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Using VRF to Achieve Net Zero

Variable Refrigerant Flow Technology

Mike Machemehl PE, CEM
Mitsubishi Electric Cooling & Heating

Carbon Neutral Societies by 2050

How can we stay below a **2°C** rise in global temperatures?

Reduce carbon emissions to **0** by **2050**

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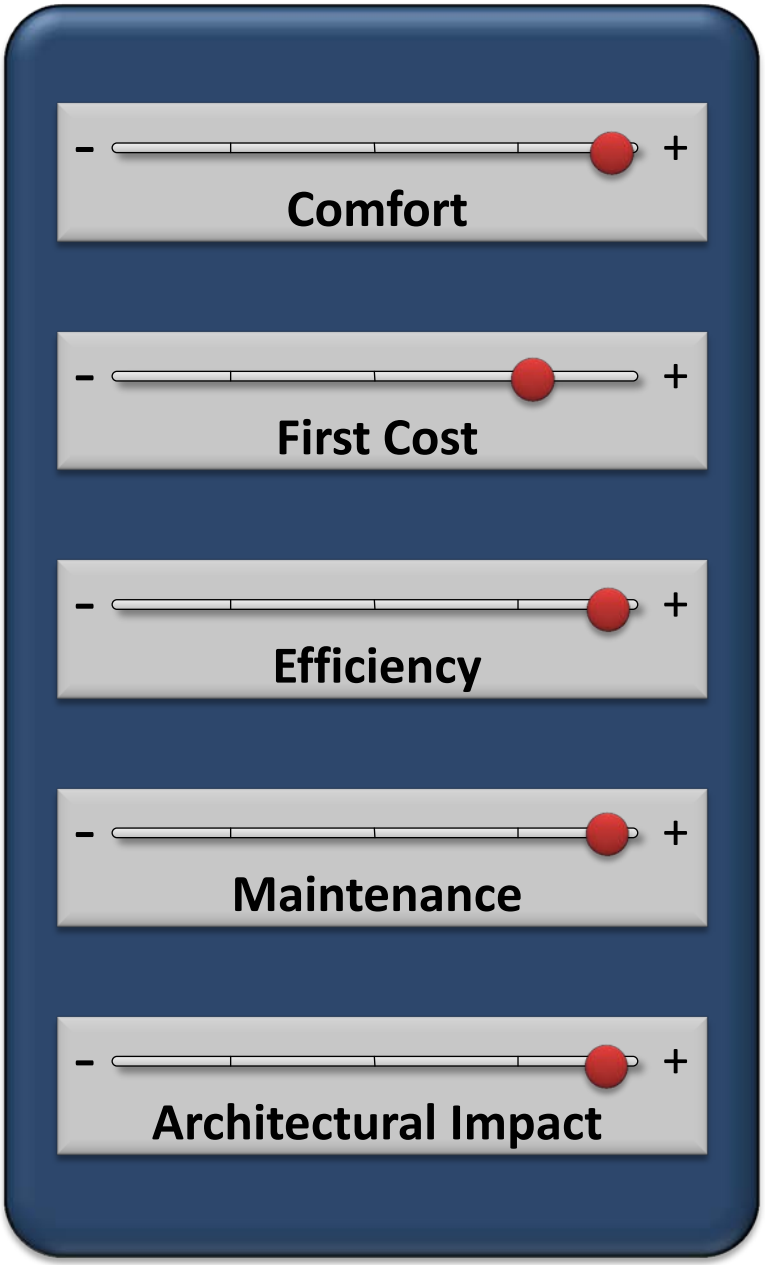
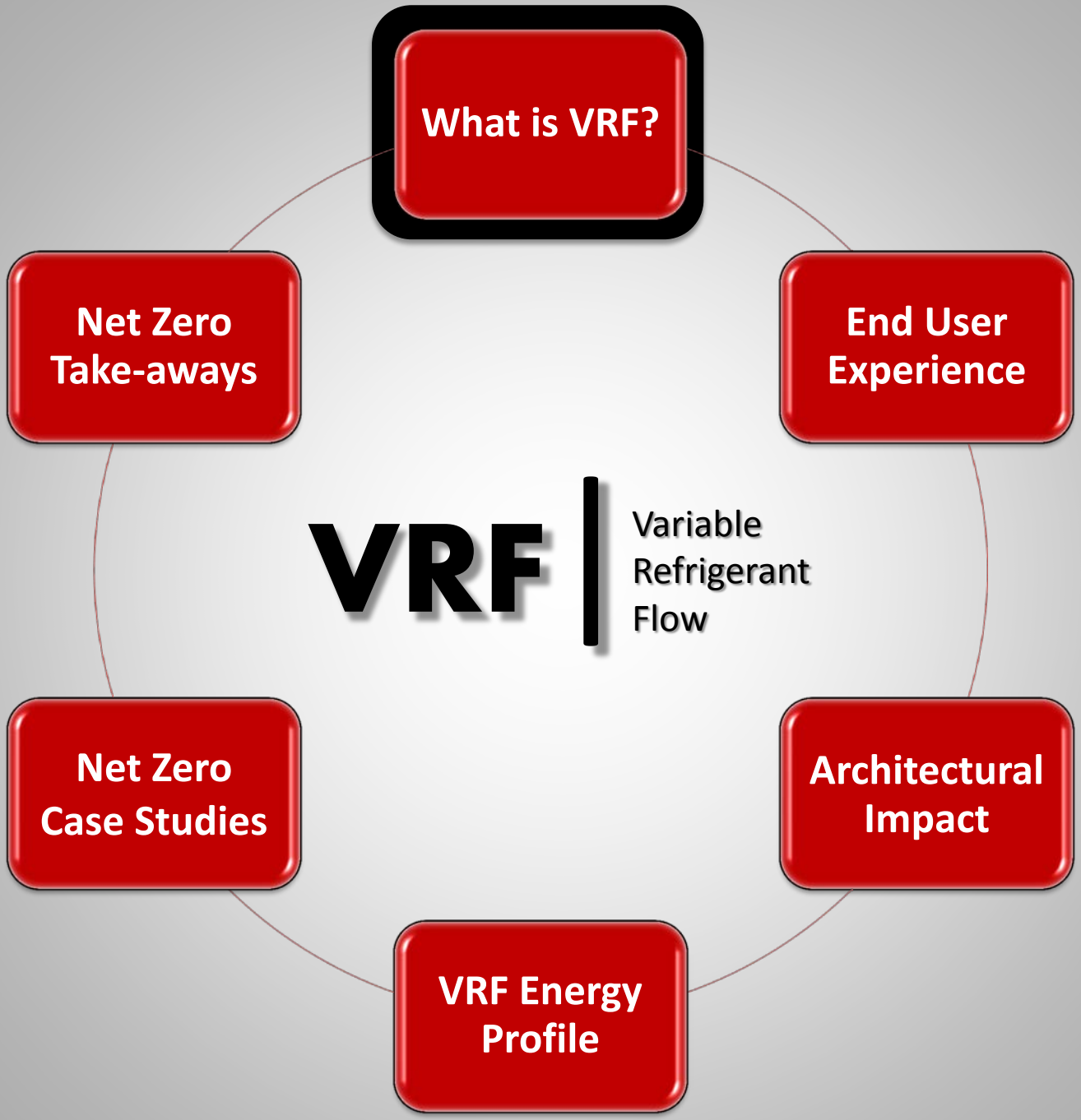
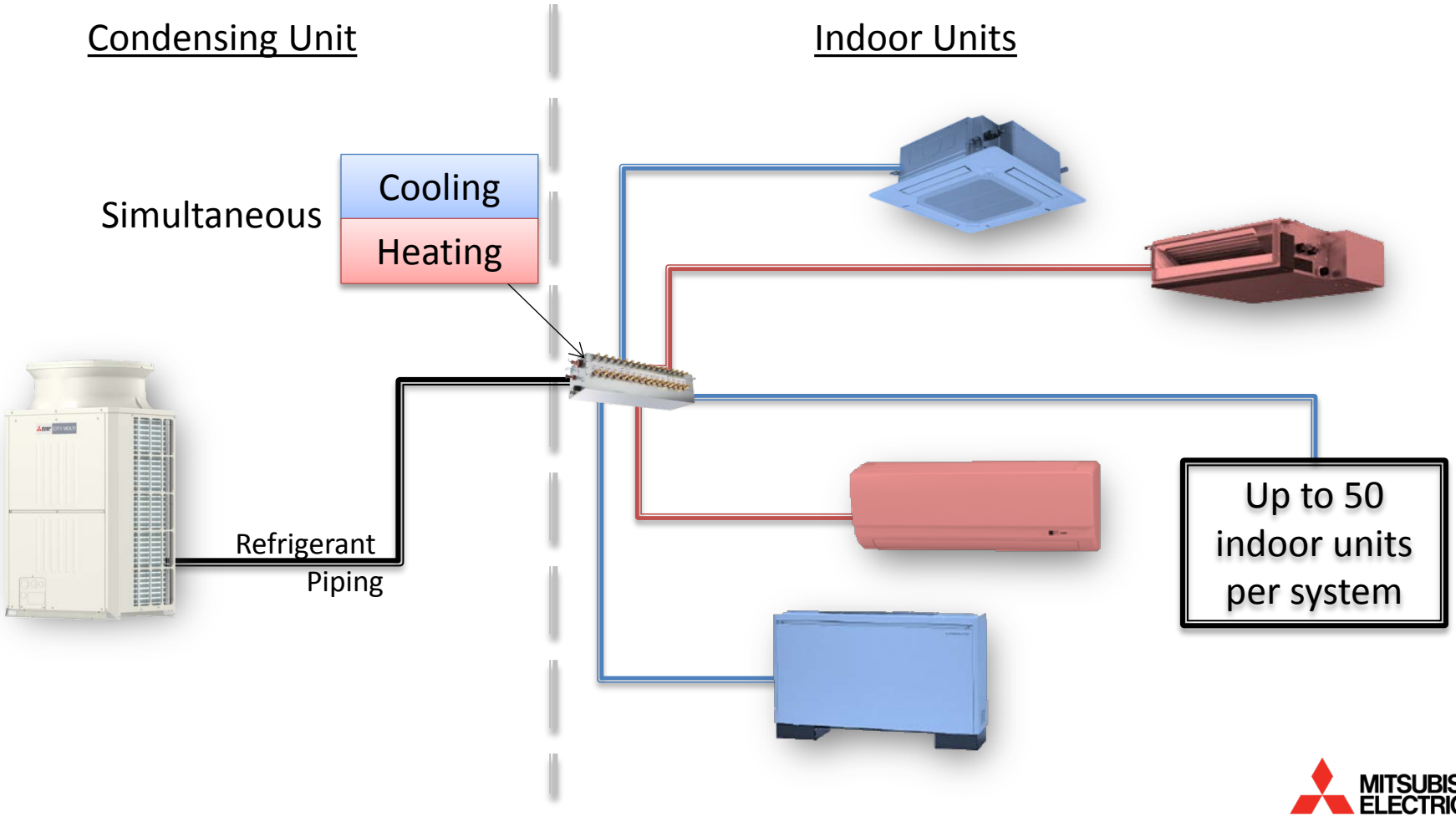


Variable Refrigerant Flow


What is VRF?
End User Experience
Architectural Impact
VRF Energy Profile
Net Zero Case Studies
Net Zero Take-aways
VRF
Variable Refrigerant Flow

Commercial System

Heat Pump with Heat Recovery



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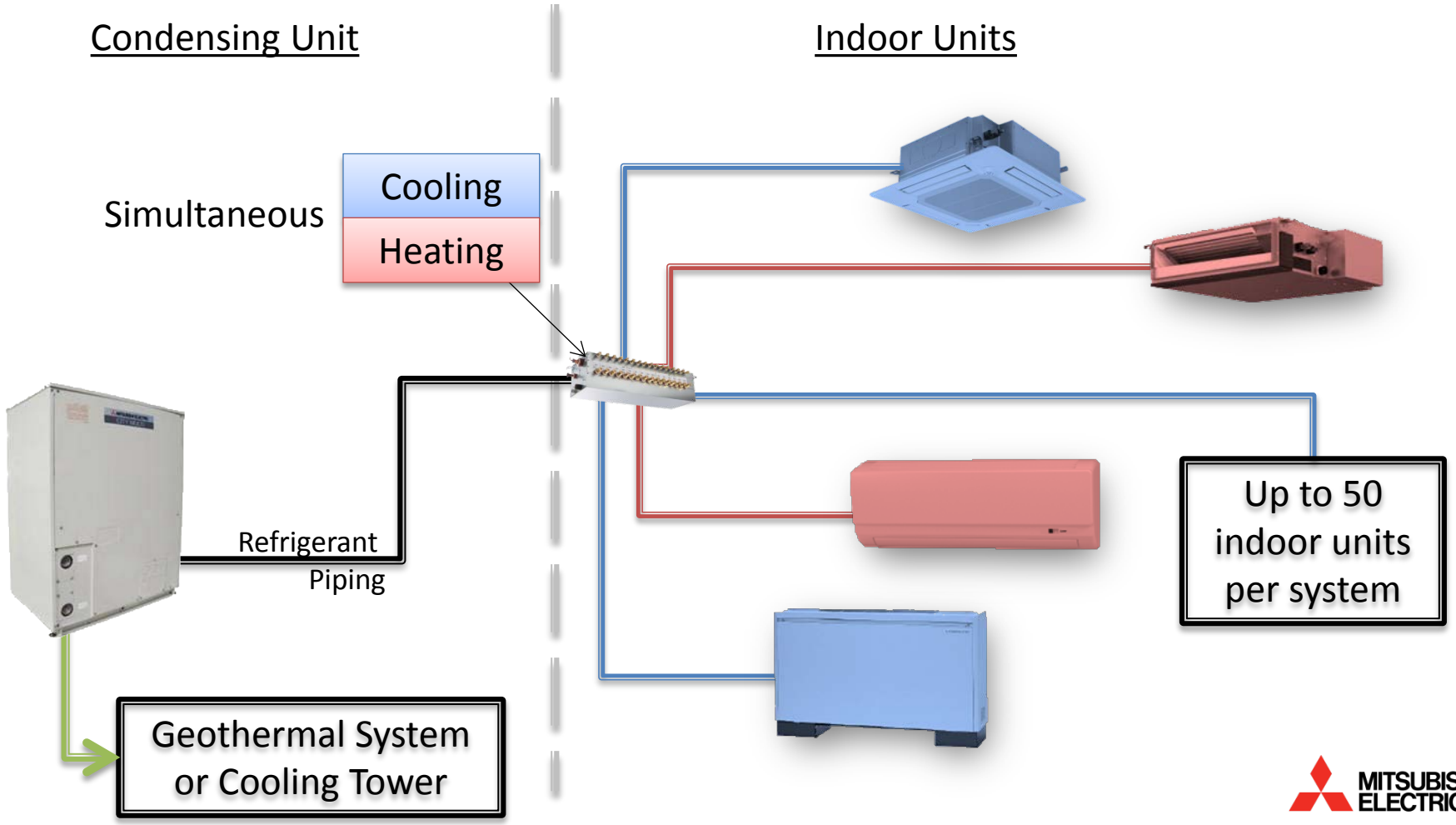
Commercial System

Heat Pump with Heat Recovery



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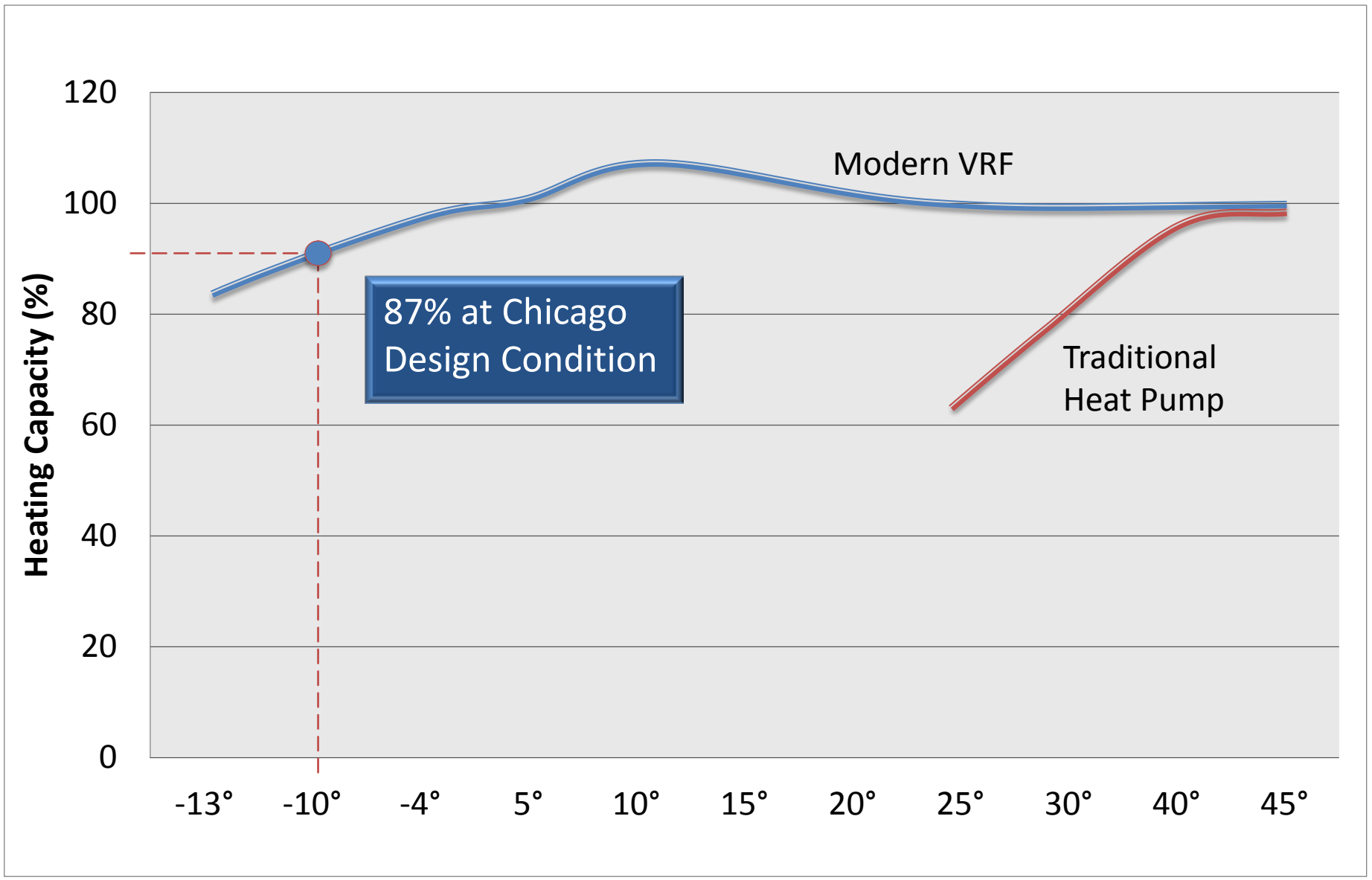
Heat in Cold Climates



Commercial System

Simultaneous Heating and Cooling Applications

- Multi-family
- Senior living centers
- Schools
- Student housing
- Hotels
- Offices
- Medical facilities

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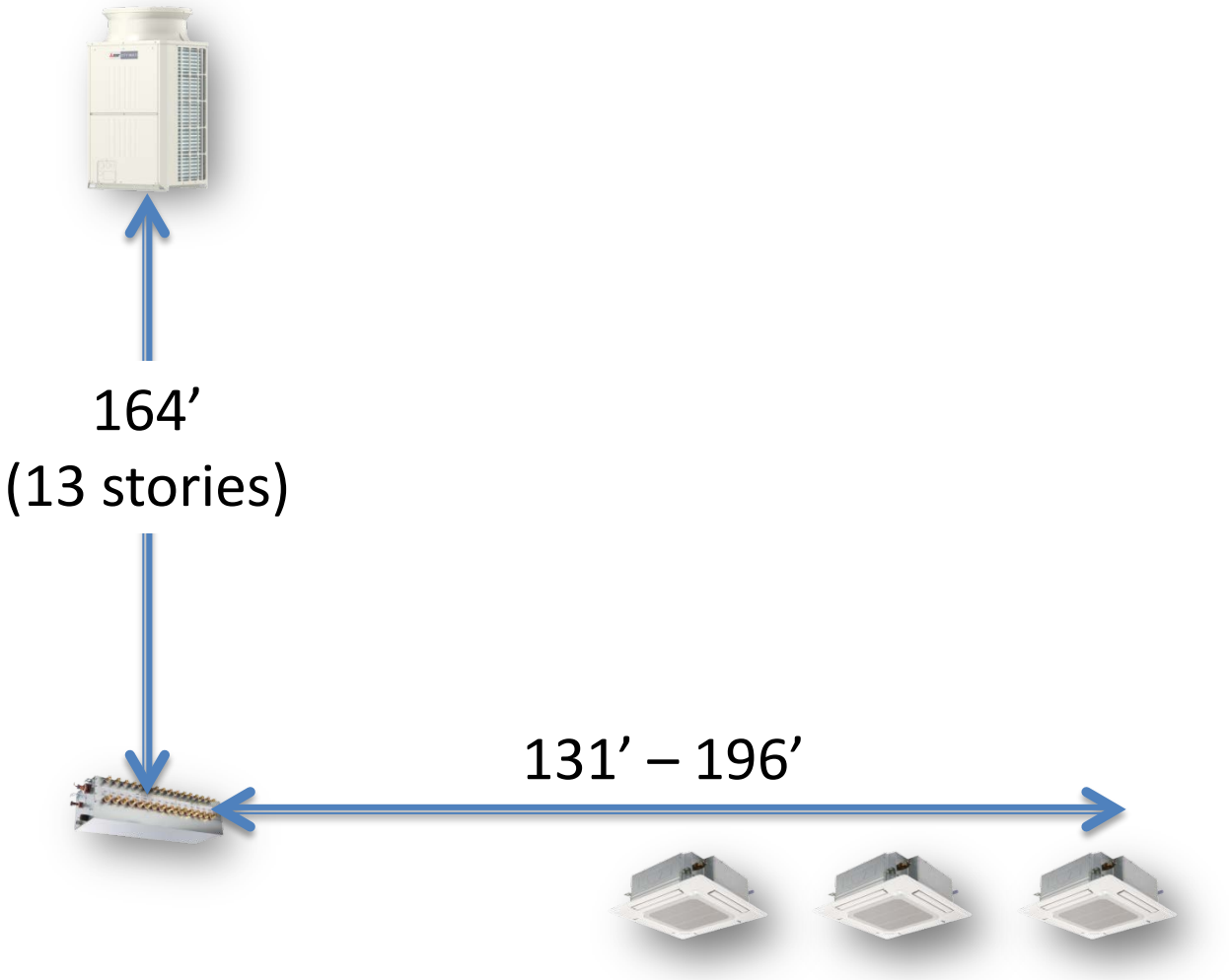
Refrigerant Lines Lengths



