radiators throughout the home

Advantages	**Disadvantages**
- Can be renewable, no GHG production - Receive Renewable Heat Incentive	- High cost - Need consistent frequent maintenance

Presenter: Keli Chen

Heat Pump

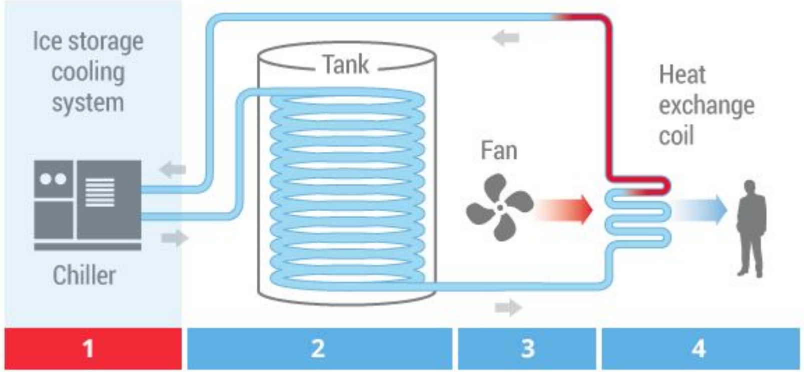


- Extracts heat or cooling from geothermal energy stored in the ground of the Earth
- Amplifies and transfers heat or cooling throughout the home

Advantages	Disadvantages
- High efficiency - Environmental source, no GHG production - Low maintenance - Low operation costs - Both heating and cooling	- Expensive to install - Significant work to install

Presenter: Keli Chen

Thermal storage + fan

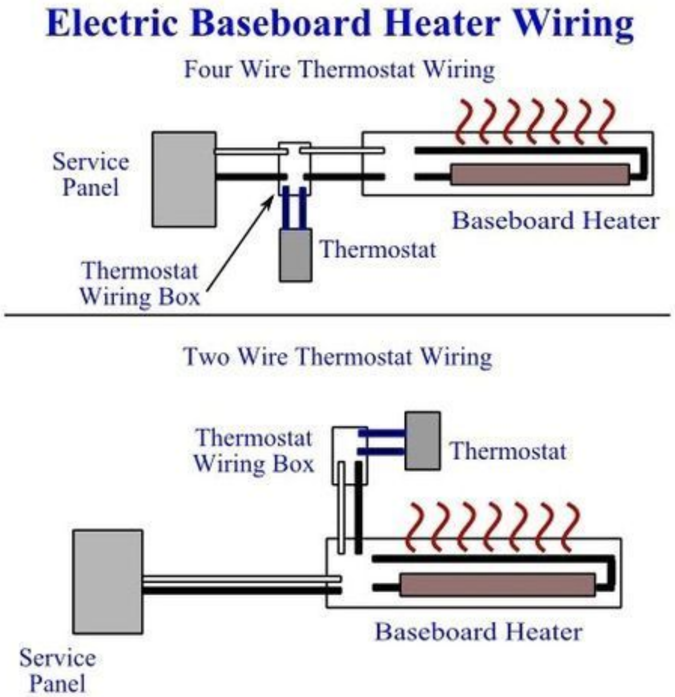


- Uses heating or cooling energy is produced by water, chemicals, etc (other mediums)
- Energy is then stored and converted to heating or cooling passed through the fan

Advantages	**Disadvantages**
- Doesn’t use fossil fuels, no GHG production - Compatible with most building materials	- Largest amount of storage - Low efficiency - Difficult to install (need suitable conditions)

