# Mechanical Systems for Deep Energy Retrofits in Multi-Family

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STAENGL ENGINEERING

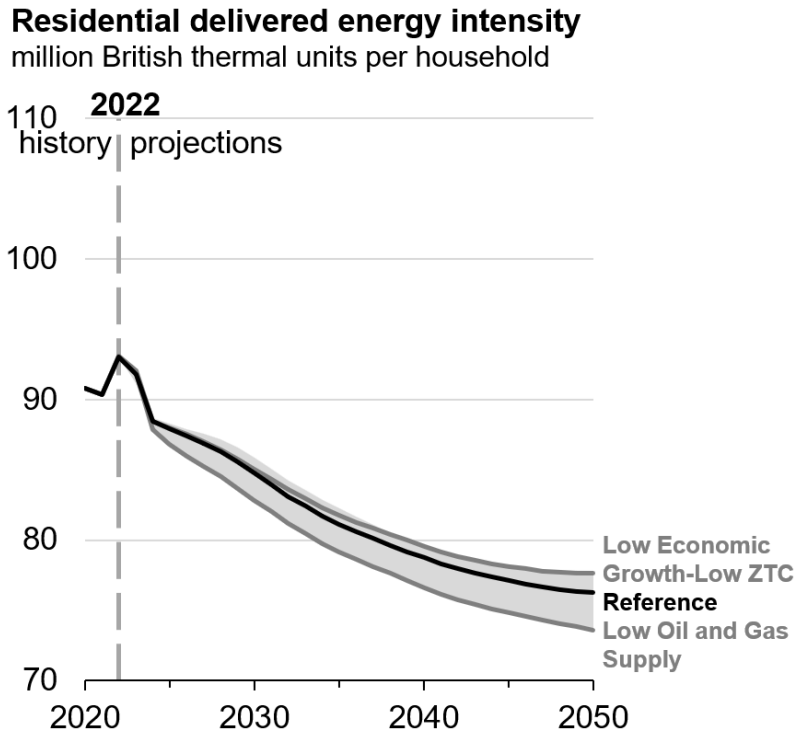
# Agenda

- Retrofit relevance
- The problem
- Electrification - reinventing fire?
- The big idea (solution approach)
- System approaches
- Case Study (Colonial II)
- Mechanical Pod Development

# The Importance of Deep Energy Retrofits

- Total Housing Units in the US: ~ 145,000,000
- New Housing Units: ~ 1%/year

Deep Energy Retrofits are key to reducing the carbon intensity of the housing sector.



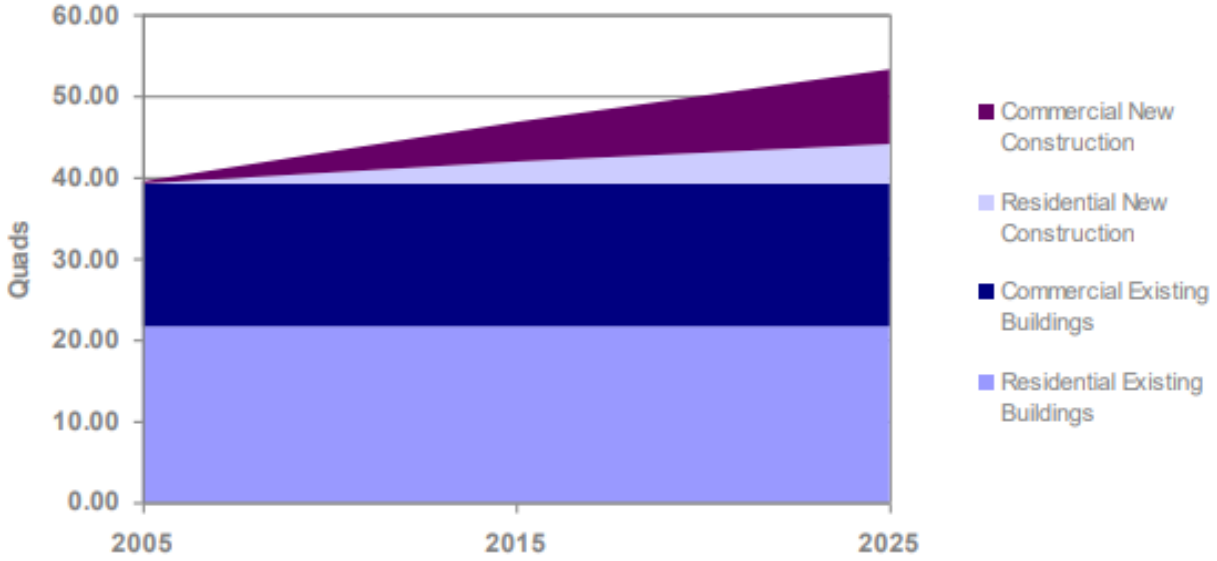
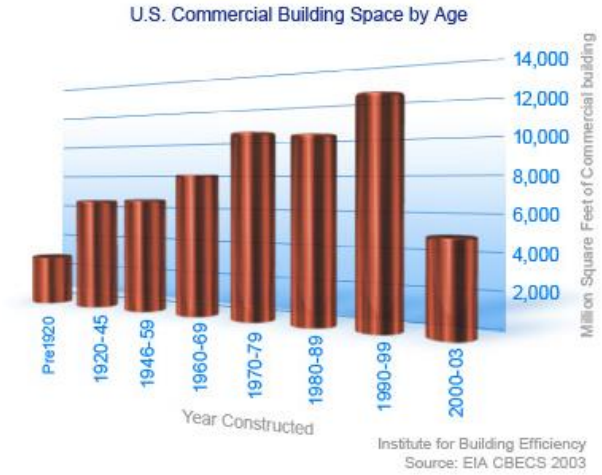




**Figure ES3. Base Case Energy Use**




U.S. Energy Information Administration

# The Opportunity


## U.S. Building Stock Characterization Study

### A National Typology for Decarbonizing U.S. Buildings

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**NREL is a national laboratory of the U.S. Department of Energy**
**Office of Energy Efficiency & Renewable Energy**
**Operated by the Alliance for Sustainable Energy, LLC**

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

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**Technical Report**
NREL/TP-5500-83063
Revised July 2022

