





Galen Staengl, PE, LEED BD+C CHPC

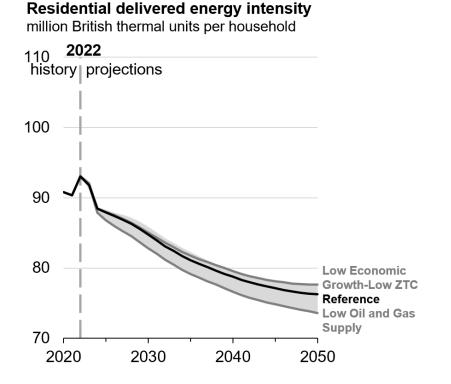
Agenda

- 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.



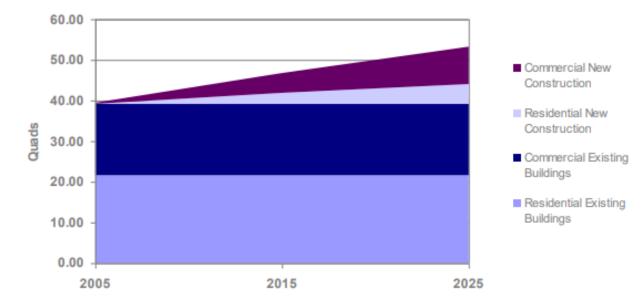
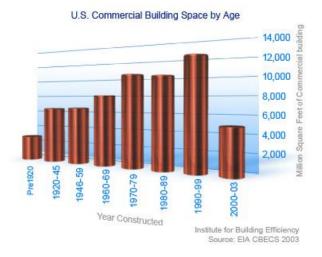


Figure ES3. Base Case Energy Use



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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Residential Segments - Mixed-Humid

RECS Building Type (with height)	Wall Structure	Vintagebin				© Mapbox © OSM	
Single-Family	Wood Frame	-	2,233	<	2,108		
Detached		1940-79		10.112K	1.864		
		>1980		10,562K	2,572		
	Masonry or	<1940	366K		1,992		
	Steel Frame	1940-79	920K		1,757		i i
		>1980	174K		2,507		F
Mobile Home	N/A	<1940	8K		2,294		
		1940-79	532K		1,085		
		>1980	2,165	<	1,317		i
Single-Family	Wood Frame	<1940	293K		2,039		ī
Attached		1940-79	640K		1,467		i i
		>1980	1,431K		1,785		i i
	Masonry or	<1940	263K		1,887		í –
	Steel Frame	1940-79	317K		1,447		i
		>1980	8K		1,583		
Multi-Family	Wood Frame	<1940	172K		3,040		
with 2 - 4 Units		1940-79	414K		2,854		i
		>1980	358K		3,356		î 👘
	Masonry or	<1940	137K		3,200		1
	Steel Frame	1940-79	117K		2,781		i
		>1980	15K		3,121		
Multi-Family	Wood Frame	<1940	21K		21,210		
with 5+Units		1940-79	130K		27,556		
(1-3 stories)		>1980	201K		25,091		i
	Masonry or	<1940	19K		17,355		[
	Steel Frame	1940-79	37K		25,320		
		>1980	15K		25,431		
Multi-Family	Wood Frame	<1940	13K		84,741		
with 5+Units		1940-79	11K		137,	651	i
(4+ stories)		>1980	12K		109,11	17	
	Masonry or	<1940	13K		85,651		
	Steel Frame	1940-79	8K		106,44	43	
		>1980	1K		123,3	367	
electrici electrici	ity_vent_fans ity_cooling ity_water_hea fuel_water_he	-		M 20M berof dings	0K 100K 200 Avg. Building I Area (ft2)	Avg.thermal Floor end-use intensity	0 500 10 Aggregatethern siteenergy (TBtu/yr)