Presenter: Keli Chen

Electric baseboard heaters

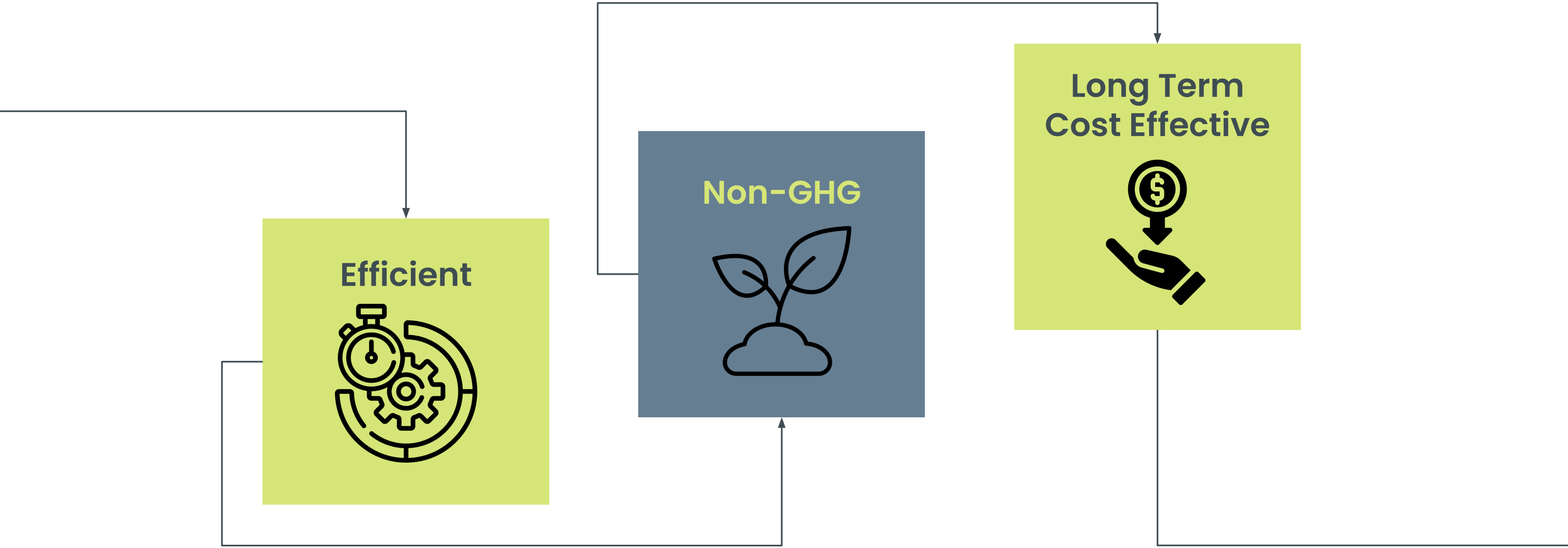


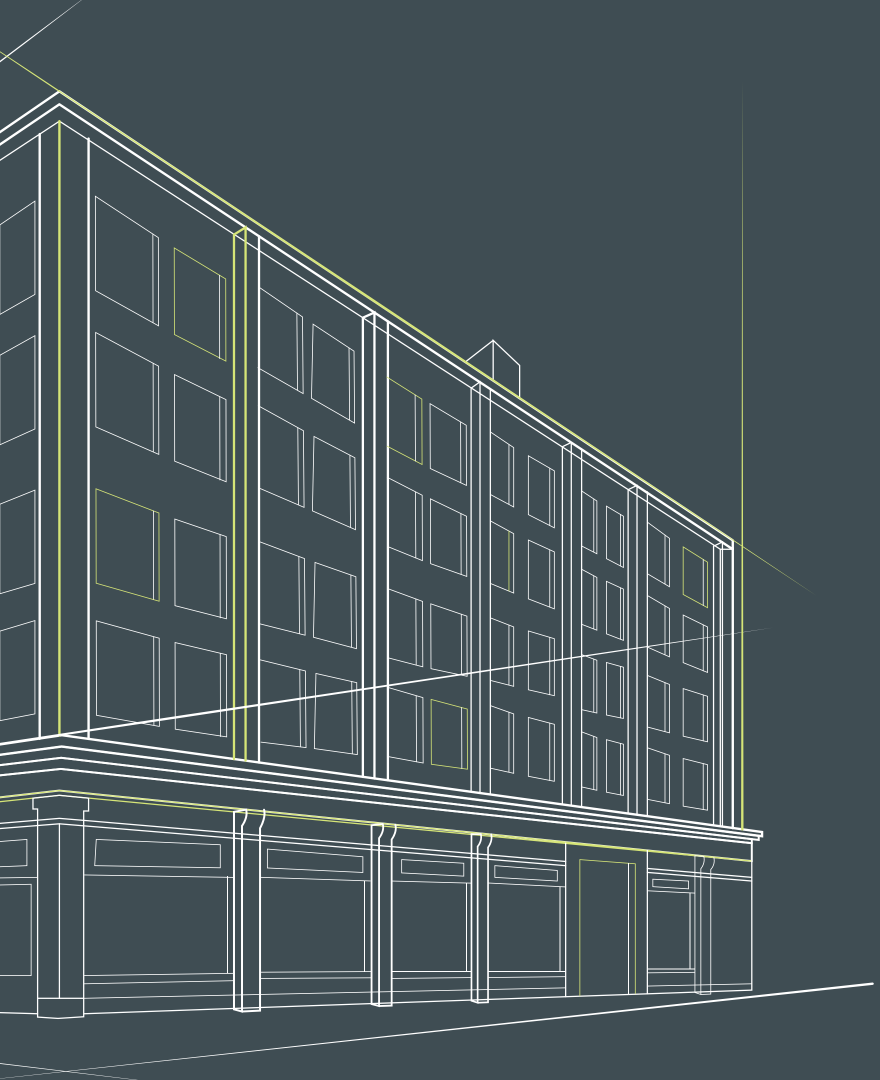
- An electric current runs through metal fins inside the unit which heats the surrounding air
- Cool air is pulled into the heater as the warm air rises, creating a convection current within home

Advantages	Disadvantages
- Separate zone heating - Quiet - Easy installation	- Expensive to operate - High electricity consumption - Non-sustainable, GHG production

Presenter: Keli Chen

The Choice: Heat Pump





Presenter:
Eleni Pethakas

02

Claim B

Using the Pugh Method, this design best meets the client's needs out of three alternatives

Ground Source Heat Pump + Thermostat

Presenter: Eleni Pethakas

Objectives	Score	Justification
GHG Emissions	+2	0.75 tonnes/yr [12]
Life Expectancy	+2	Heat pump: 20+ yr underground system: 20 - 50/yr [12]
Efficiency	+2	COP (Heating): 4.1 COP (Cooling): 3.6 [13]
Cost	+1	Estimated $0.75/hr High upfront cost Long Term savings (5-10yrs) [14]
Sensing	+0	Maintains temperature +/- 5C [14]

Presenter: Eleni Pethakas

Steam Accumulator + RTD Circuit

Objectives	Score	Justification
GHG Emissions	+1	Estimated 1.92 tonnes/yr [16]
Life Expectancy	+2	40yrs [17]
Efficiency	+1	Energy recovery efficiency up to 80%[16]
Cost	+1	$0.91/hr [16]
Sensing	+1	Error tolerance: 0.1% (-30C to 200C) [18]

Air Source Heat Pump + Infrared Sensors

Presenter: Eleni Pethakas

Objectives	Score	Justification
GHG Emissions	+1	Estimated 1.625 tonnes/yr [19]
Life Expectancy	+0	20-25 yrs [22]
Efficiency	+1	COP (Heating): 2.78 - 3.81 COP (Cooling): 3.60 - 4.54 [19]
Cost	+1	$0.89/hr [21]
Sensing	+1	Error tolerance: +/- 1.25% (-40C to 80C) [22]