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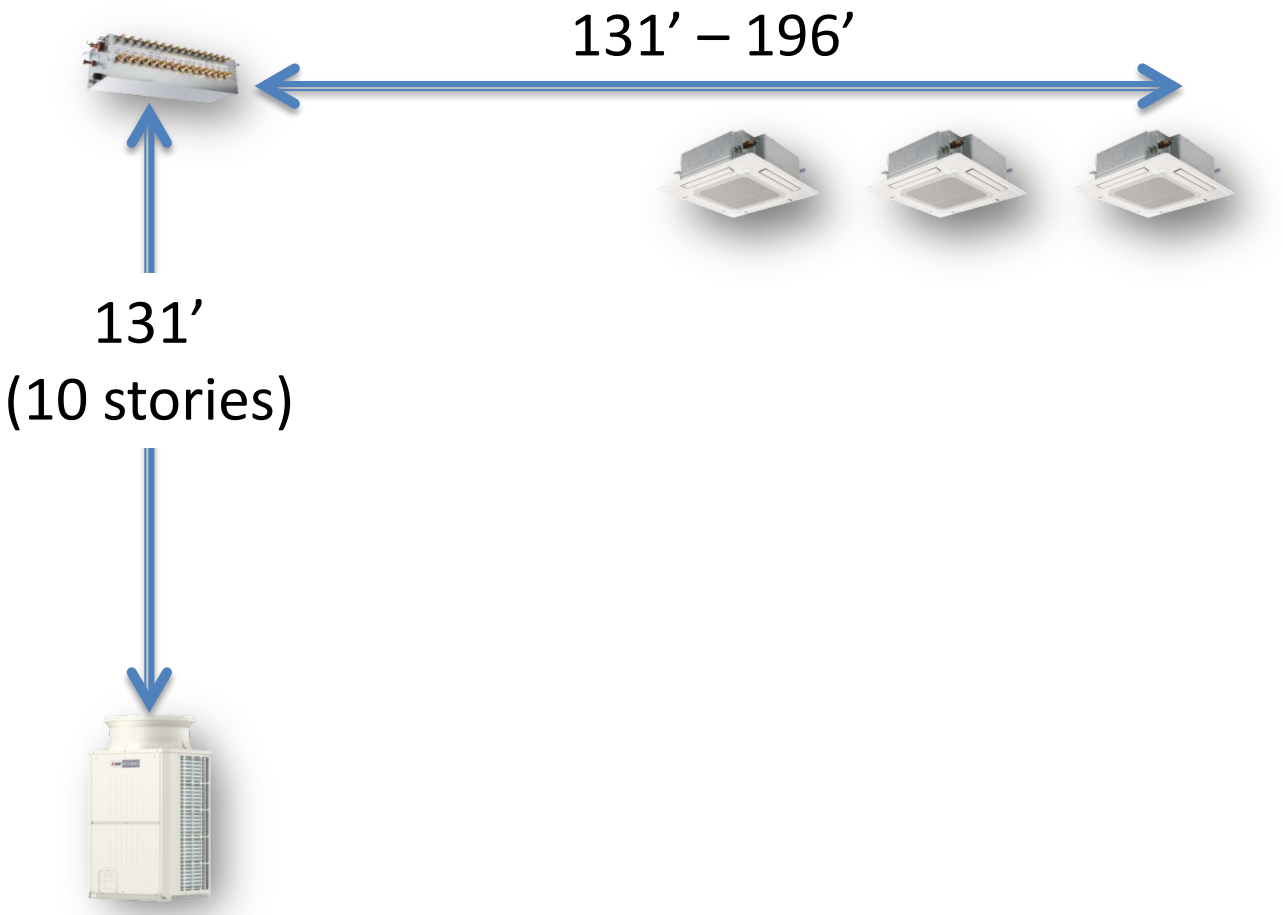
Refrigerant Lines Lengths



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Refrigerant Lines Lengths

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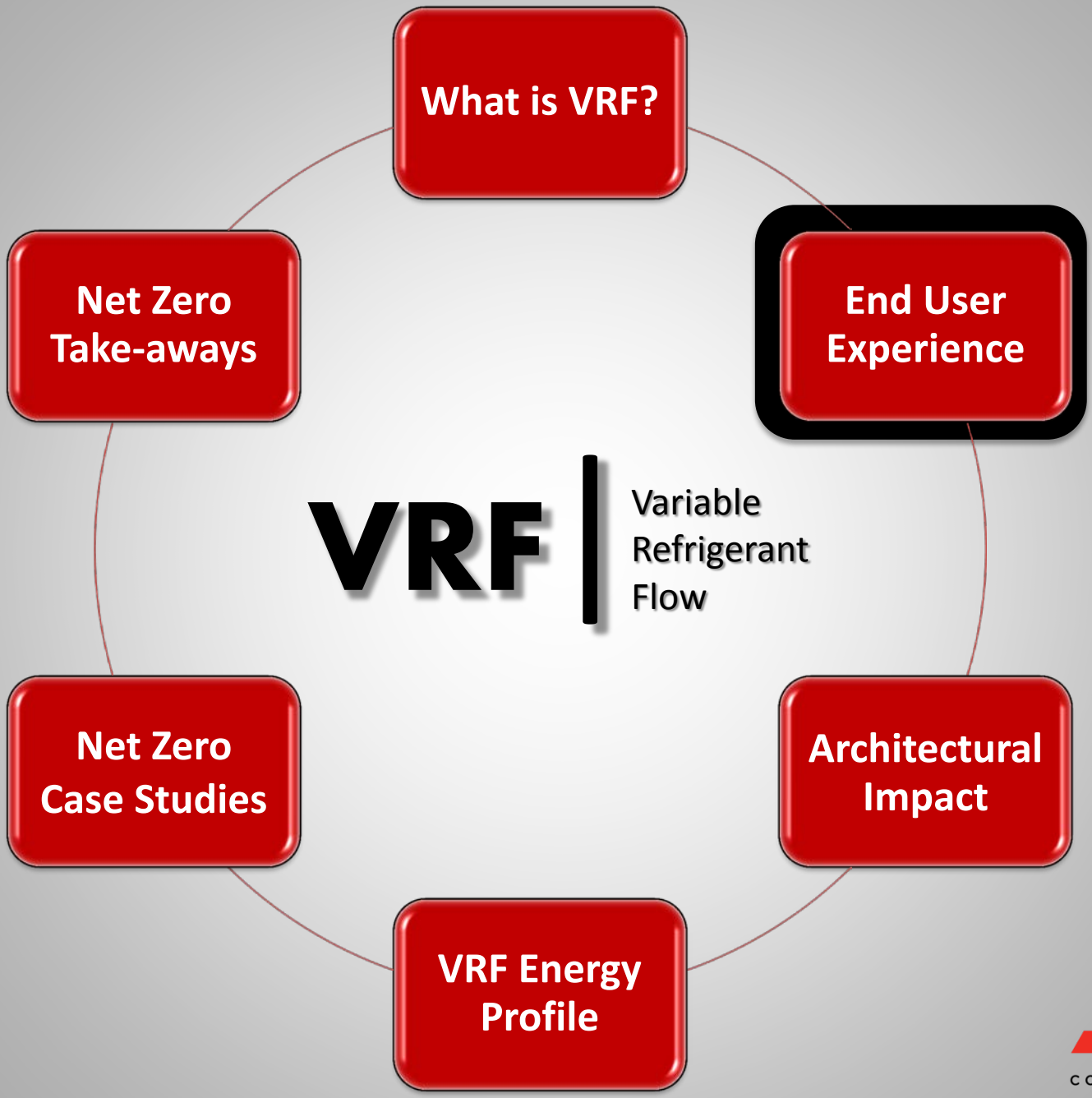

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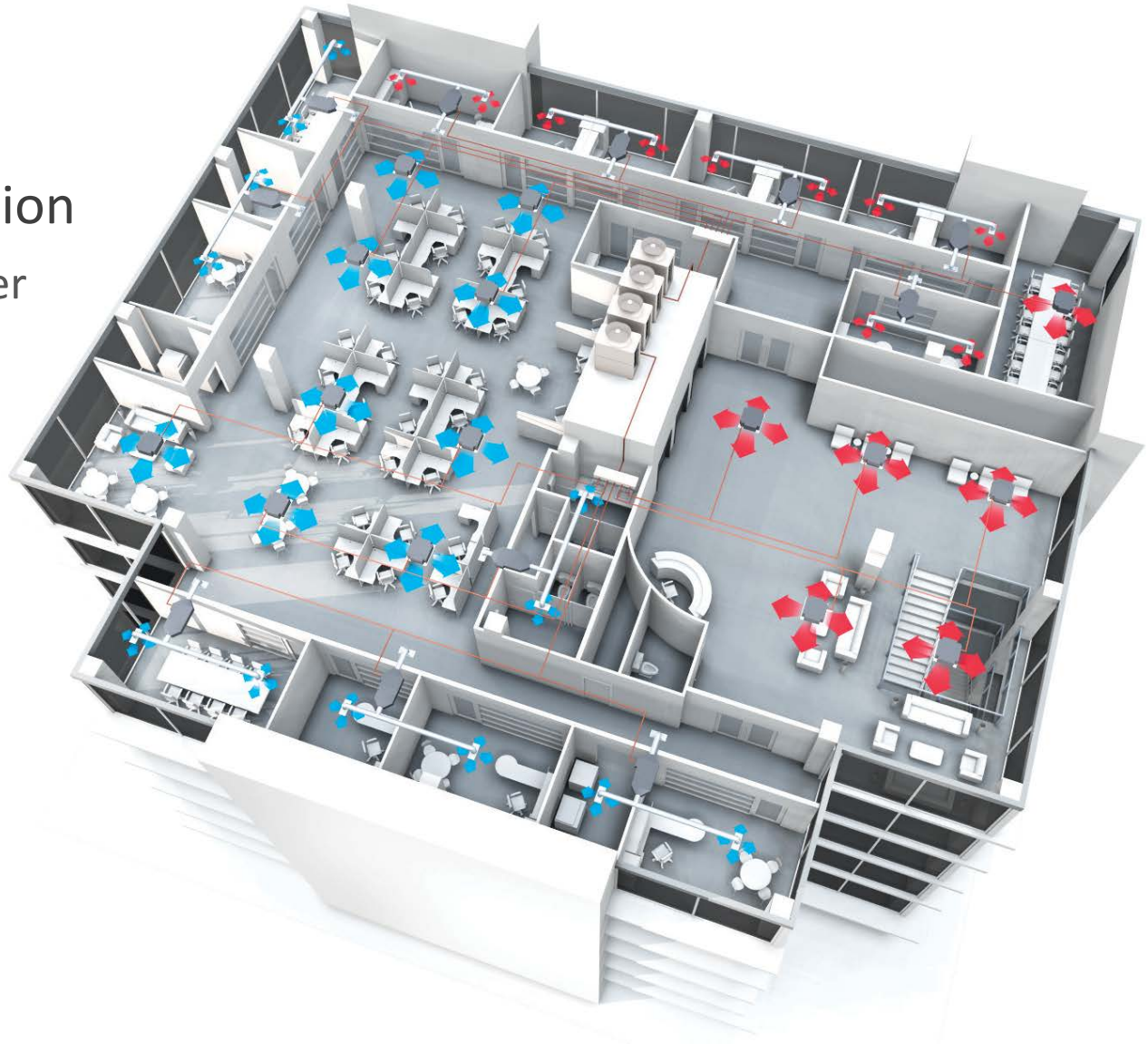
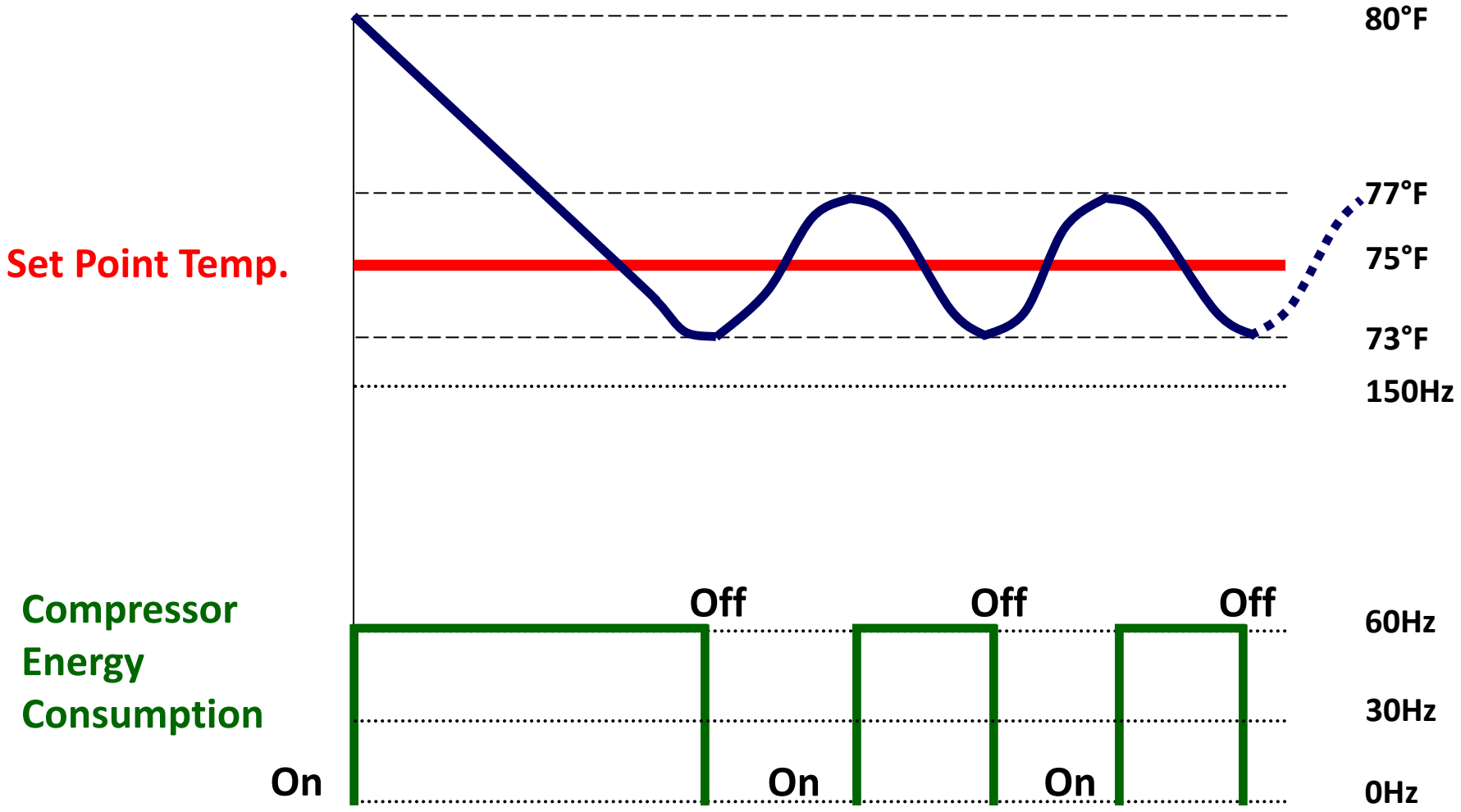
Eliminate hot and cold spots

- Individual control
- No season restriction
  - Heat in the summer
  - Cool in the winter



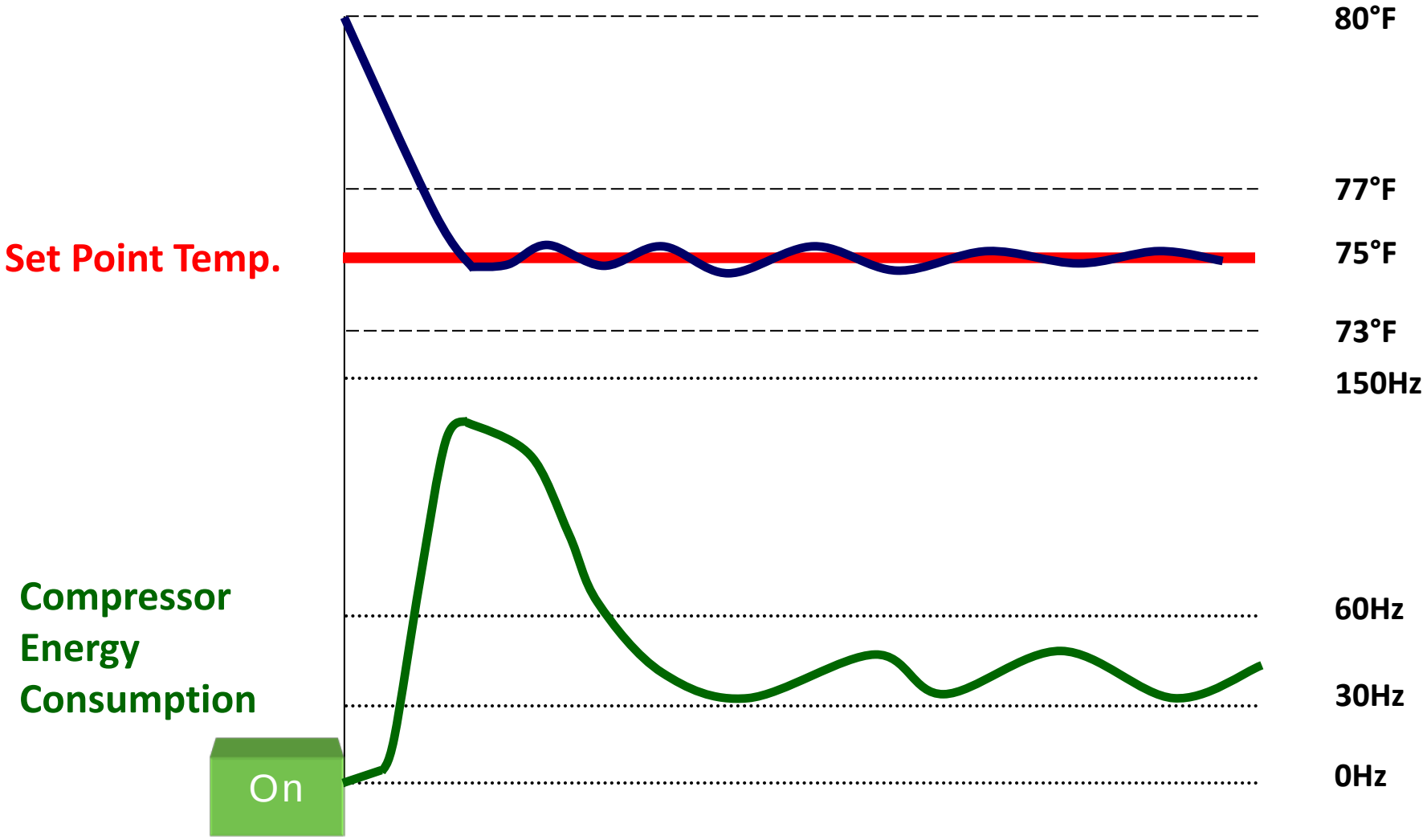
Precise Temperature Control

Traditional Compressor



Precise Temperature Control

Inverter-driven Compressor



Precise Temperature Control

- Maximum comfort
- Eliminate ON – OFF – ON – OFF annoyance
- Extends equipment life – Reduced startup amperage
- Part load dehumidification

