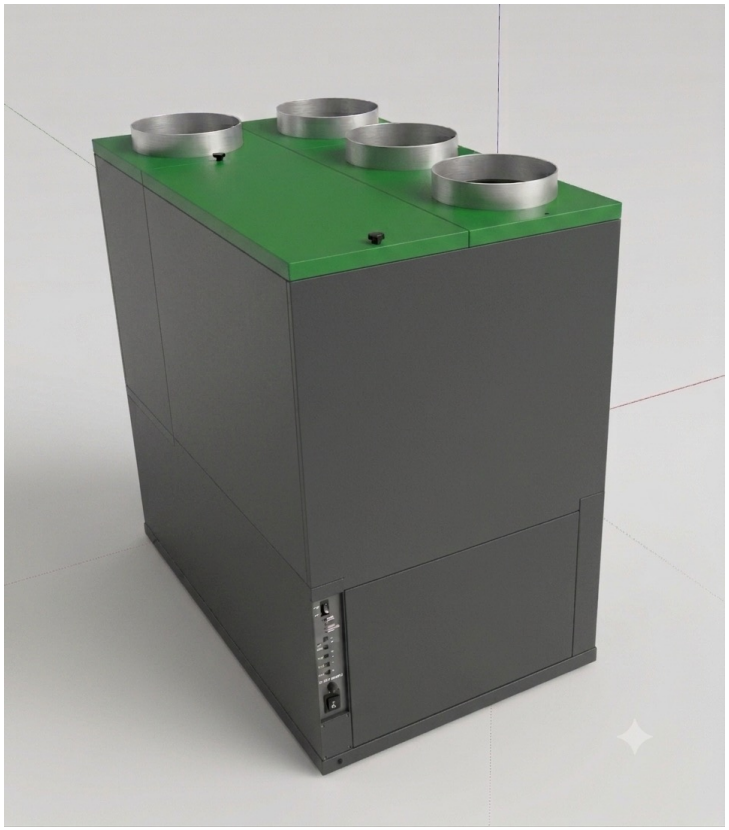
Designing a Cold Temperature Heat Pump for Air Quality and Comfort Management