Presenter: Eleni Pethakas

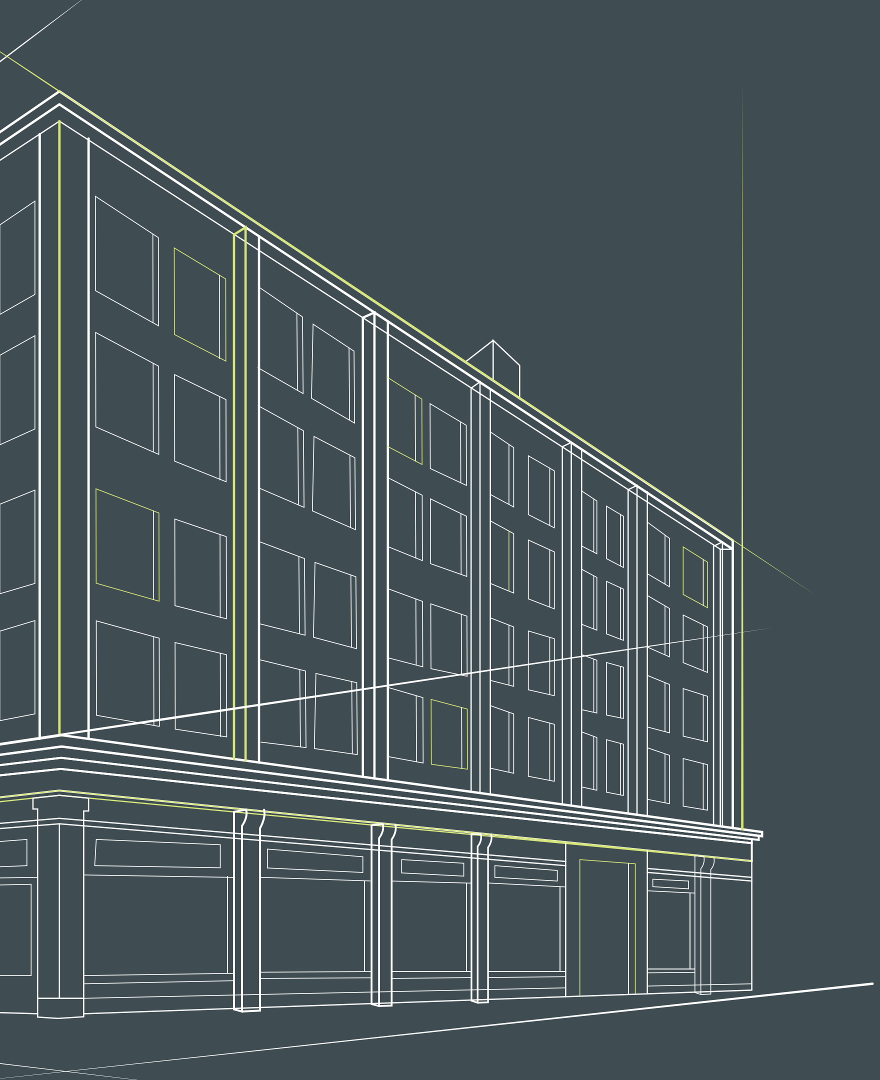
Design #2:
Steam Accumulator + RTD (Resistance Temperature Detector) Circuit

- Boiler run at high demand levels could result in a reduction in lifespan and efficiency, and increase in maintenance
- Uses steam generated typically through GHG emissions in industrial applications

Design #3:
Air Source Heat Pump + Infrared Sensors

- Not used in regions with long periods of sub zero temperatures
- Difficult to implement the design on a larger scale

Presenter:
Katelyn Lam



03

Claim C

The GSHP can meet sustainable efficiency and performance standards

Measure of Success #1

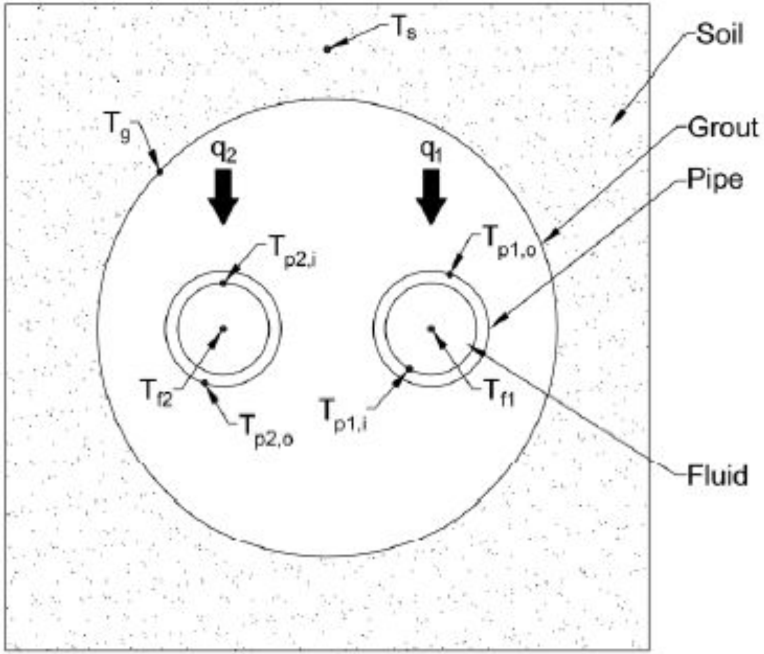
Presenter:
Katelyn Lam

Objective Measured:

Efficiency

$$\text{COP (Heating)} = \frac{\text{Heat transferred} - \text{Input Energy}}{\text{Input Energy}}$$