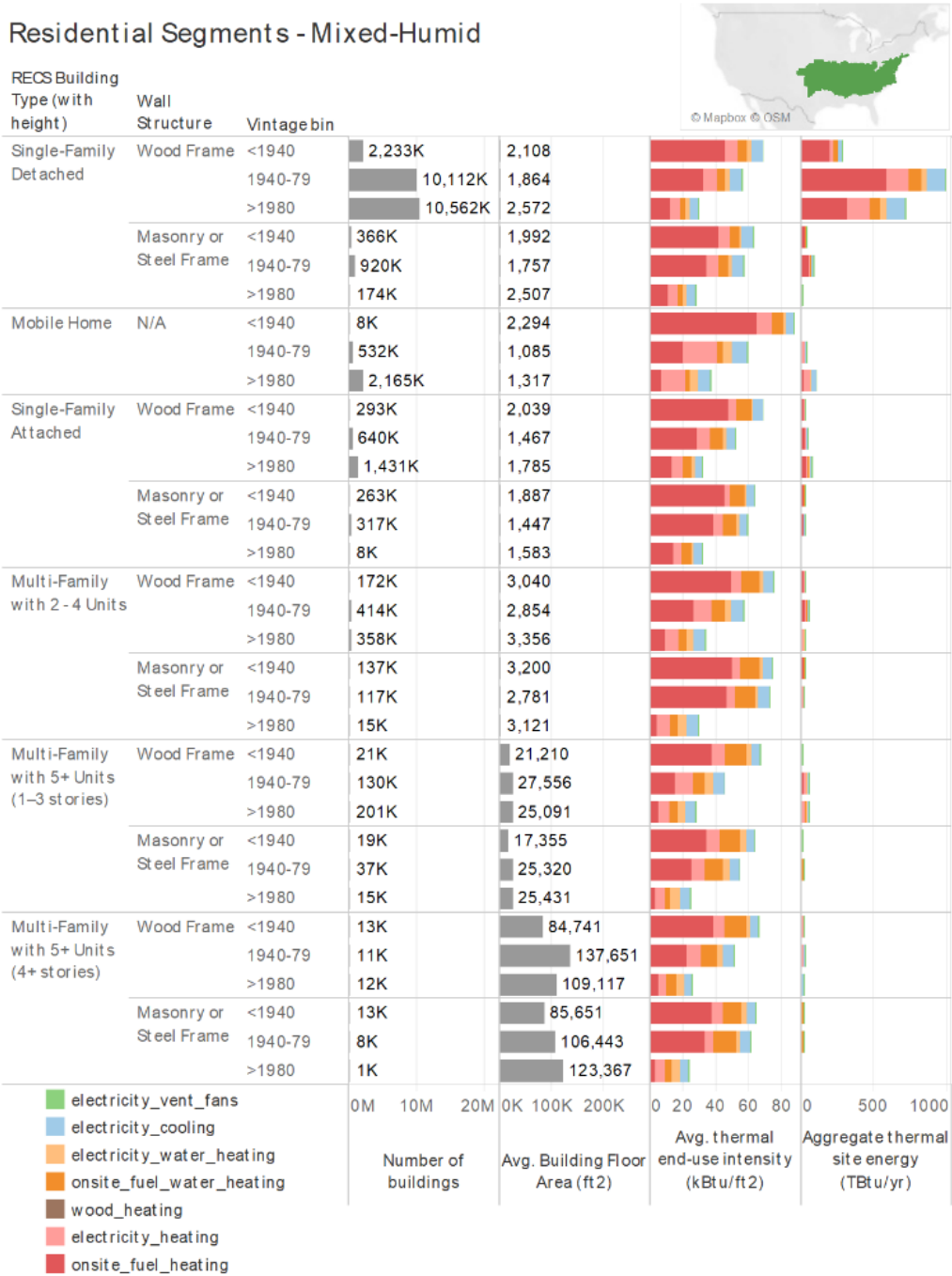



**Figure 10. Residential Mixed-Humid typology segments**

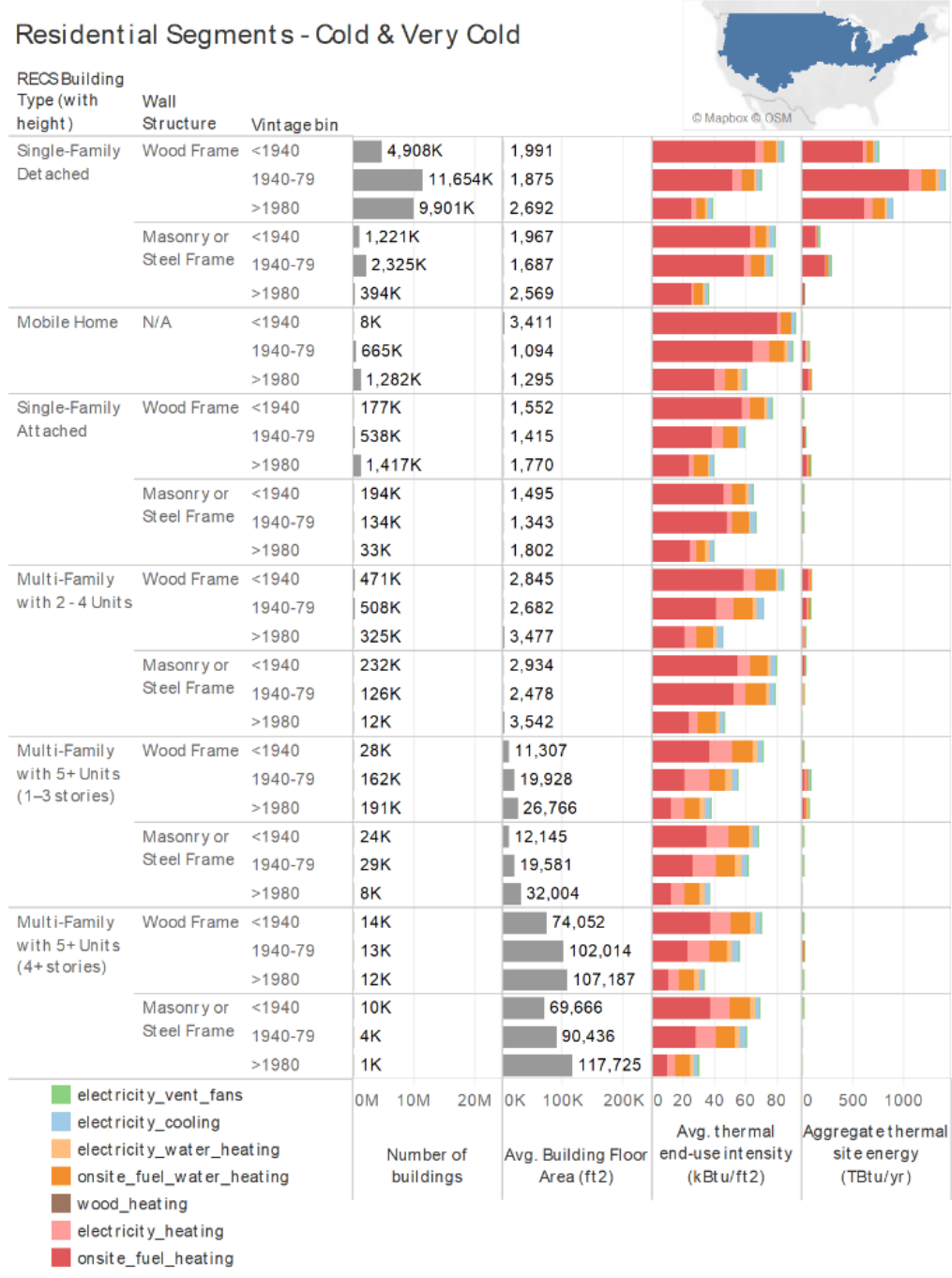



**Figure 7. Residential Cold/Very-Cold typology segments**

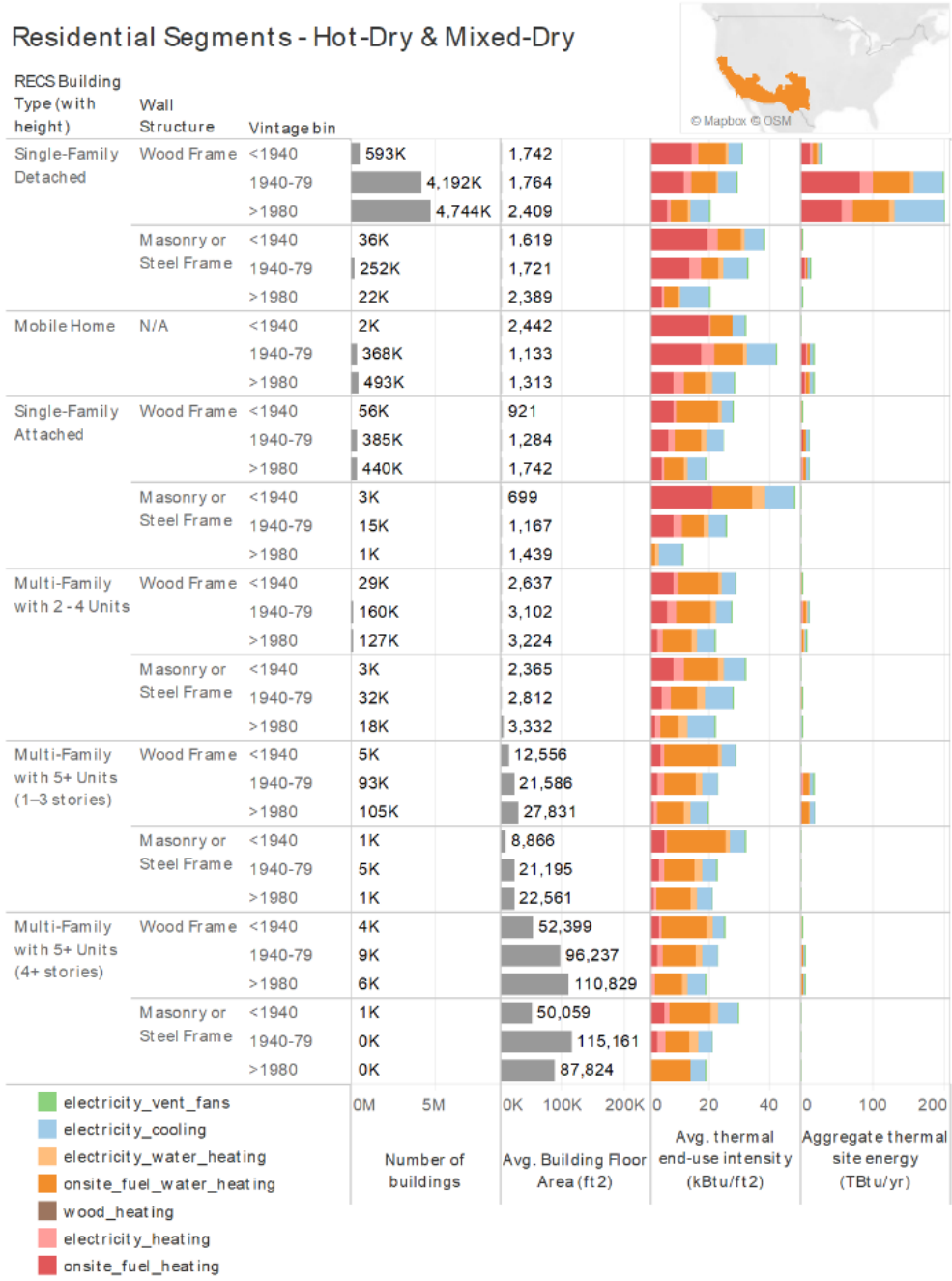



**Figure 16. Residential Hot-Dry/Mixed-Dry typology segments**

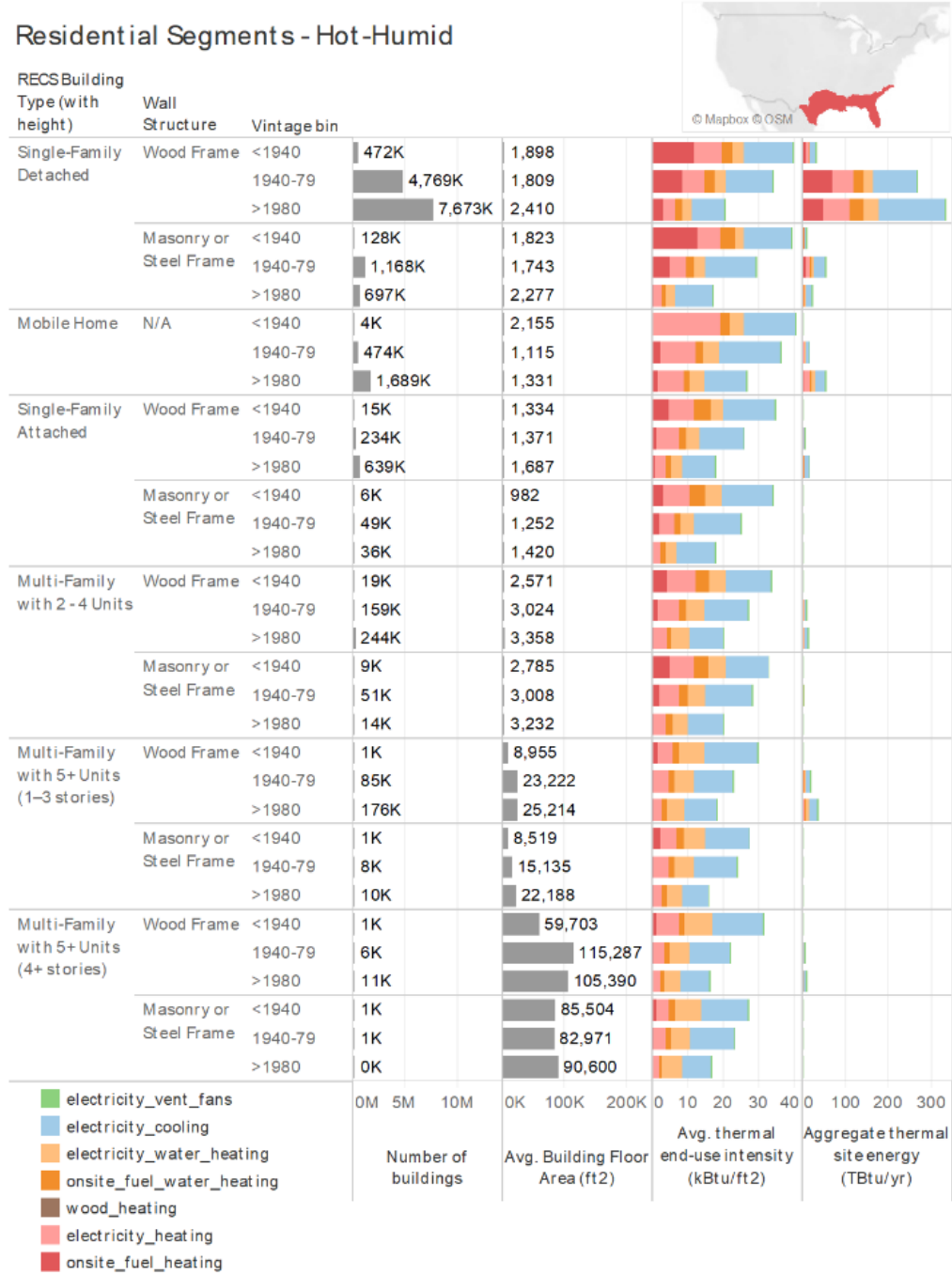
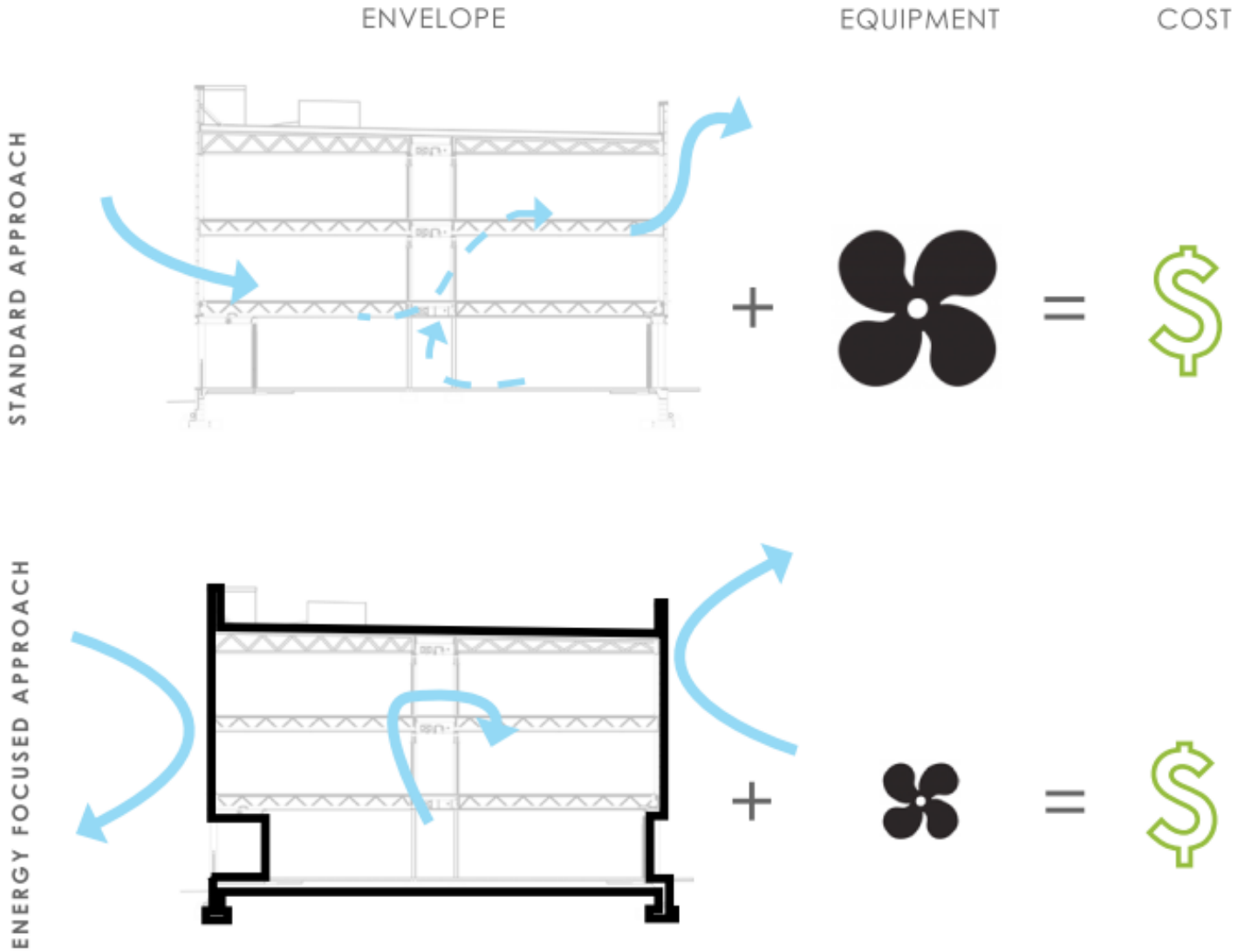



**Figure 19. Residential Hot-Humid typology segments**

# Project Optimization




Apply Passive Building Principals to Comfort and Hot Water

# The “Cost Effective” Deep Energy Retrofit

Courtesy of Monty Python

# The Holy Grail of Building Energy Savings

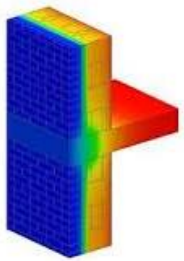
# Objectives:

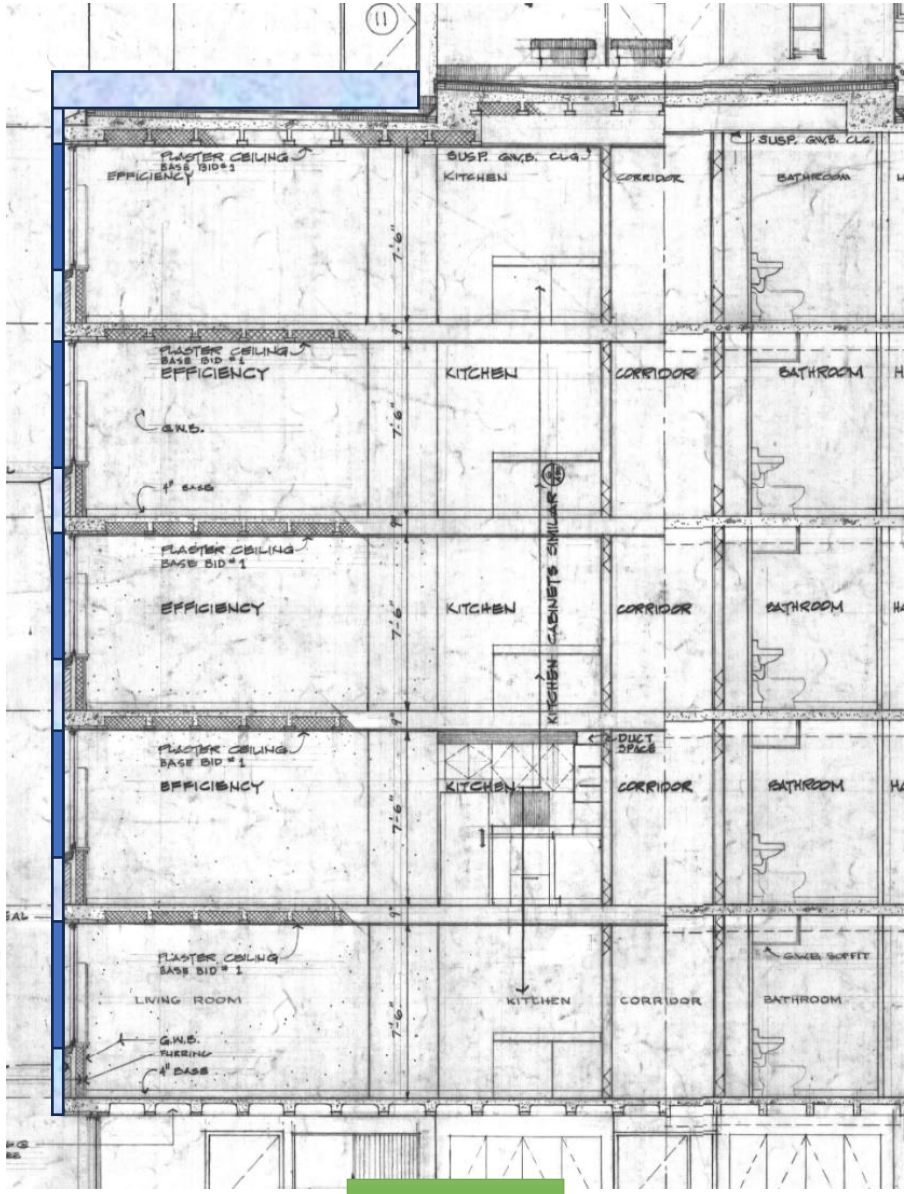
- Dramatic Building Energy Savings (>50%)
- Retrofit-in-place
- Electrification

# Challenges:

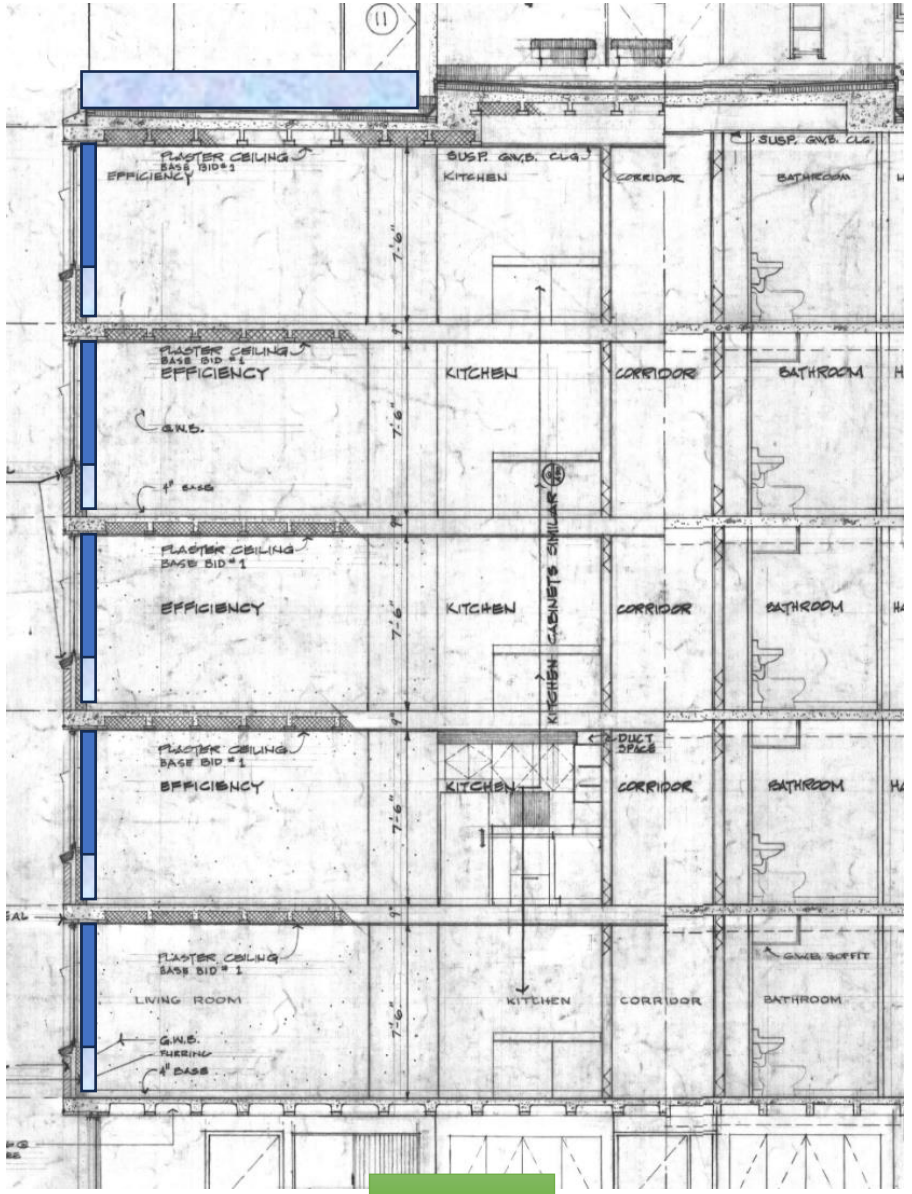
- Limitations on exterior insulation
- Electrical service capacity
- Equipment availability
- COST

# Insulate the Envelope






Exterior




Interior

# Electrification – Space Heat / Cool

## Air-to-Air


## Air-to-Water



## Water-to-Air

## Water-to-Water

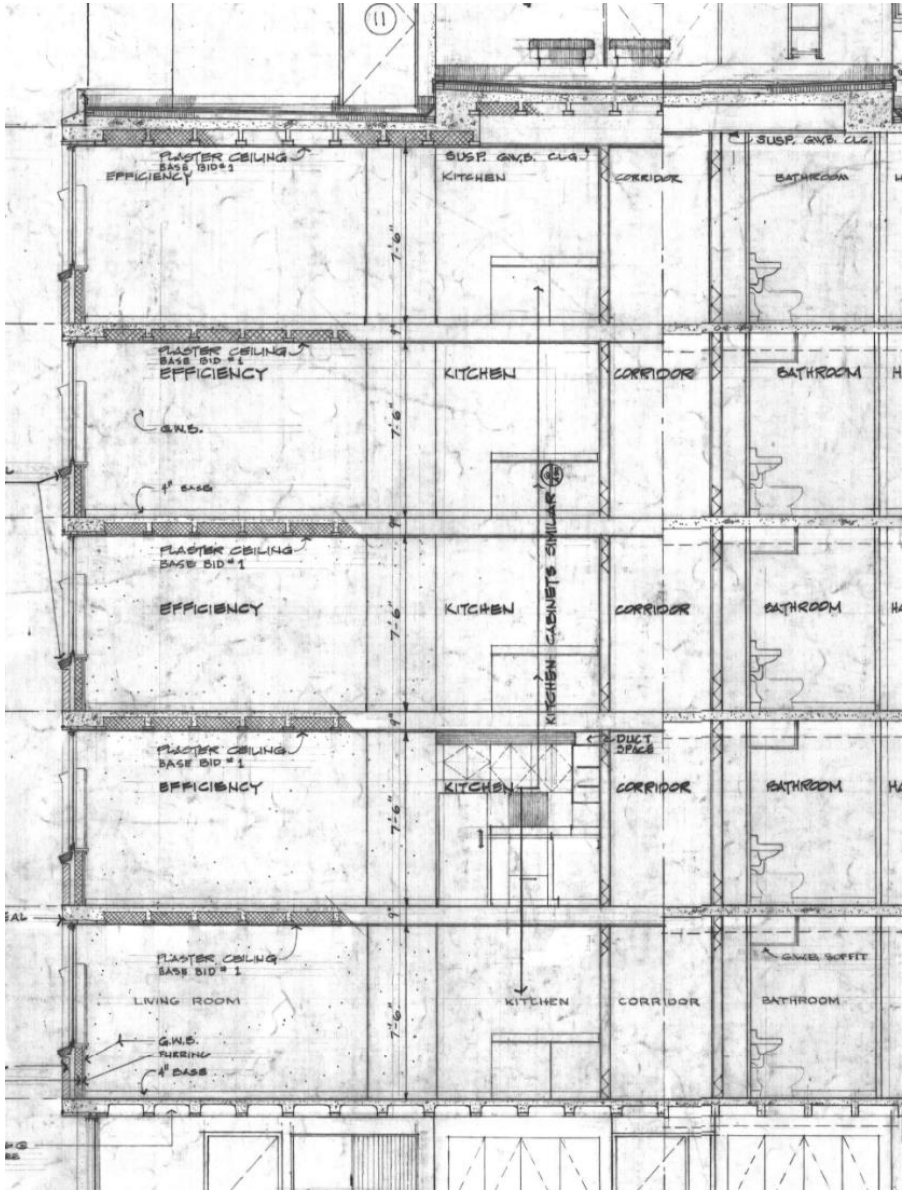

# Electrification - DHW



# System Approach

Can we penetrate the exterior envelope?

- Historic Envelope?
- Lot Line Issues?

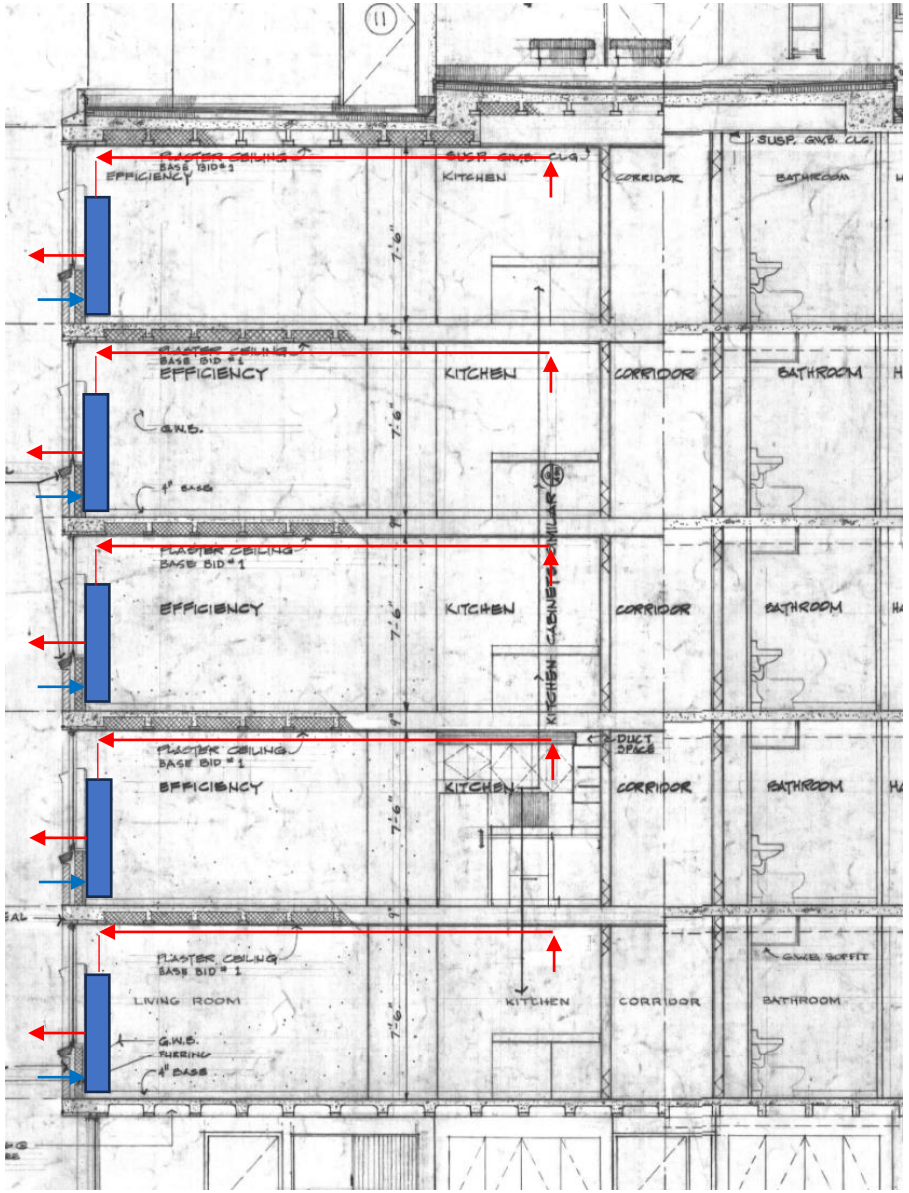


# System Approach

## Can we penetrate the exterior envelope?

YES – Apartment Level Solutions

- Ventilation and Condenser Air From Facade
- Mechanical Pod?
- PTAC?
- WSHP?