-Introducing the CERV3



Ty Newell
Build Equinox
Buildequinox.com

BUILD EQUINOX

SOLUTIONS FOR A HEALTHY, COMFORTABLE, AND SUSTAINABLE LIFESTYLE

MADE IN AMERICA
SOLAR POWERED BUSINESS

Build Equinox/Newell Instruments History

CERV R&D 2008 NA PHI conf

2005-07 DOE Solar Decathlon

Gen 1 CERV 2010

Equinox House

UL 2012

CERV2 2017

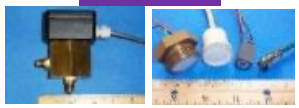
BE IAQS 2023

CERV-1000 2024

CERV3 2024 IAQ & Comfort

1990 | 2000 | 2010 | 2020 | 2030

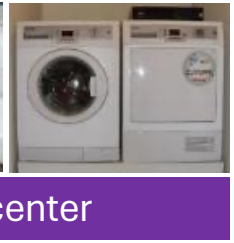
NI founded 1996 Refrig sensors



JO3C military -40C to 60C 25T ventilator

VerdeGSE 2013-19 30T-120T

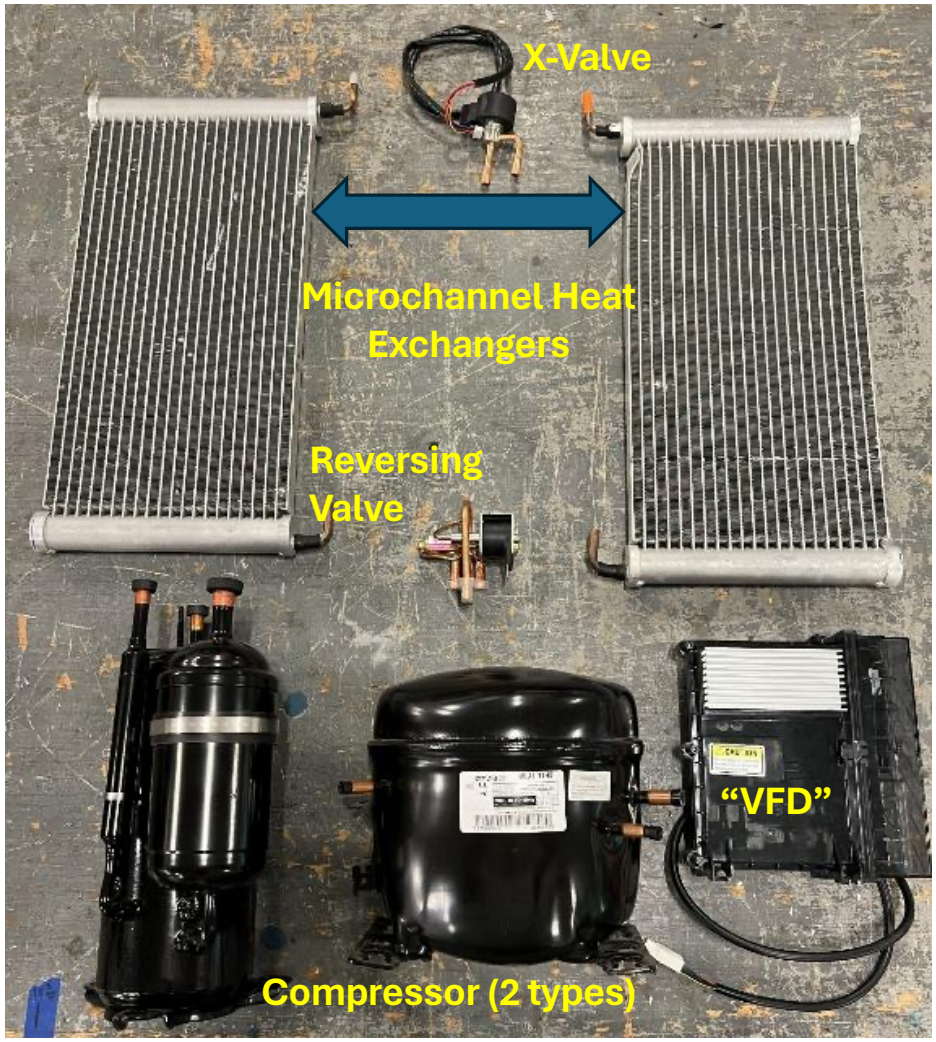
Appliance R&D HPWH, HPCD, refrig, dish, etc