Residential Segments - Cold & Very Cold

RECSBuilding



Type (with height)	Wall Structure	Vintagebin			© Mapbox © OSM	
Single-Family	Wood Frame	-	4.908K	1,991		
Detached		1940-79	11,654K	1,875		
		>1980	9,901K	2,692		
	Masonryor	<1940	1,221K	1,967		
	Steel Frame	1940-79	2,325K	1,687		
		>1980	394K	2,569		
Mobile Home	N/A	<1940	8K	3,411		1
		1940-79	665K	1,094		
		>1980	1,282K	1,295		
Single-Family	Wood Frame		177K	1,552		
Attached		1940-79	538K	1,415		
		>1980	1,417K	1,770		
	Masonry or	<1940	194K	1,495		
	Steel Frame	1940-79	134K	1,343		
		>1980	33K	1,802		
Multi-Family	Wood Frame		471K	2,845		
with 2 - 4 Units	roodriano	1940-79	508K	2,682		
		>1980	325K	3,477		
	Masonry or	<1940	232K	2,934		
	Steel Frame	1940-79	126K	2,478		
		>1940-75	126K	3,542		
Multi-Family	Wood Frame		28K	11,307		
with 5+Units	woourraine	1940-79	162K	19,928		
(1-3 stories)		>1940-75	191K	26,766		
	Masonry or	<1940	24K	12,145		
	Steel Frame	1940-79	29K	19,581		
		>1940-75	8K	32,004		
Multi-Family	Wood Frame		14K	74,052		
with 5+Units	WOOD FI ame	1940-79	13K	102,014		
(4+stories)			12K			
	Masonryor	>1980 <1940	12K	107,187		<u> </u>
	Steel Frame	<1940 1940-79	4K	90,436		
	oreentranie					
		>1980	1K	117,725		
	ity_vent_fans		0M 10M 20M	OK 100K 200K	20 40 60 80	0 500 1000
_	ity_cooling	atina			Avg.thermal	Aggregatetherma
electricity_water_heating onsite_fuel_water_heating			Number of buildings	Avg. Building Floor Area (ft2)	end-use intensity (kBtu/ft2)	siteenergy (TBtu/yr)
wood_h		caring	buildings	Area (It2)	(KDLU/ILZ)	(16(0/91)
	ity_heating					
	fuel_heating					

RECS Building Type (with height)	Wall Structure	Minterstein				© Mapbox © OS	M
Single-Family	Wood Frame	Vintage bin	593K		1,742		
Detached	woodmanie	1940-79		1.192K	1,764		
		>1980		4,744K	2,409		
	Masonry or	<1940	36K	4,/441	1,619		
	Steel Frame	1940-79	252K		1,721		
		>1940-79	252K		2,389		
Mobile Home	N/A	<1940	22K		2,389		
viobile Home	N/A	1940-79	2K 368K		1.133		
		>1940-79					
Sie ale Femilu	Weed From e		493K 56K		1,313 921		
Single-Family Attached	Wood Frame						
		1940-79	385K		1,284		
		>1980	440K		1,742		
	Masonry or Steel Frame	<1940	3K		699		
	oteenname	1940-79	15K		1,167		
		>1980	1K		1,439		
Multi-Family with 2 - 4 Units	Wood Frame		29K		2,637		
		1940-79	160K		3,102		
		>1980	127K		3,224		
	Masonry or	<1940	ЗK		2,365		
	Steel Frame	1940-79	32K		2,812		
		>1980	18K		3,332		
Multi-Family with 5+ Units	Wood Frame		5K		12,556		
(1–3 stories)		1940-79	93K		21,586		
		>1980	105K		27,831		
	Masonry or	<1940	1K		8,866		
	Steel Frame	1940-79	5K		21,195		
		>1980	1K		22,561		
Multi-Family	Wood Frame	<1940	4K		52,399		
with 5+ Units (4+ stories)		1940-79	9K		96,237		
(41 3(01103)		>1980	6K		110,829		
	Masonry or	<1940	1K		50,059		
	Steel Frame	1940-79	0K		115,161		
		>1980	0K		87,824		
electricit	y_vent_fans		0M 5	M	0K 100K 200K	0 20 40	0 100 200
	y_cooling					Avg.thermal	Aggregate therma
electricit	y_water_heat	ing	Numb		Avg. Building Floor		
onsite_fu	uel_water_hea	ating	buildi	ngs	Area (ft 2)	(kBtu/ft2)	(TBt u/yr)
wood_he	eating		-				

RECS Building Type (with	Wall						C 1	lapbox @ OSM	-	< -
height) Single Femilu	Structure	Vintage bin	4704			1 000	0	apoox & Oom		
Single-Family Detached	Wood Frame	<1940 1940-79	472K	4.769	,	1,898				
Doradinou		>1940-79	_			1,809				
	M		128K	7,	873K	2,410	_			
	Masonry or Steel Frame	<1940 1940-79		ek.		1,823				
		>1940-79	1,16 697K			1,743				
Mobile Home	N/A	<1980	4K	•						
Mobile Home	N/A		4K			2,155				
		1940-79 >1980				1,115				
Cia al a Farailla	Marad Errore		1,68	SSK		1,331				
Single-Family Attached	Wood Frame	<1940 1940-79	15K			1,334				
		>1940-79	L							
	Masonry or Steel Frame	<1940	639K			1,687 982				
		1940-79	49K			1,252				
		>1940-79	36K			1,420				
	Wood Frame		19K			2,571				
Multi-Family with 2 - 4 Units	wood Frame	1940-79	159K			3,024				
		>1940-79	244K			3,358				
	Masanry or	<1980	9K			2,785				_
	Masonry or Steel Frame	1940-79	51K			3.008				
		>1940-79	14K			3,008				
Multi-Family	Wood Frame		1K			8,955				
with 5+Units	vvood Frame	1940-79	85K			23,222				
(1–3 stories)		>1980	176K			25,222				
	Masonry or	<1940	1K			8,519			-	
	Steel Frame	1940-79	8K			15,135				
		>1980	10K			22,188				
Multi-Family	Wood Frame		1K			59,703				
with 5+Units	woodmane	1940-79	6K			115,28	7			
(4+ stories)		>1980	11K			105,390				
	Masonry or	<1940	1K			85,504				
	Steel Frame	1940-79	1K			82,971				
		>1980	oĸ			90,600				
electricit	y_vent_fans		OM 5	M 10	M		ко 10	20 30 40	0 100	200 300
_	y_cooling		5101 51		/1/1	000 1000 200				
	y_water_heat	ing	N	umber	of	Avg. Building Flo		thermal eintensitv		ate therma energy
	uel_water_hea	-		uilding		Area (ft2)		tu/ft2)		stu/yr)