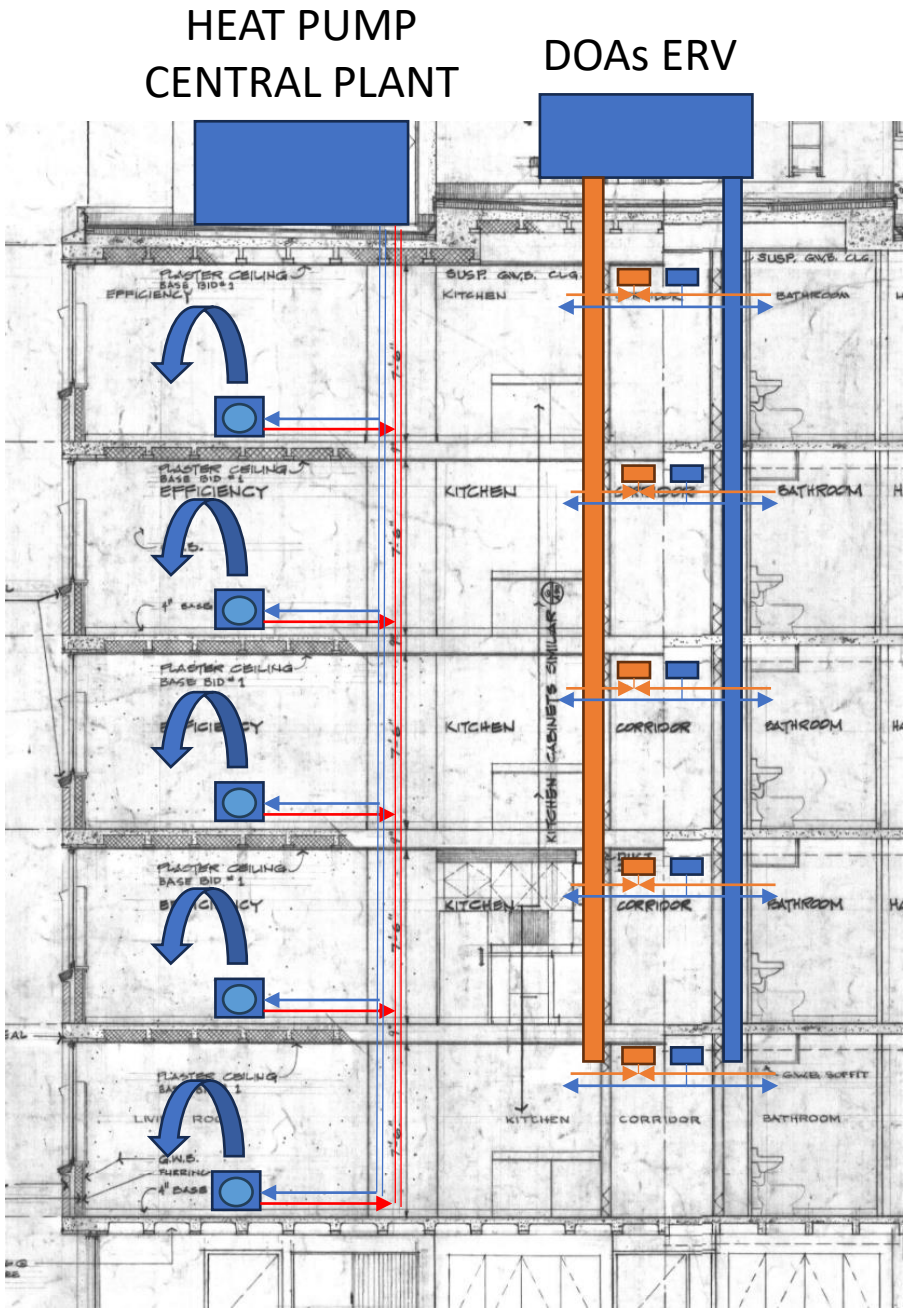



# System Approach

If we can't penetrate the exterior: Can we fit ductwork in the corridor?

YES

- Ventilation Air from Rooftop DOAS/ERV
- Space Conditioning:
  - Water source heat pumps?
  - Hydronic fan coils?
  - VRF?
- Heat Pump Based Central Plant:
  - Air Source Heat Pumps?
  - Geothermal?
  - Solar HW?
  - VRF?



# System Approach

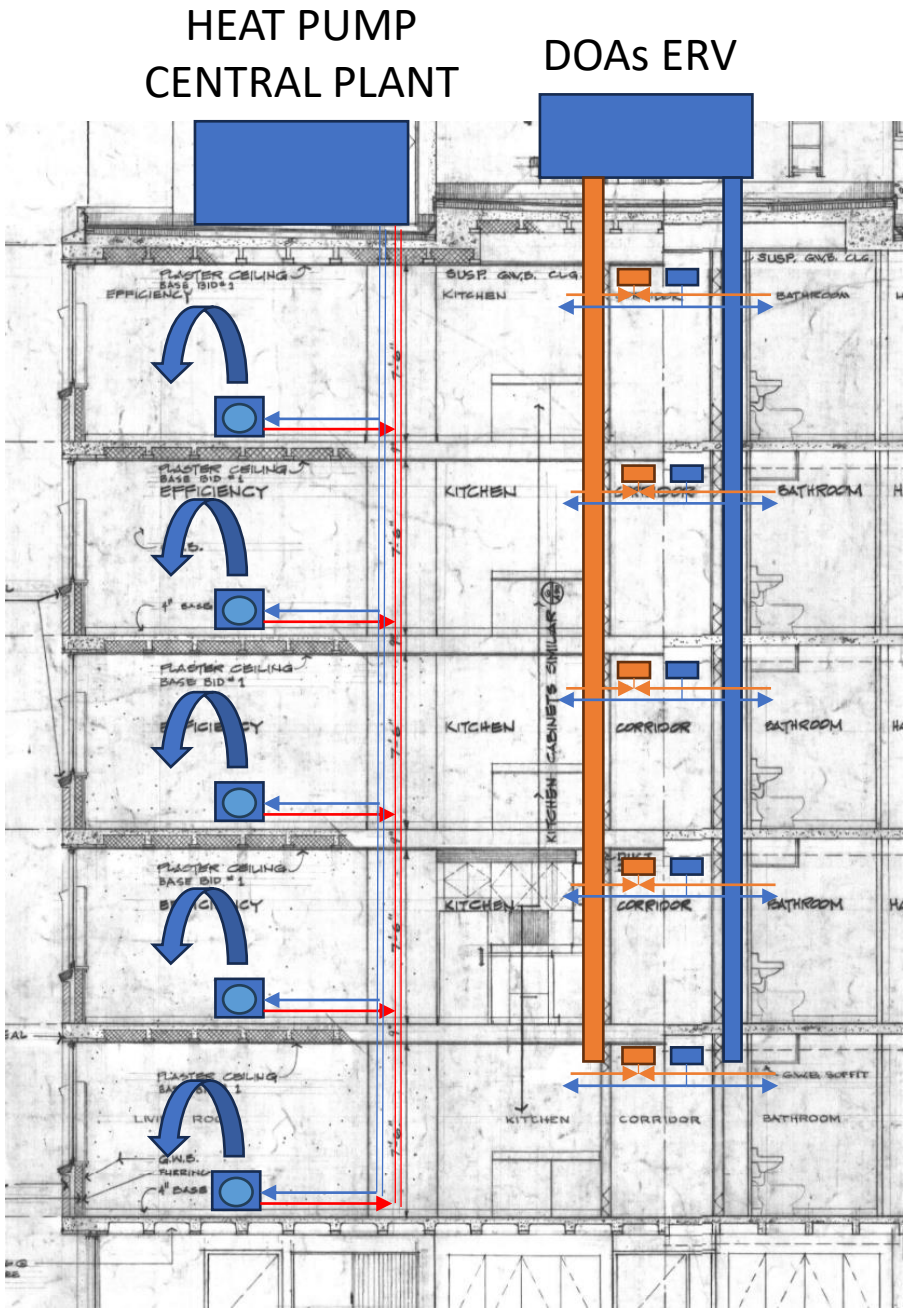
## 4-pipe or 2-pipe hydronic system

Advantages

- High Efficiency
- Opportunities for heat recovery to domestic hot water in central DHW system

Disadvantages

- Cost of piping is high if not already there



# System Approach

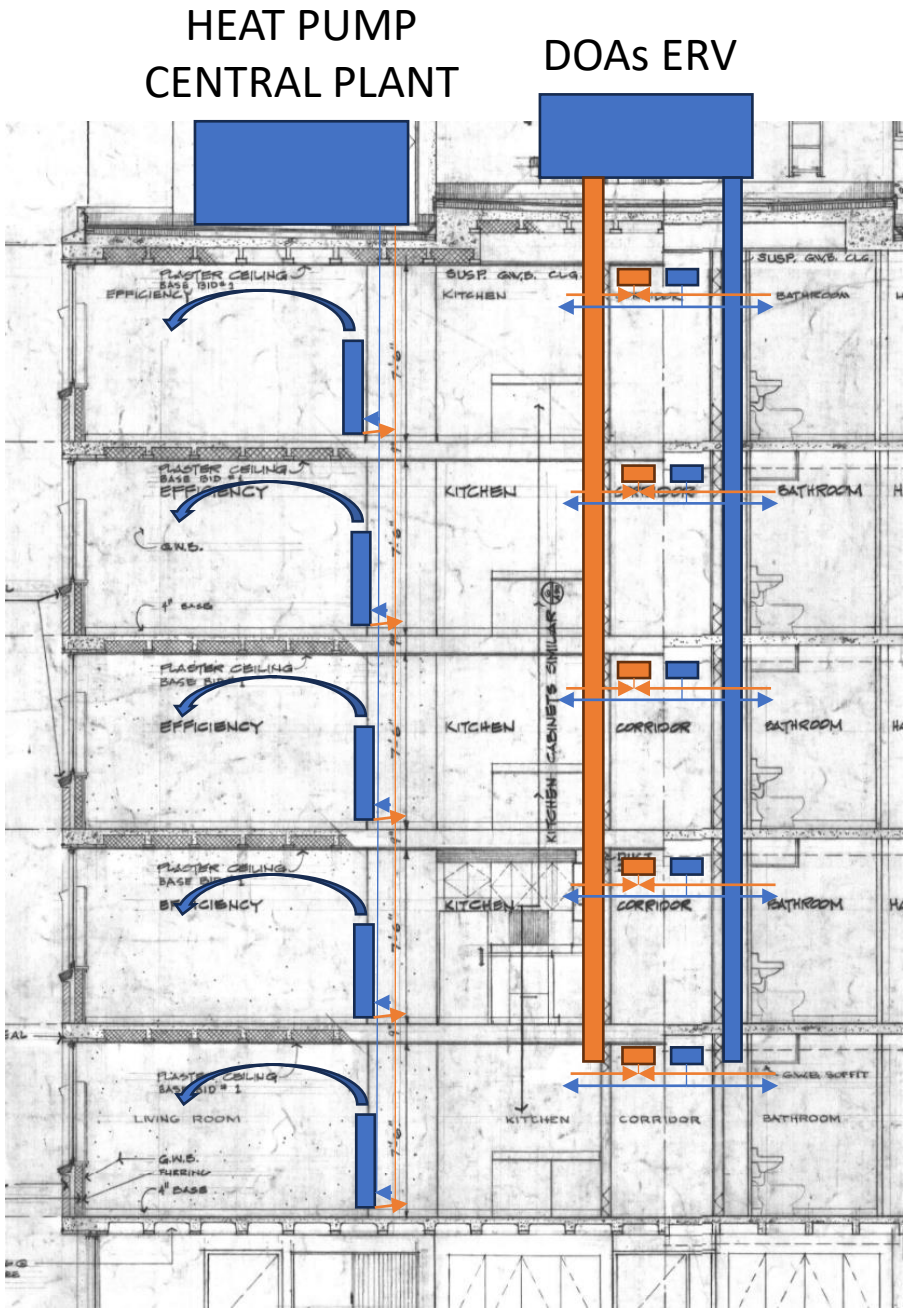
## Water-source heat pumps

Advantages

- Neutral water piped through the building. Can re-use existing heating water piping
- Can capture waste heat for domestic hot water heating in a central DHW plant