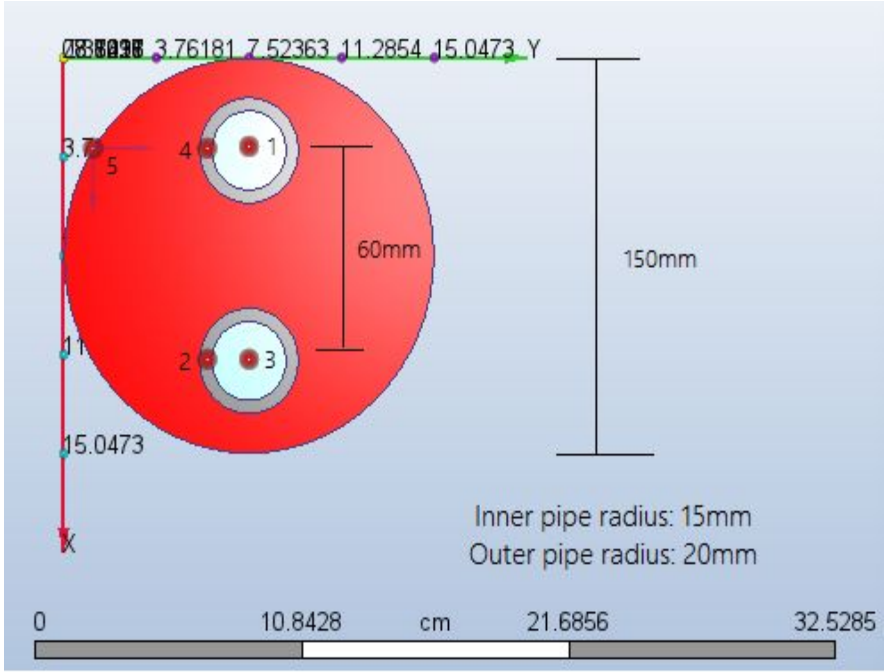
$$\text{COP (Cooling)} = \frac{\text{Heat transferred}}{\text{Input Energy}}$$

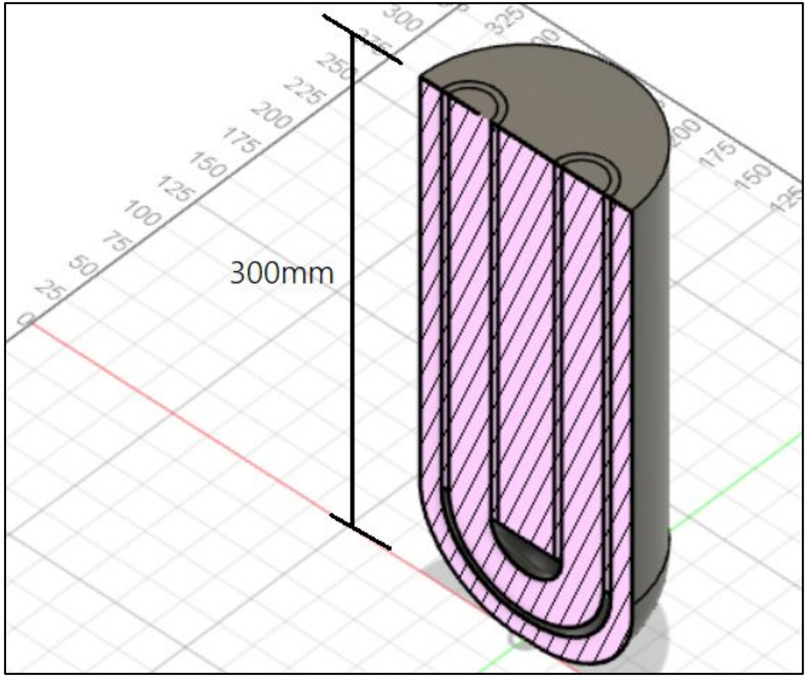


Source: [23]

Borehole Model

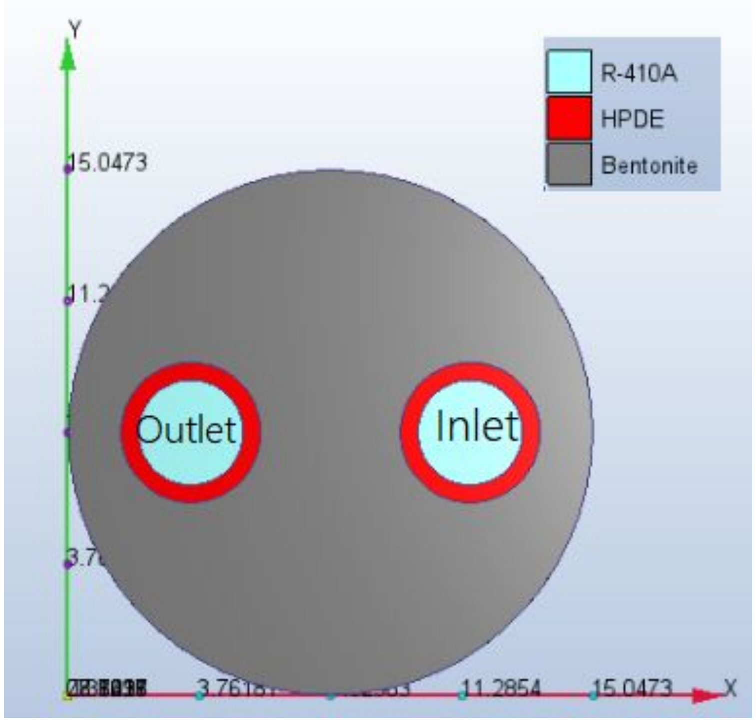
Presenter:
Katelyn Lam





Presenter:
Katelyn Lam

Setup



Materials	Boundary Conditions
R-410A Heating coefficient: 3900 W/m^{2}K [24] Specific heat: 1840 J/g-K [25]	**Soil temp**: 12C [26] **Inlet temp**: Heating: 50C [27] Cooling: 8.15C [23] **Inlet velocity**: 0.4 m/s [27] **Outlet pressure**: 0 Pa **Energy consumption**: - 7500 W/h or 2.083 W/s
HPDE Thermal conductivity: 0.48 W/m-K [28] Density: 0.95 g/cm^3 [28]	
Bentonite Thermal conductivity: 1.7 W/m-K [29] Density: 2.5 g/cm^3 [29]	