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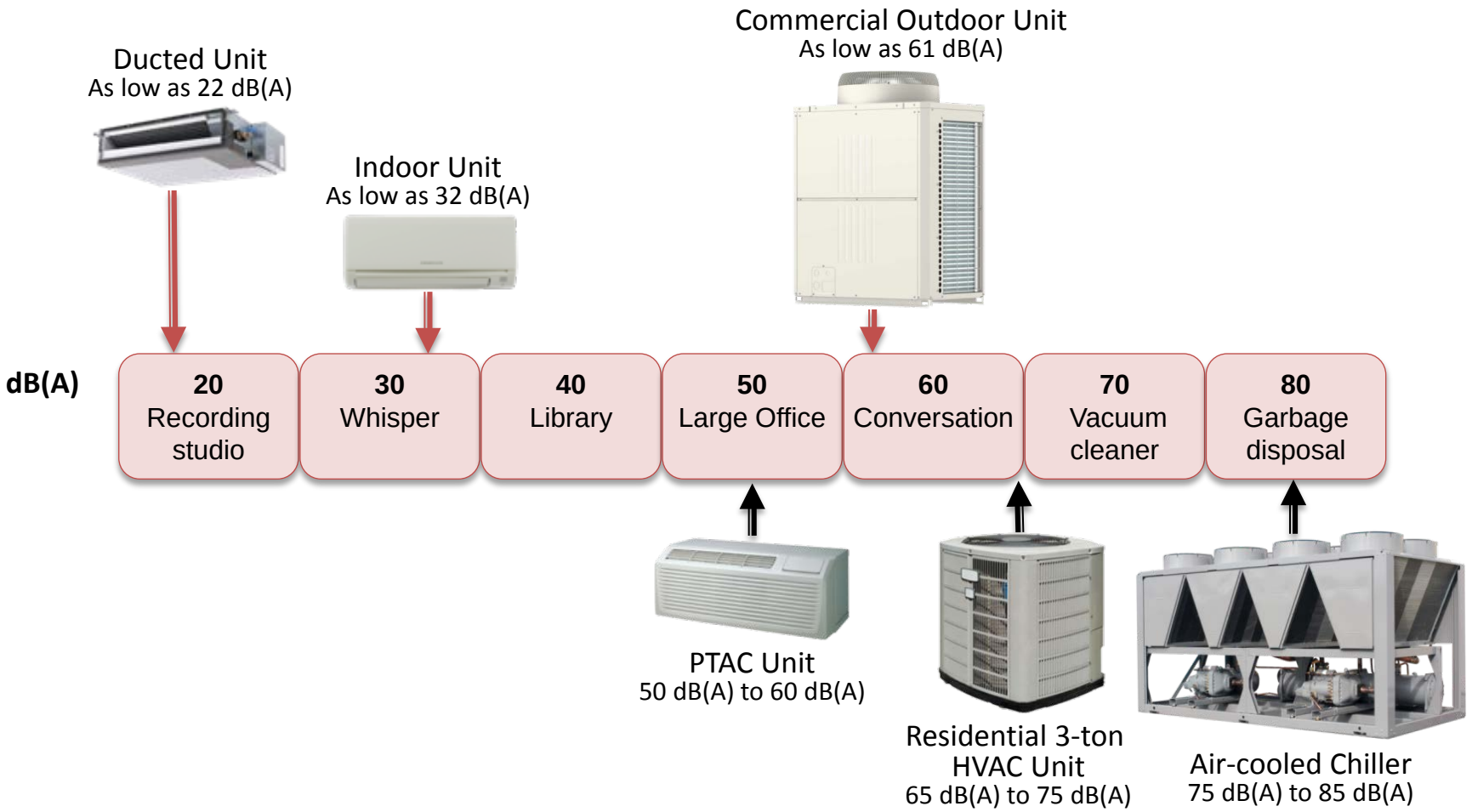
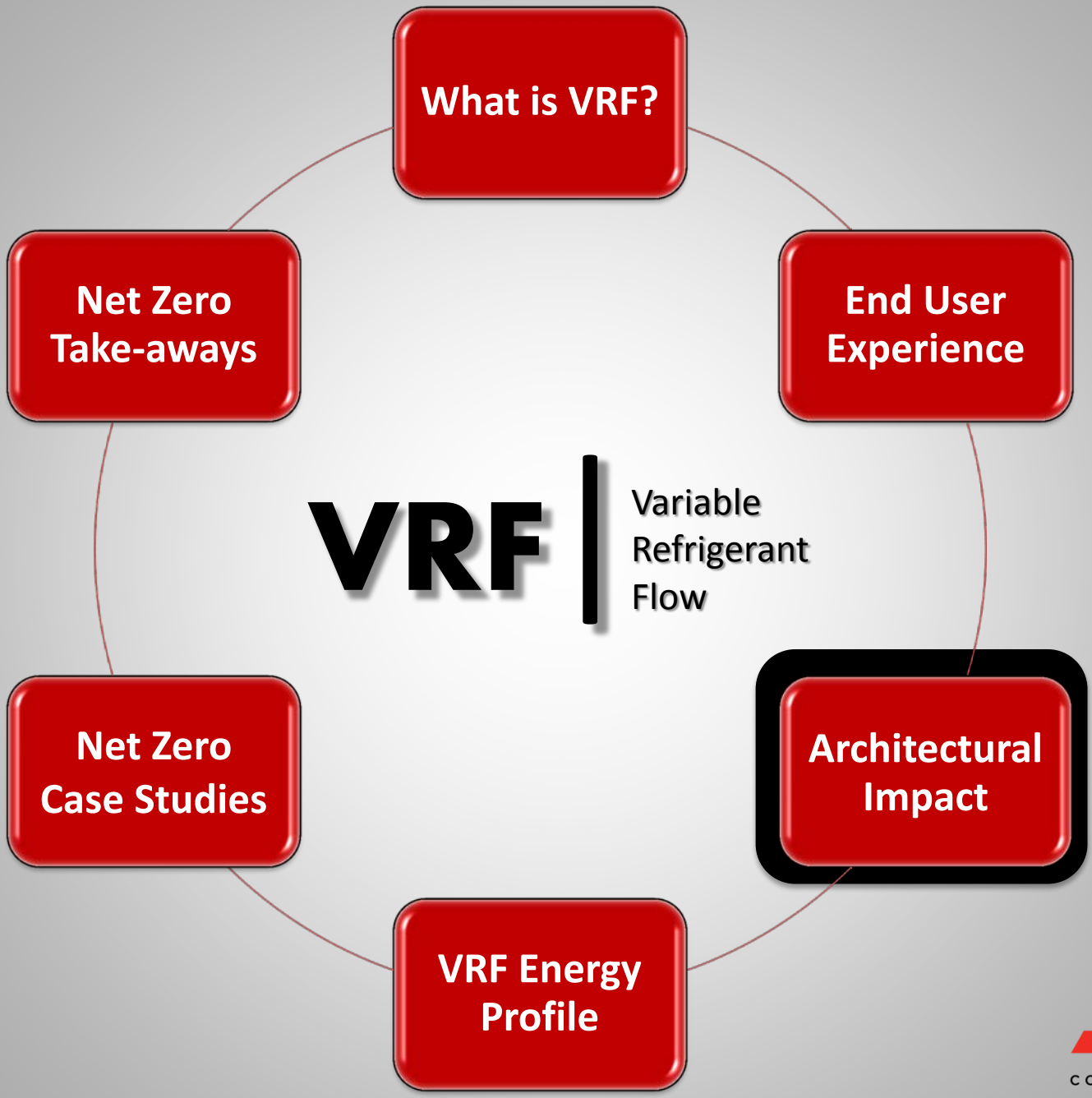
Quiet Operation





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Modular and compact design

Location flexibility – often spread around the property

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Modular and compact design

Location flexibility – often spread around the property

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Modular and compact design

Location flexibility – often spread around the property

Water cooled application

- Cooling tower
- Geothermal

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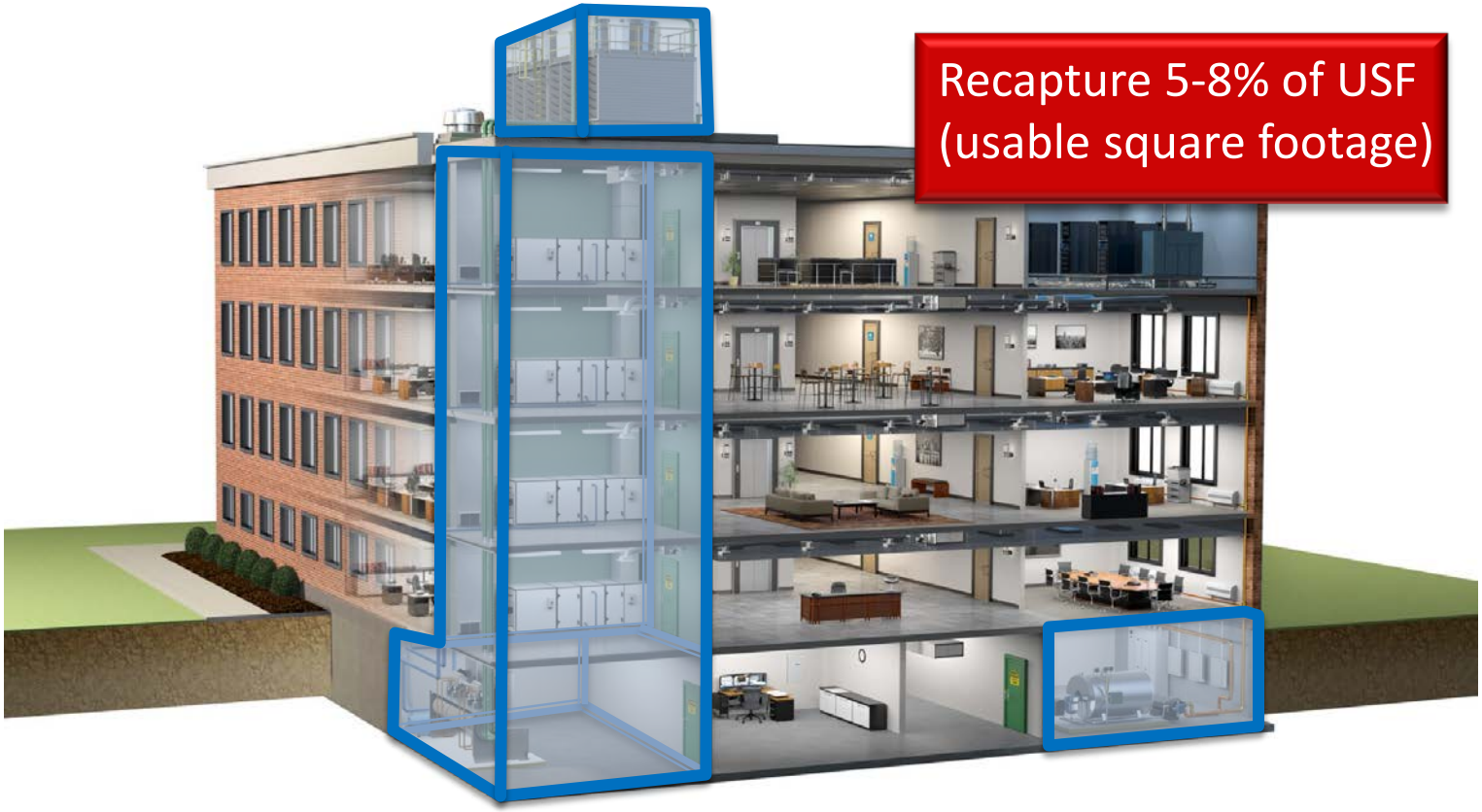
Eliminate Large Mechanical Rooms



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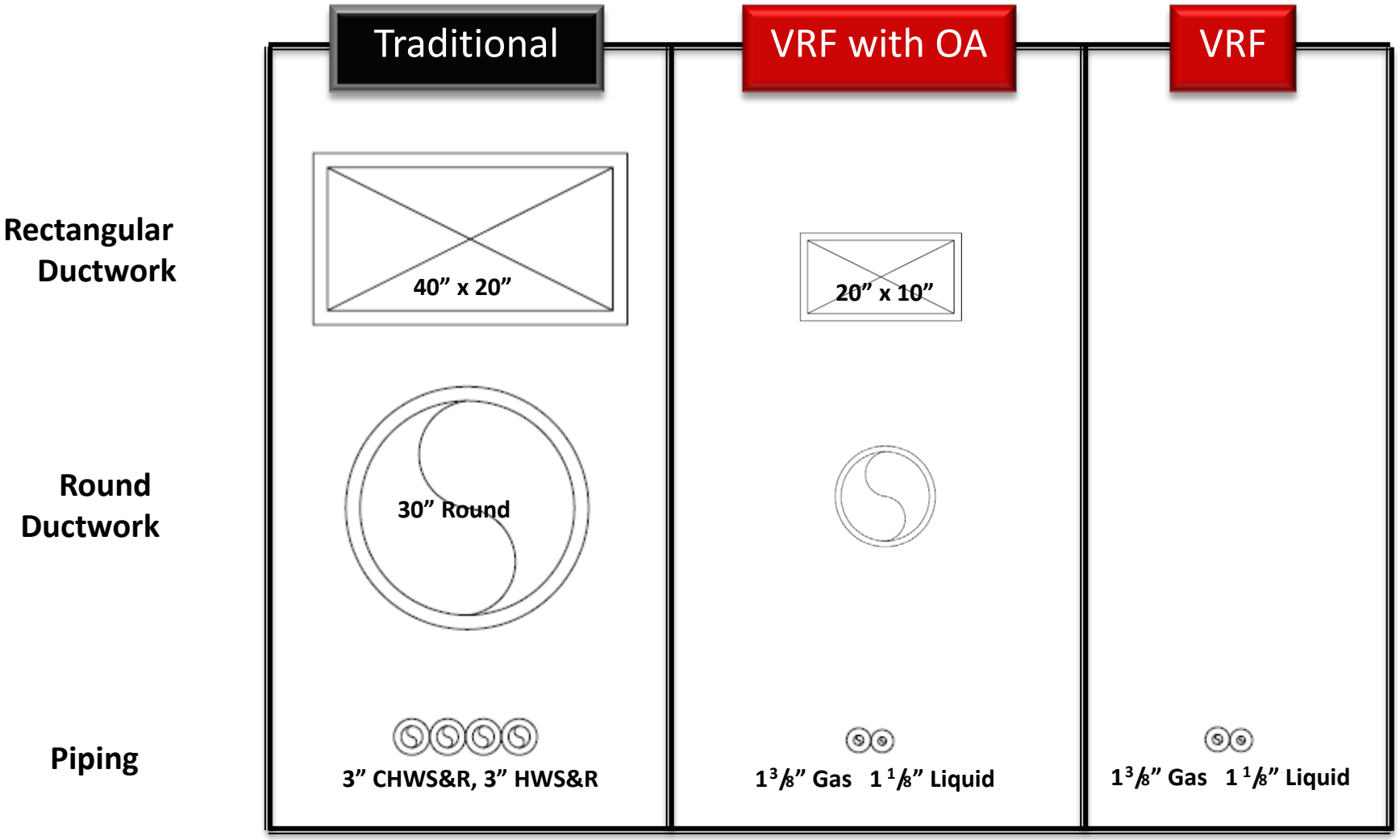
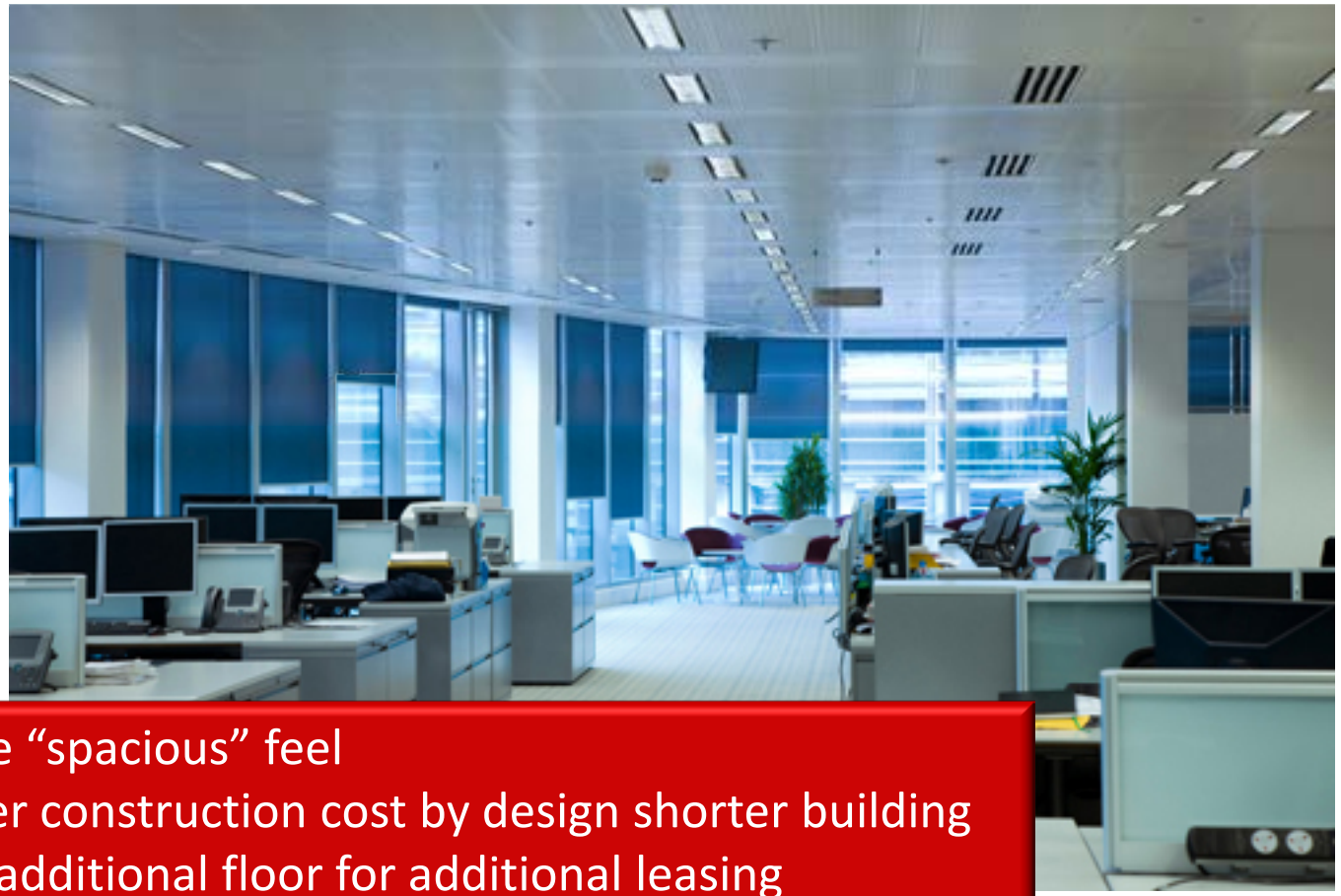
Space Savings

Space required to deliver 20 tons of cooling



Reduced ceiling plenum space



- More “spacious” feel
- Lower construction cost by design shorter building
- Add additional floor for additional leasing

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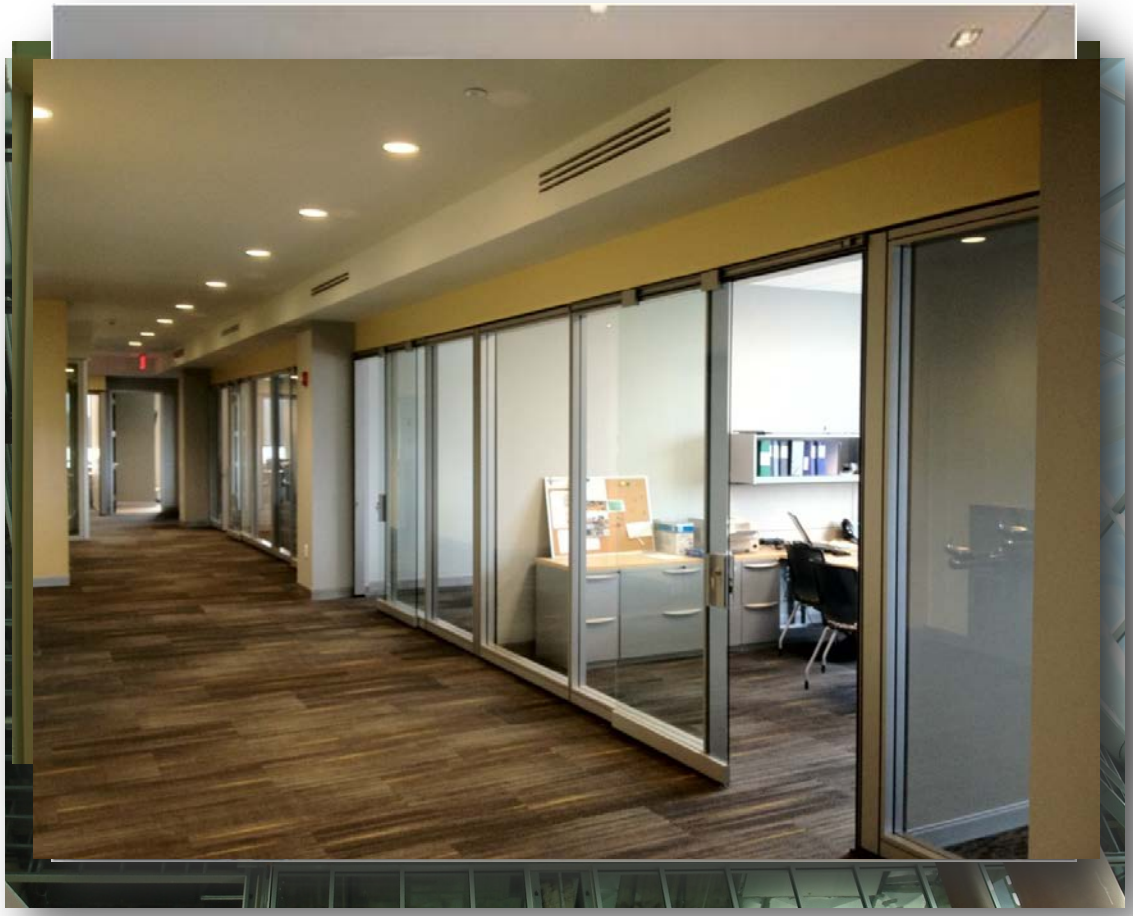
Ducted Units