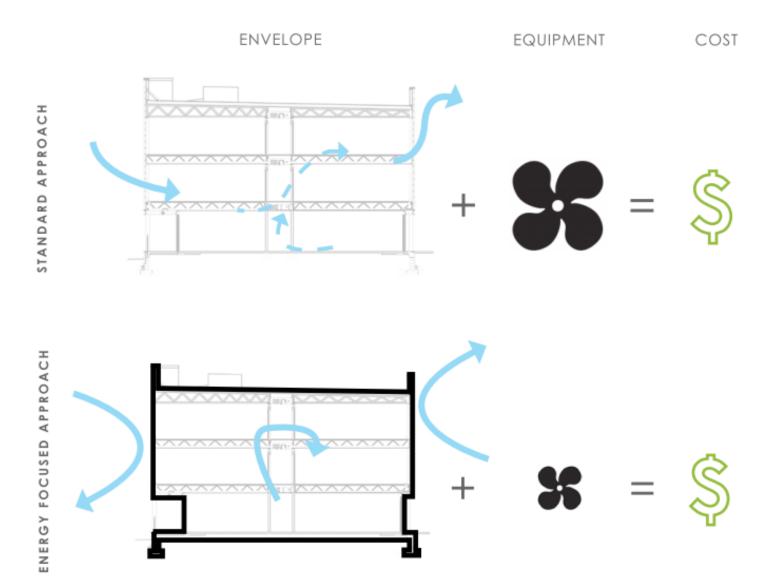
onsite_fuel_heating







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:

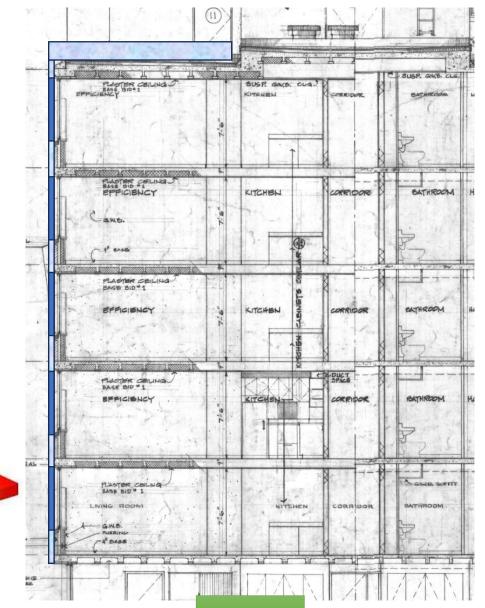
- Dramatic Building Energy Savings (>50%)
- Retrofit-in-place
- Electrification

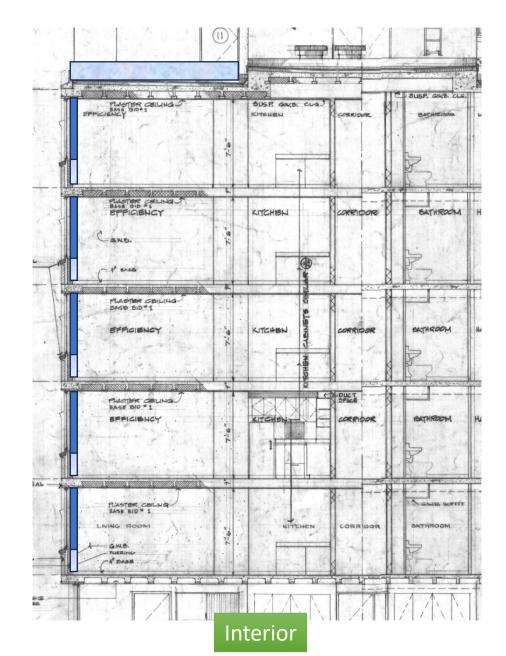
Challenges:

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



Insulate the Envelope





Exterior

Electrification – Space Heat / Cool



Electrification - DHW





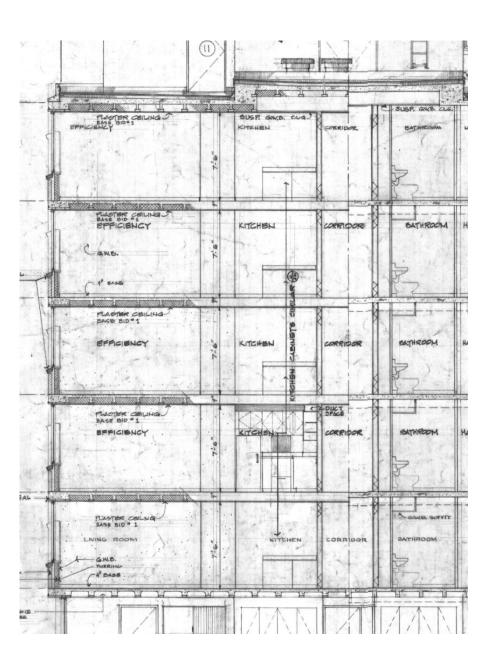


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enerblue

Can we penetrate the exterior envelope?

- Historic Envelope?
- Lot Line Issues?



Can we penetrate the exterior envelope?

- YES Apartment Level Solutions
- Ventilation and Condenser Air From Facade
- Mechanical Pod?
- PTAC?
- WSHP?



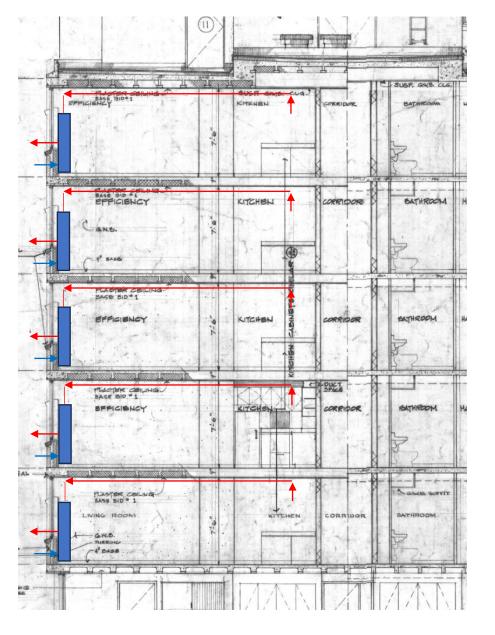
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MINOTAIR

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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?



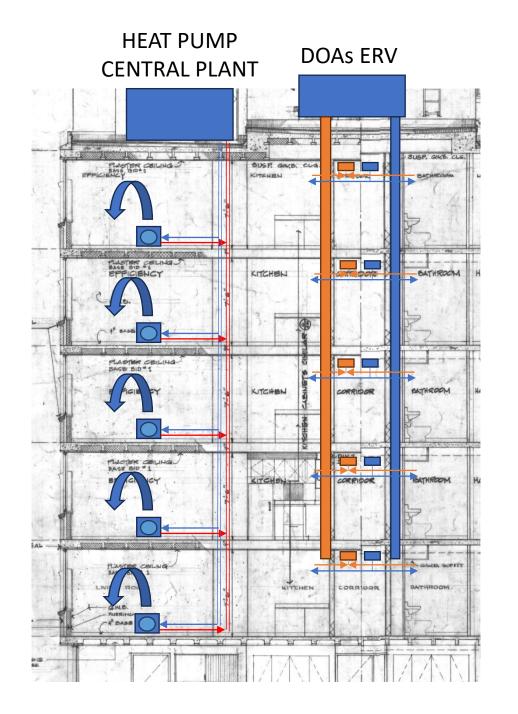
4-pipe or 2-pipe hydronic system

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



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



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



Ground Loop Vertical Wells

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

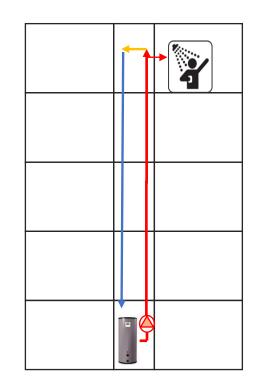


HW Heater Sizing

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

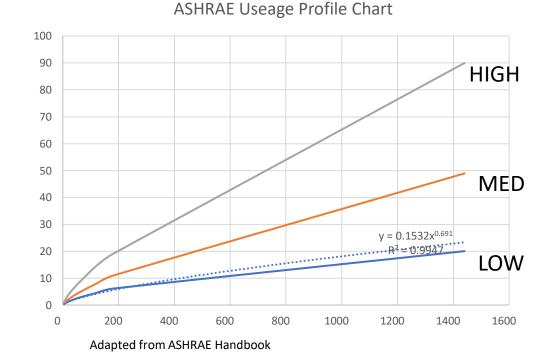
Example:

- 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

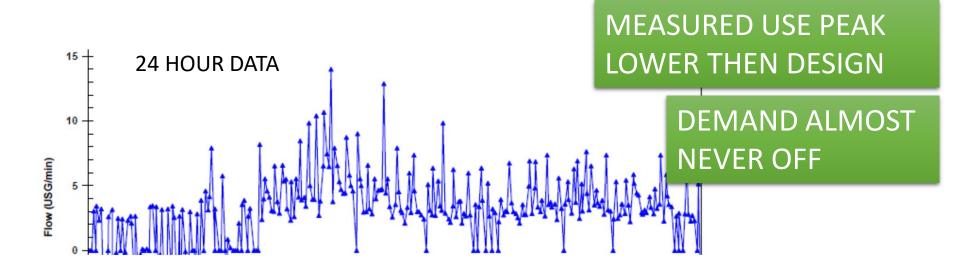


HW Consumption Design Data

- Know your population
- Use measured consumption data if possible



HW Consumption Measured Data



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 Dem	nand Calcula	tor (WDC	v2.1)		
PROJECT NAME : Click for Drop-down Menu → Multi-Family Buildin			ng -			ents in the Building→ in this Calculation→	<u> </u>	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)		COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS
	1	Bathtub (no Shower)	0	0.38	5.5	5.5		
	2	Bidet	0	0.55	2.0	2.0		Total No. of Fixtures in Calculation
Bathroom	3	Combination Bath/Shower	0	1.41	5.5	5.5		n = 385
Fixtures	4	Faucet, Lavatory	95	1.11	1.5	1.5		
	5	Shower, per head (no Bathtub)	95	0.94	2.0	2.0		99 th Percentile Demand Flow
	6	Water Closet, 1.28 GPF Gravity Tank	95	0.55	3.0	3.0		Q = 17.0 GPM
Kitchen Fixtures	7	Dishwasher	0	0.32	1.3	1.3		
Kittileli Fiktures	8	Faucet, Kitchen Sink	95	1.11	2.2	2.2		Hunter Number
Laundry Room Fixtures	9	Clothes Washer	5	1.33	3.5	3.5		H(n,p) = 3.59
Launary Room Pixtures	10	Faucet, Laundry	0	1.11	2.0	2.0		
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.11	1.5	1.5		Stagnation Probability
	12	Fixture 1	0	0.00	0.0	6.0		Pr[Zero Demand] = 3%
Other Fixtures	13	Fixture 2	0	0.00	0.0	6.0		
	14	Fixture 3	0	0.00	0.0	6.0		

DOWNLOAD	RESET	↓ Select Ur	nits for Water D	emand ↓	RUN
RESULT	WDC	GPM	LPM	LPS	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?

A Net-Zero Energy Retrofit



BEACON communities

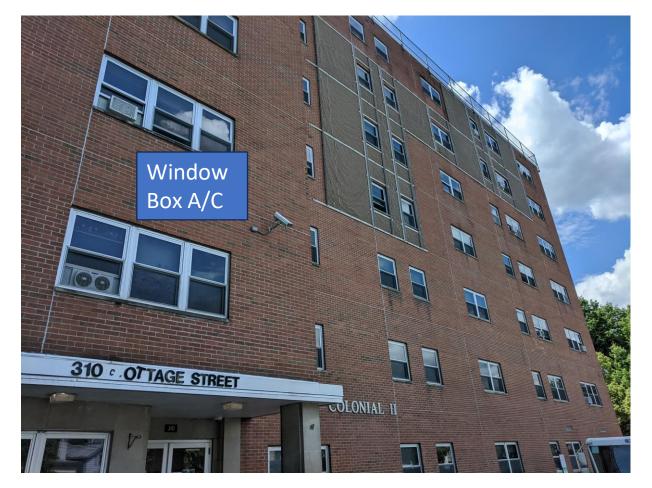




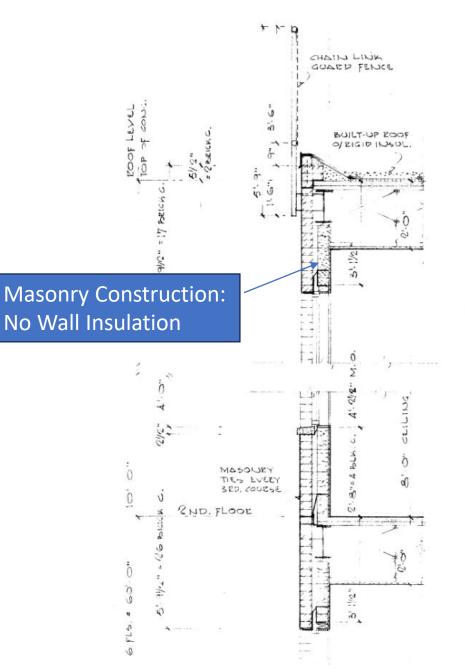






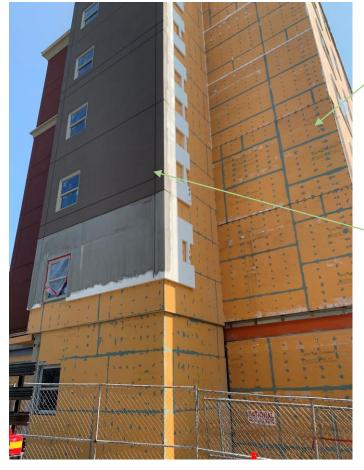


Pre- Retrofit EUI: 117 kBTU/sqft!