Set of Equations [23]

Presenter:
Katelyn Lam

Thermal Resistance → Heat transfer → Efficiency

$$R_f = \frac{1}{2\pi h r[in]}$$

$$R_P = \frac{ln(\frac{r[out]}{r[in]})}{2\pi k}$$

R_g = 0.5882 [mK/W]
R_p = 0.095388 [1/mKW]
R_f = 0.0027206 [mK/W]

$$Q_C = Q_{fluid/g} + Q_{g/fluid}$$

$$Q_{fluid/g} = \frac{T_g - T_{f2}}{R_g + R_{p2} + R_{f2}}$$

$$Q_{g/fluid} = \frac{T_g - T_{f1}}{R_g + R_{p1} + R_{f1}}$$

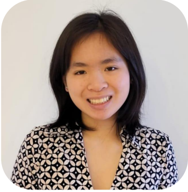
$$COP_{heating} = \frac{Q_C + W}{W}$$

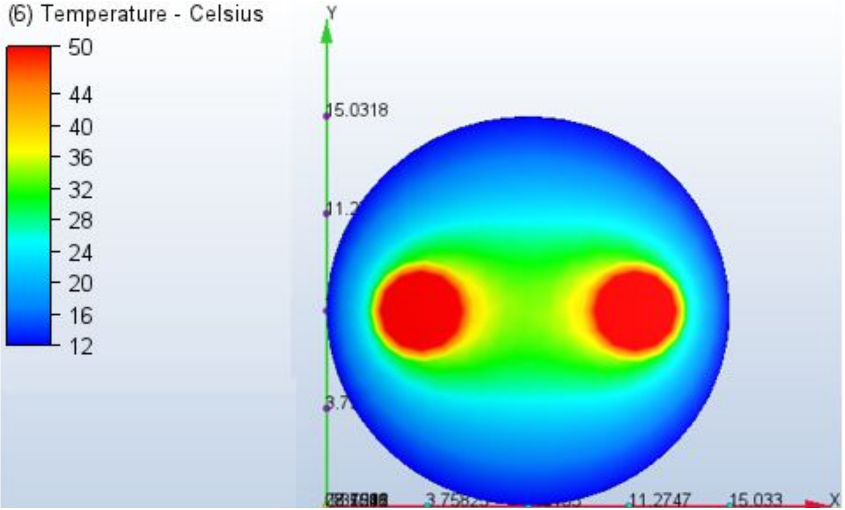
$$COP_{cooling} = \frac{Q_C}{W}$$

W = Duration [s] x Energy consumption [J/s]