Automotive

Refrigerant enhanced heat transfer test center

Heat Pumps

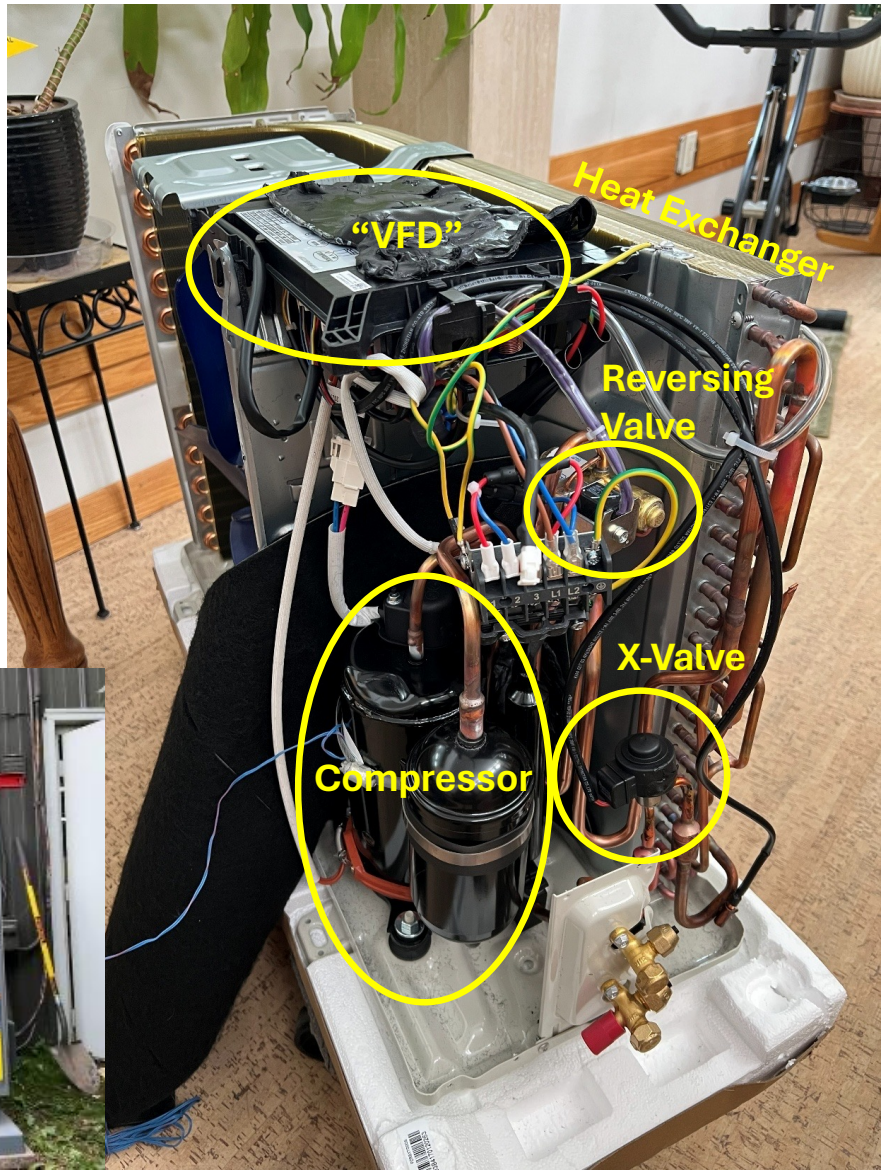


- Modern "Vapor Compression" heat pumps consist of:
  - "Electronic" Expansion Valve
  - Reversing Valve
  - Compressor (two types shown)
    - Low side sump/High side sump
  - 2 Heat exchangers ("high" side and "low" side)
    - CERV2 (and 3) heat exchangers are "aluminum microchannels" for high heat transfer, low corrosion, low refrigerant charge
  - CERV2 (with low side sump compressor) components are shown
  - CERV3 uses same architecture with double heat exchanger size and larger capacity, high side sump compressor

VFD (Variable Frequency Drive, aka, inverter or frequency drive) with electronic expansion valves paved the way for low ambient heat pumps that efficiently operate over broad temperature ranges

Minisplit Heat Pumps

1 ton Senville ODU (Outdoor Unit) components; the other heat exchanger is in the IDU (Indoor Unit).....operates to -22F; $1450 & free shipping!



Cold Temperature Heat Pumps

Cold climate heat pumps evolved ~20 years ago due to two developments:

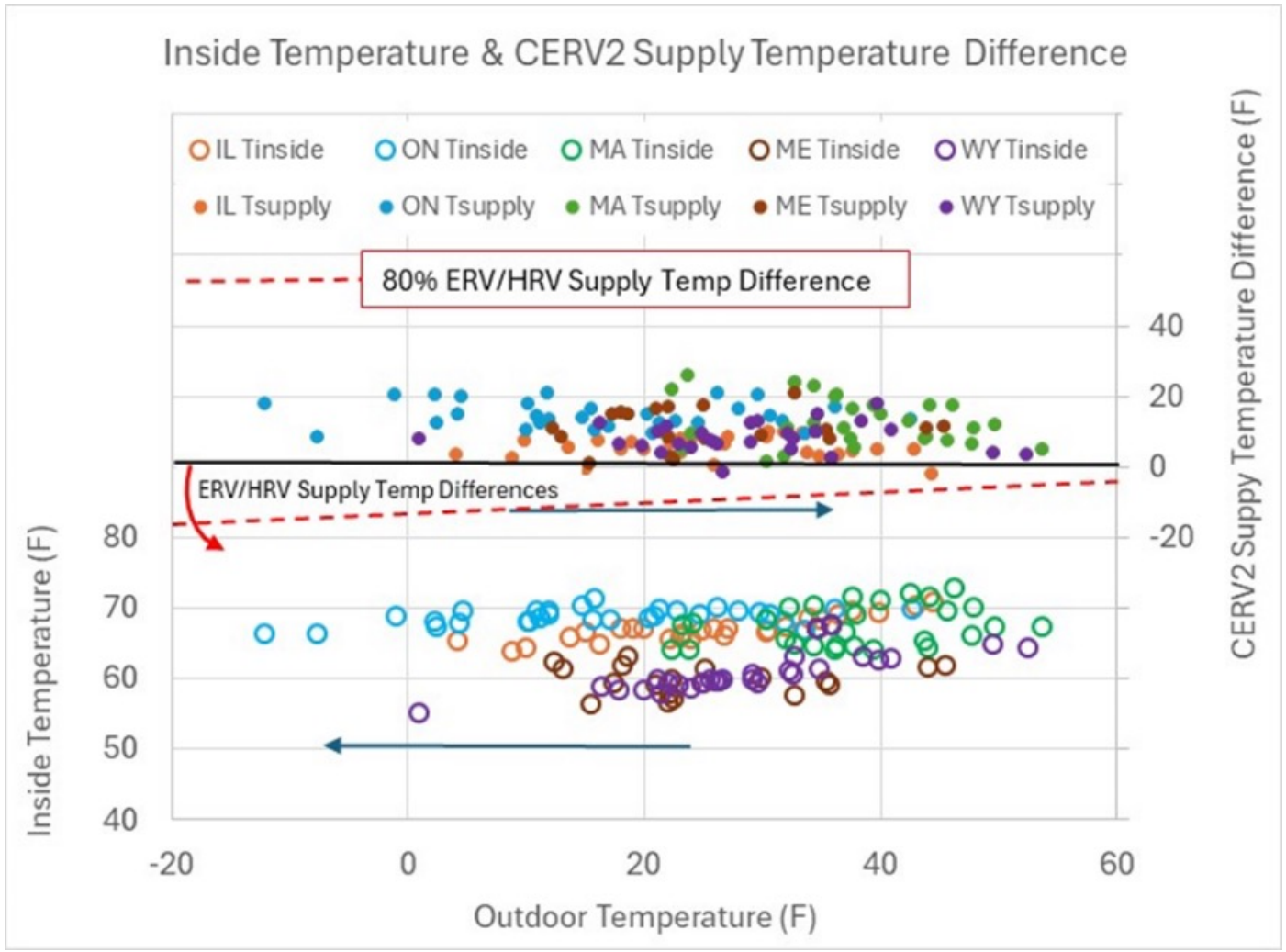
- Motor speed control (VFDs, ECM)
  - Pumps, fans, compressors, EVs
- Electronic controls (microprocessors, sensors, expansion valves, hot gas valves, suction gas valves, EVI, etc)

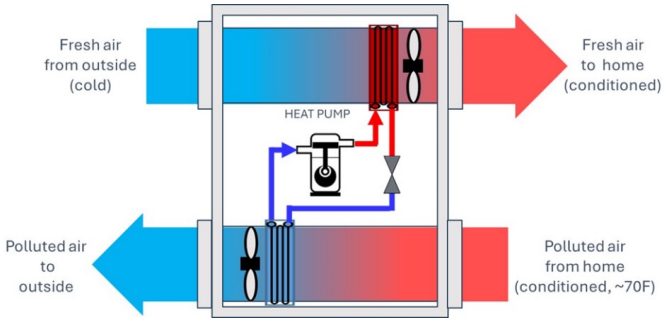
Why is Speed Control Important?

- "Refrigerants" are fluids operating between liquid and vapor states
  - Cold temperatures (heating) lower refrigerant vapor density, requiring higher compressor speeds to move more refrigerant
  - Warm temperatures (cooling) increase vapor density, requiring lower compressor speeds
- Refrigerant flow must be modulated to keep heat exchangers satisfied and avoid flooding/starving compressor of refrigerant
- Old "bang-bang" (on/off) constant speed compressors with crude refrigerant flow control (TXV) restricted operation leading to persistent myth that heat pumps cannot operate at cold temperatures

"Northeast Kingdom" Hardwick VT experienced sustained temperatures below -20F during January 2018

Heat Pump Energy Recovery – Why?