Disadvantages

- Compressor in every apartment
- Lower COP if using air-to-water heat pumps in central plant



# System Approach

## Ground / Solar-source heat pumps

Advantages

- Very low energy use
- Can be integrated with solar
- Lower maintenance costs
- Heat recovery to DHW possible

Disadvantages

- Requires real estate for geothermal wells
- High cost, but lower now with tax credits available, that apply to full HVAC system
- Compressor in every apartment

DOAs ERV


**Ground Loop Vertical Wells**

# System Approach

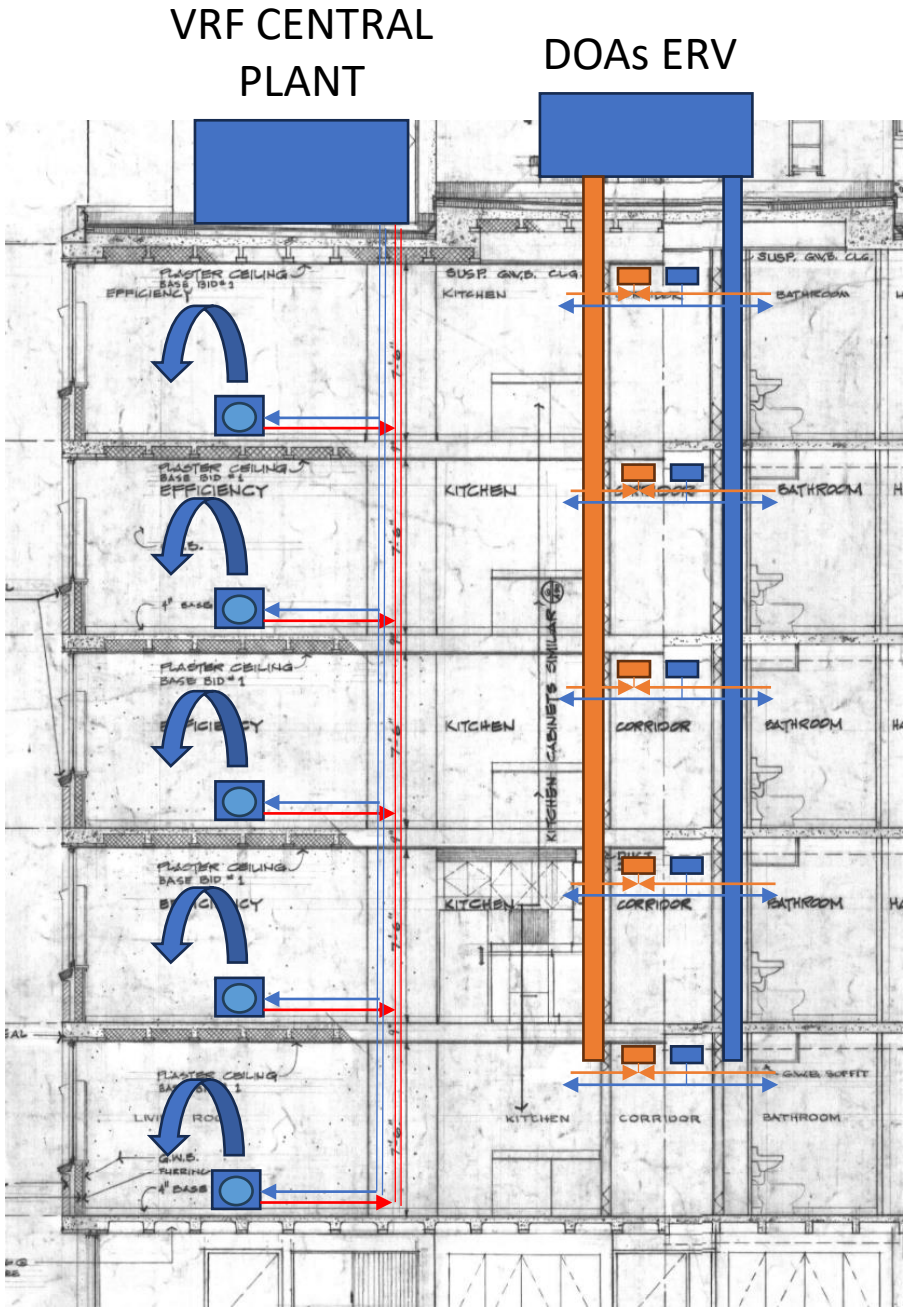
## VRF

Advantages

- Less costly than hydronic

Disadvantages

- Requires refrigerant line-sets to be run throughout the building
- High potential refrigerant loss, with high global warming potential
- High embodied carbon content of refrigerant
- High maintenance costs

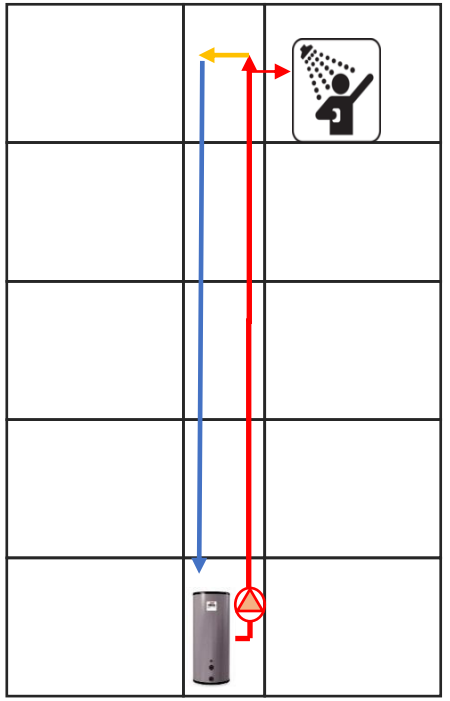


# HW Heater Sizing

HW **heaters** are oversized based on outdated assumptions for fixture flow, and occupant diversity.

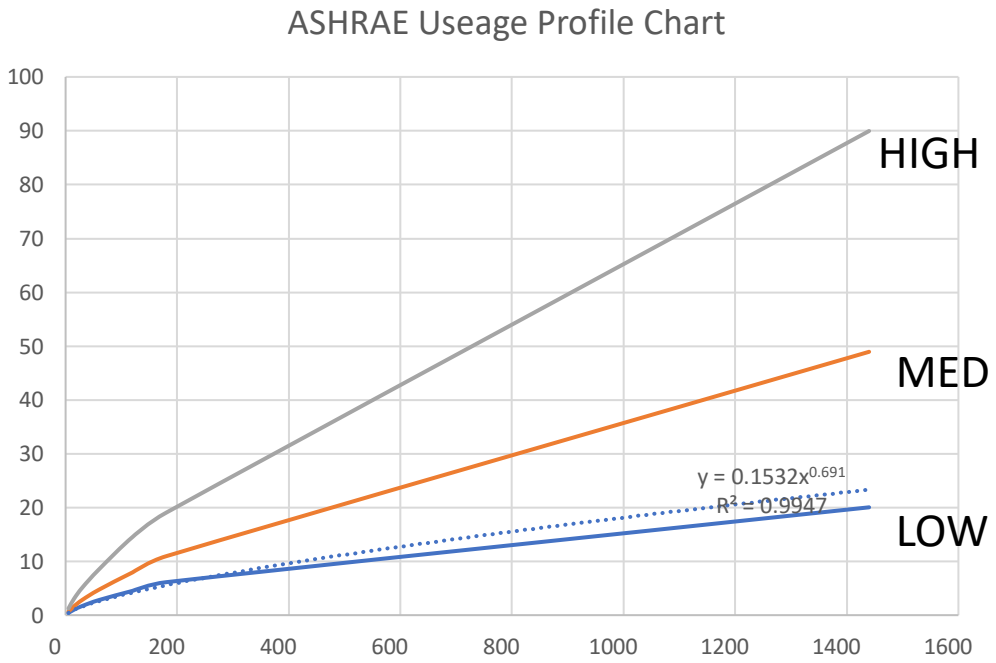
Example:

- 60 occupant apartment building
- Standard ASHRAE assumptions:
  - 210 gallons storage
  - 82,000 BTU/HR heater
- Adjusted for modern fixtures and Diversity:
  - 110 gallons storage
  - 41,000 BTU/HR heater



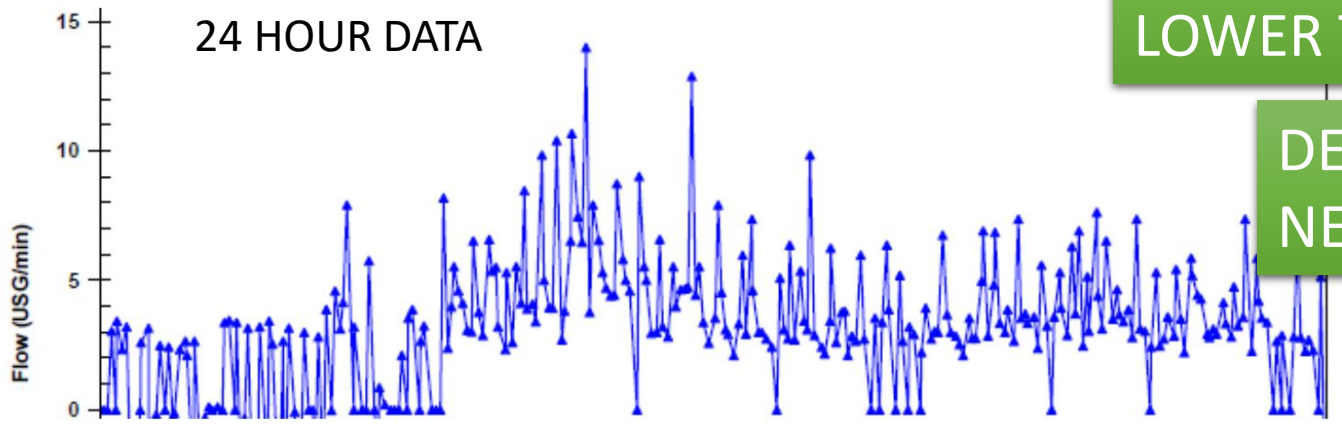
# HW Consumption Design Data

- Know your population
- Use measured consumption data if possible




Adapted from ASHRAE Handbook

# HW Consumption Measured Data




MEASURED USE PEAK LOWER THEN DESIGN

DEMAND ALMOST NEVER OFF

HW Consumption Study for 95 unit Senior Housing apartment building.

| | Range (GPM) | Duration (Minutes/day) | % | Cumulative Flow (Gallons) |
|---|---|---|---|---|
| Low Draw | 0-3 | 1152 | 80% | 1,400 |
| Med Draw | 3-6 | 230 | 16% | 280 |
| High Draw | 6-9 | 43 | 3% | 53 |
| Peak Draw | 9+ | 14 | 1% | 18 |

| | |
|---|---|
| Total Gallons per day | 1,750 |

24 hour monitoring study. Courtesy of IntelliHot

# Water Demand Calculator (WDC v2.1)

PROJECT NAME : - - - - -

Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building → 95

Total Apartments in this Calculation → 95

Monday, October 11, 2021

4:49 PM

| FIXTURE GROUPS | | FIXTURE | ENTER TOTAL NUMBER OF FIXTURES | PROBABILITY OF USE (%) | ENTER FIXTURE FLOW RATE (GPM) | MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM) |
|---|---|---|---|---|---|---|
| Bathroom Fixtures | 1 | Bathtub (no Shower) | 0 | 0.38 | 5.5 | 5.5 |
| | 2 | Bidet | 0 | 0.55 | 2.0 | 2.0 |
| | 3 | Combination Bath/Shower | 0 | 1.41 | 5.5 | 5.5 |
| | 4 | Faucet, Lavatory | 95 | 1.11 | 1.5 | 1.5 |
| | 5 | Shower, per head (no Bathtub) | 95 | 0.94 | 2.0 | 2.0 |
| | 6 | Water Closet, 1.28 GPF Gravity Tank | 95 | 0.55 | 3.0 | 3.0 |
| Kitchen Fixtures | 7 | Dishwasher | 0 | 0.32 | 1.3 | 1.3 |
| | 8 | Faucet, Kitchen Sink | 95 | 1.11 | 2.2 | 2.2 |
| Laundry Room Fixtures | 9 | Clothes Washer | 5 | 1.33 | 3.5 | 3.5 |
| | 10 | Faucet, Laundry | 0 | 1.11 | 2.0 | 2.0 |
| Bar/Prep Fixtures | 11 | Faucet, Bar Sink | 0 | 1.11 | 1.5 | 1.5 |
| Other Fixtures | 12 | Fixture 1 | 0 | 0.00 | 0.0 | 6.0 |
| | 13 | Fixture 2 | 0 | 0.00 | 0.0 | 6.0 |
| | 14 | Fixture 3 | 0 | 0.00 | 0.0 | 6.0 |

**COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS**

| Total No. of Fixtures in Calculation |
|---|
| n = 385 |

| $99^{th}$ Percentile Demand Flow |
|---|
| Q = 17.0 GPM |

| Hunter Number |
|---|
| H(n,p) = 3.59 |

| Stagnation Probability |
|---|
| Pr[Zero Demand] = 3% |

DOWNLOAD RESULT

RESET WDC

↓ Select Units for Water Demand ↓

GPM | LPM | LPS

RUN WDC

IAPMO

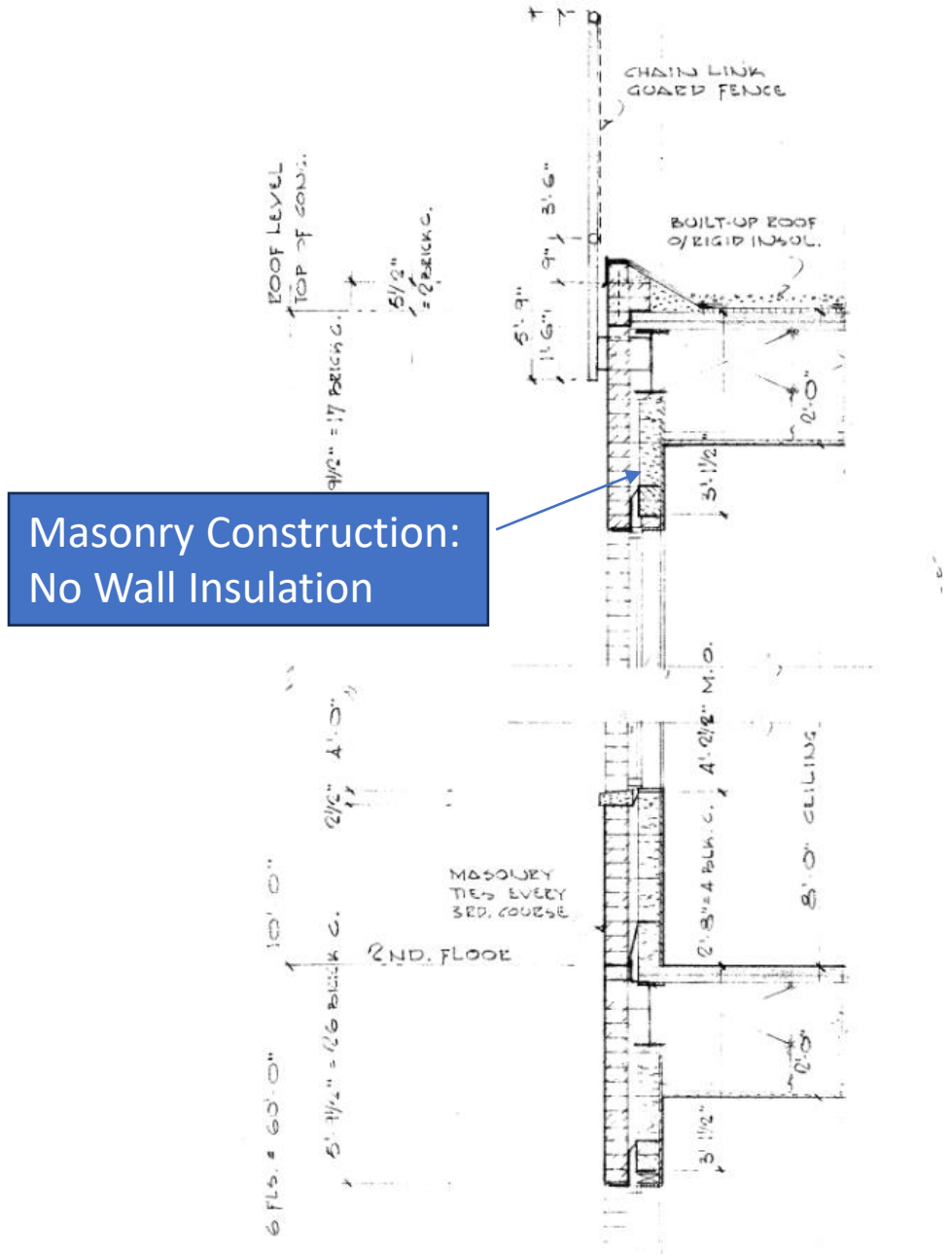
# Electrification

- Benefits
  - Carbon reduction
  - Safety
  - IAQ
  - Local Air Quality
- Barriers
  - Heating loads
  - Electrical Infrastructure
  - Relative cost of Gas / Electricity
  - Immature heat pump market in the US
  - Outside design temperature?

# Colonial II

A Net-Zero Energy Retrofit

# Colonial II


Pre- Retrofit EUI: 117 kBTU/sqft!

# Colonial II

Ancient Gas Boilers:
2 x 2.6 MMBTU/hr

Gas HW Heaters:
2 x 300kBTU/hr

# Colonial II

New Air Barrier

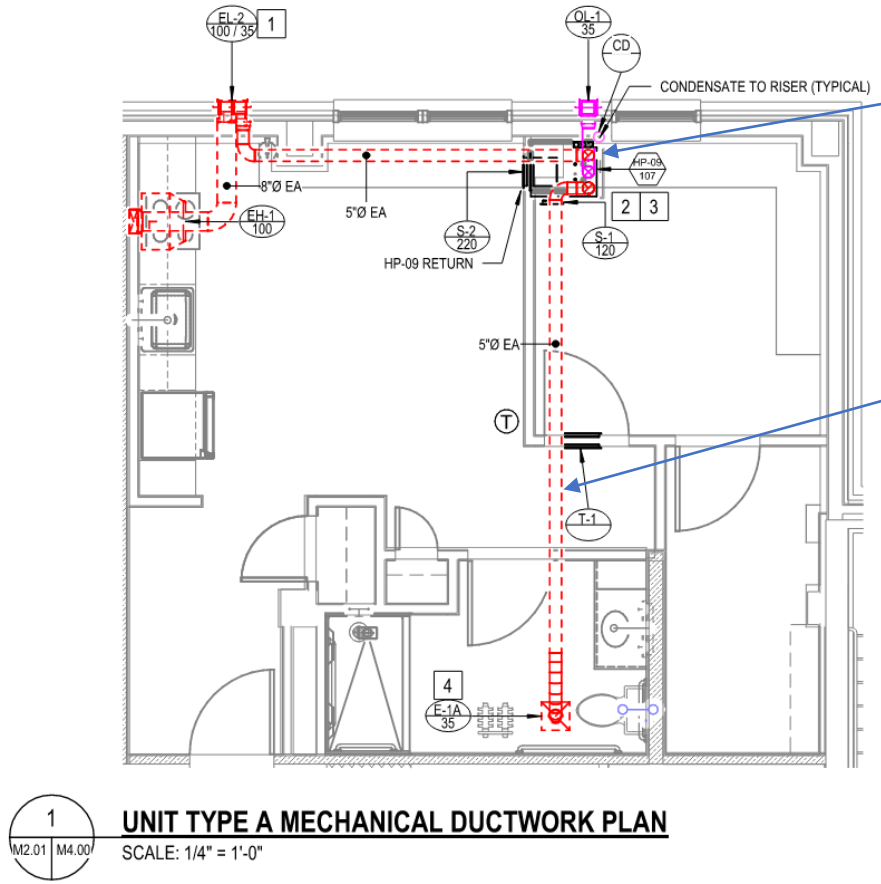
New Exterior Insulation

New Windows

# Colonial II

ERV

WATER-SOURCE HEAT PUMP




1 M2.01 M4.00 **UNIT TYPE A MECHANICAL DUCTWORK PLAN**

SCALE: 1/4" = 1'-0"