Borehole Model - Heating

Presenter:
Katelyn Lam





Duration of transfer: 15.36s

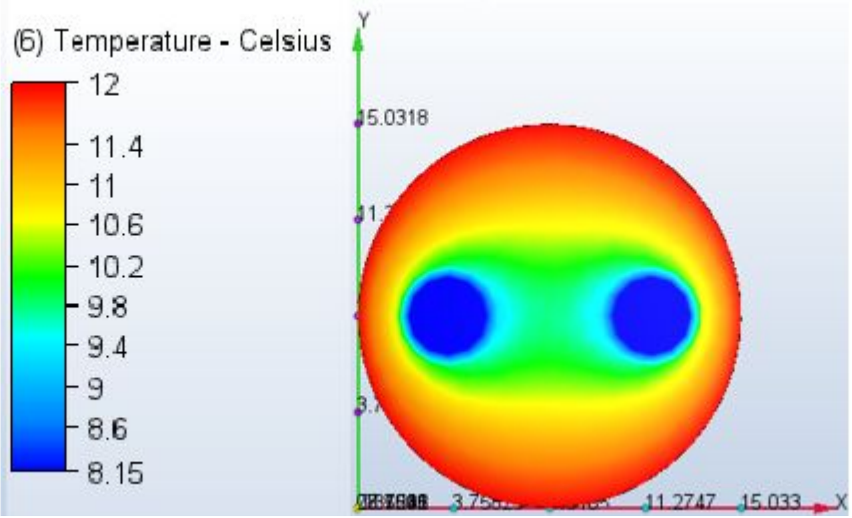
Energy consumption: 31.99488 J

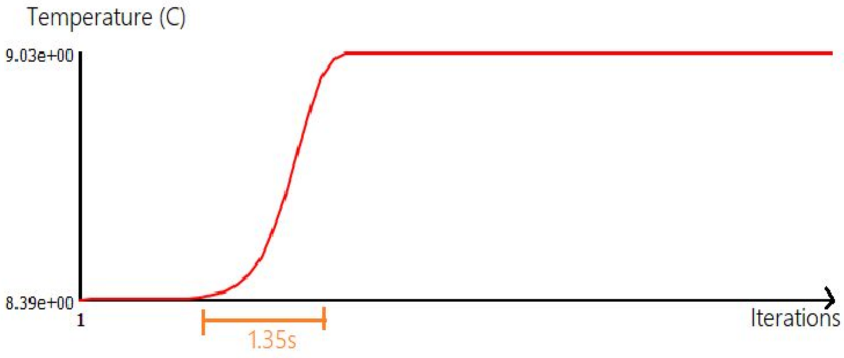
Total heat transferred: 77.5332 J

Calculated COP: 3.42

Borehole Model - Cooling

Presenter:
Katelyn Lam





Duration of transfer: 1.35s

Energy consumption: 2.81205 J

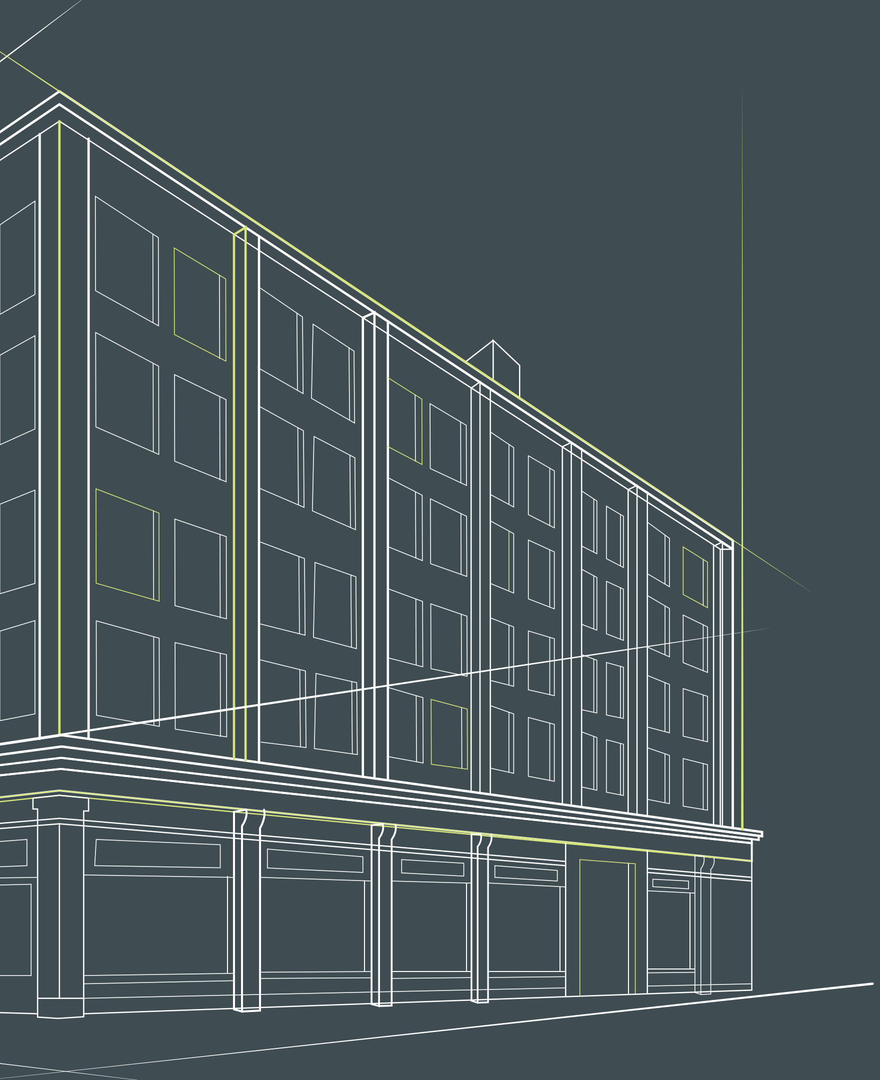
Total heat transferred: 11.75365 J

Calculated COP: 4.17

Presenter:
Katelyn Lam

Results

COP	Objective	Constraint	Experimental Result
Heating (8.3C)	3.40 [*8]	3.20 [*9]	3.42
Cooling	4.69 [*8]	3.13 [*9]	4.17