Medium Static
Ducted Unit

Low Profile
Ducted Unit

High Static
Ducted Unit

Vertical
Ducted Unit

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Ceiling Recessed Cassettes

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Ceiling Recessed Cassettes

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Ceiling Mounted Units

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Wall Mounted Units

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Floor Mounted

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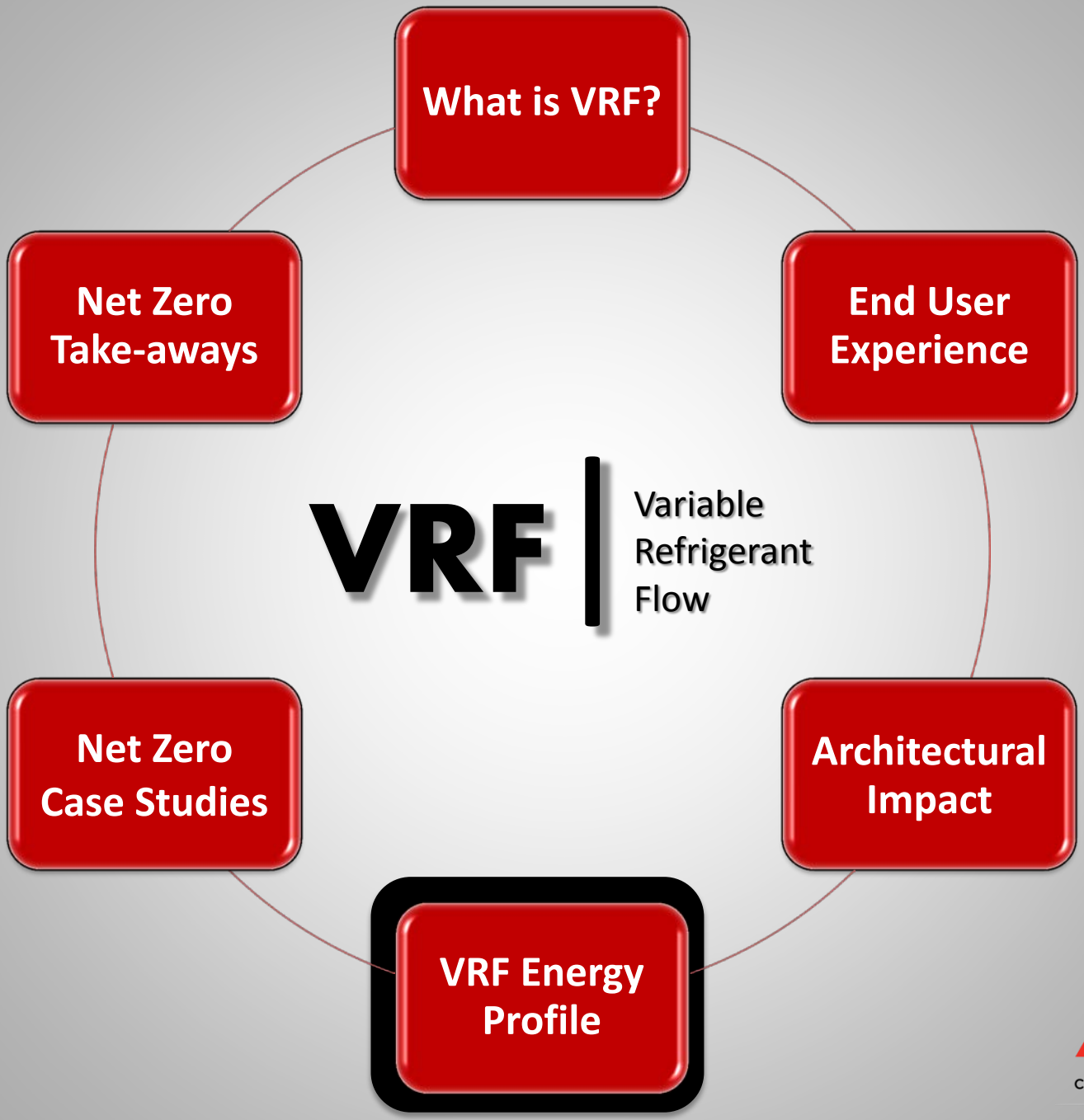

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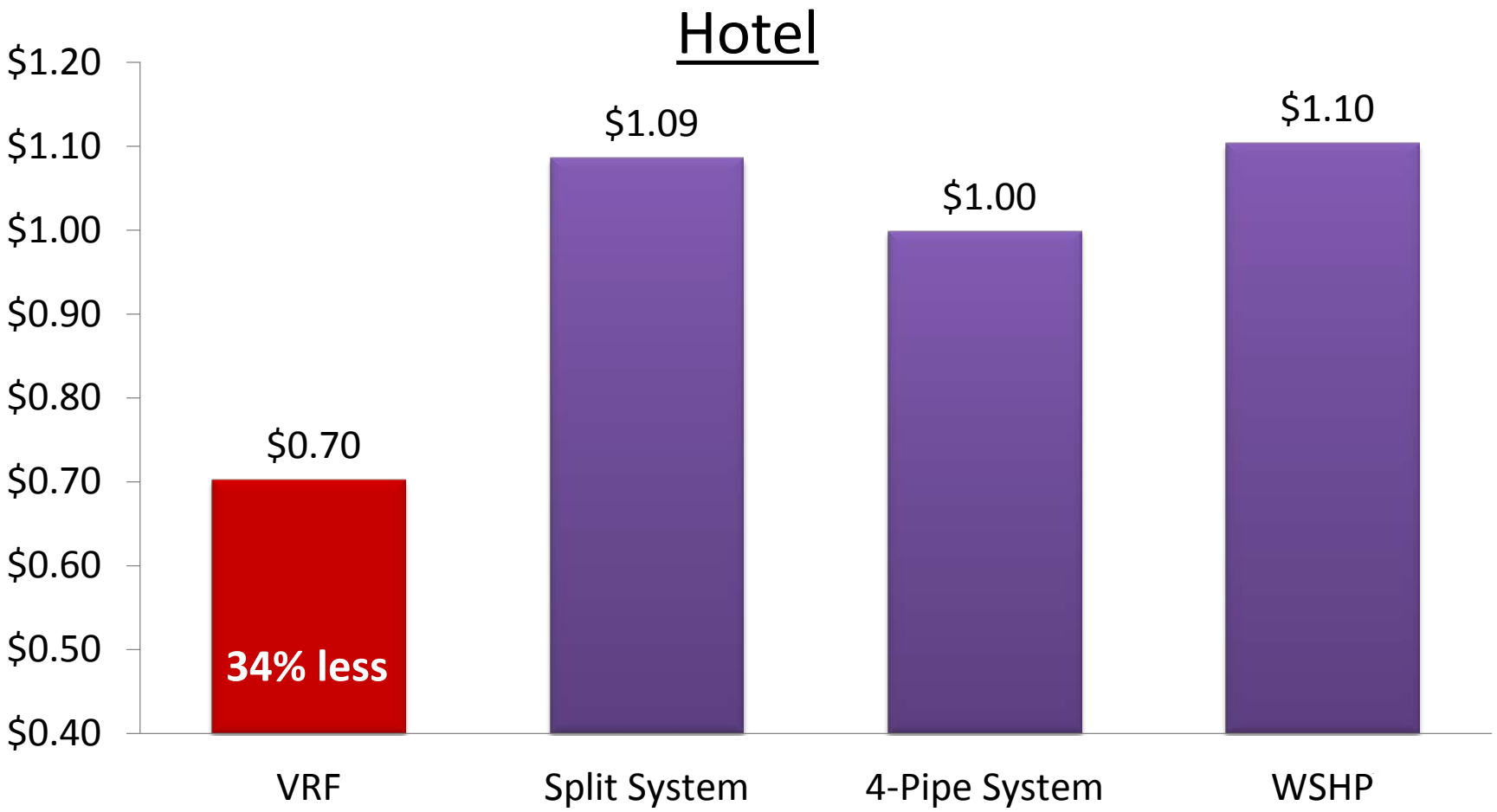
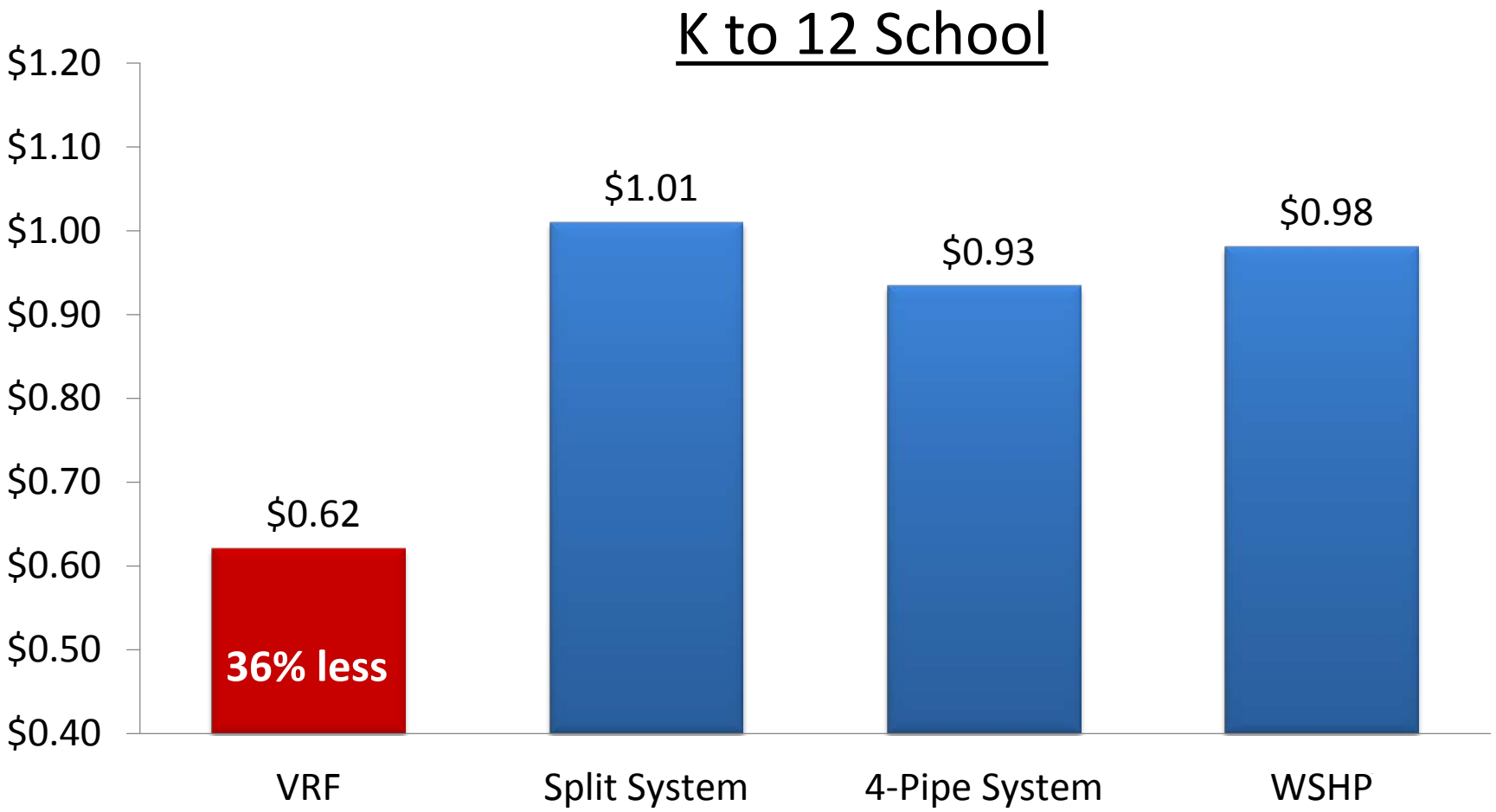
Energy Usage & Utility Costs?

- Controllability
- Energy
- LEED
- Maintenance
- Cost
- Expandability

Annual HVAC Energy Cost ($ / SF / Year)



Annual HVAC Energy Cost ($ / SF / Year)



Annual HVAC Energy Cost ($ / SF / Year)

<u>Typical VRF Savings Compared to Conventional HVAC Systems:</u>

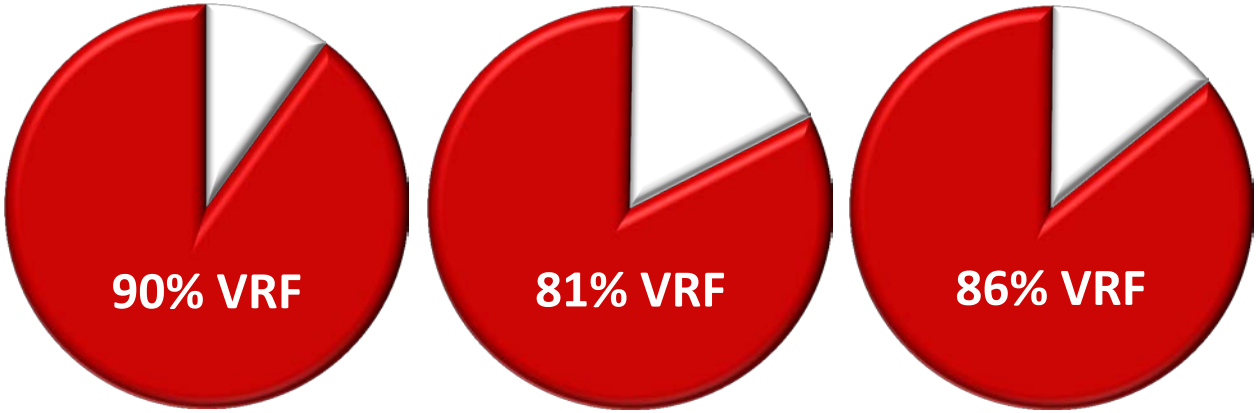
- 25% to 40% (New versus New)
- Up to 75% (New versus Old)

Energy – Why is VRF so efficient?

- VRF uses the “free” heat in the building
- Advanced Heat Pump Cycle (fossil fuel friendly)
- Inverter matches load & equip capacity
- ECM low static fan motors – 50% typical
- Zero or minimal pumping energy

Energy around the world

- Electric rates 3-6x higher than US
- Use of VRF validates energy efficiency



Japan

7.2M Systems

Europe

7.6M Systems

China

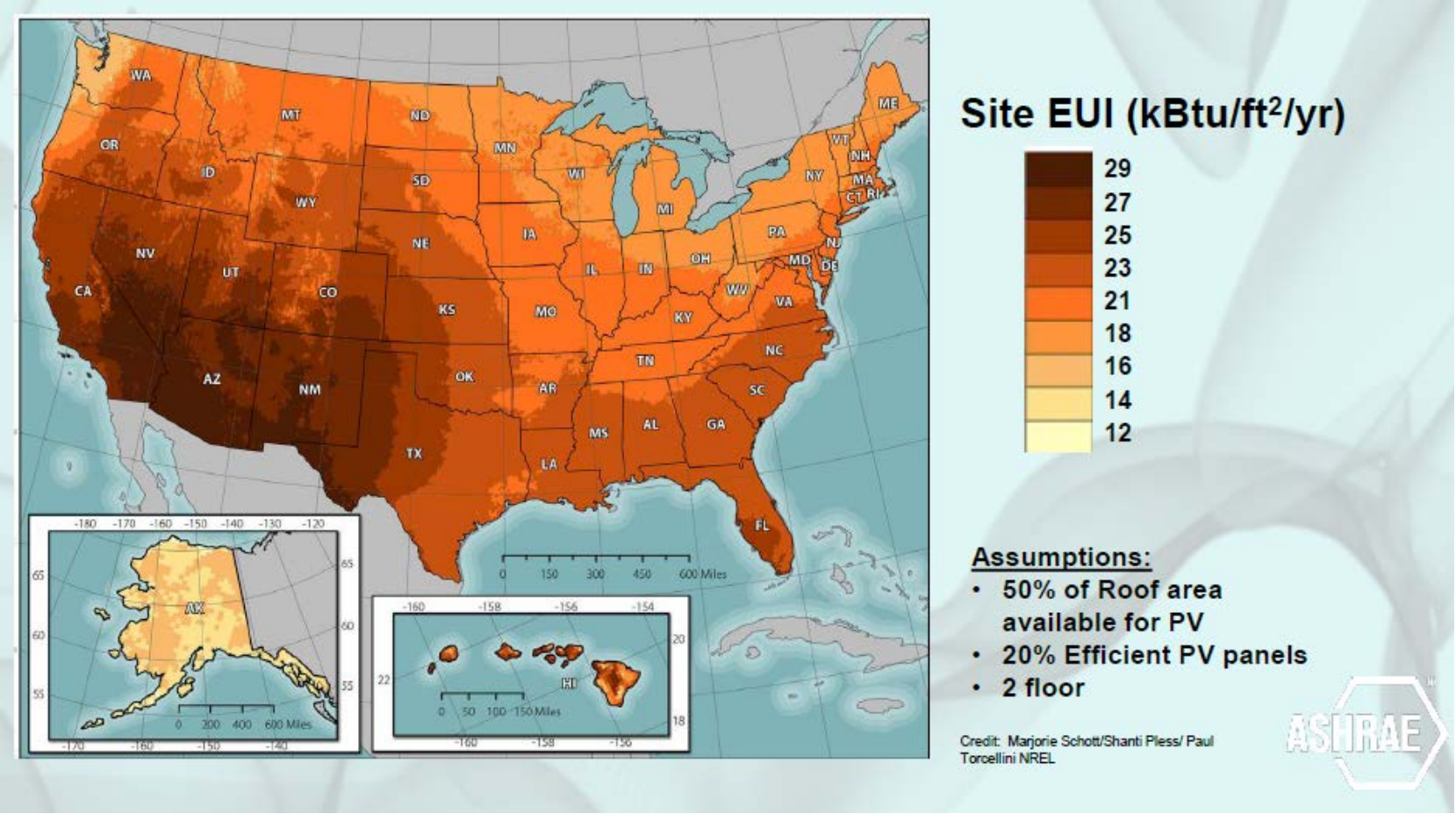
16.7M Systems

- Controllability
- Energy
- LEED
- Maintenance
- Cost
- Expandability

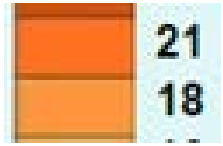
What about First Cost for NZEB Options?

