# Heating, Ventilation, and Air Conditioning (HVAC) System Design
## *with a concentration in indoor air quality*


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# Company Background

## EPIC Engineering Group, LLC

- Full-service MEP (mechanical, electrical, plumbing) Design Firm

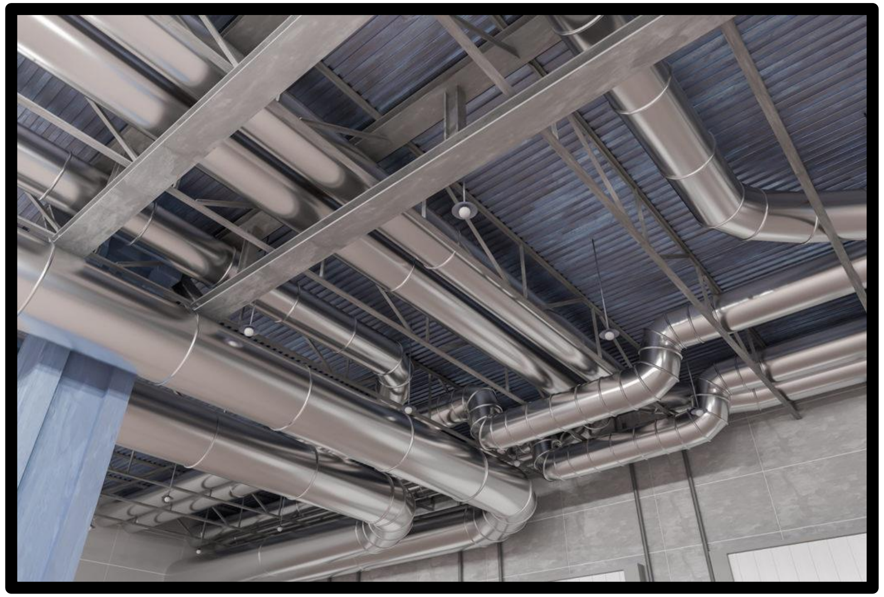


*Image source: [1]*

# Project Statement

- Design an HVAC system for a proposed office building
- Implement ventilation strategies for preventing the spread of COVID-19

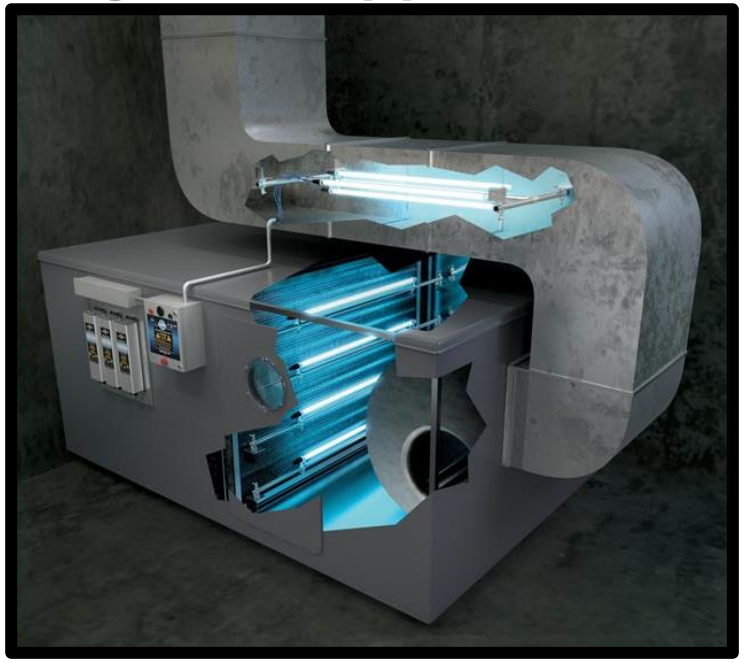


*Image source: [2]*

## Customer Needs

- Load Calculation
- Compliance with ASHRAE

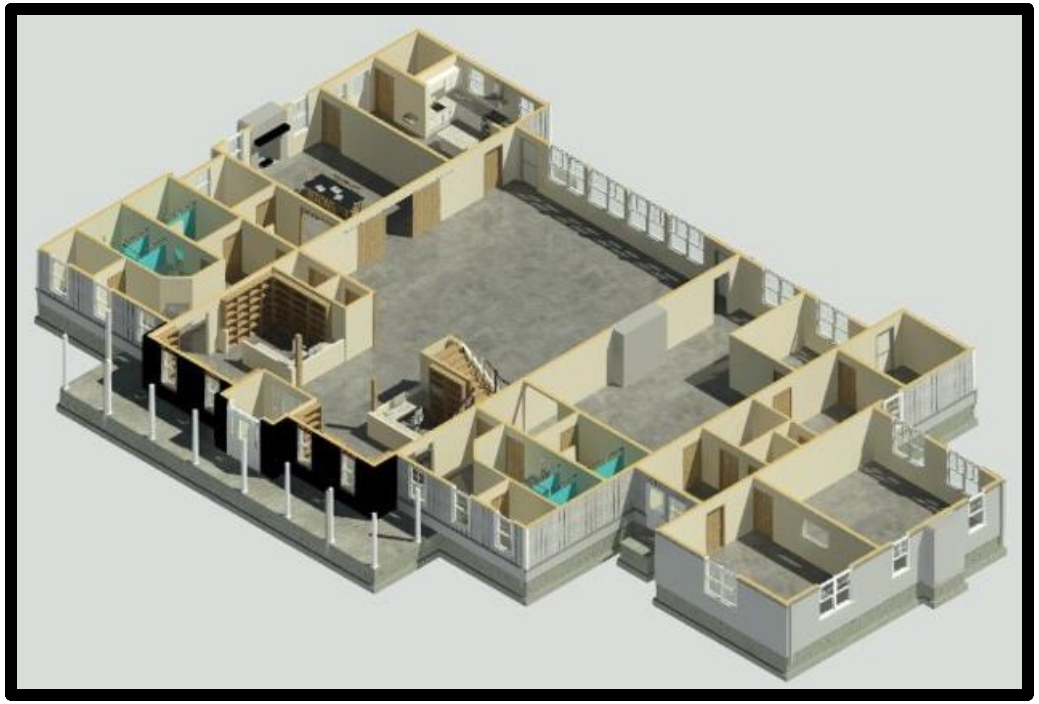
*The American Society of Heating, Refrigeration and Air-Conditioning Engineers*