All-In One Heat Pump

Simple Ductwork

~1,000,000 BTU/HR OF HEAT PUMP INSTALLED

Interior Retrofit 99 to 74 Apartments

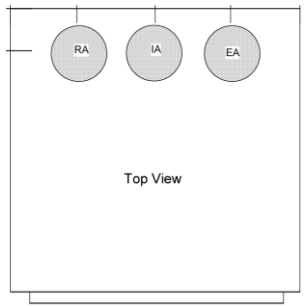
# Colonial II

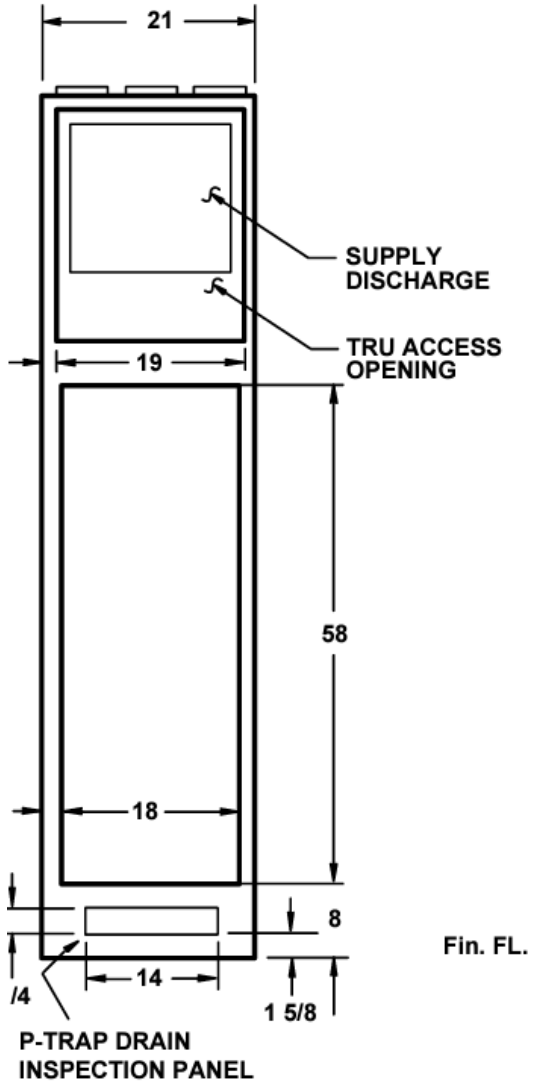

~0.9 W/SQFT

ASE 85%

TRE 67%

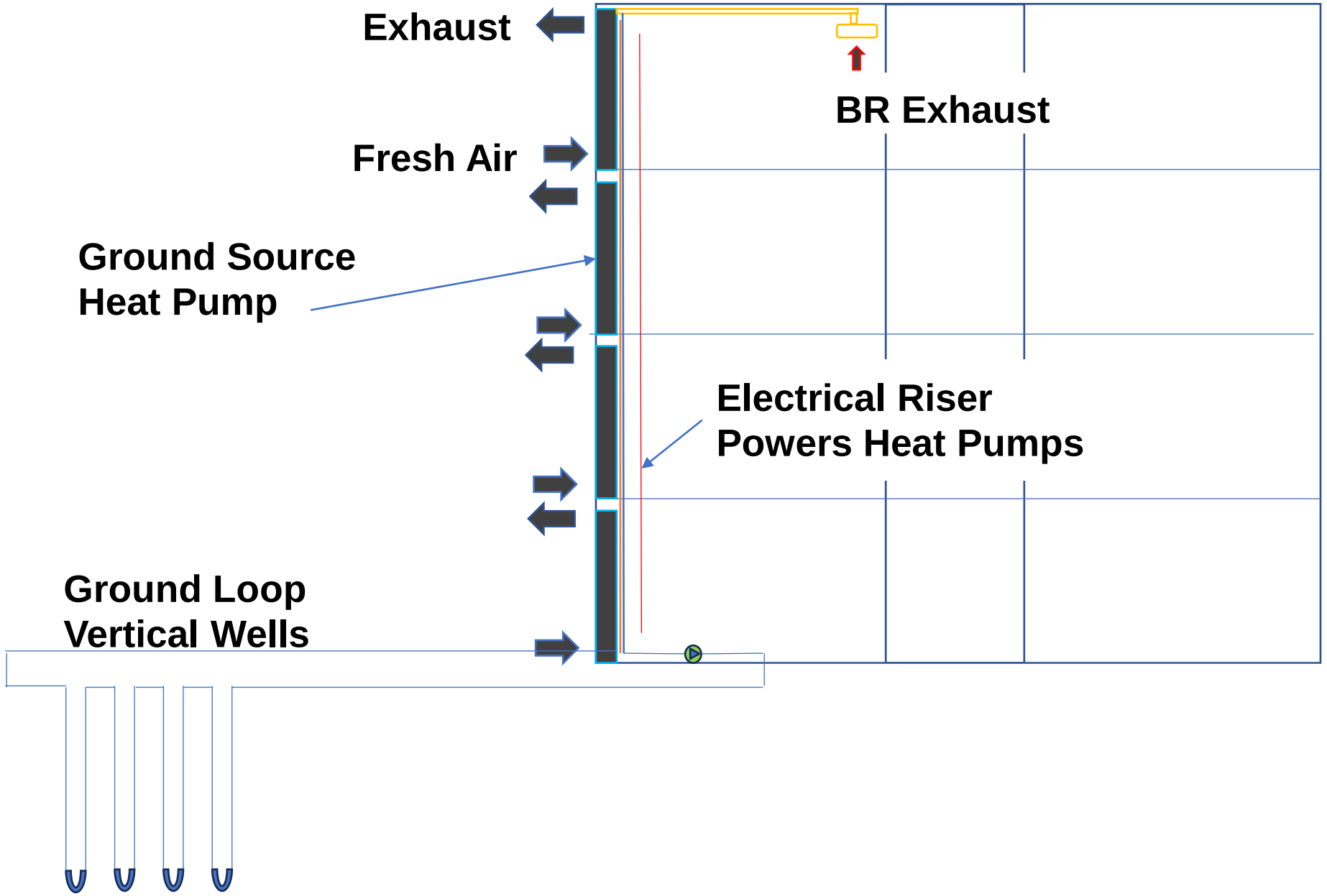
INTEGRATED HEAT PUMP WITH ERV



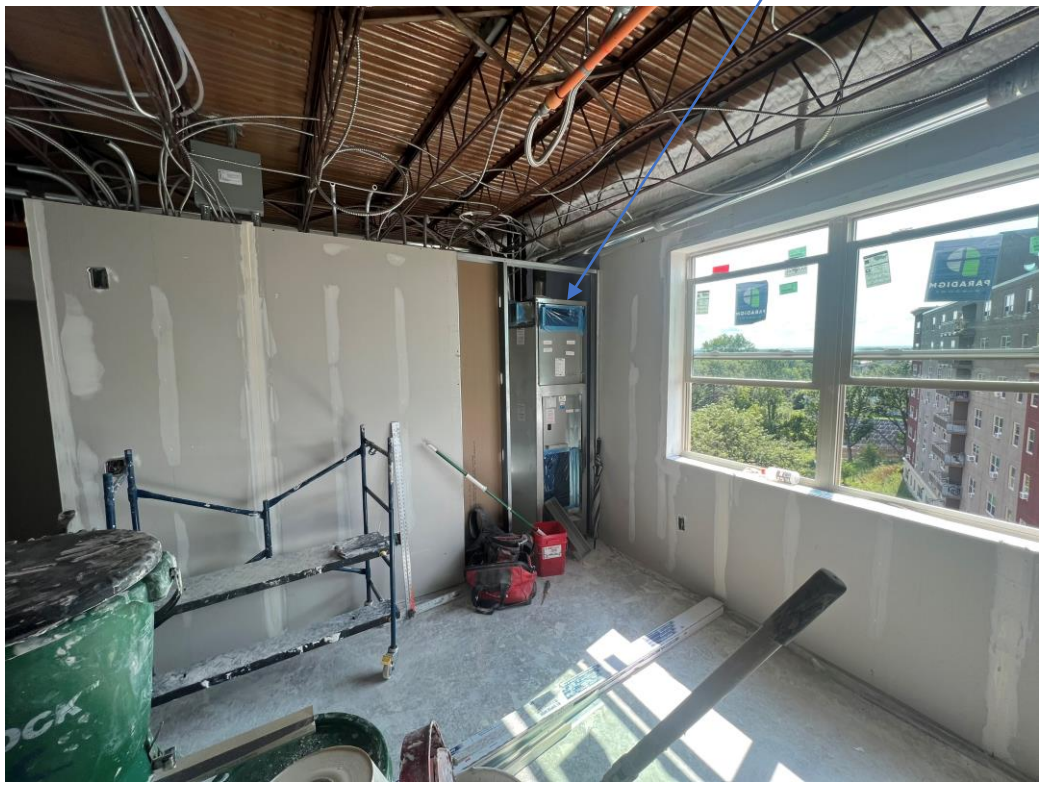

FRONT VIEW

# Colonial II


Exhaust
BR Exhaust
Fresh Air
Ground Source
Heat Pump
Electrical Riser
Powers Heat Pumps
Ground Loop
Vertical Wells

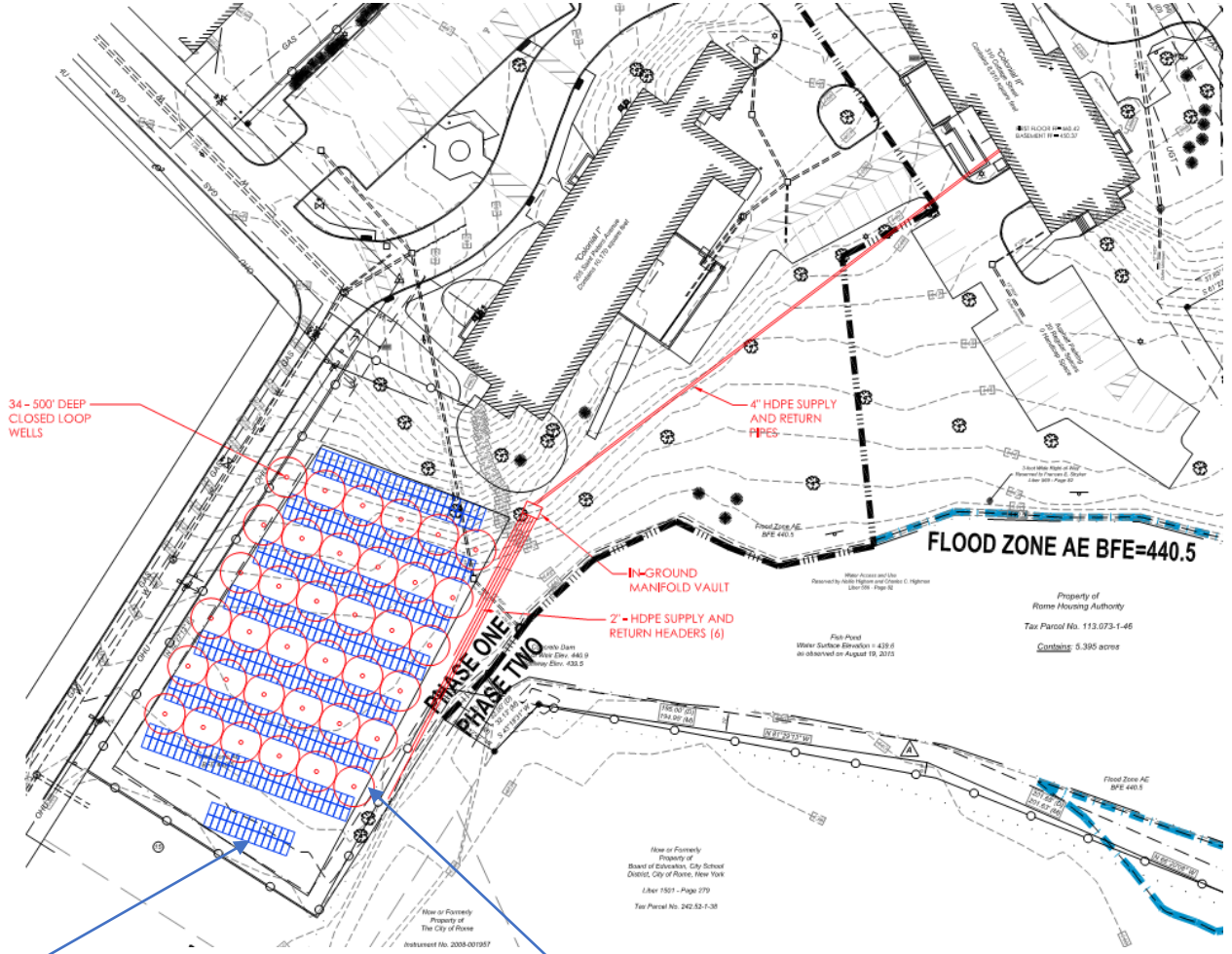
# Colonial II

All-in One WS Heat Pump



Geothermal Manifold

# Colonial II




Solar Field Above Well Field

Vertical Geothermal Well Field

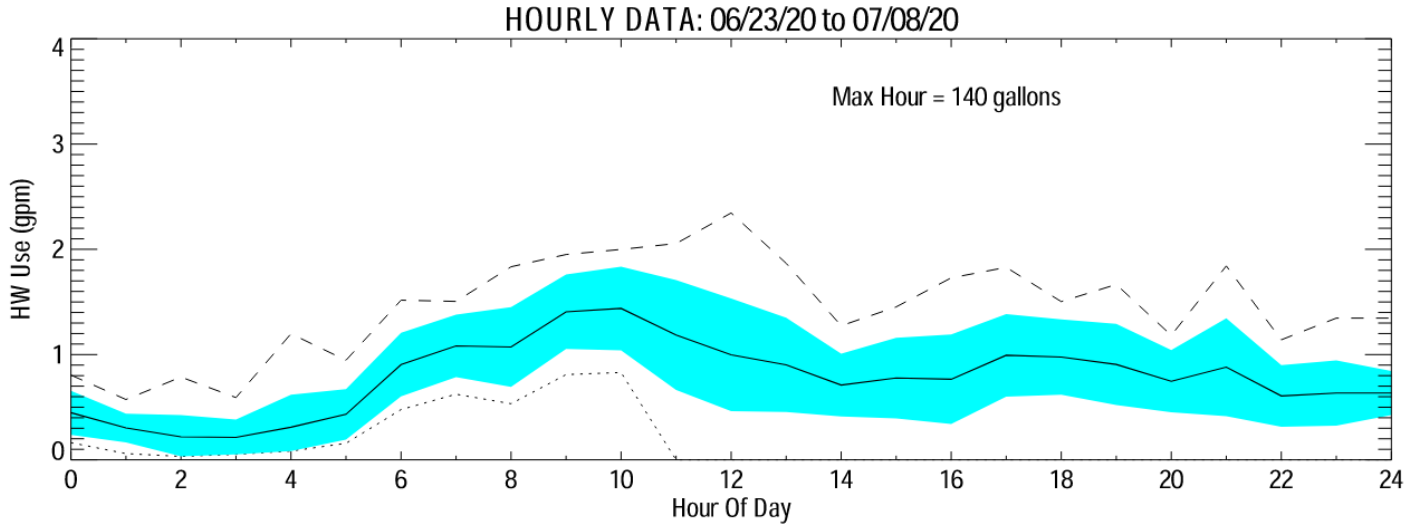
# Colonial II

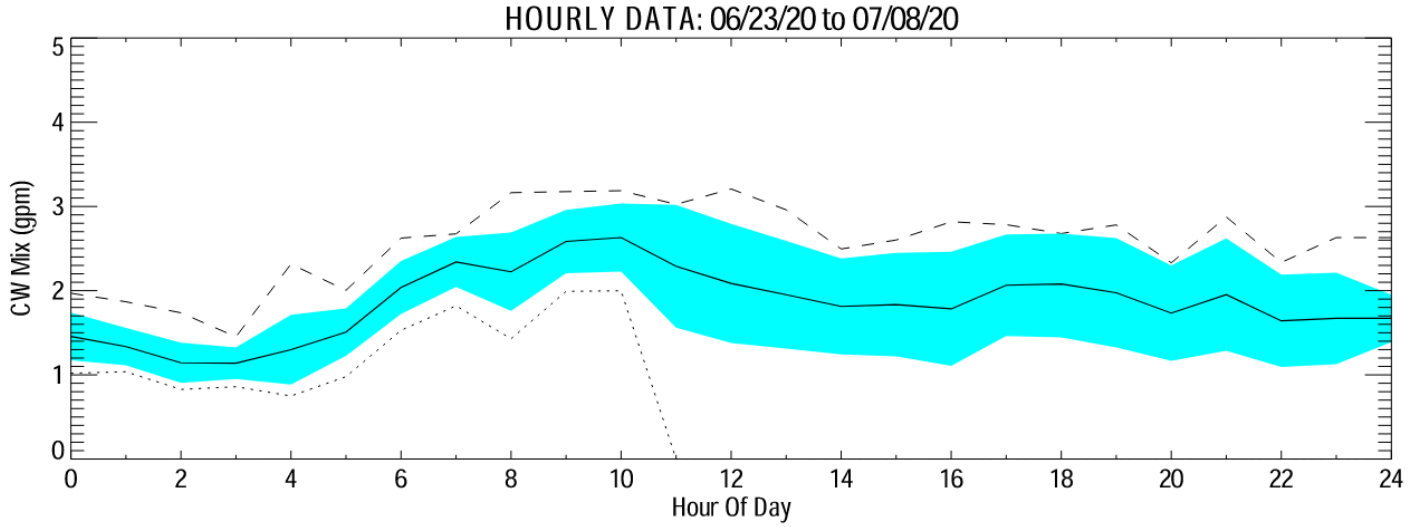
- New electrical service – 3000 A / 208 V / 3 Phase
- Old electrical service - 1400 A / 208 V / 3 Phase