- Controllability
- Energy
- LEED
- Maintenance
- Cost
- Expandability

Midwest United States NZEB - Dilemma # 1



Less sunshine per annum



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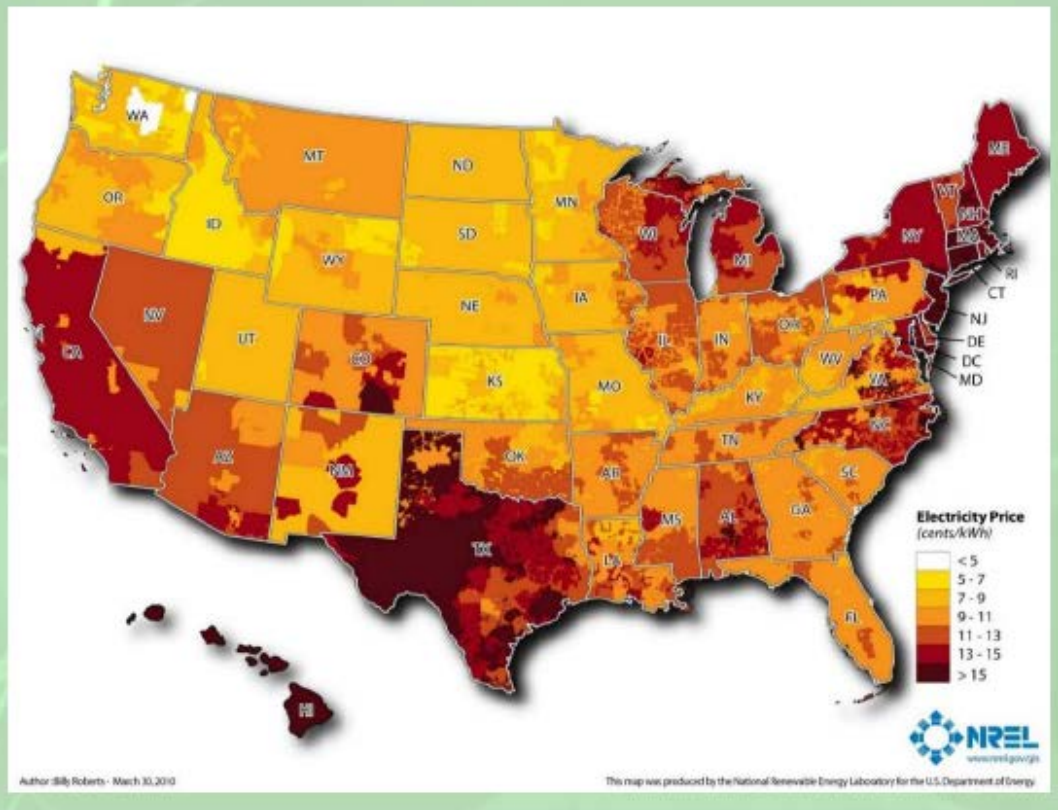
Midwest United States NZEB - Dilemma # 2

Electricity

Costs



Low electricity costs

Midwest United States NZEB - Dilemma # 3

SOUTHERN CALIFORNIA EDISON

Three Phase Variable Refrigerant Flow (VRF) Equipment*

Equipment Type	Tier	Size Category	Sub-Category	Full Load Cooling Efficiency	Incentive ($/ton)
VRF Heat Pump	1	<960 kBtuh (<80 tons)	Heat Pump	Interim Department of Energy Waiver	$990
	1	≥960 kBtuh (≥80 tons)		Interim Department of Energy Waiver	$630
VRF Heat Recovery	1	<960 kBtuh (<80 tons)	Heat Recovery	Interim Department of Energy Waiver	$1,530
	1	≥960 kBtuh (≥80 tons)		Interim Department of Energy Waiver	$1,170

AEP OHIO
A unit of American Electric Power

Variable Refrigerant Flow Air Conditioners: Air-Cooled	< 65,000 Btuh (5.4 tons)	14 SEER	$20.00
	65,000 - 134,999 Btuh (5.4 - 11.1 tons)	12 EER***	
	135,000 - 239,999 Btuh (11.2 - 19.9 tons)	12 EER***	
	≥240,000 Btuh (≥ 20 tons)	10.8 EER***	

Modest utility rebates for energy efficiency

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HVAC Net Zero Options

Modular or Custom AHU

Traditional VAV

HW & CW Pumps

Heat Pump Chiller

Option # 1A: Geo Heat Pump Chiller-Heater w/ Conventional AHU – VAV

- First Cost — $ 38 to $ 46 PSF (Average $ 42)
- Utility Cost — $ 1.20 PSF per year
- Relative Maintenance Cost — 2.0

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HVAC Net Zero Options

Modular or Custom AHU

Traditional VAV

HW & CW Pumps

Heat Pump Chiller

Option # 1A: Geo Heat Pump Chiller-Heater w/ Conventional AHU – VAV

- Makes ~ 120 F Hot Water (Must size HW Coils and VAV's appropriately)
- Not capable of simultaneous Heating and Cooling

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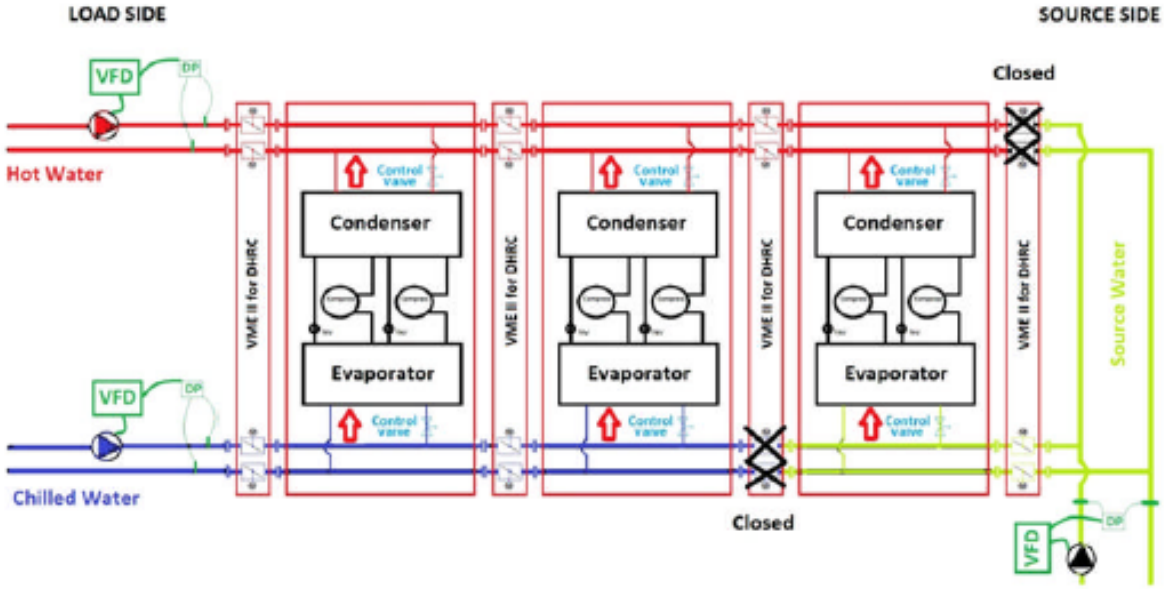
HVAC Net Zero Options

2 Cooling
3 Heating
1 Source extracting
2 Simultaneous load



Simultaneous Heat / Cool Available with Modular Chiller

Option # 1B: Modular Geo Heat Pump Chiller-Heater with AHU – VAV

- First Cost — $ 38 to $ 46 PSF (Average $ 42)
- Utility Cost — $ 1.00 PSF per year
- Relative Maintenance Cost — 2.0

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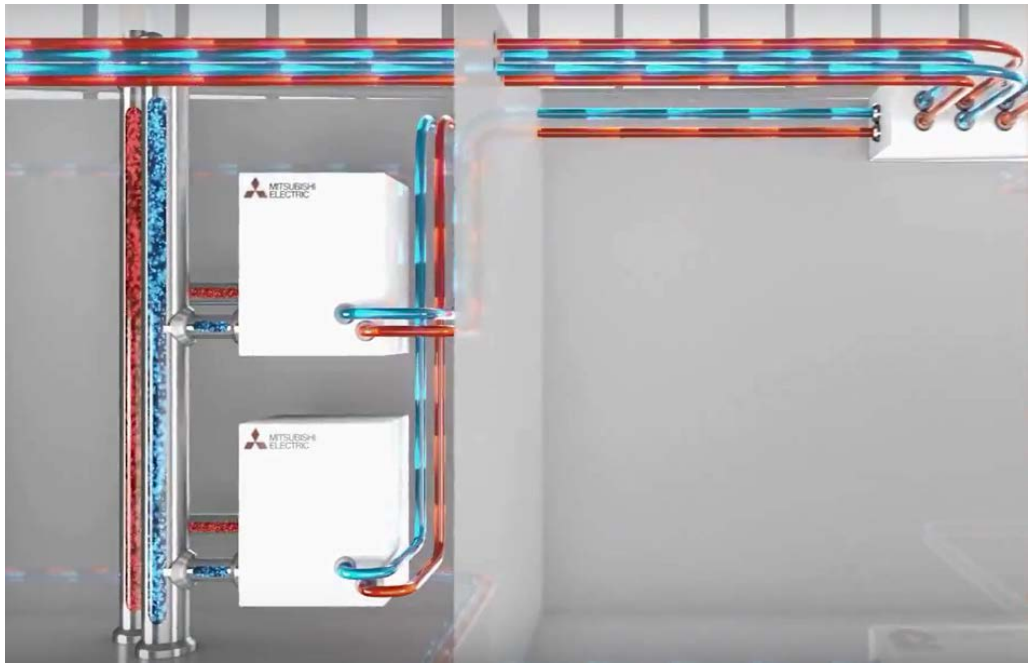
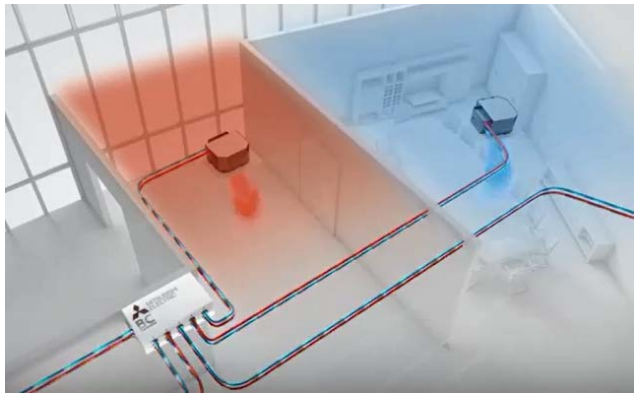
HVAC Net Zero Options





Option # 2: Geothermal VRF

- First Cost $ 28 to $ 36 PSF (Average $ 32)
- Utility Cost $ 0.80 PSF per year
- Relative Maintenance Cost 0.80

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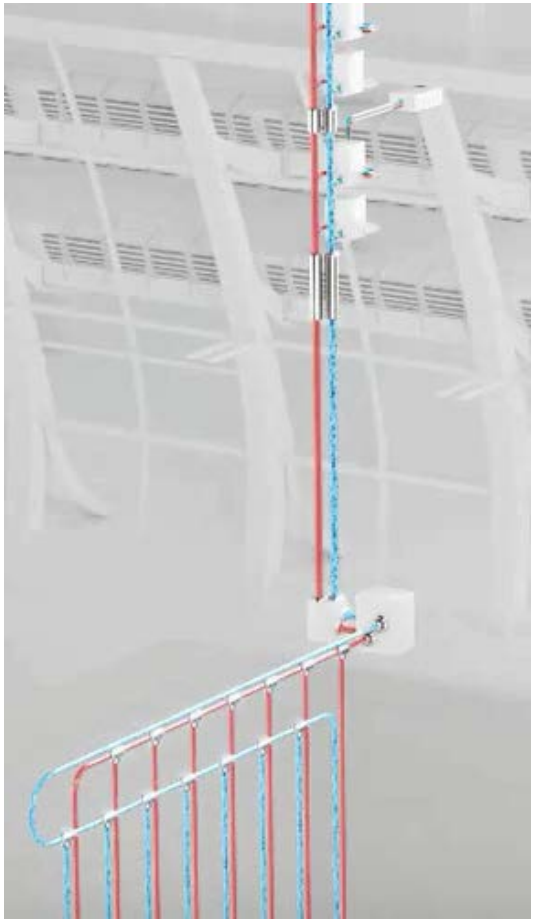
HVAC Net Zero Options

Domestic Water Preheat with waste heat



Option # 2: Geothermal VRF

- First Cost — $ 28 to $ 36 PSF (Average $ 32)
- Utility Cost — $ 0.80 PSF per year
- Relative Maintenance Cost — 0.80

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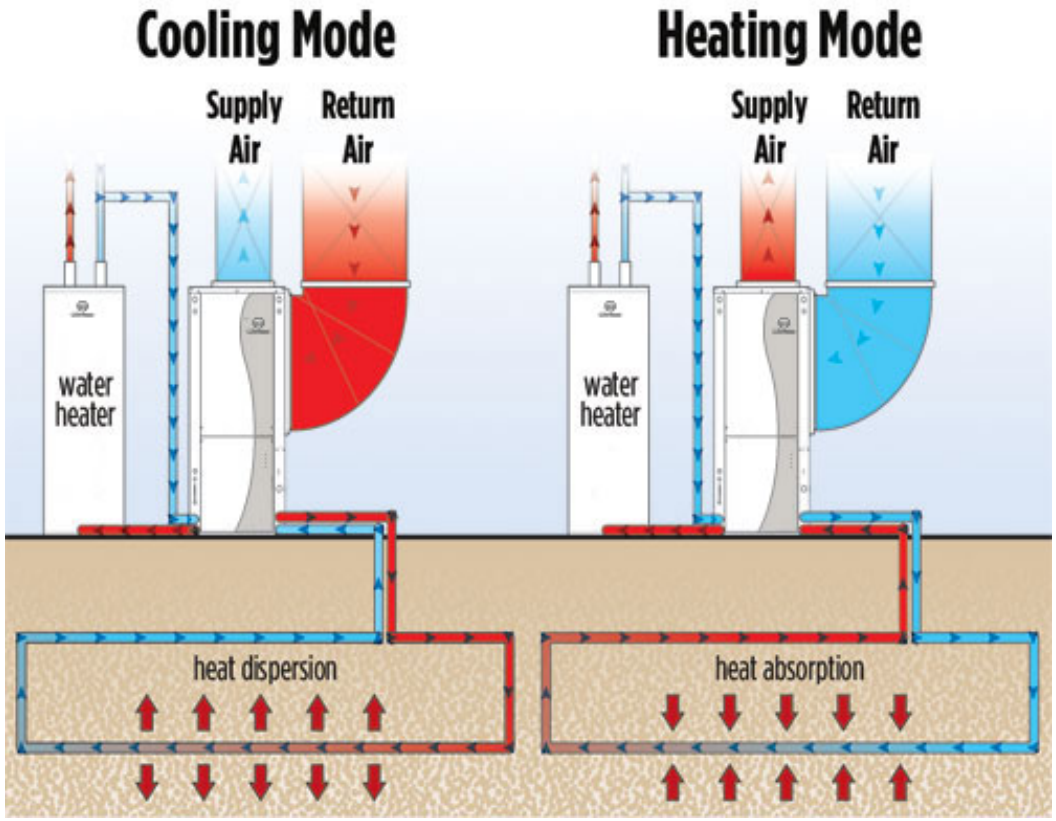
HVAC Net Zero Options



Option # 3: Traditional Geothermal GSHP

- First Cost — $26 to $ 34 PSF (Average $ 30)
- Utility Cost — $ 0.90 PSF per year
- Relative Maintenance Cost — 1.20

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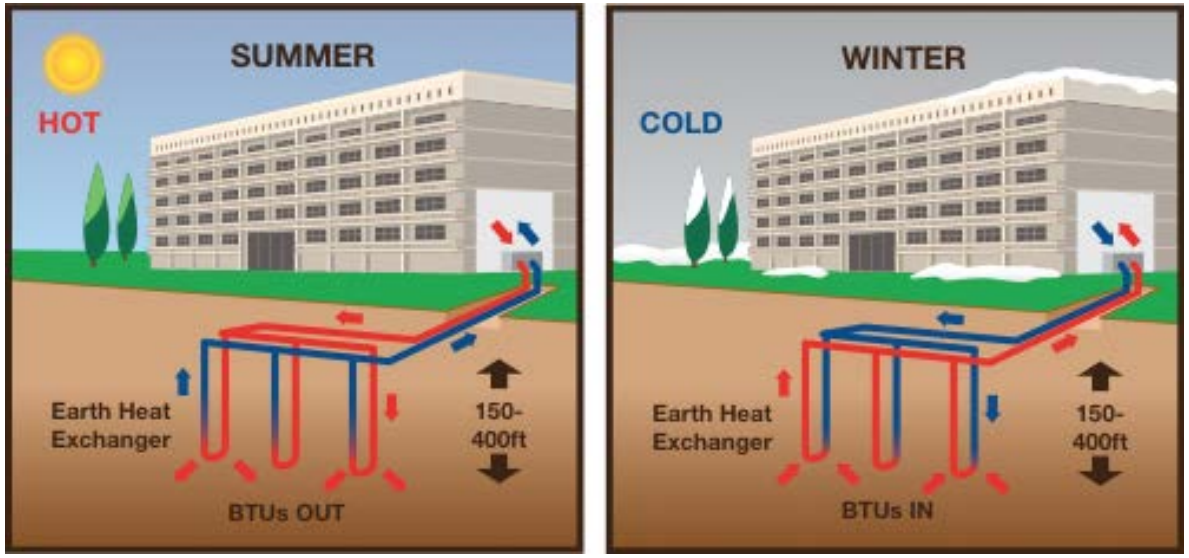
HVAC Net Zero Options



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- Relative Maintenance Cost — 1.20

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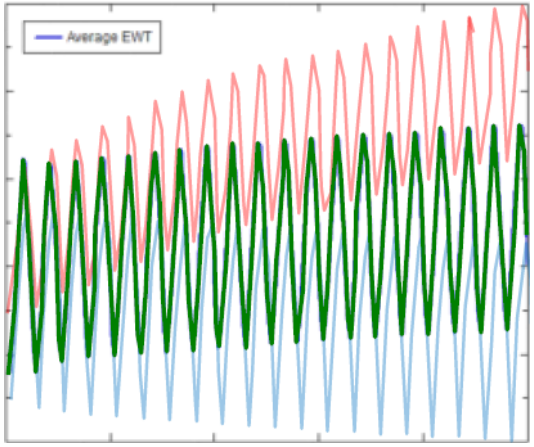
Geothermal Consideration – Load Balance?

	Church			
	Cooling		Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	4906	25	189734	385
Feb	6202	83	135120	366
Mar	12177	185	81304	312
Apr	20866	260	36614	170
May	33946	310	11152	65
Jun	52094	372	3180	28
Jul	62358	497	886	24
Aug	62393	417	1725	32
Sep	49245	360	5479	53
Oct	13821	169	24702	137
Nov	7571	79	86784	298
Dec	4884	22	146775	348
	330463	497	723455	385
	EFLH	665	EFLH	1877

	Retail Store			
	Cooling		Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	19906	25	89734	385
Feb	28202	83	65120	366
Mar	30177	185	41304	312
Apr	40866	260	16614	170
May	53946	310	3152	65
Jun	82094	372	180	28
Jul	102358	497	0	0
Aug	102393	417	125	32
Sep	89245	360	2379	53
Oct	63821	169	9702	137
Nov	41571	79	36784	298
Dec	27884	22	76775	348
	682463	497	341869	385
	EFLH	1373	EFLH	887

	Multi-family Residential			
	Cooling		Heating	
	kBtu	kBtu/hr	kBtu	kBtu/hr
Jan	4906	25	149734	385
Feb	6202	83	105120	366
Mar	16177	185	71304	312
Apr	30866	260	26614	170
May	53946	310	11152	65
Jun	72094	372	3180	28
Jul	102358	497	886	24
Aug	92393	417	1725	32
Sep	49245	360	5479	53
Oct	23821	169	14702	137
Nov	7571	79	66784	298
Dec	4884	22	126775	348
	464463	497	583455	385
	EFLH	935	EFLH	1514



- **Same Peak Load but different aggregate load**
- **Which of these is best balanced?**
- **What happens to ground temp over time?**

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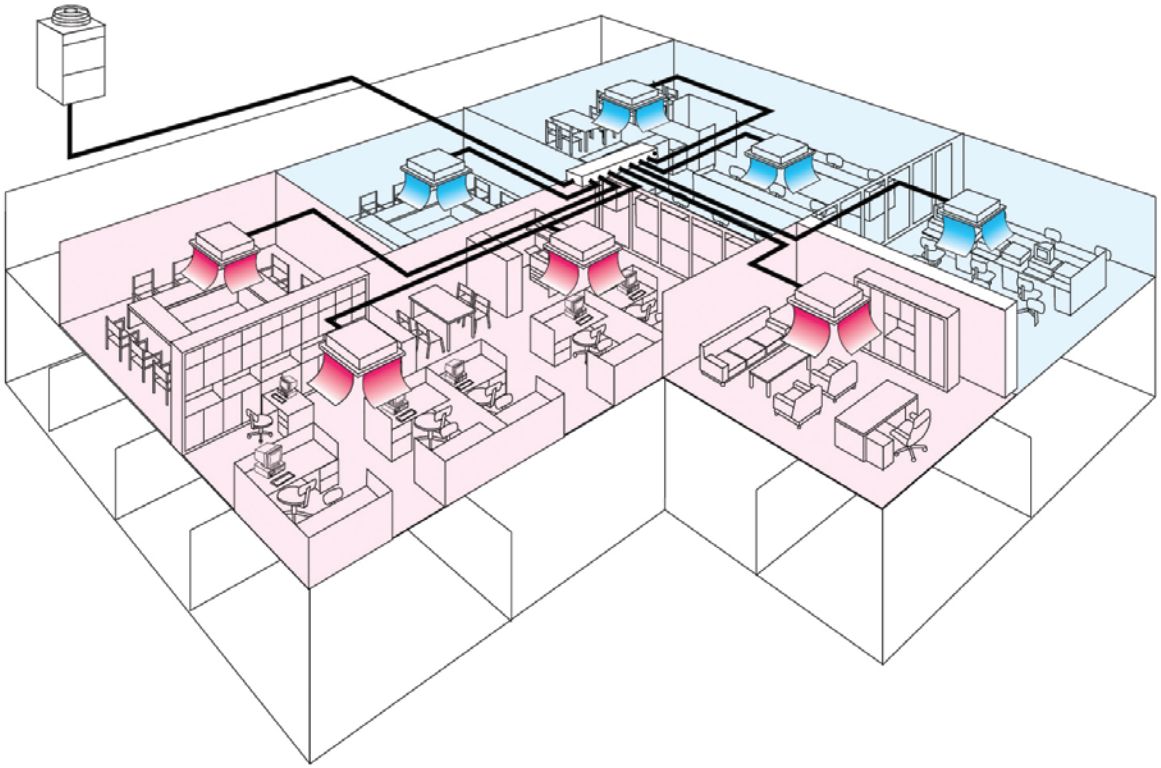
HVAC Net Zero Options



Option # 4: Air Source VRF

- First Cost $ 18 to $ 22 PSF (Average $ 20)
- Utility Cost $ 1.10 PSF per year
- Relative Maintenance Cost 1.0

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HVAC Net Zero Options Summary

Net Zero HVAC System Type	Average First Cost	Average Operating Cost	Relative Maintenance Cost	Achilles Heal
GEO Heat Pump Chiller Heater	$ 42 PSF	$ 1.00 PSF / YEAR	2	First Cost, Maint Cost
GEO VRF	$ 32 PSF	$ 0.80 PSF / YEAR	0.8	First Cost
Traditional GEO GSHP	$ 30 PSF	$ 0.90 PSF / YEAR	1.2	First Cost, # of Compressors
Air Source VRF	$ 20 PSF	$ 1.10 PSF / YEAR	1	Extreme Winter Days

Payback of Traditional GEO vs Air Source VRF

- First Cost Increase $ 10 PSF
- Utility Cost Savings $ 0.20 PSF
- Simple Payback 50 Years

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HVAC Net Zero Options Summary

Net Zero HVAC System Type	Average First Cost	Average Operating Cost	Relative Maintenance Cost	Achilles Heal
GEO Heat Pump Chiller Heater	$ 42 PSF	$ 1.00 PSF / YEAR	2	First Cost, Maint Cost
GEO VRF	$ 32 PSF	$ 0.80 PSF / YEAR	0.8	First Cost
Traditional GEO GSHP	$ 30 PSF	$ 0.90 PSF / YEAR	1.2	First Cost, # of Compressors
Air Source VRF	$ 20 PSF	$ 1.10 PSF / YEAR	1	Extreme Winter Days

Payback of GEO VRF vs Traditional GEO

- First Cost Increase — $ 2 PSF
- Utility Cost Savings — $ 0.10 PSF
- Simple Payback — 20 Years
- Life Cycle Cost Payback — 2 to 4 Years

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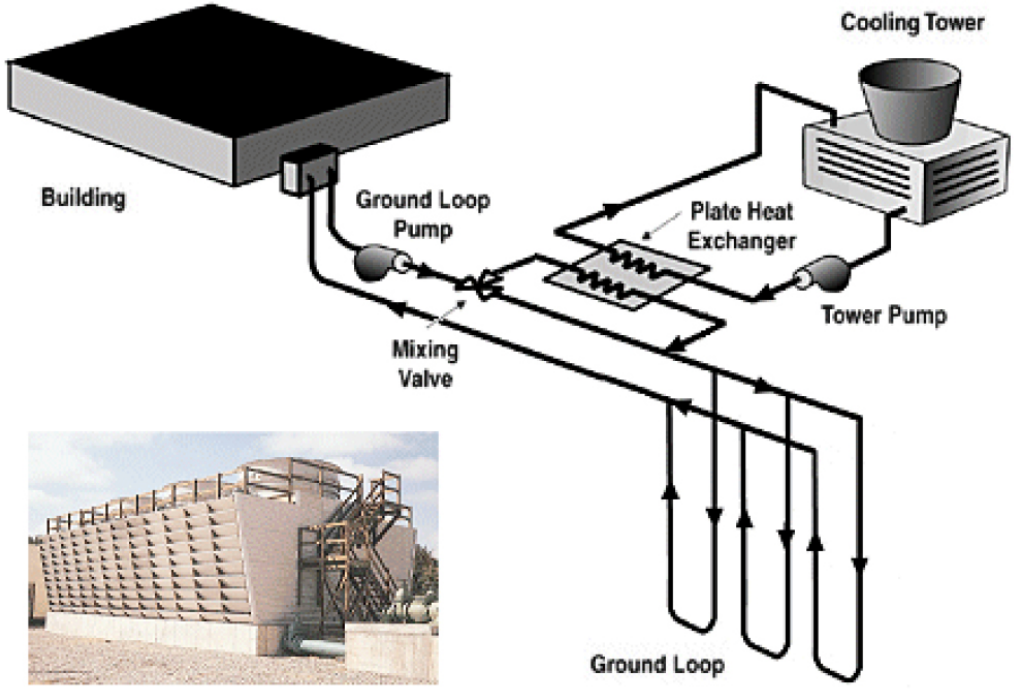
What about Hybrid Geothermal Systems?