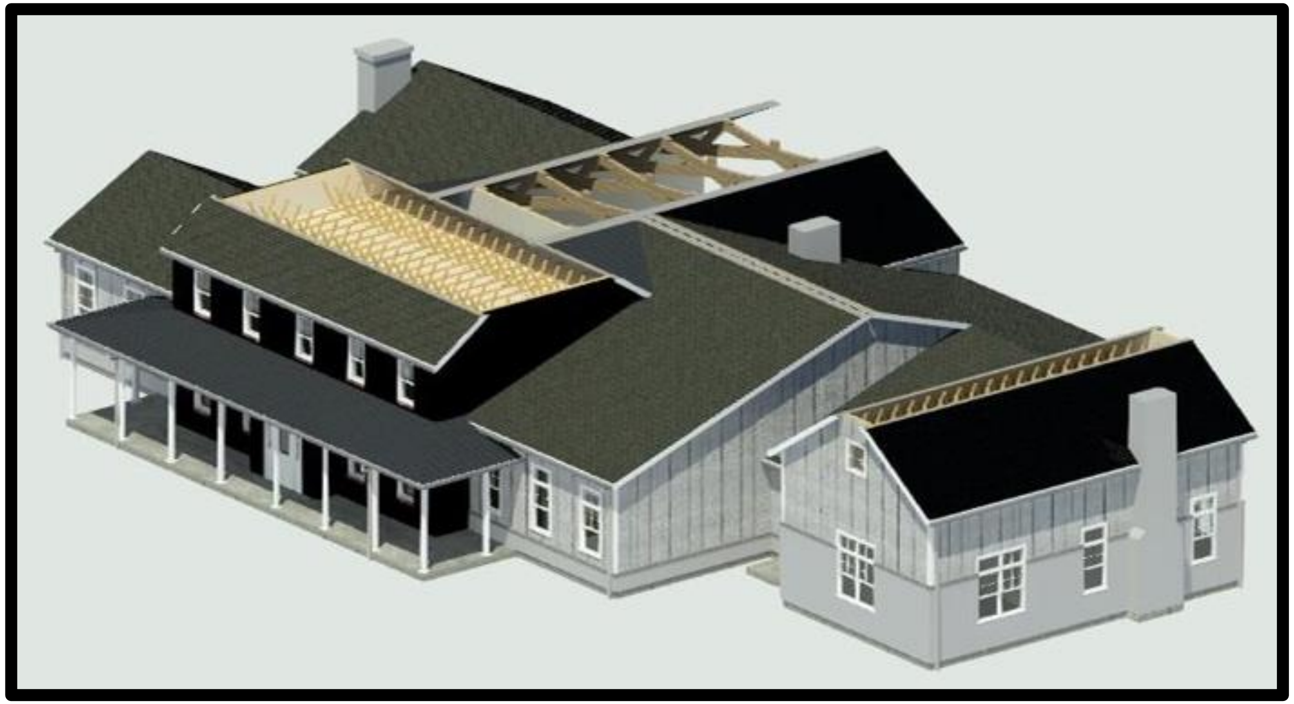
- HVAC System Design
- Flow Regulation
- Indoor Air Quality
- *Insulation*

## Target Specifications

- Flow Rates
- Air Velocity
- Meet Standards (ASHRAE) Requirements
- Low Percent Errors