New Windows

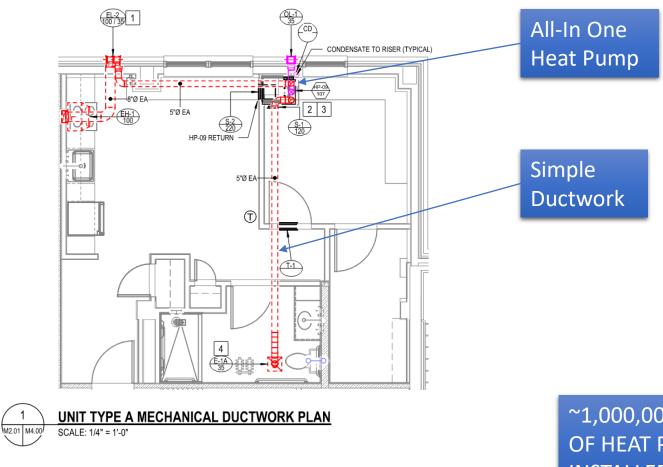


New Air Barrier

New Exterior Insulation



ERV WATER-SOURCE HEAT PUMP

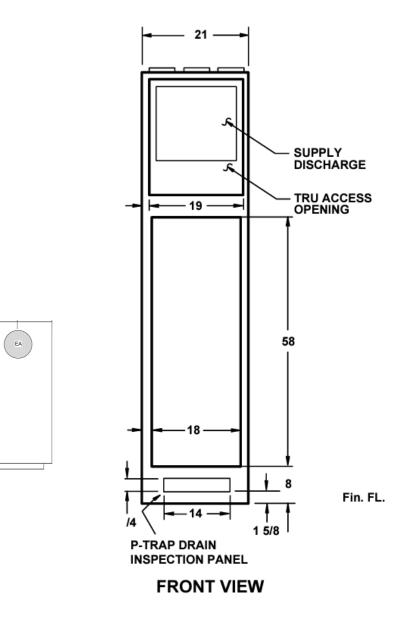


Interior Retrofit 99 to 74 Apartments

1

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

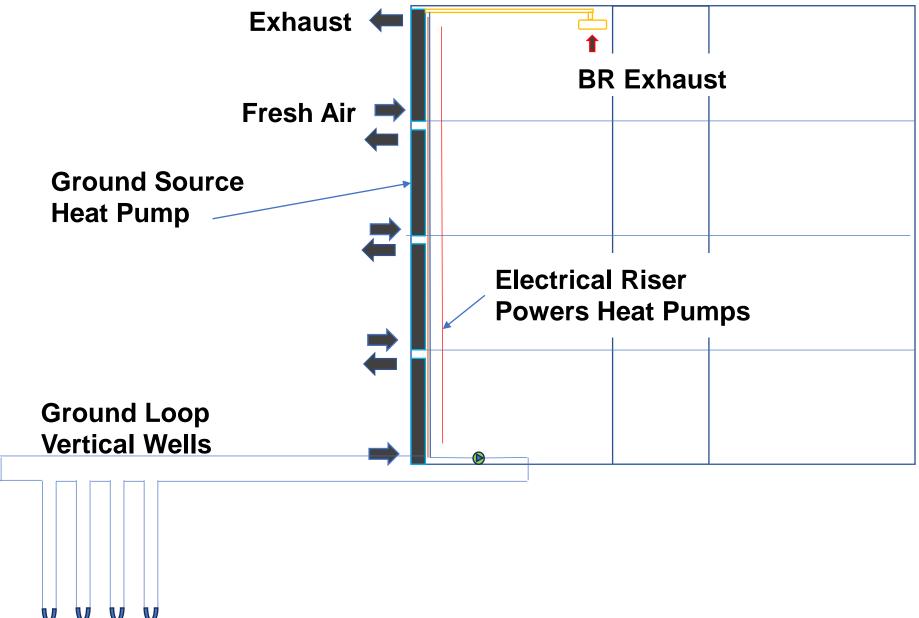




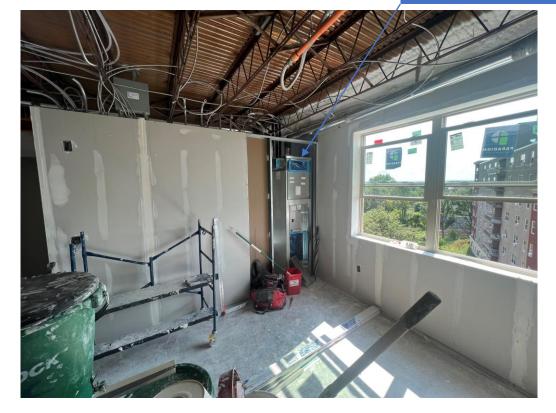
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Top View