- Heat pump energy recovery delivers comfortable temperatures to indoor space
- No frost "protection" needed … frost contributes heat to indoors
- Can turn off energy exchange when unfavorable
- Data from Illinois, Ontario, Massachusetts, Maine and Wyoming show a broad range of winter conditions

Heat Pump Development

Developing a heat pump requires testing! Laboratory test facilities provide controlled (steady and transient) conditions. Field testing is essential. No indoor testing can replicate real weather!

- 10 outdoor temperatures
- 5 indoor temperatures
- 3 indoor humidities
- 3 outdoor humidities
- 4 indoor air flows
- 4 outdoor air flows
- 6 compressor speeds
- 6 refrigerant charges
- 6 expansion valve positions
- **~1,500,000 tests to try every combination**
  - Design of experiments and observation to reduce tests
- And then, UL listing, various certifications…..

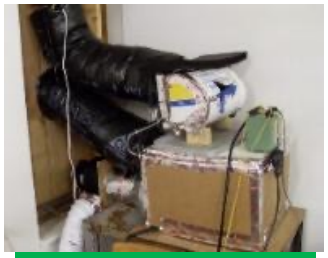
- **CERV online monitoring provides Build Equinox with real world operating data.**
- **OTA (over-the-air) provides seamless upgrading and algorithm improvements**
- **Data is never sold!**
- **CERV units do not require online operation**

3 Generations of CERV

Conditioning Energy Recovery Ventilator
CERV; Pronounced “serve”
….its purpose is to serve you!
Prototype circa 2007; initial data at 2008 Duluth North American Passive House Conf
Primary Purpose: Maintain a healthy indoor environment in an energy efficient manner