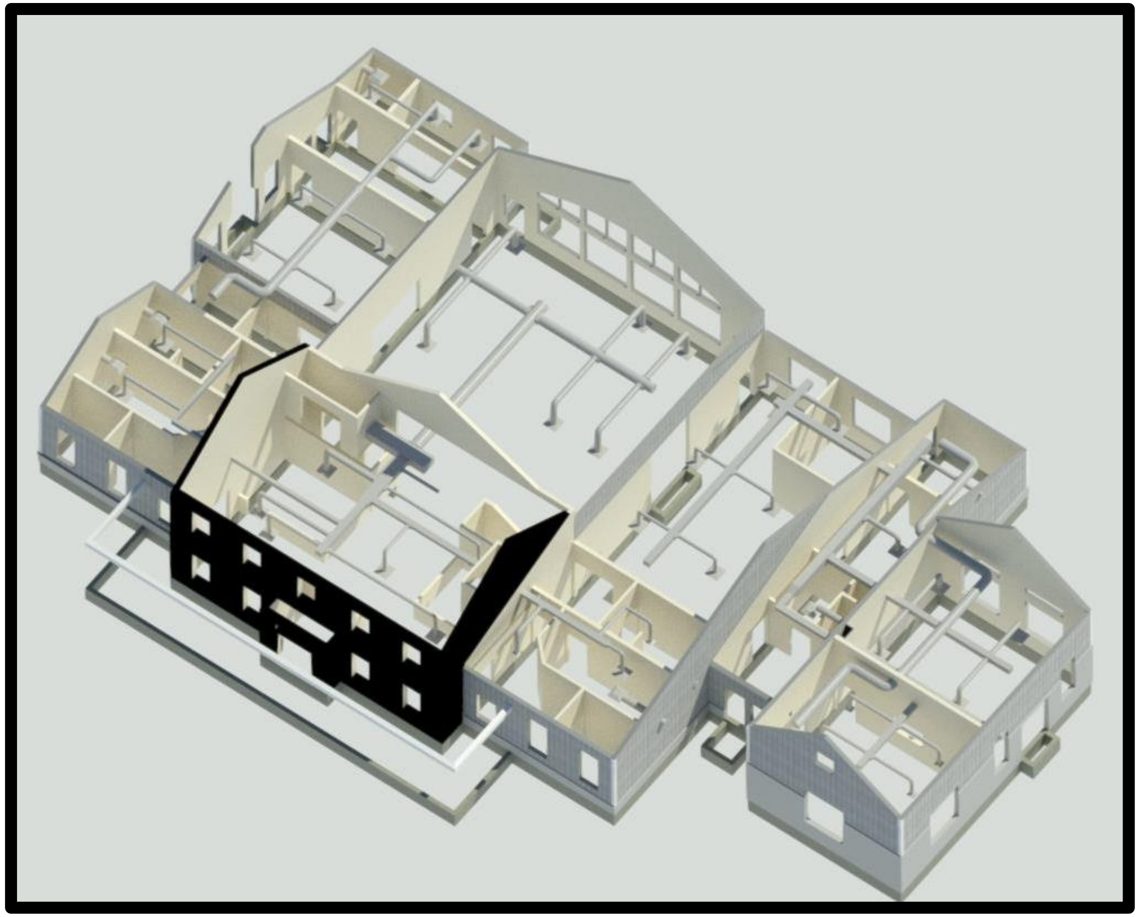
# Building Overview

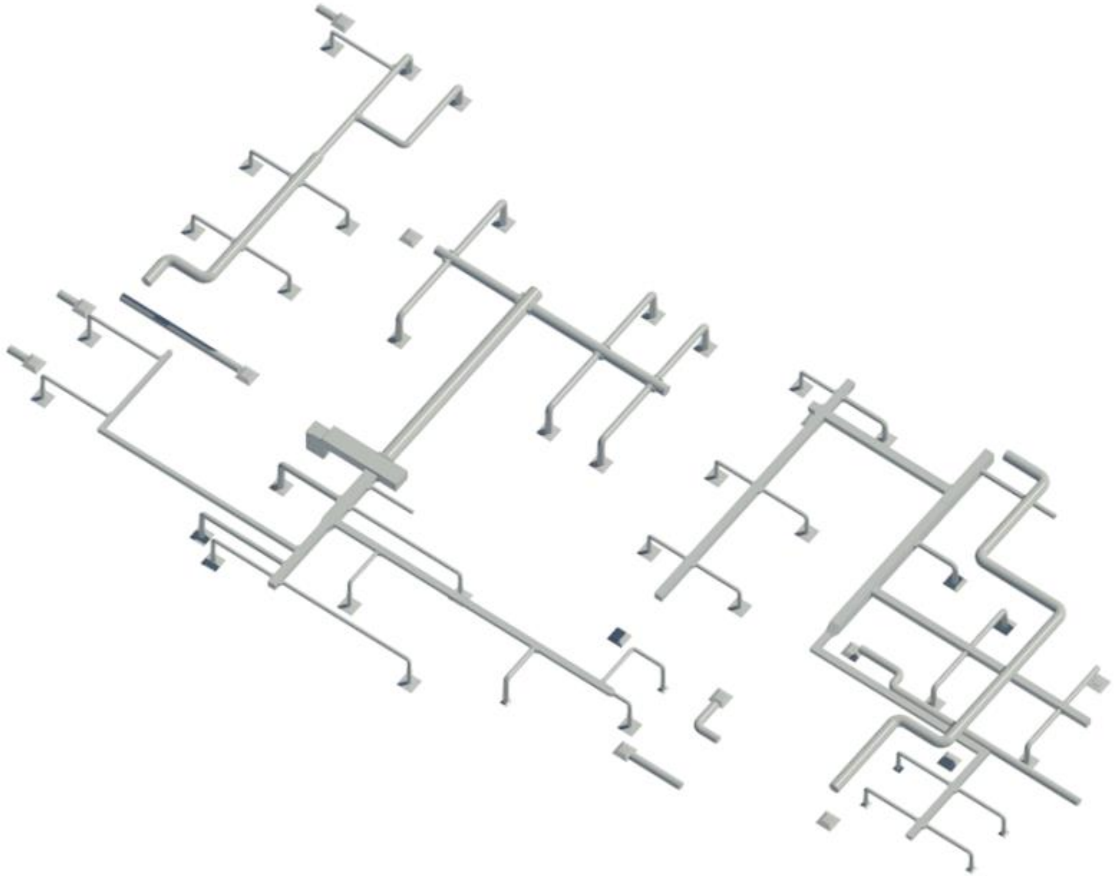




One story office building with 31 rooms
(roughly 7,000 square feet)

# Final Design Overview – Duct System





**Factors influencing decisions:**

- Building Structure
- Heating Load Calculations
- Pressure Drop Calculations
- ASHRAE Compliance

# Supply Air Styles

## Mixed Ventilation

- Supply from ceiling
- Return to ceiling
- Most practical design given building structure

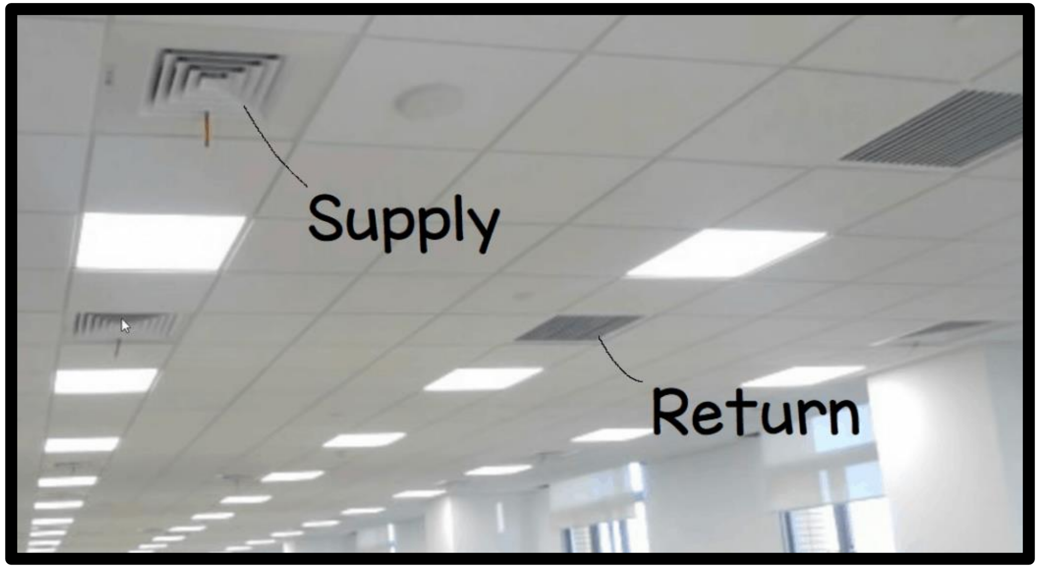



Image source: [3]

## Exposed Ductwork

- Rooms with a vaulted ceiling and no space for hidden duct system


Image source: [4]