RA

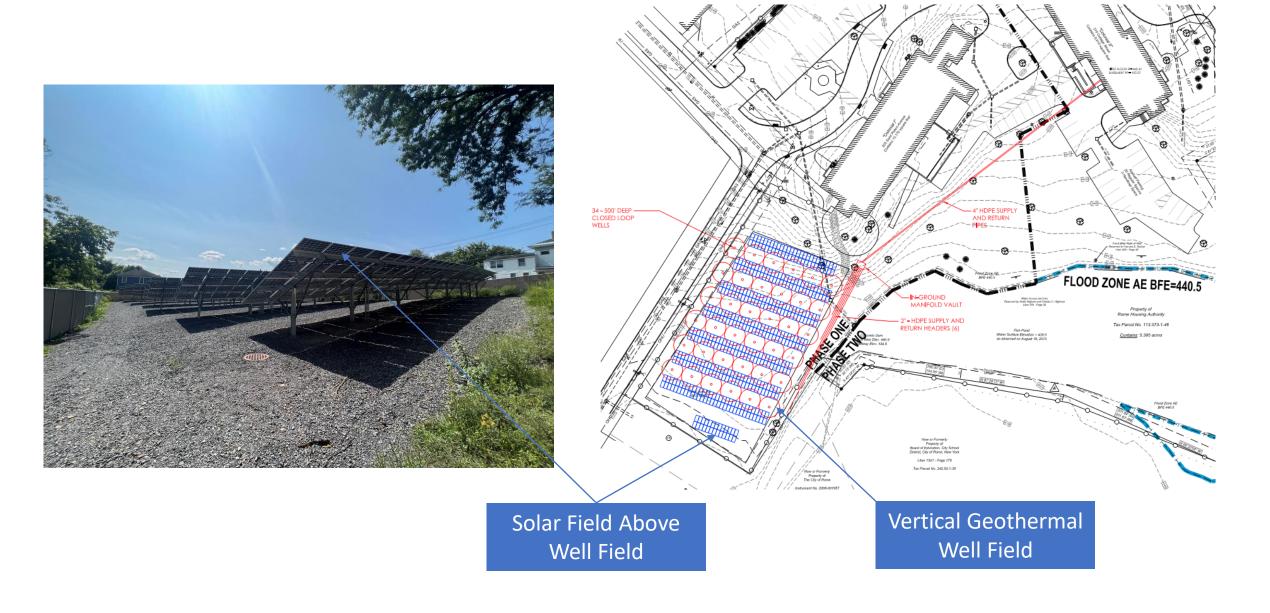


All-in One WS Heat Pump

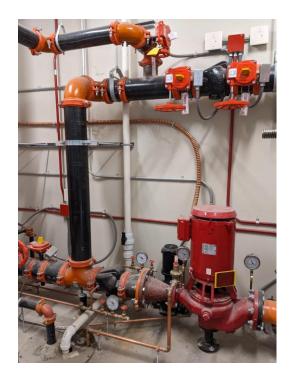




Geothermal Manifold

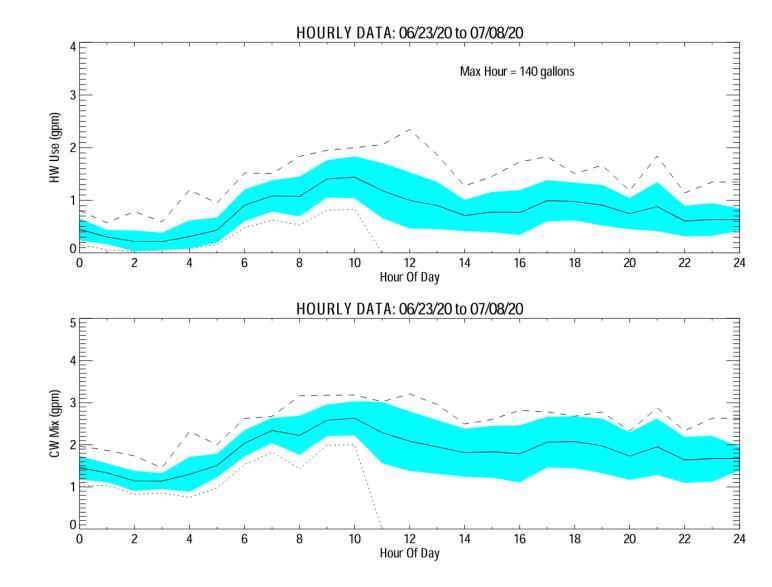


- New electrical service 3000 A / 208 V / 3 Phase
- Old electrical service 1400 A / 208 V / 3 Phase