Presenter:
Bob-Yiqiu Chen

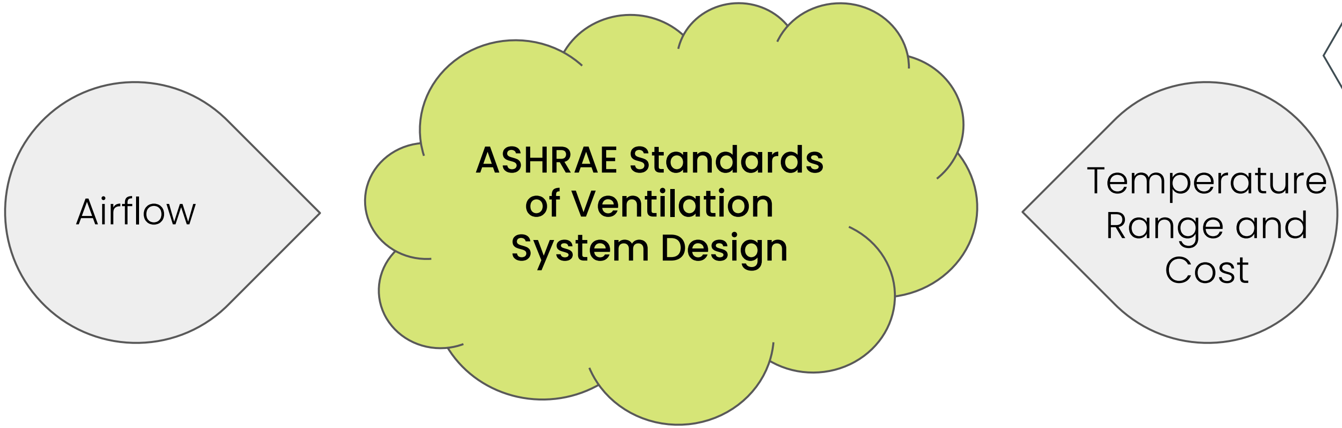
04

Claim D

The design reaches ventilation and indoor thermal standards

Presenter:
Bob-Yiqiu Chen

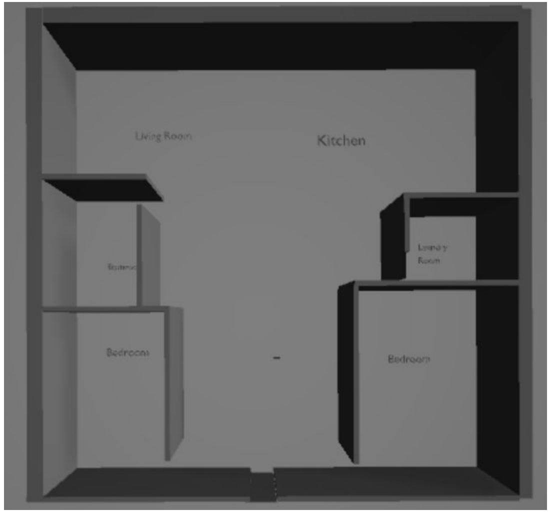
How to measure comfortability



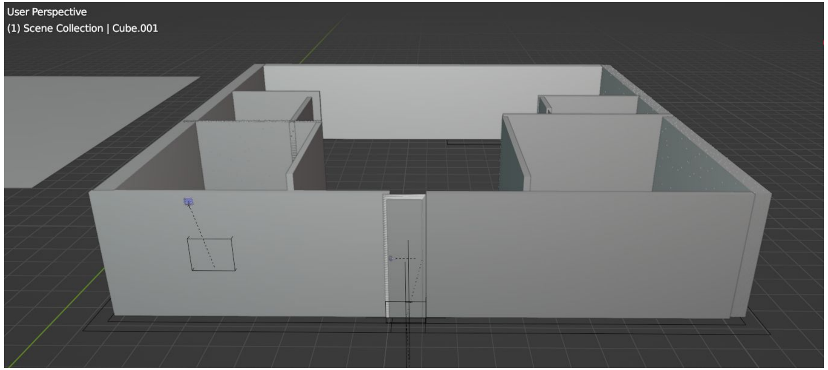
Presenter:
Bob-Yiqiu Chen

Unit Models

k^ direction view



$(1/\sqrt{2}, 0, 1/\sqrt{2})$ view

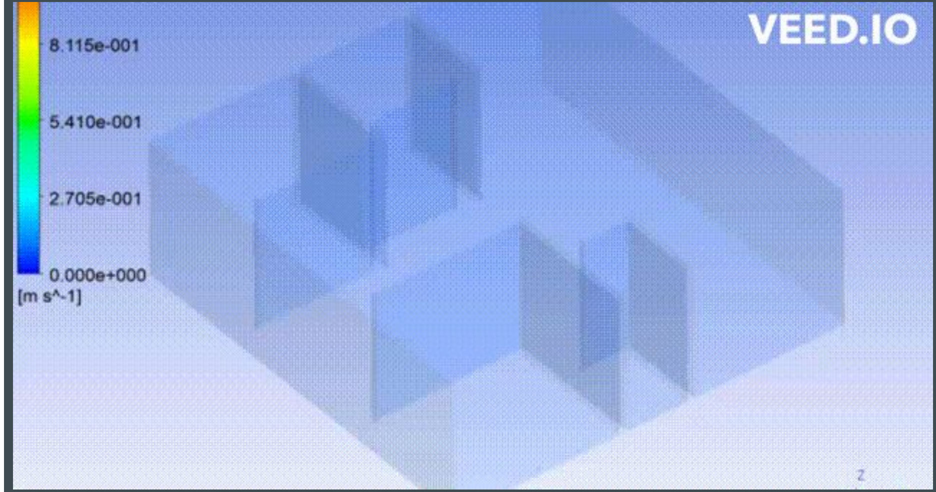


Modelling Airflow

Presenter:
Bob-Yiqiu Chen

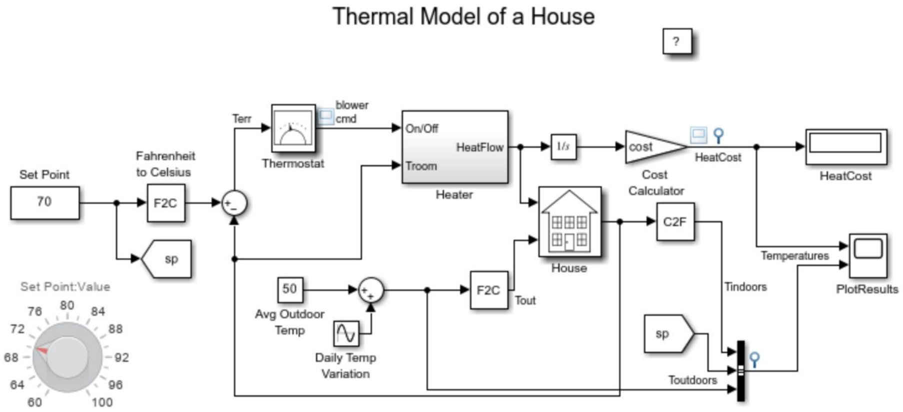
xy plane

Full Vectorial View



Presenter:
Michael Silver

Acceptable Temperature Range for Living



$$\frac{dQ}{dt} = (T_{heater} - T_{room}) \cdot Mdot \cdot c$$

$$\left(\frac{dQ}{dt}\right)_{losses} = \frac{T_{room} - T_{out}}{R_{eq}}$$

$\frac{dQ}{dt} =$ heat flow from the heater into the room

$$\frac{dT_{room}}{dt} = \frac{1}{M_{air} \cdot c} \cdot \left(\frac{dQ_{heater}}{dt} - \frac{dQ_{losses}}{dt}\right)$$