# Return, Exhaust, and Outdoor Air

**EXHAUST**

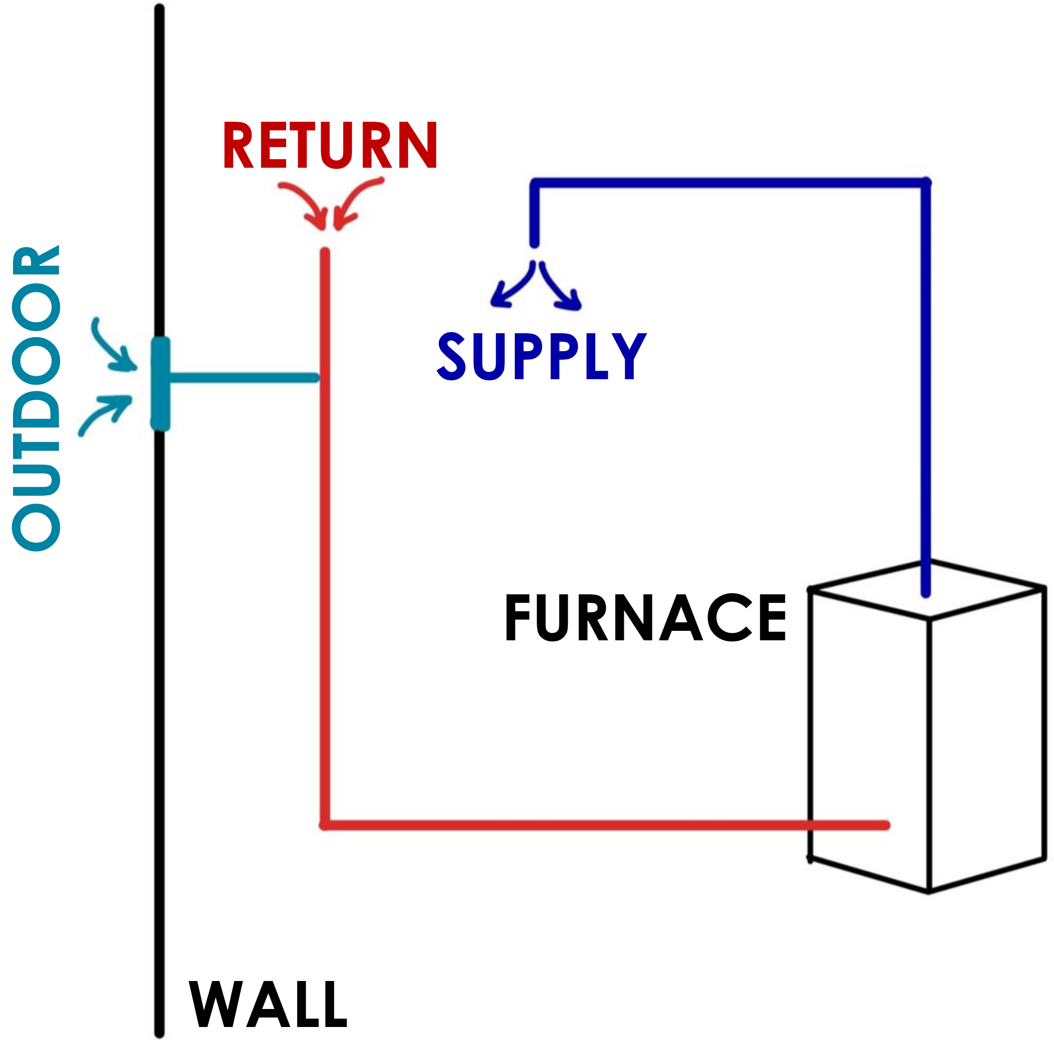
- Leaves the building

**RETURN**

- Gets "recycled" back to the furnace

**OUTDOOR**

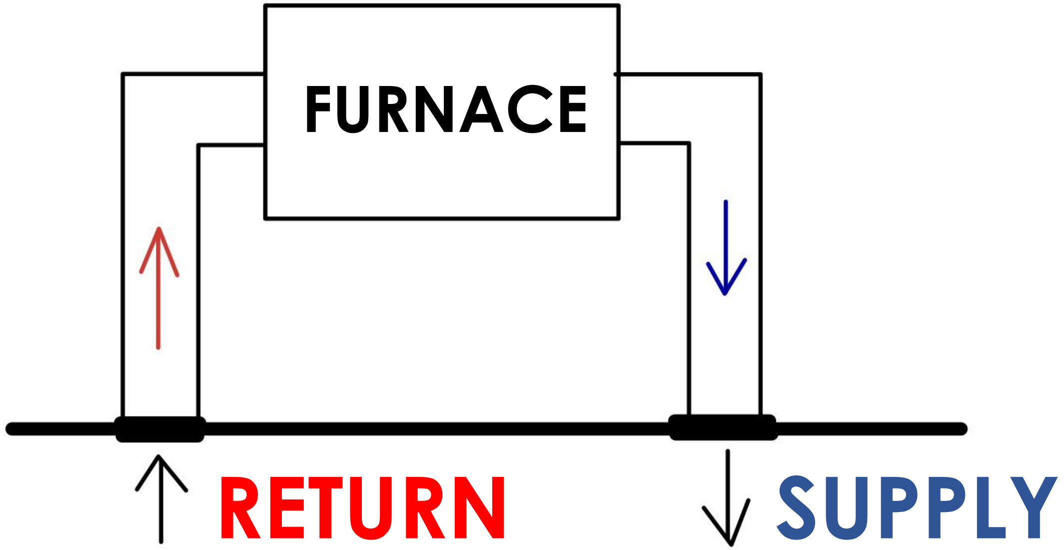
- Mixes with return to add fresh air to the building
  - Prevents $CO_2$ from becoming prominent in air
  - Gets conditioned (heated or cooled) to prevent adding humid / cold air to building, ensures thermal comfort



# Return Styles

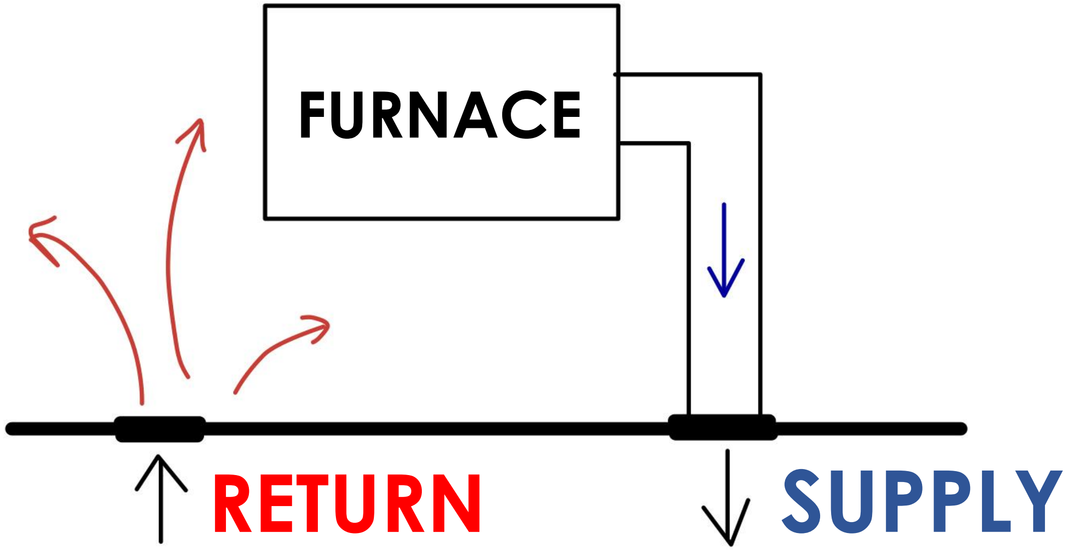
## Ducted (Forced) Return

- Necessary in areas lacking a useful plenum space
- Duct sized calculated the same way as supply
- Used in areas where plenums are not allowed, per the Ohio Mechanical Code




## Plenum (Free) Return

- Inexpensive (no ductwork required)
- Utilized wherever possible



# Exhaust Calculations

Exhaust air only from restrooms

- ***Rexhaust***

Rate of exhaust (cfm/unit)