Considerations:

- Well Field can decrease by half or more
- $ 4 to 5 PSF first cost savings
- Can do predictive conditioning of geothermal well field
- Complicates controls

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New PLFY Large Cassette

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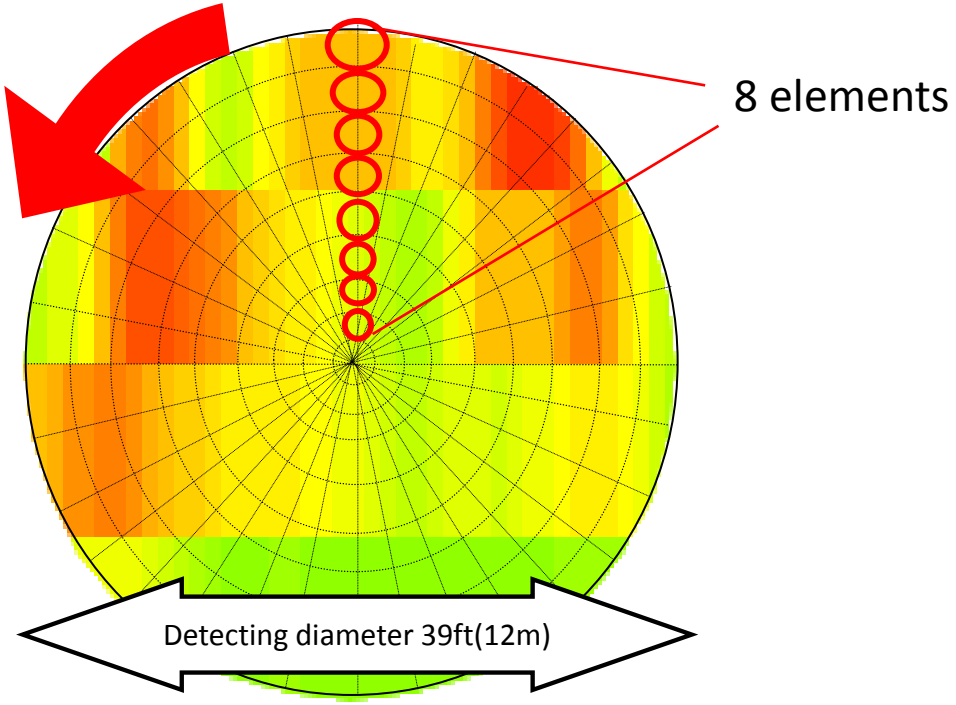
New PLFY - 3D Infrared Sensor

Sensor elements detect 1,856 temperature points



※When ceiling height 8.8ft(2.7m)

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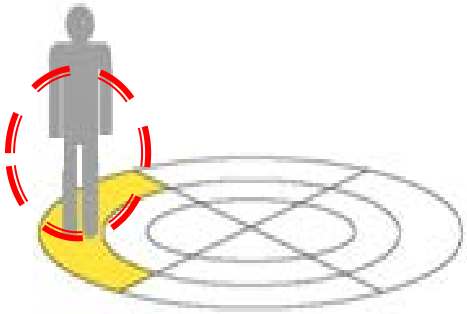
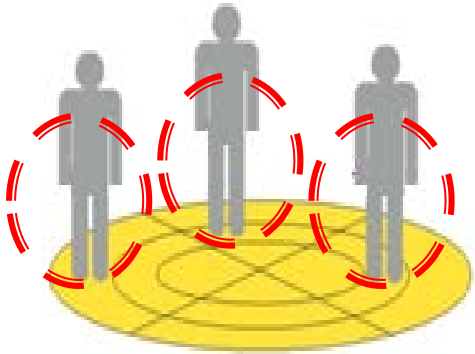
3D Infrared Sensor Features

Detects occupant location



Counts number of people in the room



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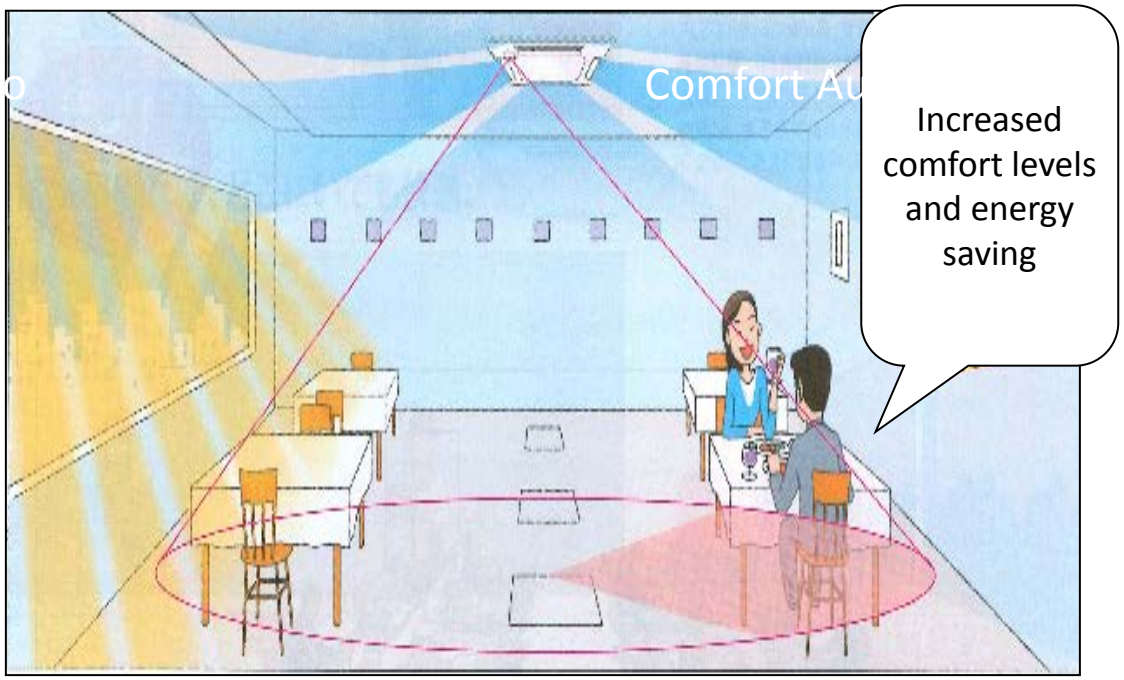
3D Infrared Sensor



3D Infrared sensor detects temperature where occupants are located and ignores hot spots if they are not occupied. This prevents unnecessary cooling or heating without decreasing comfort levels.

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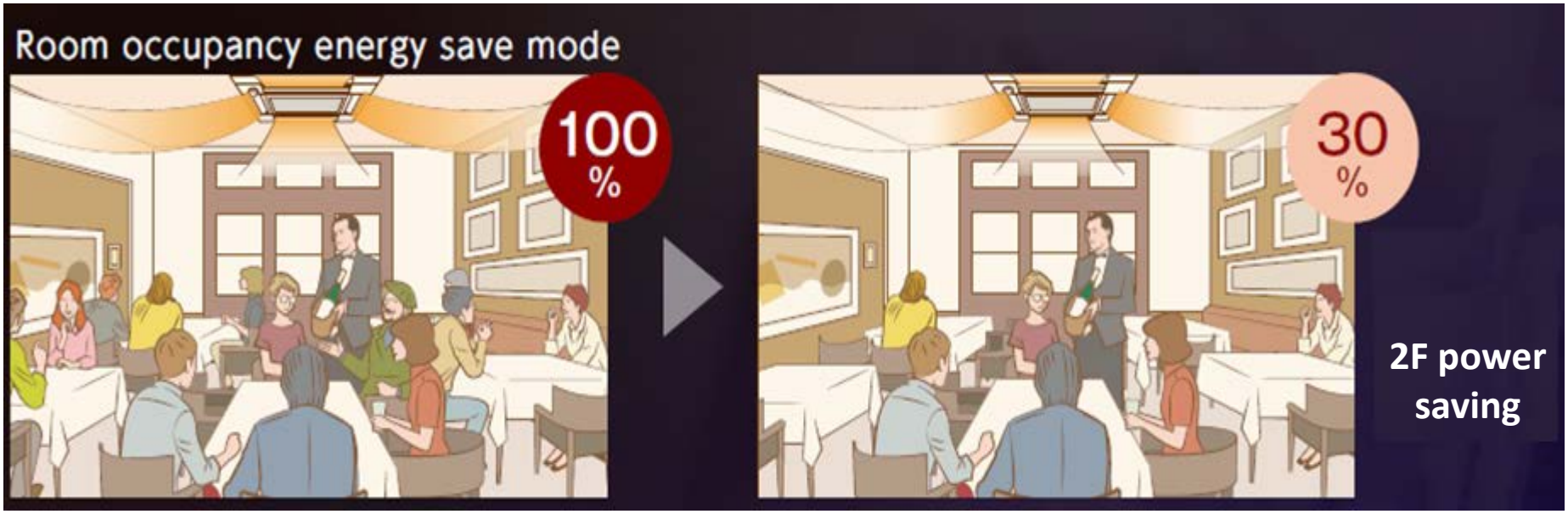
Occupancy Energy Save Mode



The room temperature is automatically adjusted according to the number of people in the room detected by the 3D i-see-sensor.

When the i-see sensor detects room occupancy is approximately 30% energy consumption is reduced by offsetting the set temp by +/- 2F

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Unoccupied Energy Save Mode

When the room is empty for more than 60 min, energy is saved by adjusting the set temp by +/- 4F

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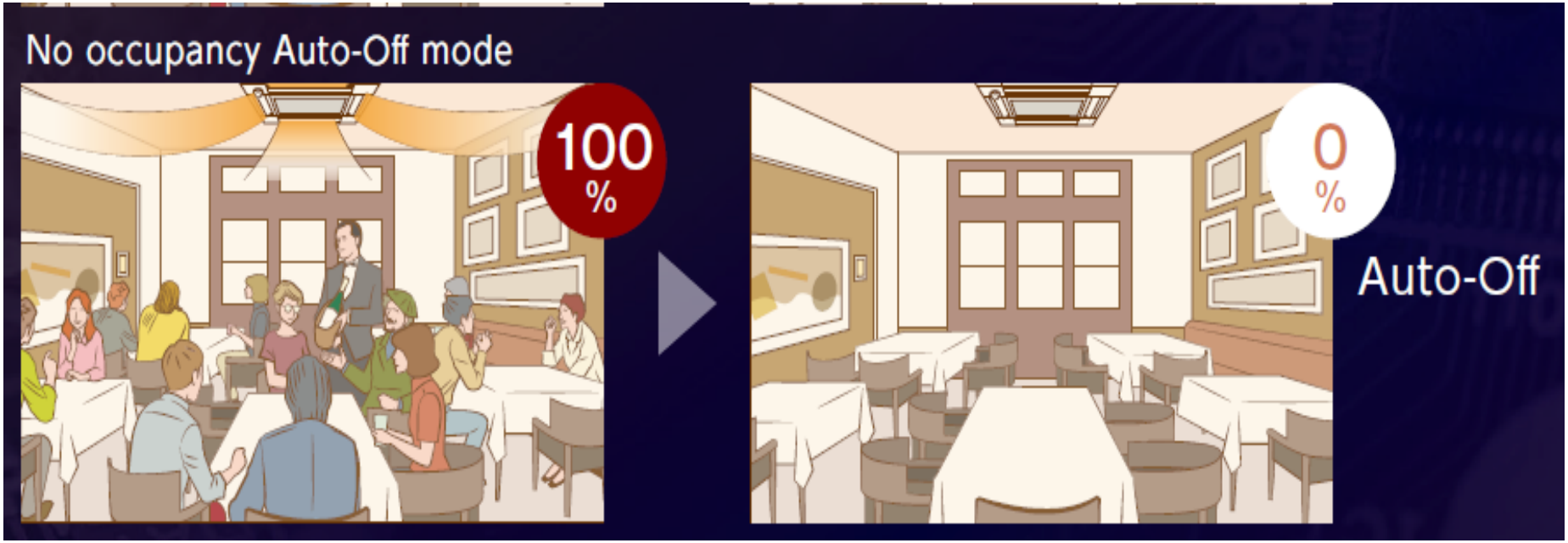
Unoccupied Auto Off Mode



When the room is unoccupied for 60-180 min, the units stop automatically.
(Adjustable in 10 min increments)

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Smart Controls with Motion Sensor

Function	Occupied -> Vacant	Vacant -> Occupied
(1)ON/OFF control	ON -> OFF	OFF -> ON
(2)Setback control*1	Into Setback mode	Back to normal mode
(3)Indoor unit thermo control	Thermo off	Thermo on
(4)Set temperature slide	During Cool mode: set temp. xxF up During Heat mode: set temp. xxF down	Back to normal setting
(5)Fan speed control	Low fan speed	Back to normal speed

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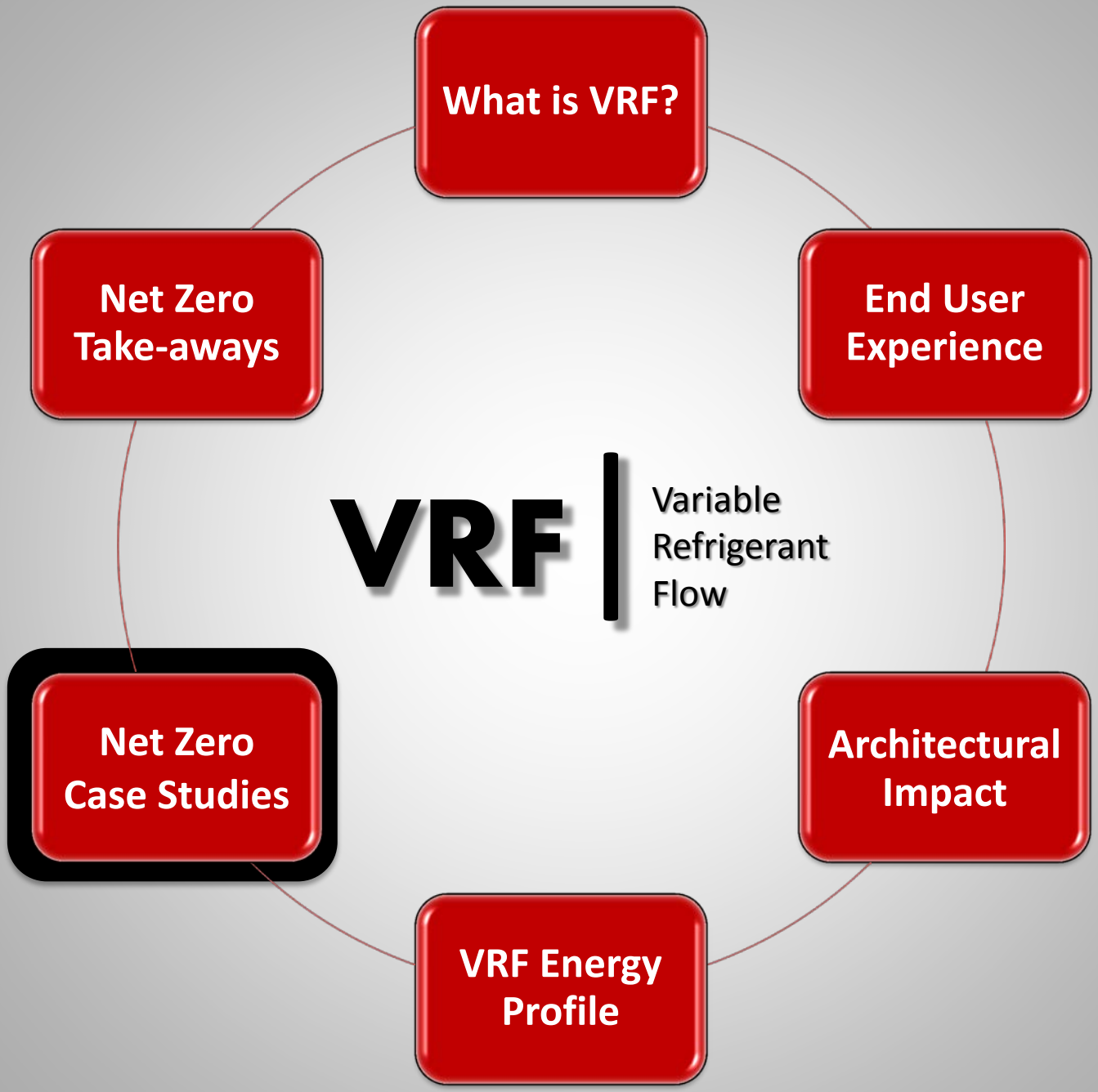
What is VRF?
End User Experience
Architectural Impact
VRF Energy Profile
Net Zero Case Studies
Net Zero Take-aways
VRF
Variable Refrigerant Flow

Living Building / Brock Environmental Center

Virginia Beach, VA

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Brock Environmental Center

- 10,500 Square Feet
- 80 Seat Conference Center
- Energy Star Rating of 100
- Annual EUI: 14 Kbtu/sf
- Net EUI: - 12 Kbtu / sf
- Carbon Footprint: 0
- Building Cost: $ 4.3 Million
- Building Cost: $ 409 / sf

- First US Building to have Federal certification use rainwater as drinking water
- Analyzed Traditional Geothermal versus VRF Geothermal
- PV cost - $ 0.20 / KWH
- Wind cost - $ 0.38 / KWH

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Brock Environmental Center

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- 80 Seat Conference Center
- Energy Star Rating of 100
- Annual EUI: 14 Kbtu/sf
- Net EUI: - 12 Kbtu / sf
- Carbon Footprint: 0
- Building Cost: $ 4.3 Million
- Building Cost: $ 409 / sf

- Selected Geothermal VRF over traditional GSHP due to energy savings
- 21 tons of Water Cooled Heat Recovery VRF with 18 Indoor VRF fan coils
- 18 Closed Loop Geo Wells at 250’ deep