$c =$ heat capacity of air at constant pressure

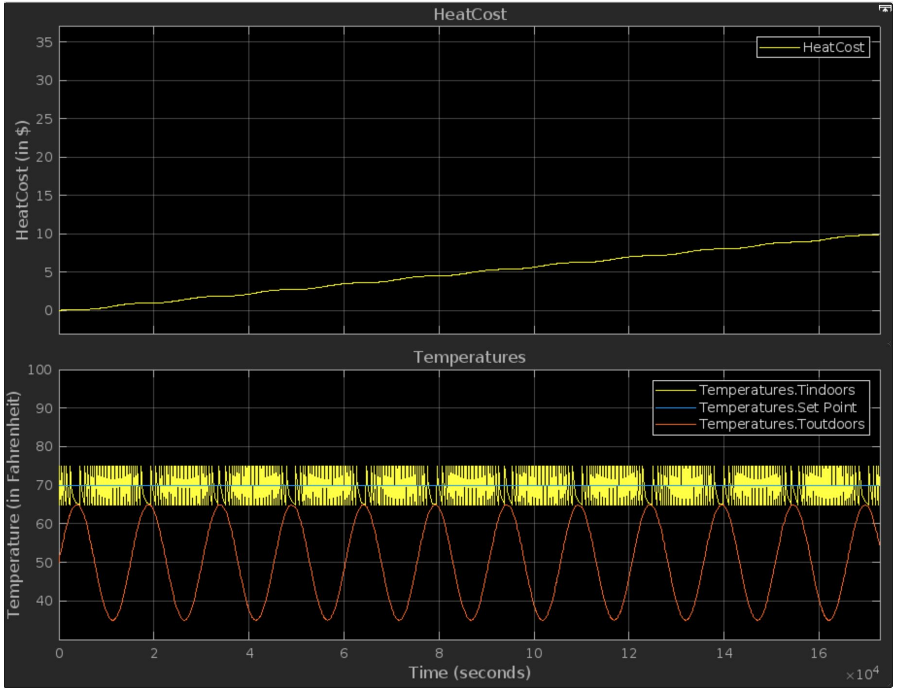
$M_{air} =$ mass of air inside the house

$Mdot =$ air mass flow rate through heater (kg/hr)

$R_{eq} =$ equivalent thermal resistance of the house

$T_{heater} =$ temperature of hot air from heater

$T_{room} =$ current room air temperature

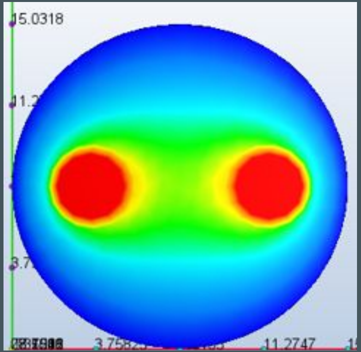


Presenter:
Michael Silver

05 Conclusion: Why this design was chosen

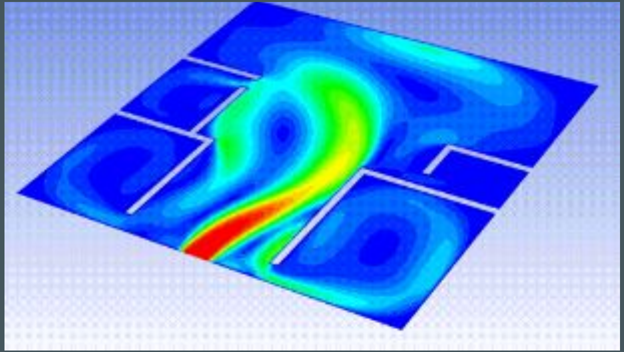
- Reduces GHG emissions (4 tonnes -> 0.75 tonnes)
- Works better than two alternative designs
    - Steam Accumulator + RTD
    - ASHP + Infrared Sensors

Meets efficiency requirements



(Borehole model)

Meets thermal comfort requirements

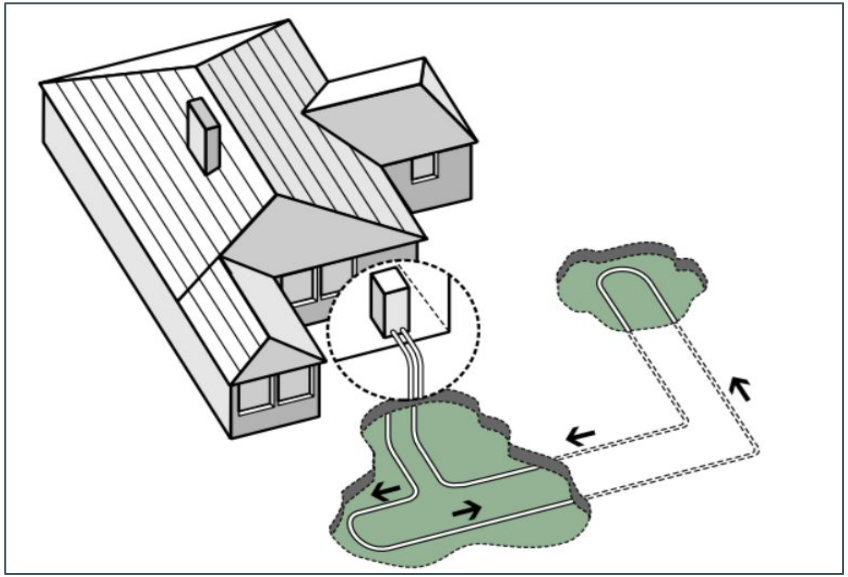


(Apartment Unit Model)

Presenter:
Michael Silver

Implementation Recommendations

- Generally heat up to 45 - 50C[30]
- Can make use of active or passive cooling [30]
- Closed Loop: 120 to 180 m pipe/ton heat capacity [30]



Source: [30]

Presenter:
Michael Silver

Implementation

Downtown Condo Developments [31]

UofT Front Campus [32]

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