- ***N***

Number of plumbing fixtures

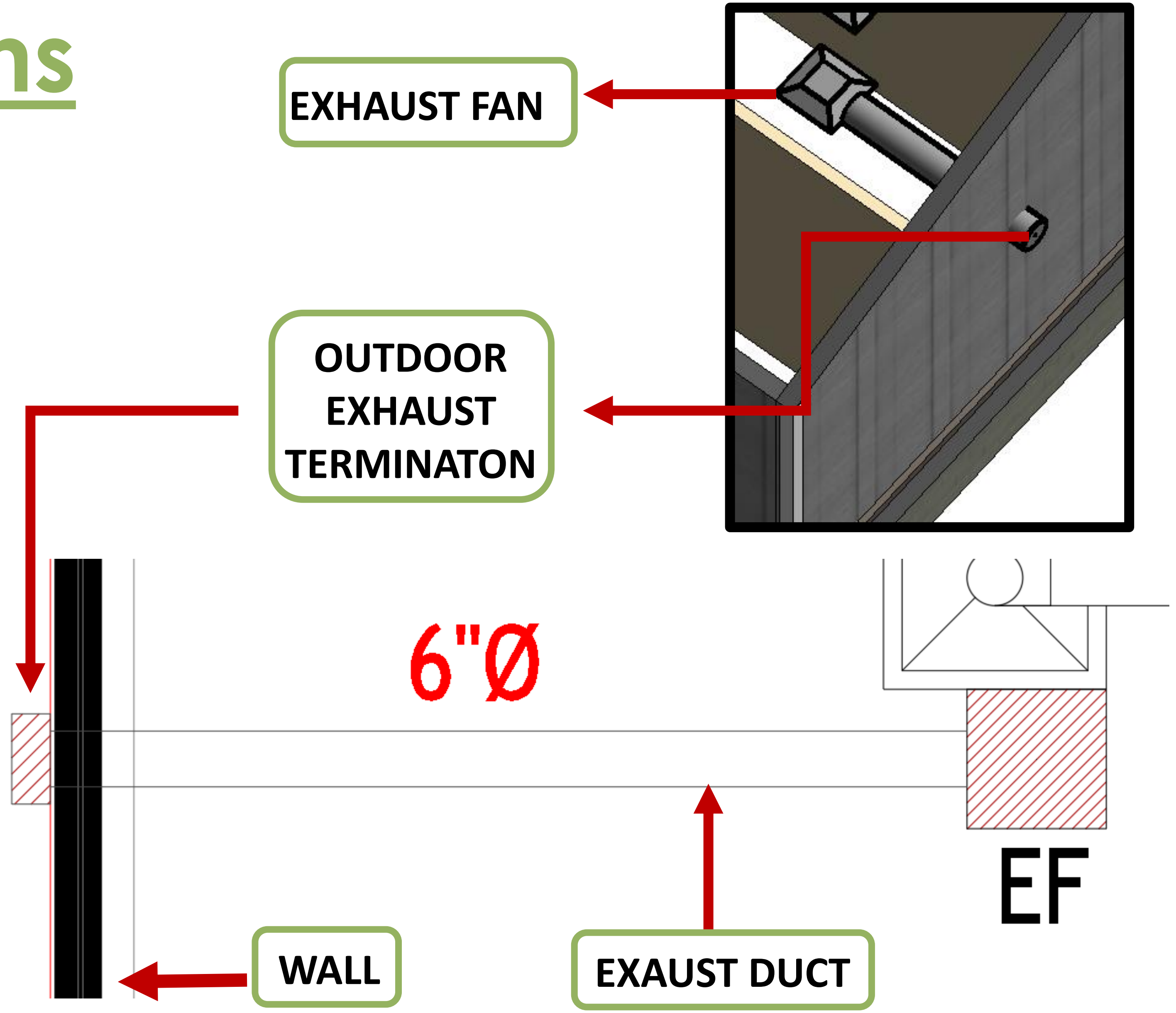
***Required exhaust rates based on ASHRAE 62.1***

***Target Specification***

**Example:**

$R_{exhaust} * N$

A restroom with two water closets exhausts 75 cfm per unit, or 150 cfm total



# Ventilation (Outdoor Air) Calculations

- ***$V_{bz}$*** : Breathing Zone Outdoor Airflow
- ***$E_z$*** : Zone Air Distribution Effectiveness
  - 0.8 for ceiling supply, ceiling return
- ***$V_{ot}$*** : Required Zone Outdoor Airflow
- ***P*** : Occupants
- ***A*** : Floor Area
- ***$R_a$*** : Airflow Rate based on Floor Area
- ***$R_p$*** : Airflow Rate based on Occupants

$$V_{bz} = PR_p + AR_a$$

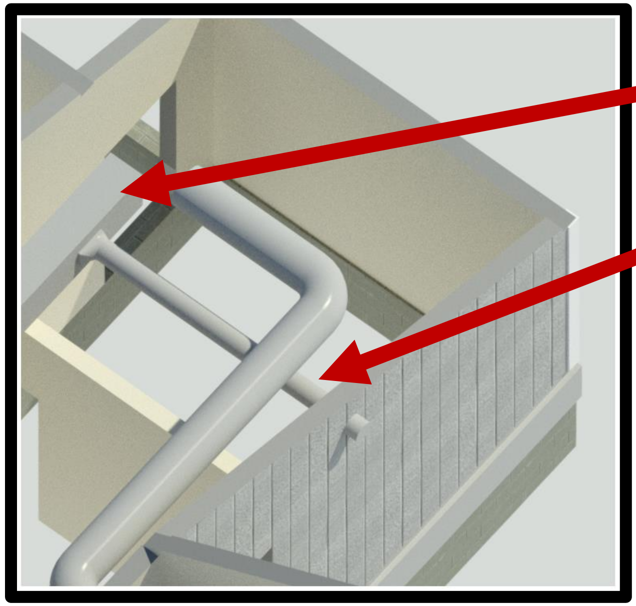
$$V_{ot} = \frac{V_{bz}}{E_z}$$

***Required values based on ASHRAE 62.1***

***Target Specification***

# Ventilation Requirement Results

| ROOM NAME | AREA (ft$^2$) | ROOM TYPE | OCCUPANT DENSITY (/1000 ft$^2$) | OCCUPANTS | CFM PER PERSON | CFM PER ft$^2$ | Vbz | TOTAL Ez | Vot |
|---|---|---|---|---|---|---|---|---|---|
| OFFICE | 184 | OFFICE SPACE | 5 | 1 | 5 | 0.06 | 15.6 | 0.8 | 19.6 |
| CLOSET | 14.1 | STORAGE ROOMS | 0 | 0 | 0 | 0.12 | 1.7 | 0.8 | 2.1 |
| MECH | 138.7 | STORAGE ROOMS | 0 | 0 | 0 | 0.12 | 16.6 | 0.8 | 20.8 |
| VESTIBULE | 142.9 | OFFICE-LOBBY | 10 | 1 | 5 | 0.06 | 15.7 | 0.8 | 19.6 |
| CLOSET | 26 | STORAGE ROOMS | 0 | 0 | 0 | 0.12 | 3.1 | 0.8 | 3.9 |
| **TPS CONTROL ROOM** | **404.6** | **OFFICE SPACE** | **5** | **2** | **5** | **0.06** | **34.4** | **0.8** | **43.0** |
| TPS STUDIO | 495.4 | OFFICE SPACE | 5 | 2 | 5 | 0.06 | 42.1 | 0.8 | 52.6 |
| | | | | | | | | TOTAL REQ'D: | 239.1 |



**RETURN AIR DUCT**

**OUTDOOR AIR DUCT (8"Ø)**

**239* CFM of outdoor air required – brought in from outside through louvers**

**239 CFM → 8"Ø DUCT**

*for the calculation shown, some rooms were excluded for the sake of clarity.