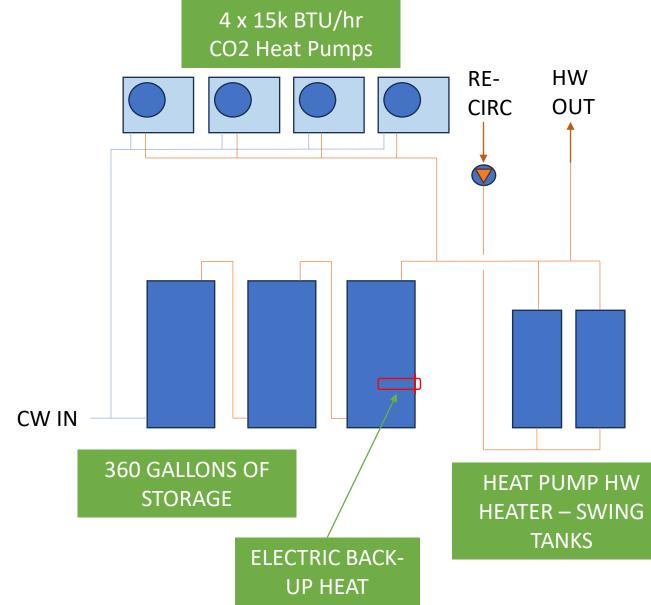


Required New Fire Pump, and Solar Field Required Electrical Service Upgrade

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

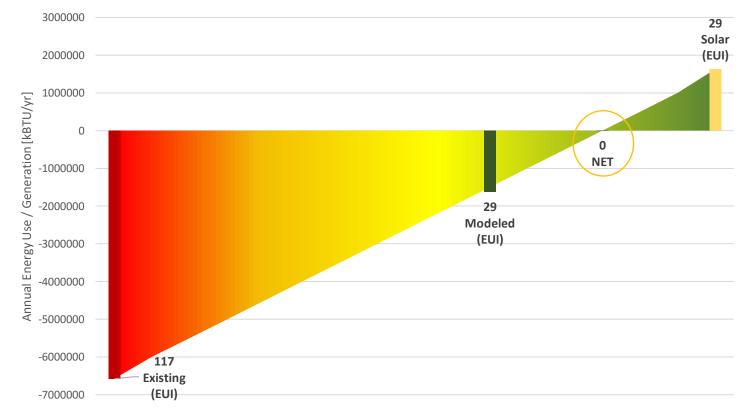


Measured HW Consumption: Courtesy of Klein and Skinner



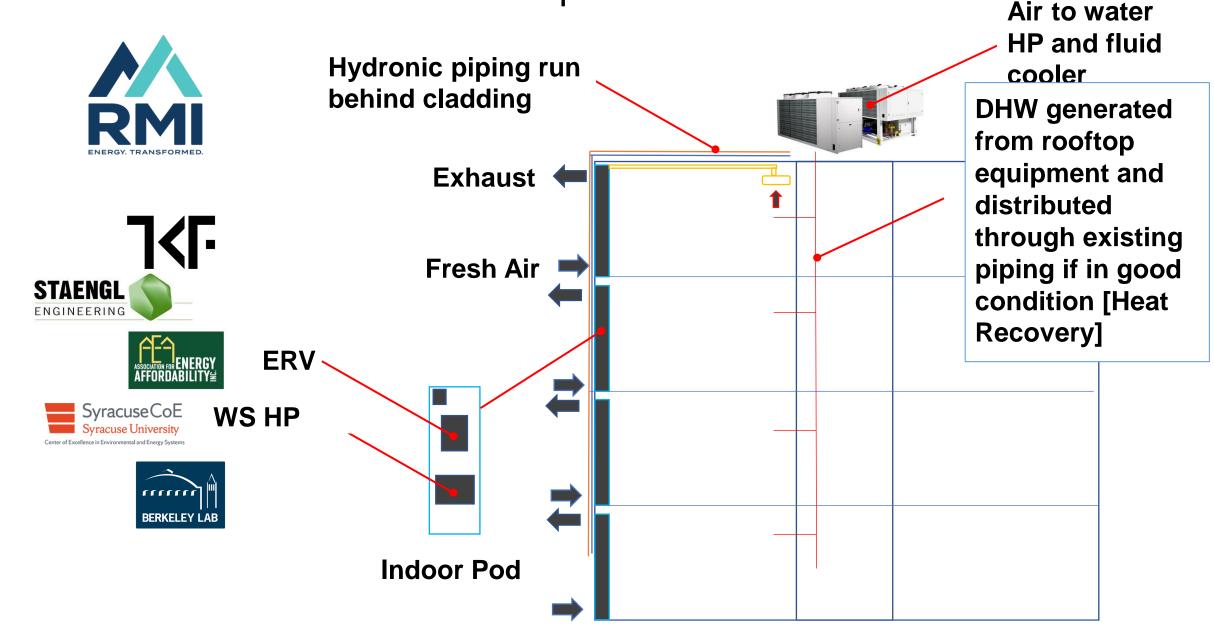


HEAT PUMP CAPACITY ~12% OF ORIGINAL GAS CAPACITY!



Pre-Retrofit and Modeled Energy Performance

Mechanical Pod Development





Thank You

Galen Staengl, PE, LEED BD+C CHPC

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