CERV-1000

High occupant density
1000cfm fresh air
3 tons low temp heat pump



2007 prototype

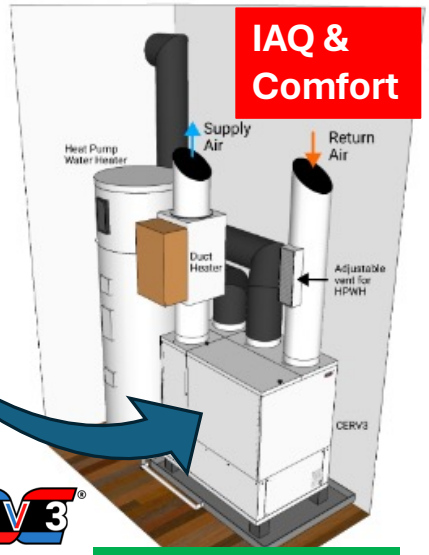
CERV IAQ

1st Gen – 2010 to 2017

CERV2 IAQ

2nd Gen – 2018

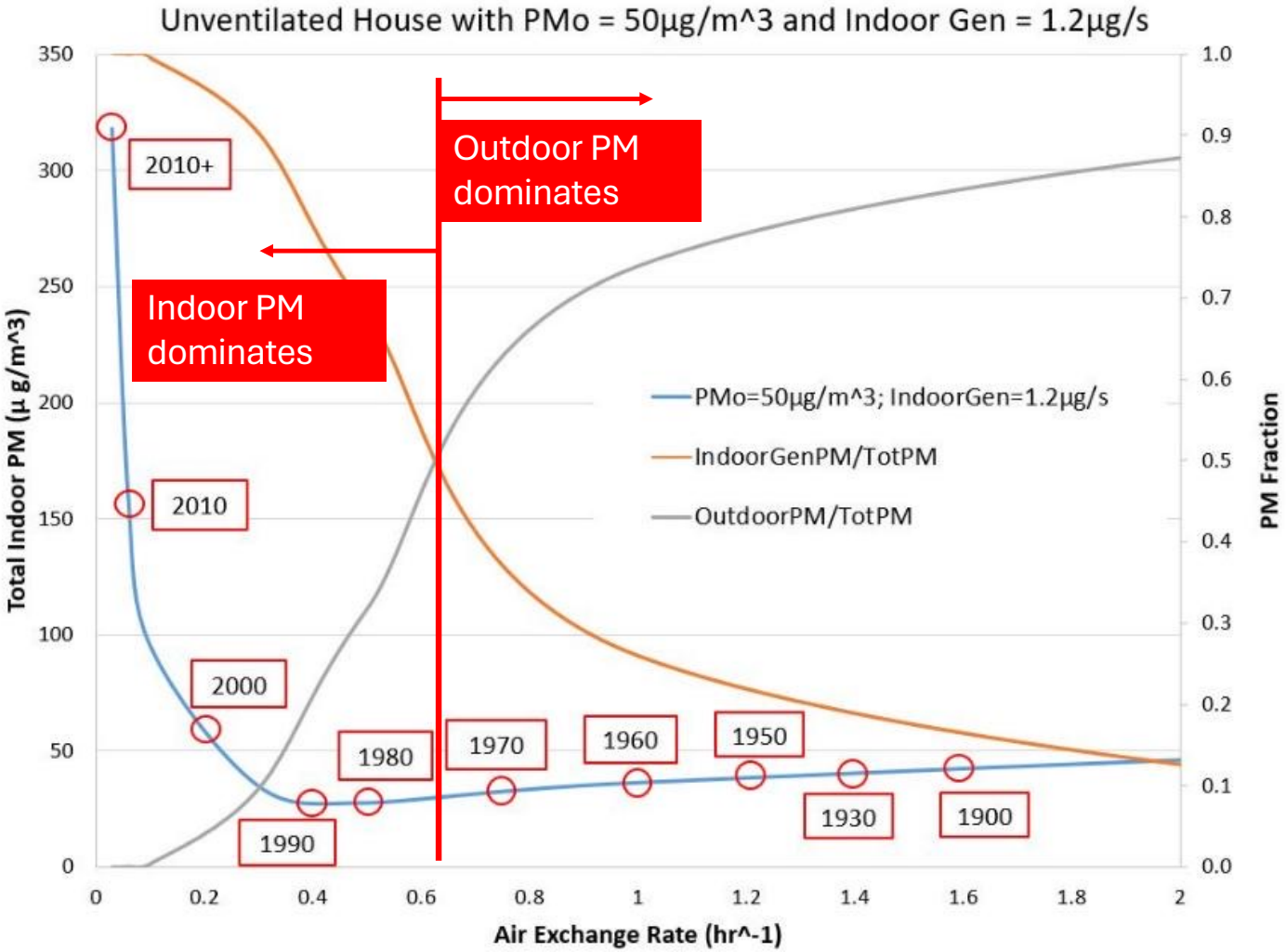
CERV3 IAQ & Comfort



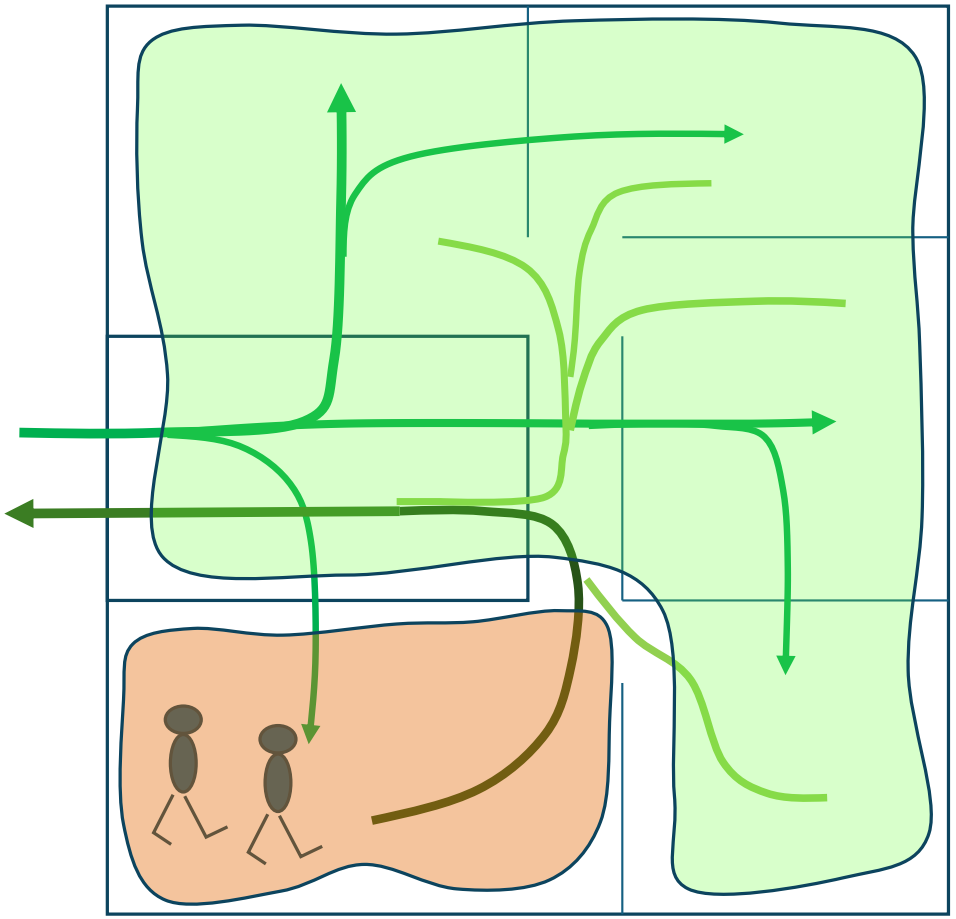
3rd Gen – 2026!

Indoor Environment Has Changed!

- Residential air exchange rates since 1894 from LBNL
- As homes have become better sealed (even today's poorly sealed conventional homes are much better sealed than past homes)