# Infection Control
## Bipolar Ionization VS UV-C

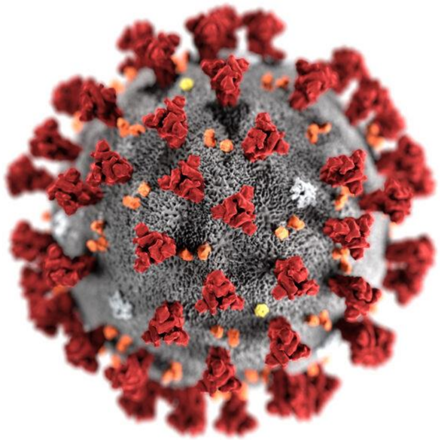


Image source: [5]

- **Limitations of BI:**
  - Specially used for allergens, dust and chemical particulates
  - Require specific electric potential for specific size of virus or bacteria.

- **Why UV-C over Bipolar**
  - Used for last two decade primarily in health care environment.
  - Designed specifically to eliminate bacterial or viral particles.
  - UV satisfies target specification.

# UV Lights Selection

**Sized based on:**

- Infection Control Needs (Covid, Flu, etc.)
- Velocity of supply air
- Duct size and shape
- Number of UV lamps


*Image Credit: Nevada HVAC*

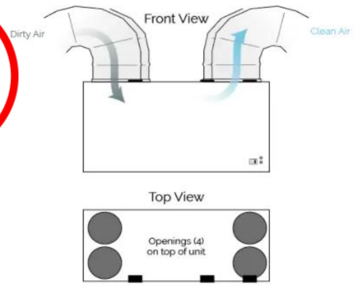
***Infection control increases the longer air is in contact with lights***

# Available UV Lights

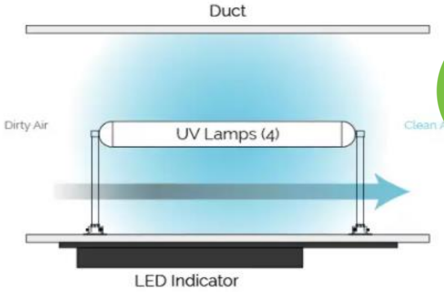
SANUVOX

- Air Disinfection Units were manufactured by **Sanuvox**.
- Models S1000 and Biowall were compared.
- S1000 fits with 6'' ducts which does not fit our designed duct.

*Requires 6'' ducts*




***Model:S1000***




***Model: BIOWALL***

# UV Light: Biowall

- *Adjustable Stand*


**Properties:**

- UV Lamp Length: 24 in
- No of Lamps: 5
- Lamp Change out time: 17,000 hours
- Lamp Warranty: 3 years
- Run parallel to airstream

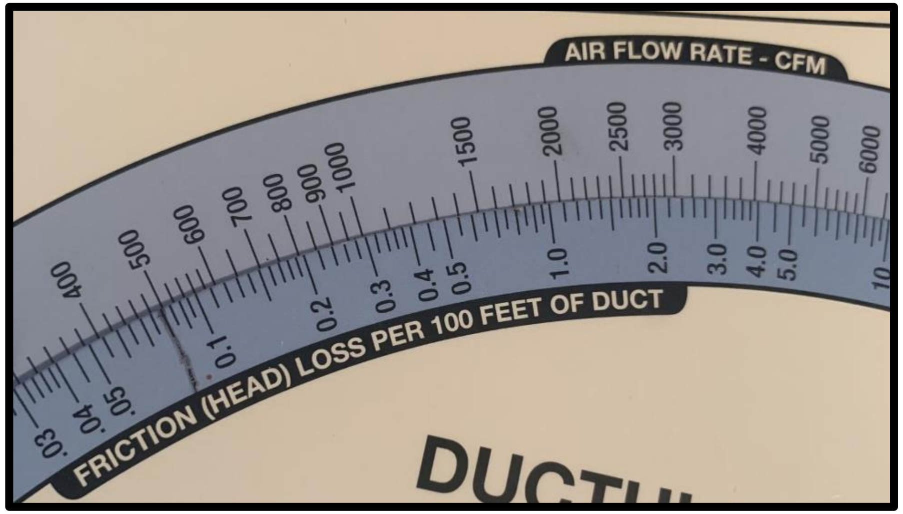
- One set of lamp is placed in supply duct of each zone.


- *Fits in any duct system.*
- *Easy to replace.*
- *Helps purify odor too.*

# Additional Analyses

## Confirming Industry Standards

- Pressure drop calculations




## Lifecycle Cost Analysis

- Furnaces
- Fan-coil Units
- Variable Refrigerant Flow

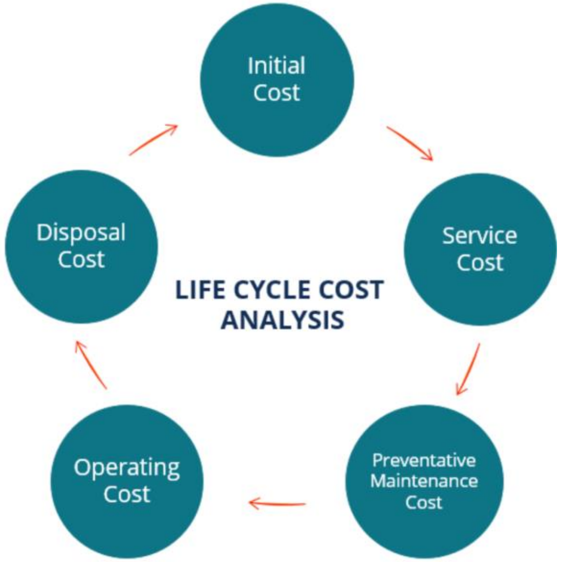



*Image Credit: Corporate Finance*

# Duct Dimensions and Properties

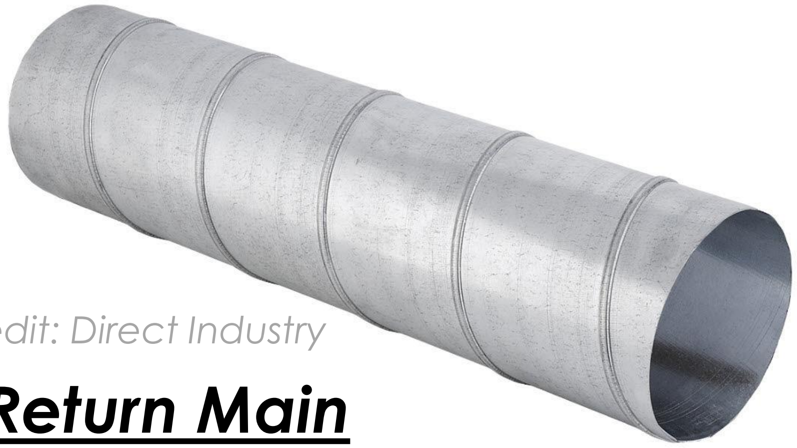


Image Credit: Direct Industry

**Supply Branch**

- Galvanized Steel
- (roughness = 0.00049 ft)
- 10" Ø diameter
- 8'-6" in length
- (100' for comparison)