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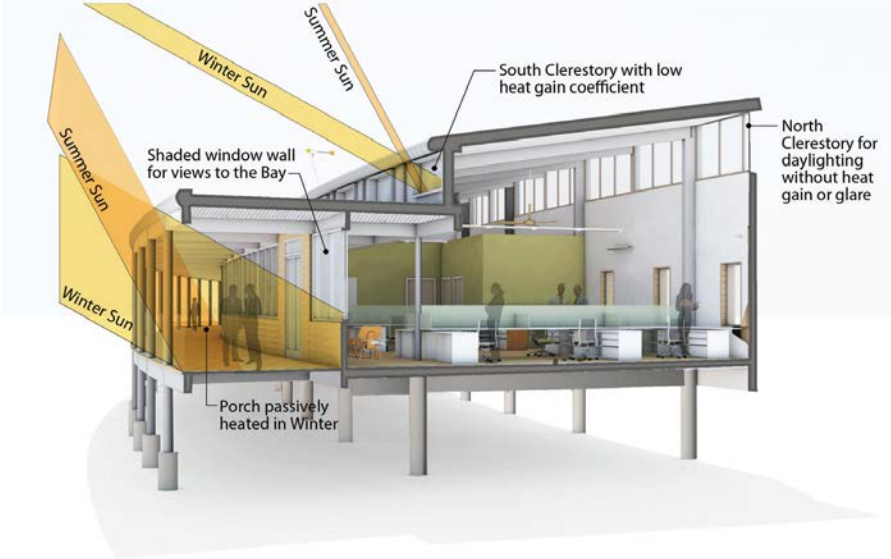
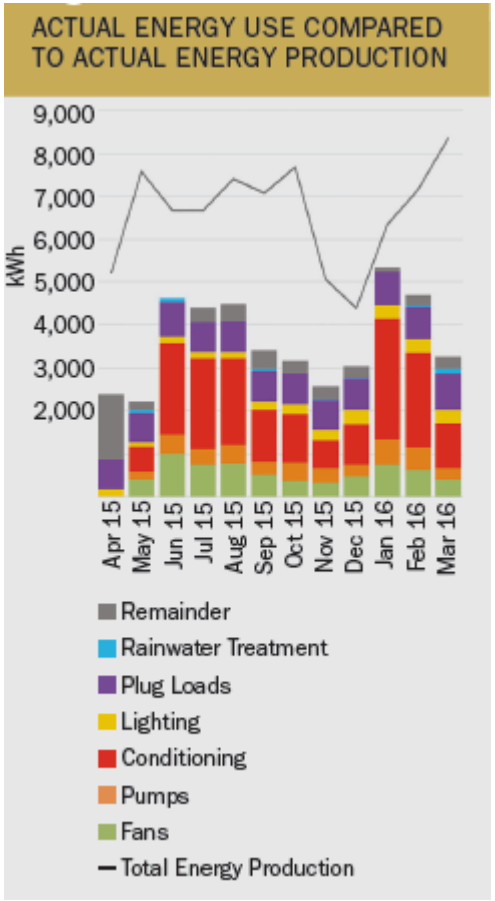
Brock Environmental Center





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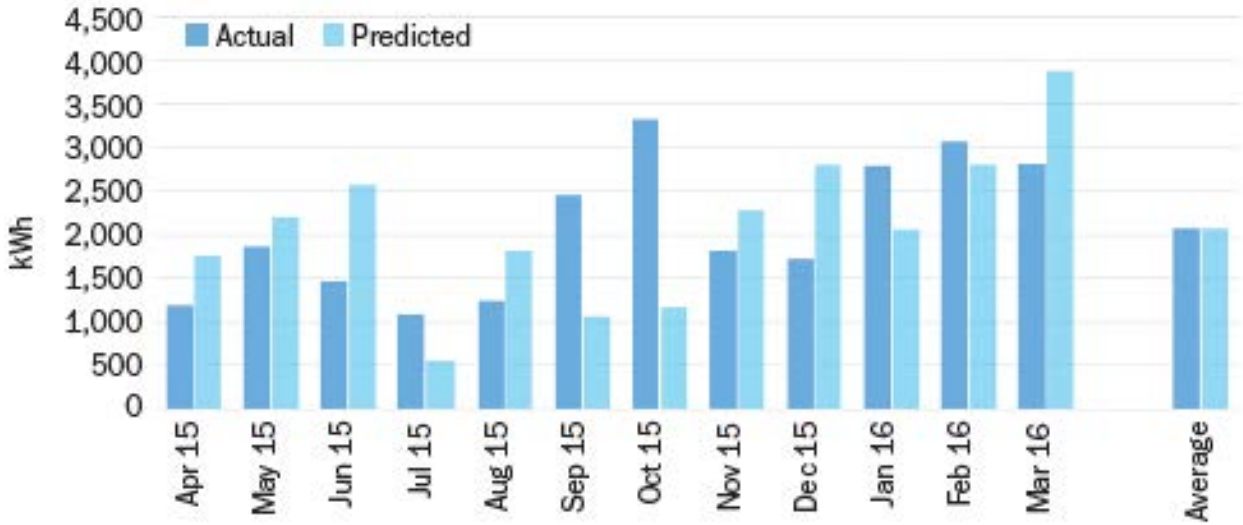
Brock Environmental Center

Figure 3 WIND TURBINE OUTPUT: PREDICTED VS ACTUAL



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Living Building / Willow School

Gladstone, NJ

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Willow School

- Selected Air Cooled VRF over Traditional GSHP
- 20,000 Square Feet
- Annual EUI: 21 Kbtu/sf
- Annual EUI: 15 Kbtu / sf (less kitchen)
- Largest Living Building Challenge Certified School in the US

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Willow School

"A conventional facility built to code uses between 100-150 kBtu per square foot … but this building uses only 21 kBtu per square foot – and that was including our commercial kitchen. If you remove the kitchen, it would only use 15 kBtu per square foot. When people look at this building, they're looking at one of the most energy-efficient buildings in the country."

- Mark Biedron, co-founder, The Willow School

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Net Zero Energy Center / IBEW Local 595

San Leandro, CA

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IBEW Local 595

- 45,000 Square Feet / 1000 Student Peak Occupancy
- Annual EUI: 15 Kbtu/sf   (Modeled 17.9)
- Net EUI: -5.5 Kbtu/sf
- Cost: $ 13 Million (Renovation)
- Cost: $ 288.88 psf

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IBEW Local 595

- $ 81,000 Utility Incentive for Owner / $ 25,000 Utility Incentive for Design Team
- 4 KW Wind Turbines
- 11.3 KW Solar Tree Entry Canopy
- 154.8 KW Roof Mounted Photo Voltaic Panels
- VRF Heat Recovery System with Fan Coils interlocked with Operable Windows

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IBEW Local 595

FIGURE 2 **VARIABLE REFRIGERANT FLOW DIAGRAM**

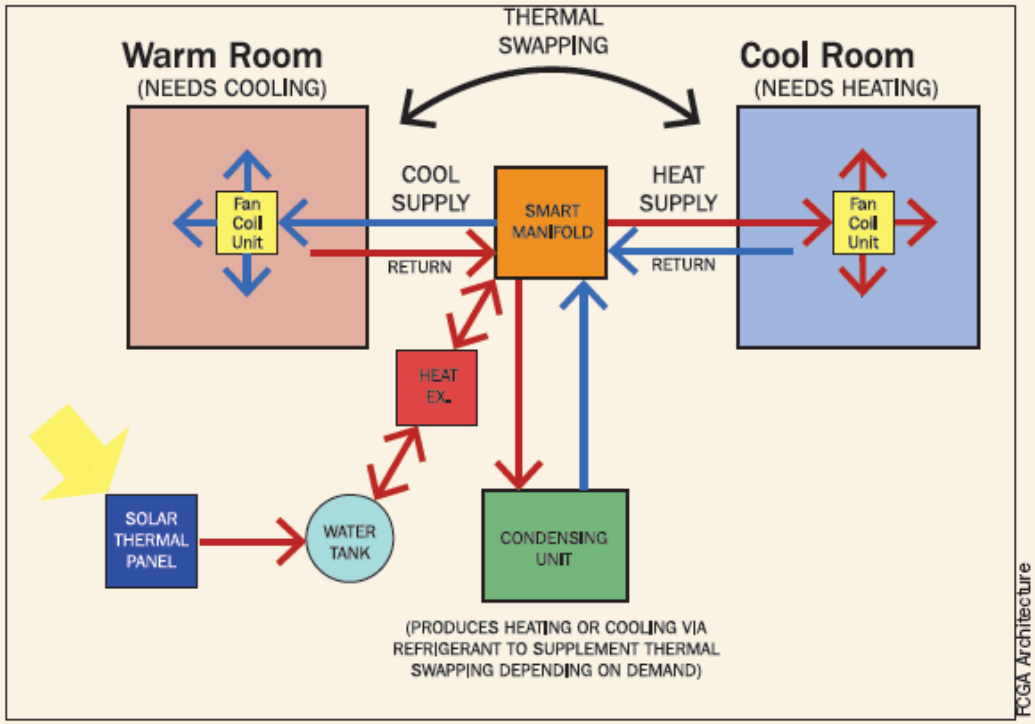
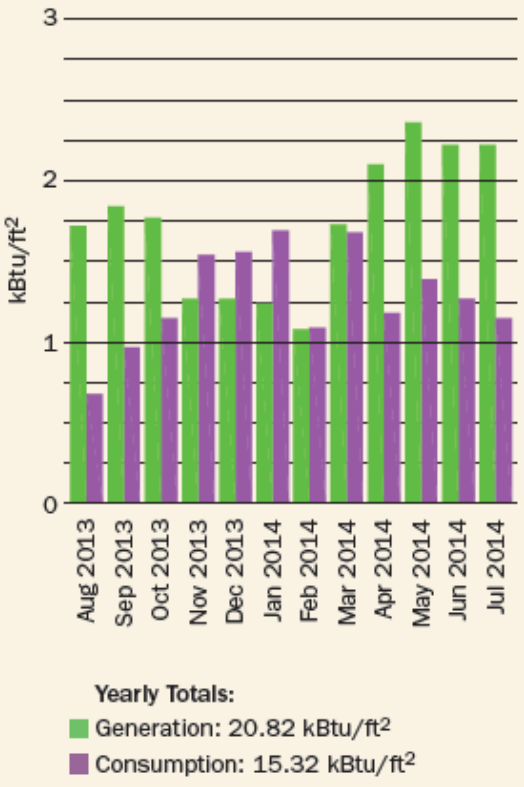


FIGURE 1
MONTHLY GENERATION VS. CONSUMPTION



- Domestic water preheat using both VRF and Solar

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IBEW Local 595

The team selected a two pipe variable refrigerant flow (VRF) condensing unit/fan coil system (*See VRF System* and *Figure 2*). The VRF system performs better and cost $1 million less than a traditional code baseline forced-air HVAC system. Additionally, the VRF system eliminated the need for roof mounted units, which would have increased the roof retrofit cost and reduced the area available for PV.

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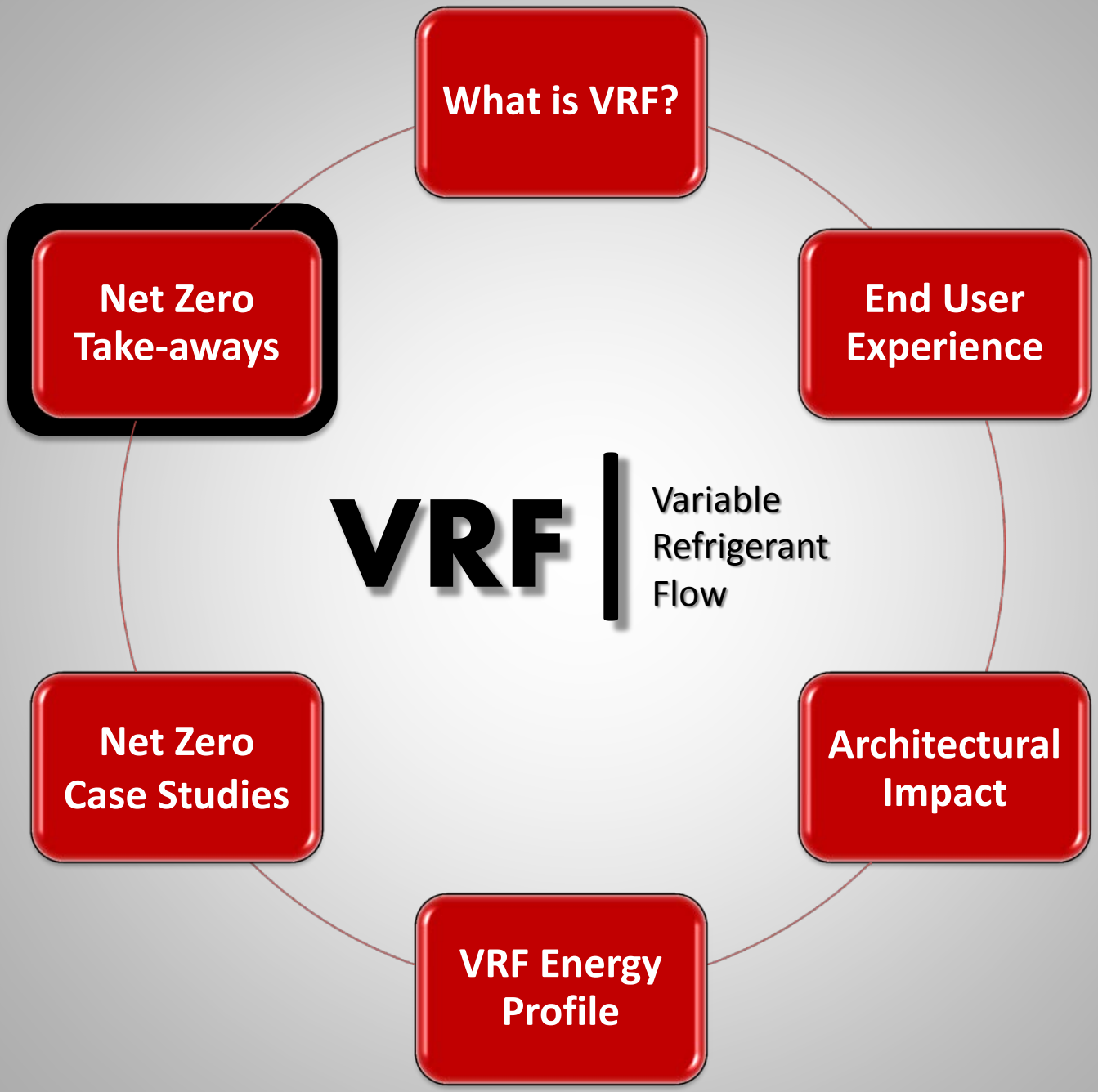
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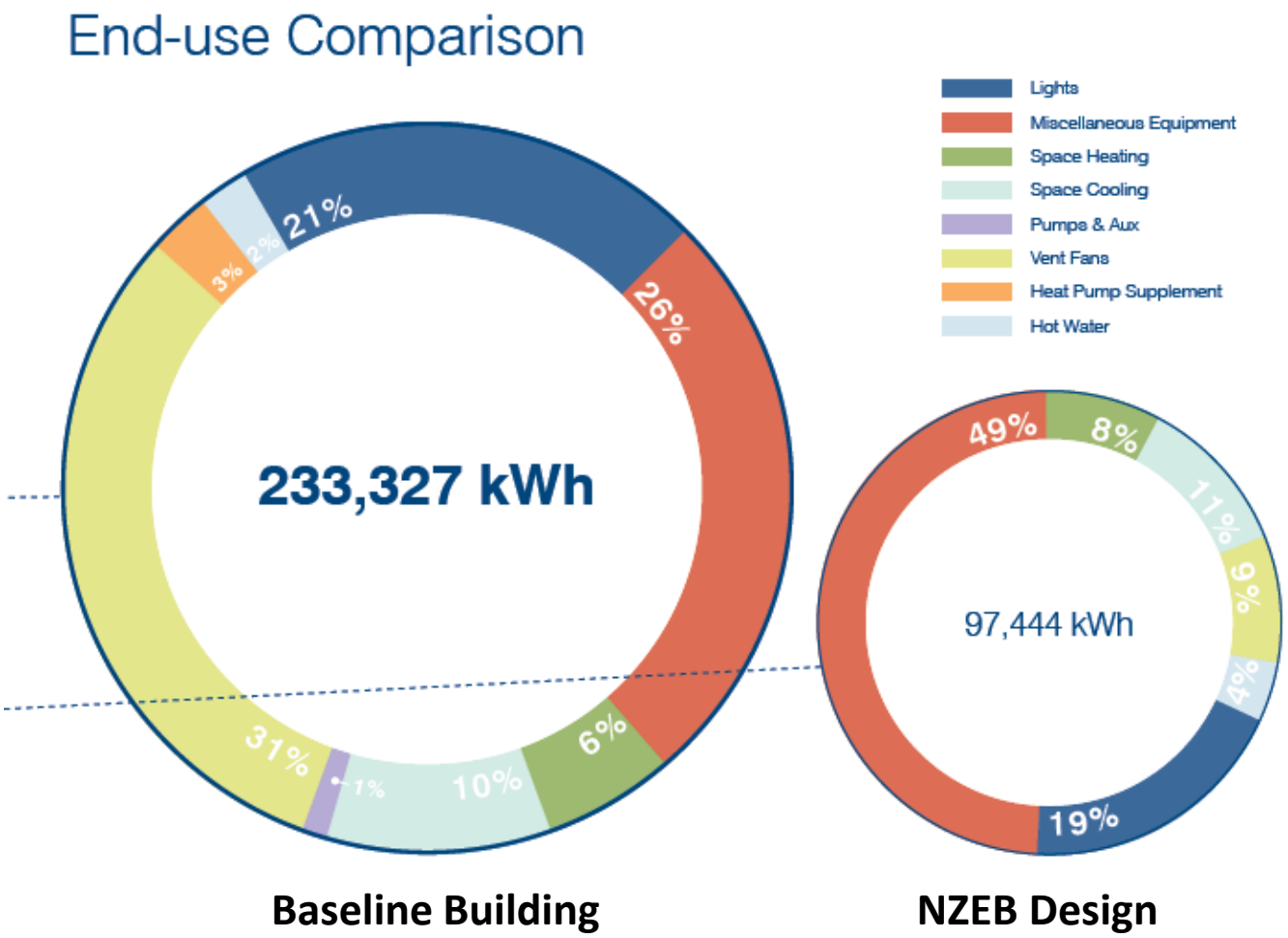
Net Zero / 15,000 S.F Office Building



Baseline Building **NZEB Design**

Plug Loads become a larger share of the pie as other loads shrink

Sustainable Energy Fund 2015 Study

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Net Zero / 15,000 S.F Office Building

Decreasing Return from overspending on the envelope

	BASELINE	NZE READY		
		"Good" Envelope	"Better" Envelope	"Best" Envelope
		Shaded fields are the final design utilized in the energy and cost model		
ROOF INSULATION	**R-38** - Uninsulated roof cavity w/ insulated attic R-38 loose fill cellulose insulation	**R-29** - 8¼" EPS SIPs	**R-41** - 6½" Polyurethane SIPs	**R-52** - 12¼" Graphite enhanced EPS SIPs
WALL INSULATION *Notes:* *1. R-Values in this chart are not degraded for thermal bridging. The energy model does, however, degrade assemblies based on thermal bridging.* *2. Metal SIPs do not receive additional exterior cladding; they are the exterior finish.*	**R-14.4** - 1½" XPS exterior rigid insul, sheathing, 6" metal studs w/R-13 fiberglass batt insulation	**R-28** - 3½" Metal EPS SIPs w/ 2x3 interior wall	**R-40** - 5" Metal EPS SIPs* w/ 2x3 interior wall	**R-48** - 6" Metal EPS SIPs* w/ 2x3 interior wall
		R-26.9 - 5½" semi rigid mineral wool w/6" fiberglass clips, sheathing, 2x6 metal studs w/o insulation	**R-47.0** - 5½" semi rigid mineral wool w/6" fiberglass clips, sheathing, 2x6 wood studs w/4" closed cell spray foam	**R-54.3** - 5½" semi rigid mineral wool w/6" fiberglass clips, sheathing, 2x6 wood studs w/5½" closed cell spray foam
				R-52.6 - cladding, sheathing,11 7/8" TJI's @ 24" o.c. w/ dense packed cellulose insulation, sheathing, 2x3 interior wall
WINDOWS	Thermally broken extruded aluminum storefront w/ 1" IGU w/ Low-E on face 2	Insulated fiberglass frame windows w/ ultra-wide IGU w/ suspended film	High performance insulated fiberglass frame windows w/ ultra-wide IGU w/ twin suspended film	High performance insulated fiberglass frame windows w/ ultra-wide IGU w/ twin suspended film
SLAB ON GRADE INSULATION	No insulation	R-10 6' from perimeter	R-10 Continuous	R-10 Continuous
ENVELOPE COST	Highest	Lowest*	Mid-range	High

Sustainable Energy Fund 2015 Study

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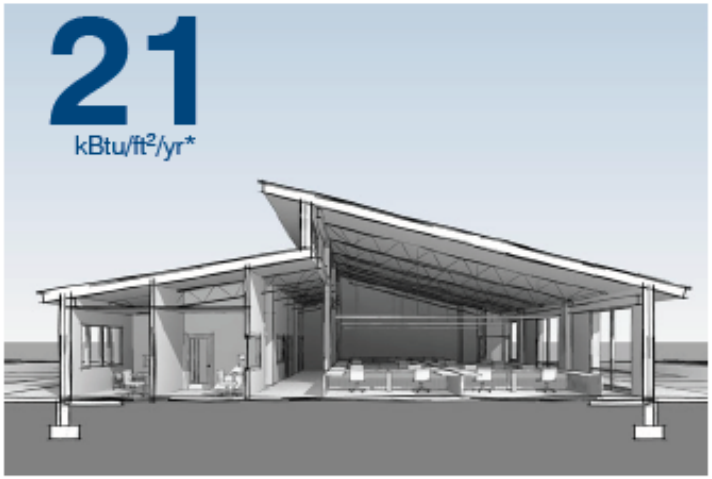
Net Zero / 15,000 S.F Office Building

Getting the NZE Ready design to be more energy efficient than the Baseline was straightforward. However, it took numerous iterations to find the sweet spot for energy efficiency and first cost. An EUI of 21 kBtu/ft^2/yr was not the lowest possible, but the "smartest" level balancing first cost with anticipated return.