Required New Fire Pump, and Solar Field Required Electrical Service Upgrade

# Colonial II

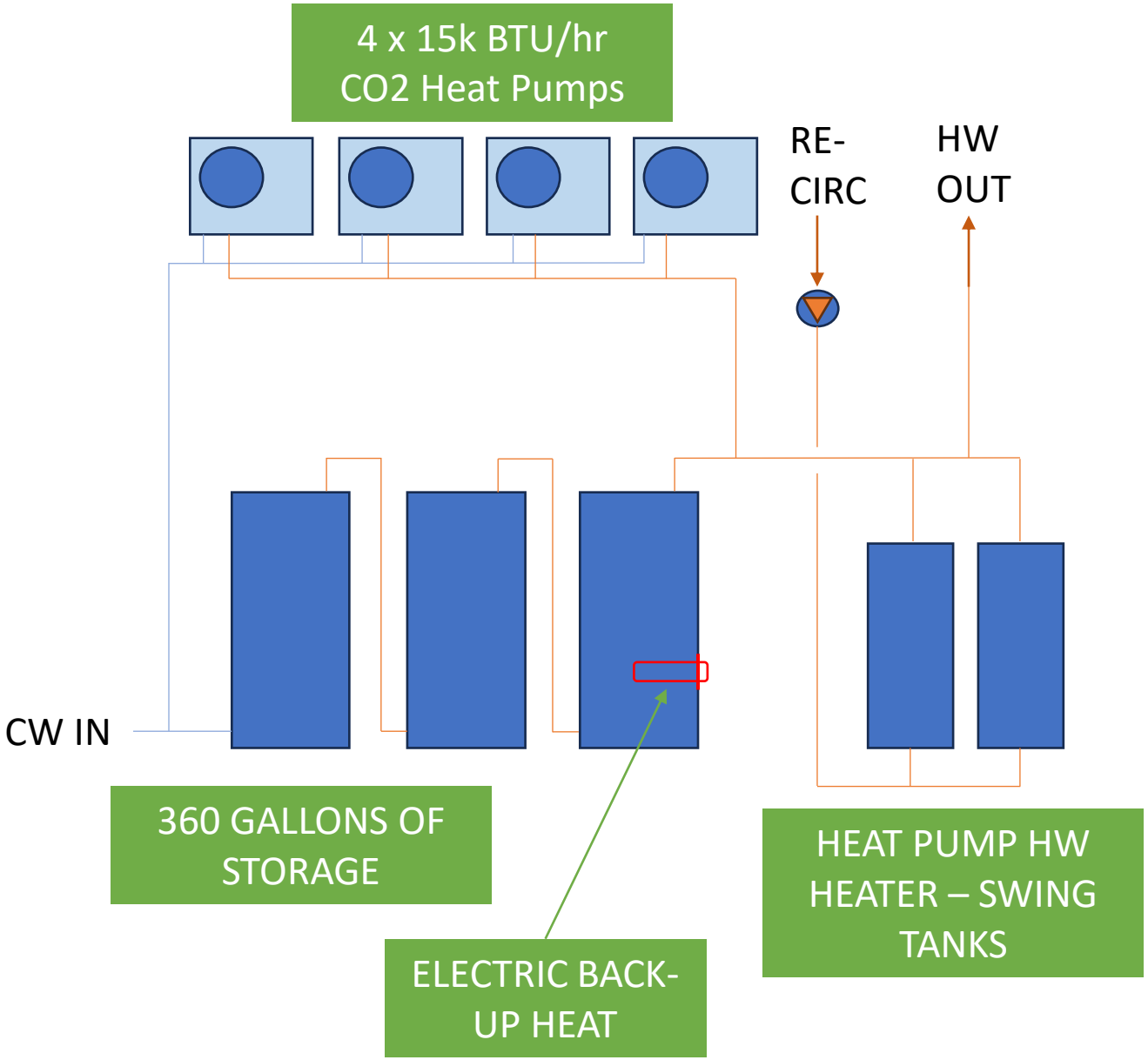
- HW consumption of building population measured prior to retrofit
- Pre-retrofit condition:
  - 99 Apartments
  - Low flow fixtures




Measured HW Consumption: Courtesy of Klein and Skinner

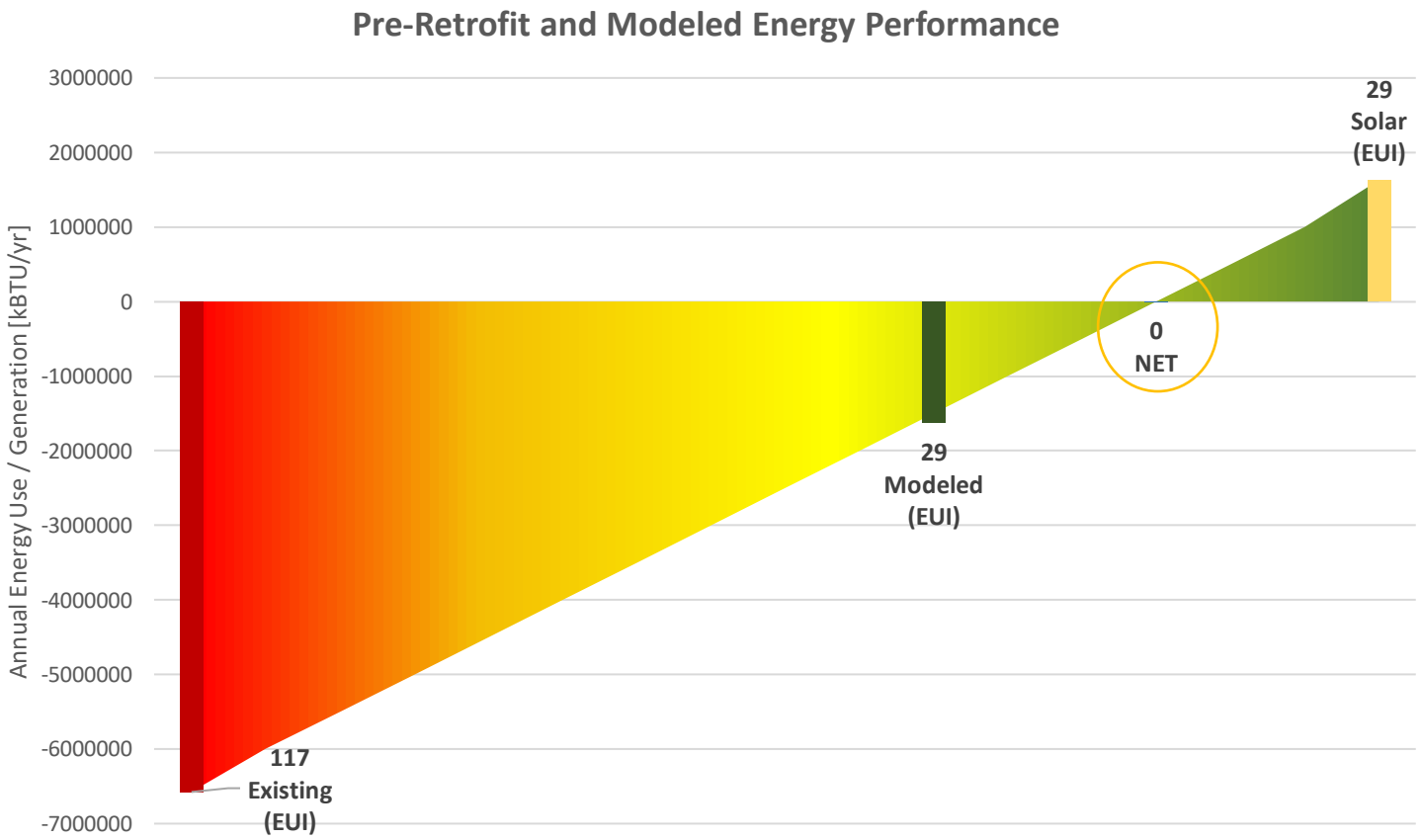
# Colonial II



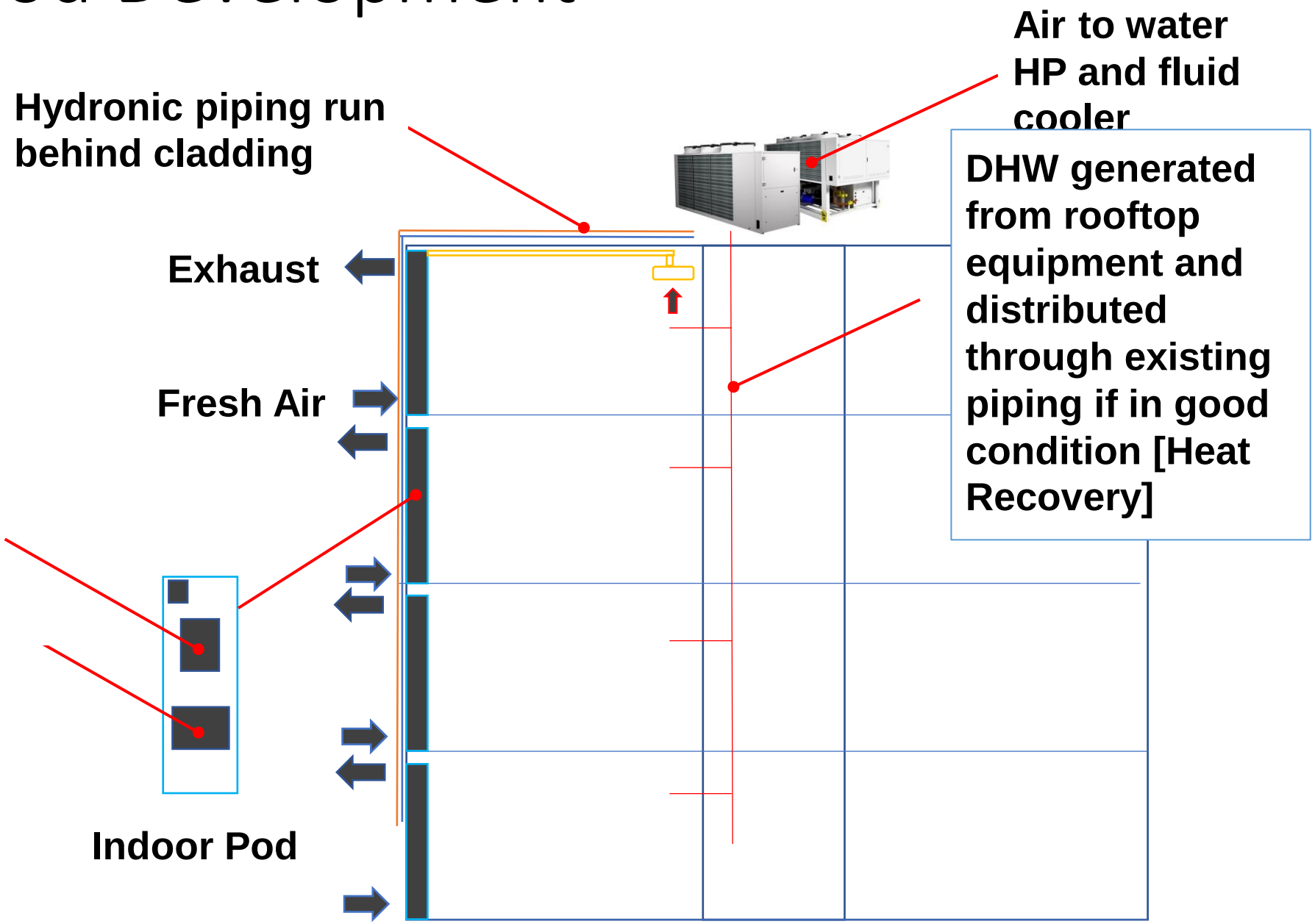


HEAT PUMP CAPACITY ~12% OF ORIGINAL GAS CAPACITY!

# Colonial II


Pre-Retrofit and Modeled Energy Performance
Annual Energy Use / Generation [kBTU/yr]
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
-6000000
-7000000
29
Solar
(EUI)
0
NET
29
Modeled
(EUI)
117
Existing
(EUI)

# Mechanical Pod Development



# Thank You

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Photo Credit: Ezra Staengl