**Supply Main**

- Galvanized Steel
- (roughness = 0.00049 ft)
- 26"x18" (21.3"Ø hydraulic)
- 7'-6" in length
- (100' for comparison)

**Return Main**

- Galvanized Steel
- (roughness = 0.00049 ft)
- 12"x8" (9.6"Ø hydraulic)
- 7'-1" in length
- (100' for comparison)

**Target Specification** ✓

| Maximum Duct Velocities (FPM) | | | | |
|---|---|---|---|---|
| Application | Main Ducts | | Branch Ducts | |
| | Supply | Return | Supply | Return |
| General Offices | 2000 | 1500 | 1600 | 1200 |

*[19] Engineering Cookbook (2018)*

# Pressure Drop Calculations

**Friction Factor**

$$f = \frac{0.25}{\left[ln\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

ε – roughness (feet)
D – diameter (feet)
L – length (feet)
Re – Reynolds Number
v – velocity (feet/second)
ρ – air density (lbm/ft³)

**Darcy-Weisbach**

$$h_f = f_{D-W}\frac{L}{D}\frac{V^2}{2g}$$

**Pressure Drop**

$$\Delta P = \rho h_f$$

***Industry Standards :***
**0.1 inches of water per 100 feet of duct (supply)**
**0.08 inches of water per 100 feet of duct (return)**

***Supply Branch*** ✓
- Pressure Drop: 0.103" W.C.

***Supply Main*** ✓
- Pressure Drop: 0.094" W.C.

***Return Main*** ✓
- Pressure Drop: 0.074" W.C.

***Results confirm industry standards are valid.***

# Lifecycle Cost Analysis

- Assessing total cost of building including:
  - Purchase
  - Installation
  - Operation
- Useful when project have different alternatives
- Select most cost-efficient system.


Image credit: Lucrum consulting

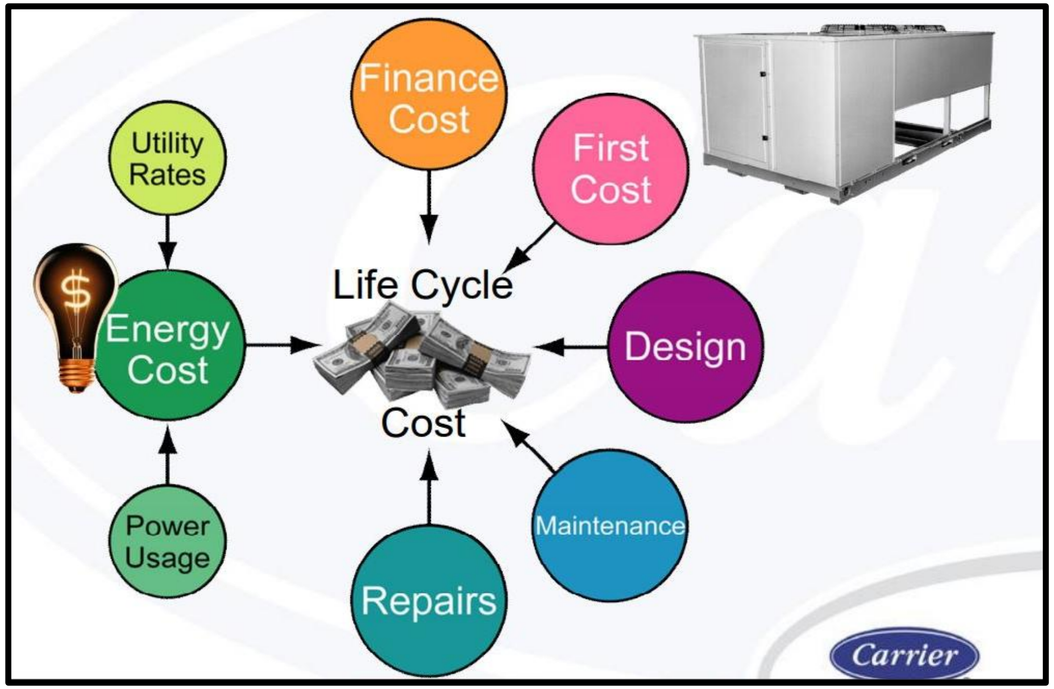



Image credit: Carrier

**Analysis was done using *Engineering Economic Analysis (EEA)* by Carrier**

# Systems Compared for LLC


**Electric fan coil unit**

*Image credit: Mitsubishi Electric*

**Gas furnace**

*Image credit: Carrier*

**Variable refrigerant flow**


*Image credit: Samsung*

- Selected based on Energy Efficiency
- Heating and Cooling Capacity, Heating efficiency, fan power were noted.
- Properties used as input for Software

# Assumptions:

- Annual energy Cost: Annual energy usage and maintenance cost.
- Energize one hour before the building is occupied
- Deenergize one hour after the building is unoccupied.
- No outdoor air in unoccupied mode.

| | | |
|---|---|---|
| **Escalation Rate** | Electric Cost | 2.5 %/year |
| | Natural Gas Cost | 4 %/year |
| | Maintenance | 2 %/year |

*[18] RMF Engineering (2018)*

***Escalation rate:***
*Change in cost goods in each economy over a period*

*Image credit: Times communication*

# Cost Analysis

| | GAS FURNACE | ELECTRIC FANCOIL | VARIABLE REFRIGERANT FLOW |
|---|---|---|---|
| **Purchase** | **$2340/UNIT** | **$2000/UNIT** | **$3600/UNIT** |
| **Install** | **$3500** | **$2500** | **$4200** |
| **Fuel Cost/year** | **$42800** | **$36500** | **$34200** |
| **Maintenance/year** | **$1200** | **$800** | **$600** |