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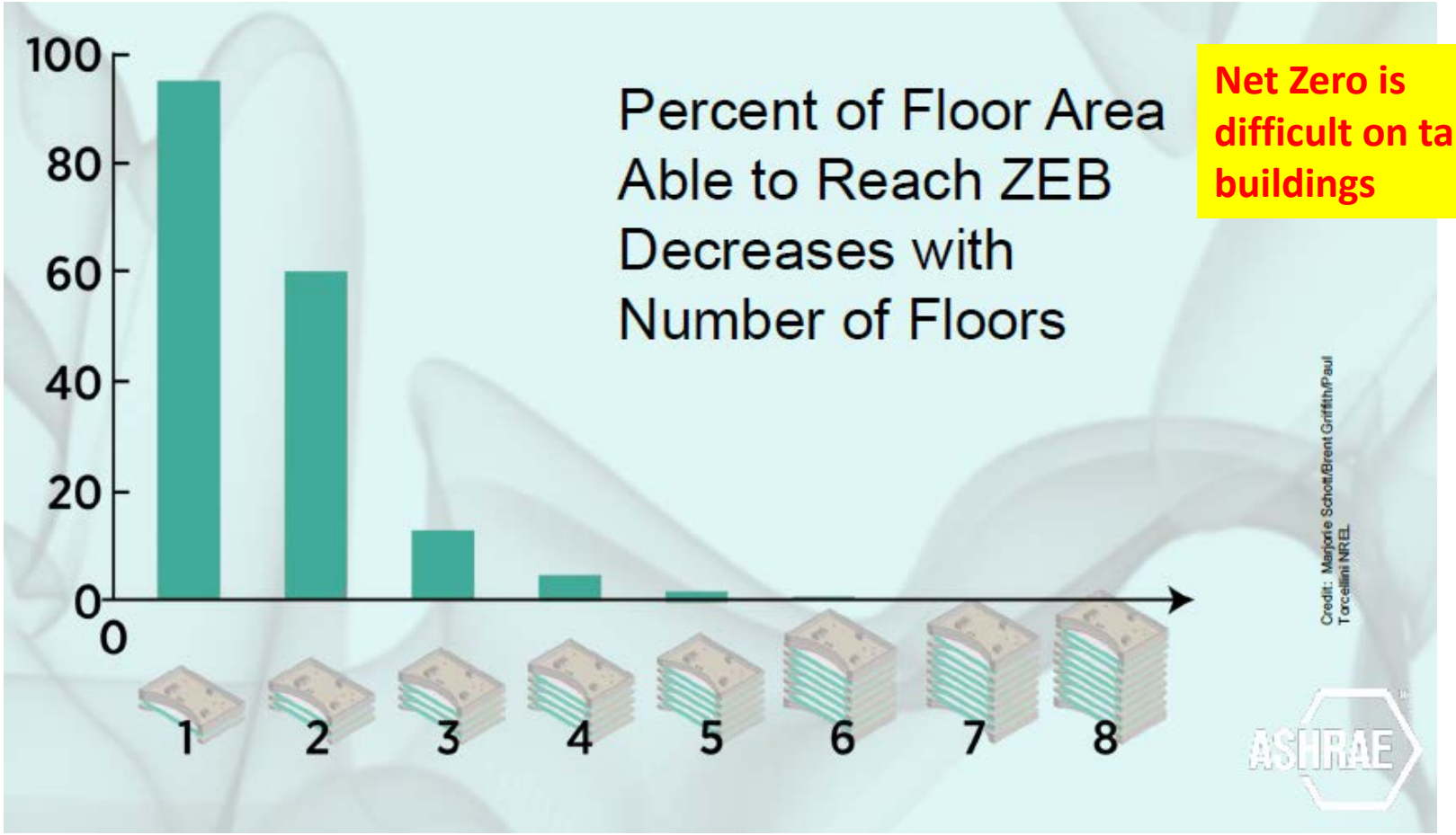
Other Considerations



Net Zero is difficult on taller buildings

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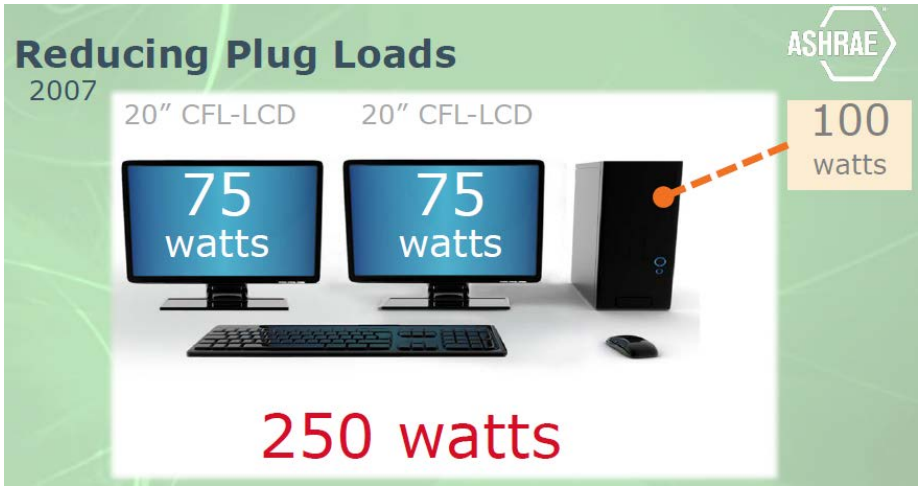
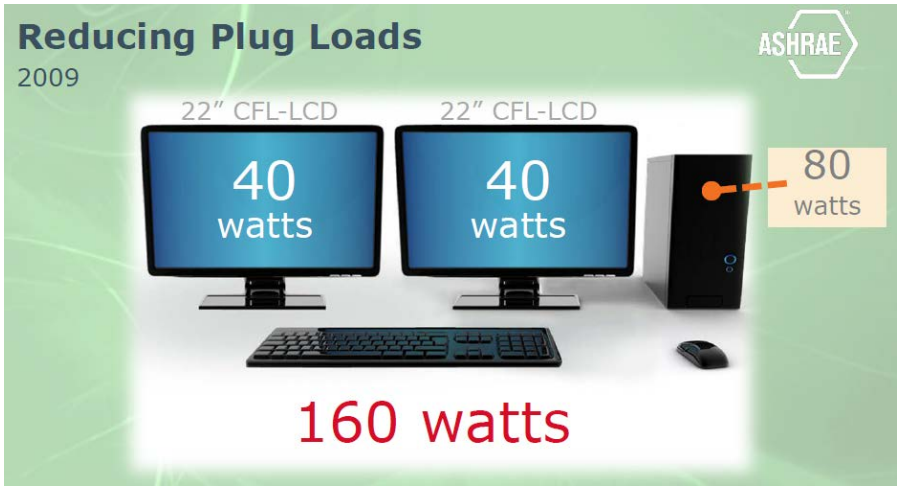
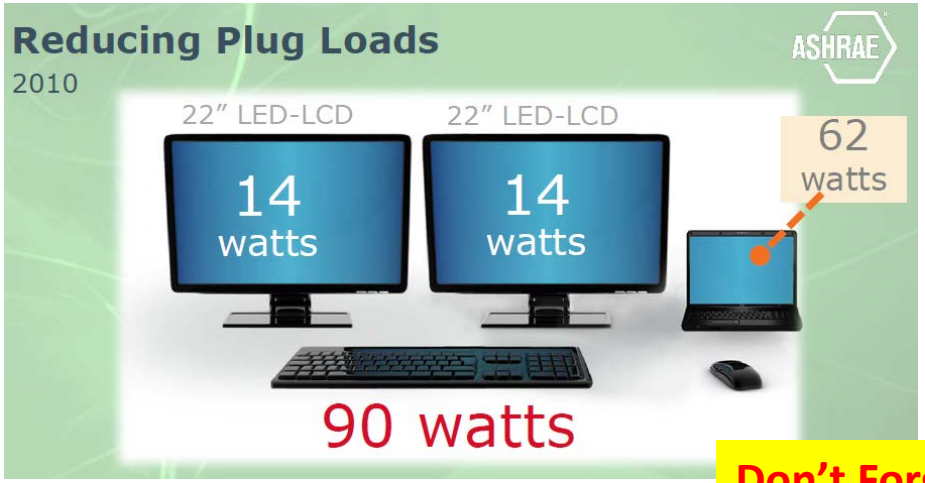
Other Considerations







Don't Forget Management of Plug Loads

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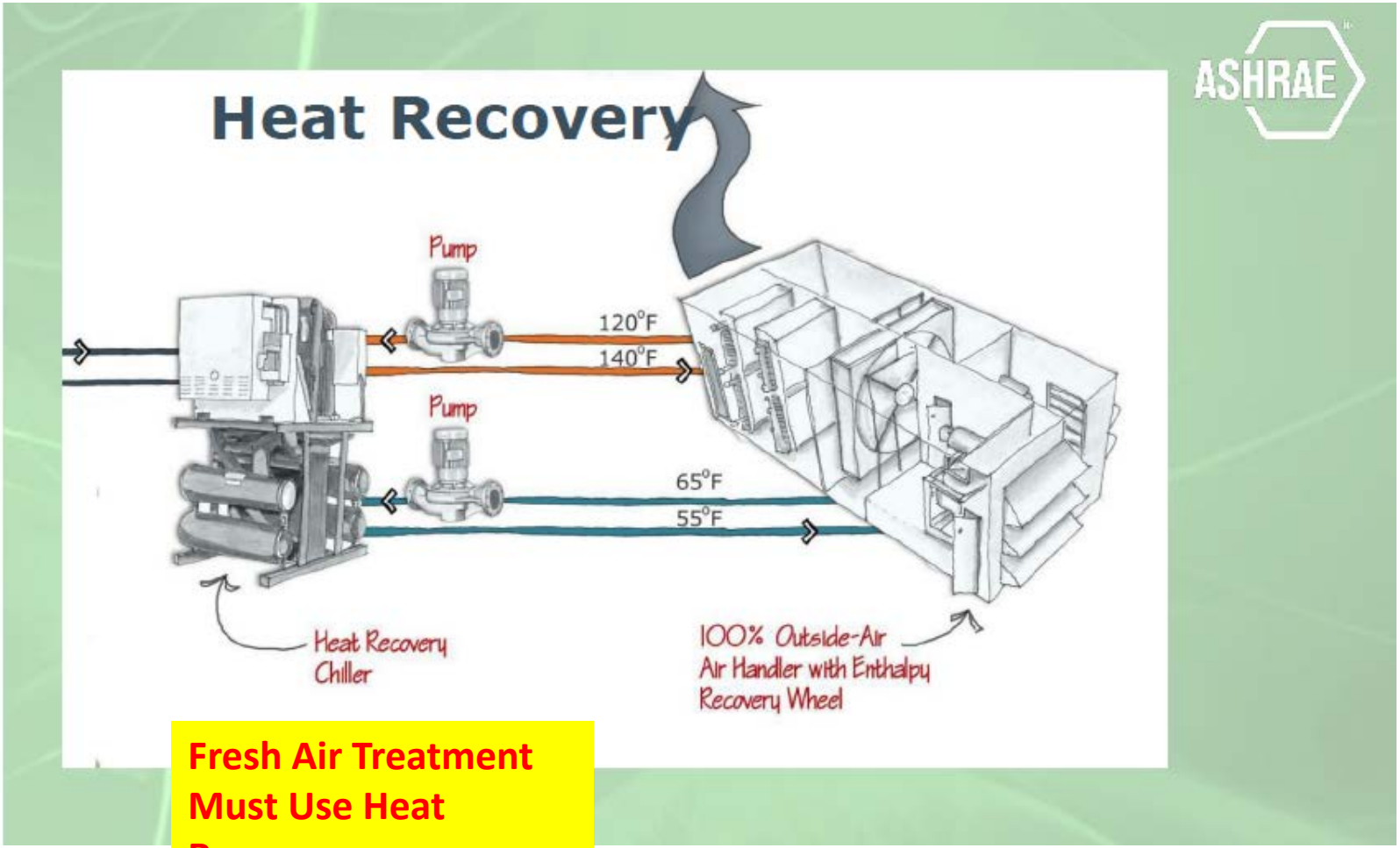
Other Considerations



Fresh Air Treatment Must Use Heat Recovery

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Other Considerations

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Other Considerations

Wind Energy is about double the cost of PV as a site generated utility

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Other Considerations

PV

The Workhorse

Solar Power is the Workhorse
But only buy how much you need

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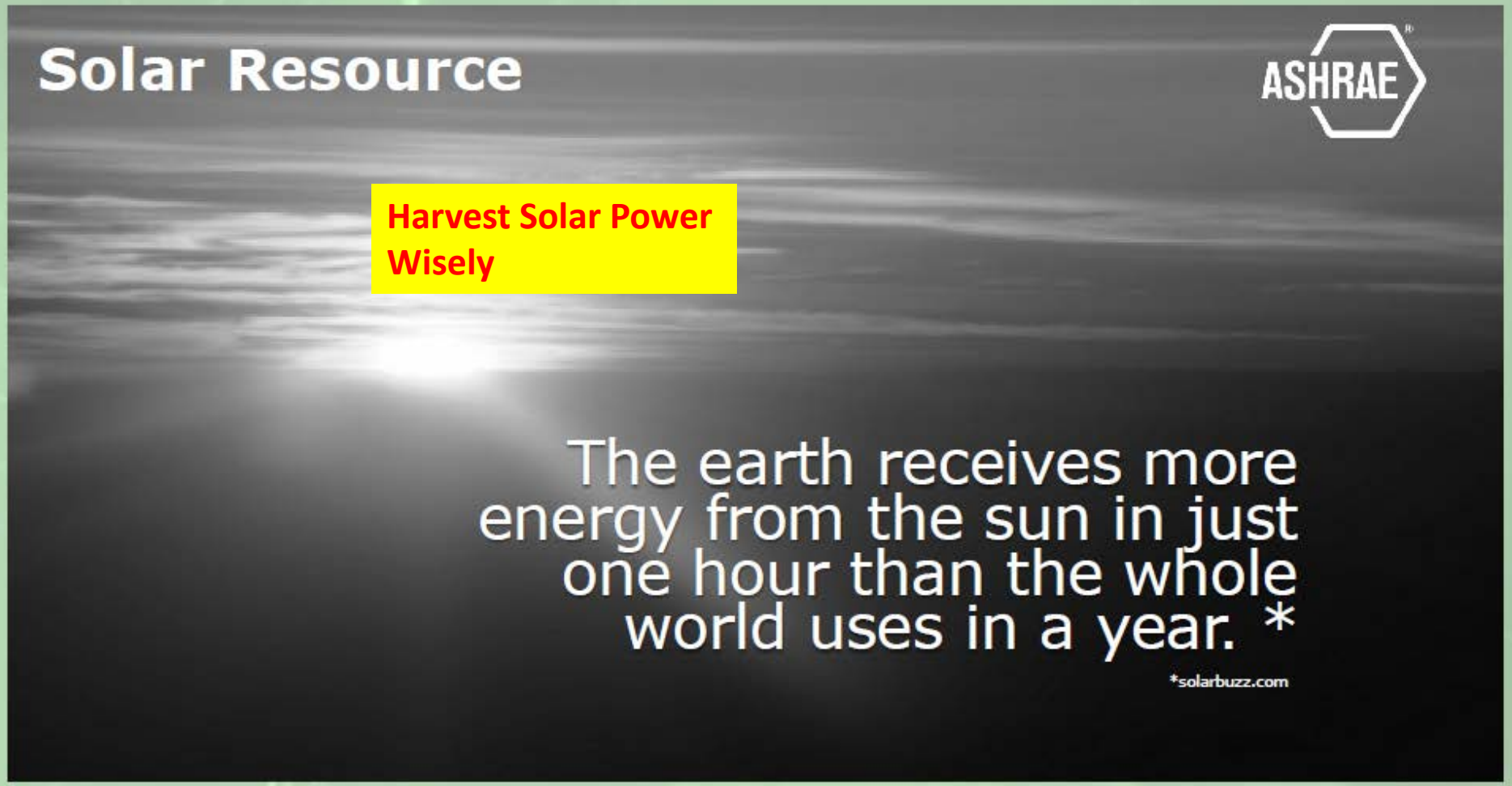
Other Considerations



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Net Zero – What is the best bang for the buck?

• Lighting and Plug Loads	**Yes – Mandatory**
• Occupant Training	**Yes – Mandatory**
• Building Orientation	**Yes – If Possible**
• Building Envelope	**Yes – But How Much?**
• HVAC System Selection	**Yes – VRF, Geo, or Geo VRF**
• On Site Renewables	**Yes – Which Ones?**
– Photo Voltaic	
– Wind	
– Solar Water Heating	

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PACE Financing

What is PACE Financing?

- Established in 2009 by U.S. Department of Energy
- Financing for energy efficient projects
- PACE is a property-secured financing framework
- Connects property owners to the capital markets through a tax lien in the amount the property owner desires to have financed
- The capital provider enjoys the benefit of a senior lien
- The property owner enjoys the benefit of lower interest rates and convenient repayment

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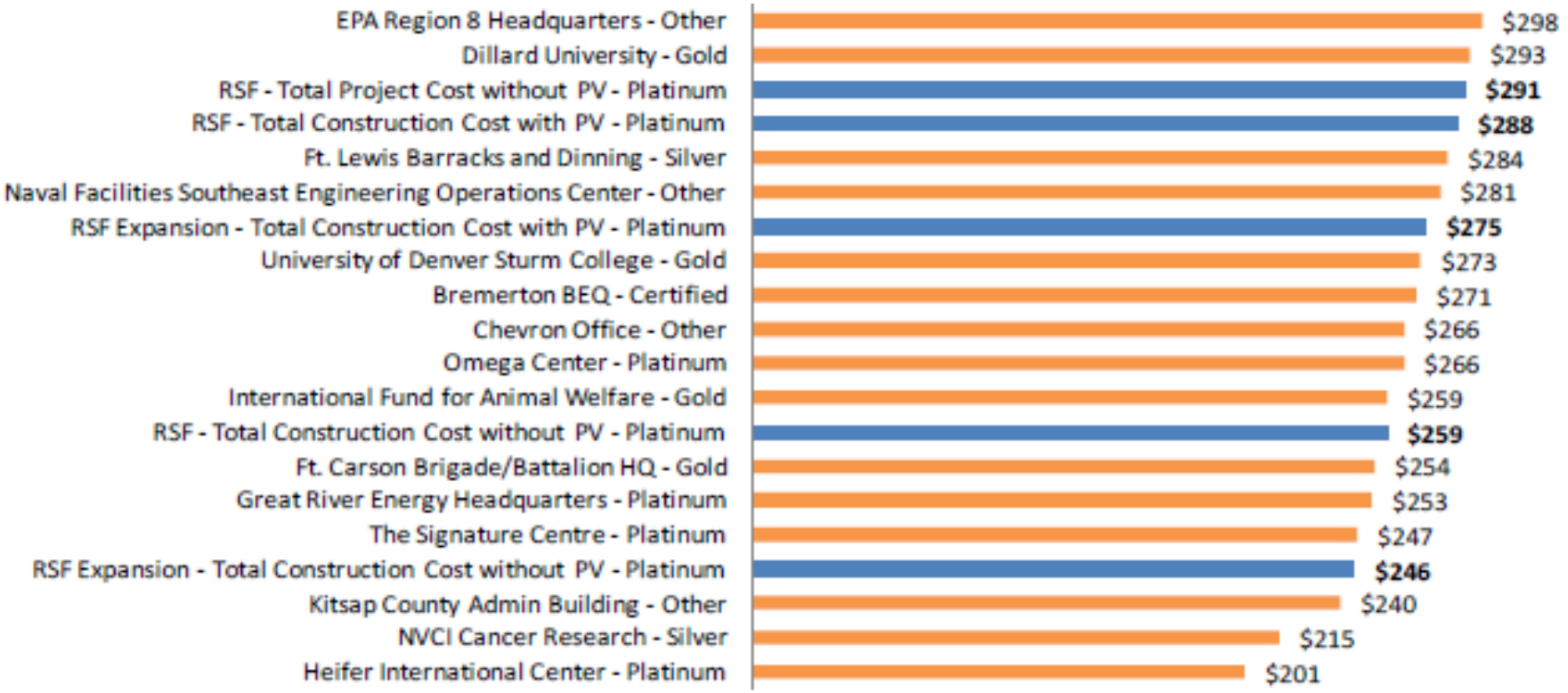
For NZEB to be Commercially Viable…….



NZEB PROJECTS UNDER $ 300 PSF per DBIA

…….We will need to utilize COST EFFECTIVE technologies.

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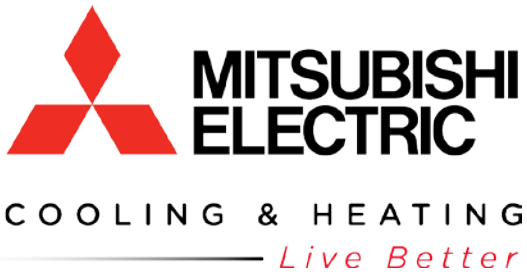
Thank you for your time!

Questions?



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