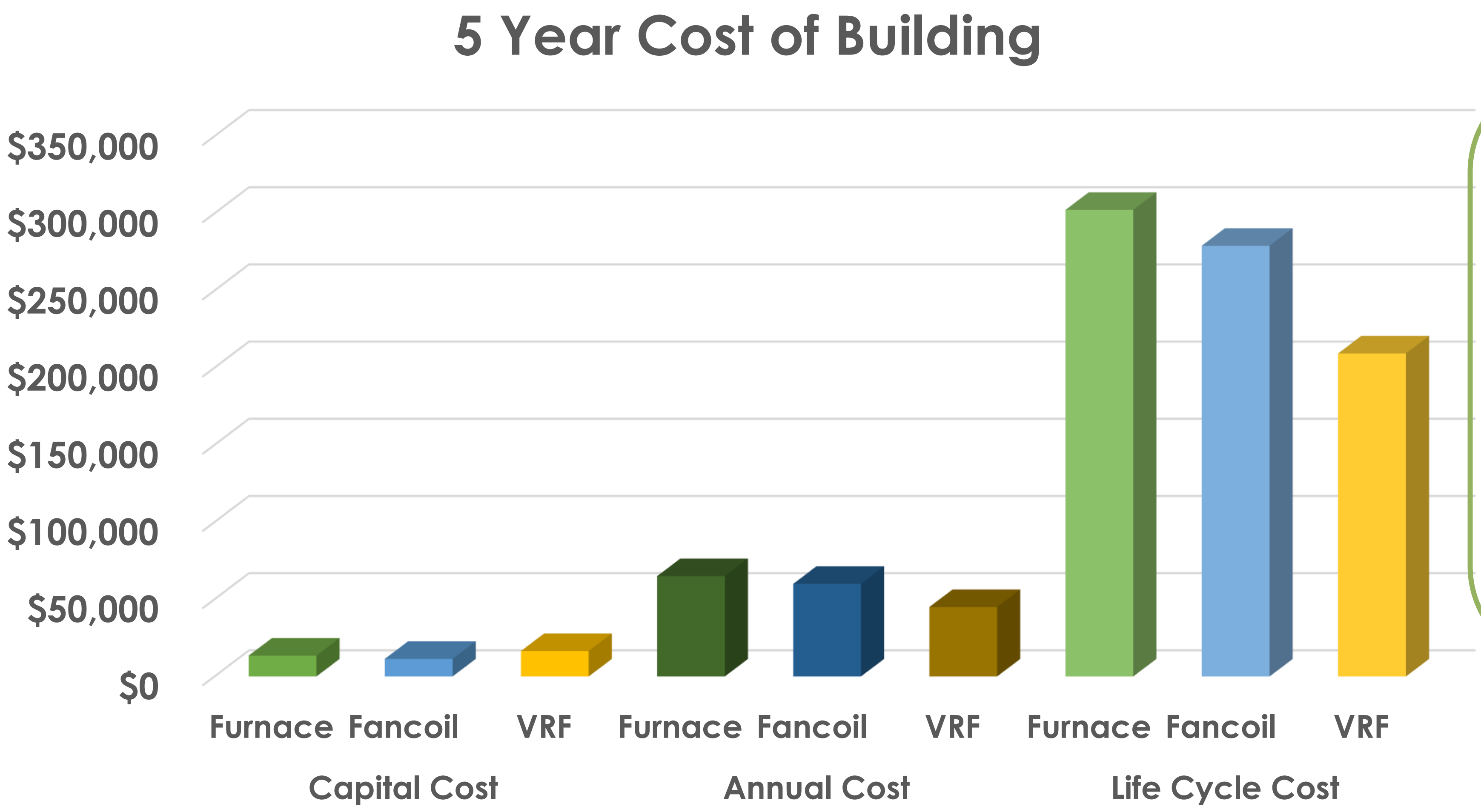
*[18] RMF Engineering (2013)*

$$LCC = Capital\ Cost + \sum_{n=1}^{p} \frac{C_n}{(1+d)^n}$$

*[18] RMF Engineering (2013)*

Where LCC: Life-cycle Cost
$C_n$: costs occurred in year
*d*: expected real discount rate per annum
*p*: period of analysis
n: number of years between base data and occurrence of the cost

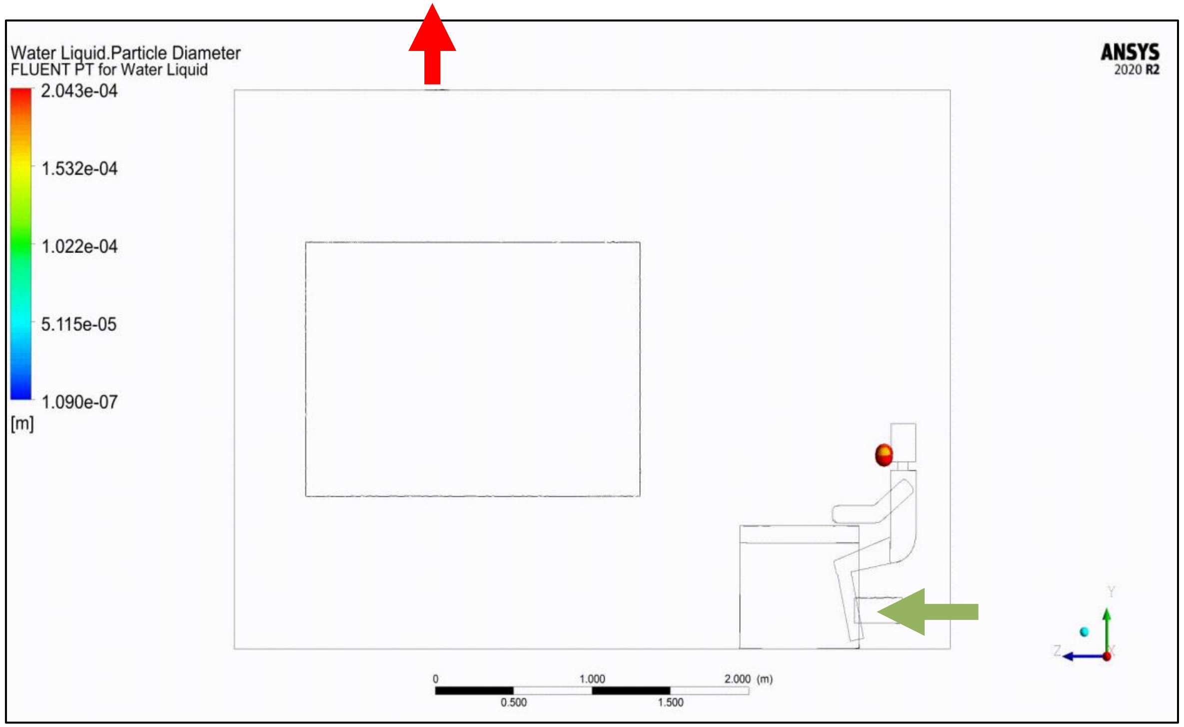
# Lifecycle Cost Analysis:




- VRF has the lowest annual energy cost.
- VRF cost 27.4% less than other modeled system in 5 year long run

# Further Improvements:

- **Duct System with Displacement Ventilation**
  - Better for infection control in the room however expensive to install.
  - Supply requires underground duct system which is not feasible.
  - Limited to specific building.




Displacement Ventilation

- **VRF System**
  - Expensive installation but could be considered.

    **Pros:** Energy efficient, variable capacity, compact

    **Cons:** No/poor unit connection for outdoor air (ventilation issues)

# Timeline/Schedule Summary

| | |
|---|---|
| ***Winter Break Plan*** | |
| **Task** | **Completion Date** |
| Refine supply air ductwork system | 12/23/2020 ✓ |
| Coordinate duct sizes with structural plans | 1/6/2021 ✓ |
| Transfer AutoCAD files to REVIT | 1/6/2021 ✓ |
| ***Spring Semester Plan*** | |
| **Task** | **Completion Date** |
| Add return air, outdoor air, and exhaust to system | 1/20/2021 ✓ |
| Incorporate displacement ventilation where possible | 2/5/2021 ✗ |
| Cost analysis / equipment selection for UV lights / bipolar ionization | 2/19/2021 ✓ |
| Adjustments to system based on EPIC's review | 3/5/2021 ✓ |
| Additional analyses per EPIC's requests | N/A ✓ |

# QUESTIONS?

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