- Air conditioning has closed homes during the summer, and high efficiency furnaces with sealed combustion air have sealed homes in the winter



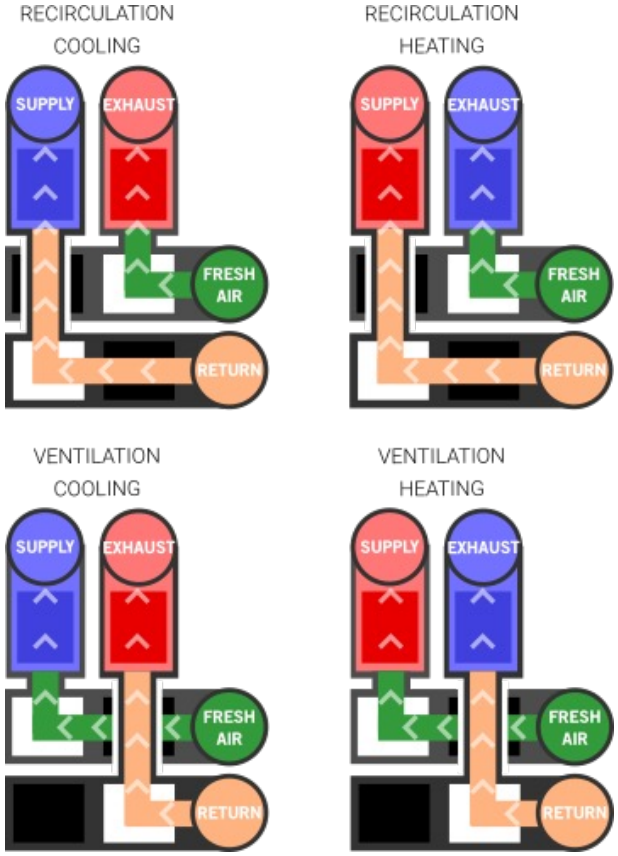
Constant Flow Ventilation – Inefficient & Ineffective



Ventilation airflow subdivided without recirculation, comfort conditioning and zone control:

- Poor air quality in occupied areas
- Wasted fresh air in unoccupied areas
- No indoor particulate filtering
- Poor comfort control
  - Rooms without conditioned air are pulled away from comfort
  - Exiting airflow prevents conditioned airflow from entering rooms

CERV2/3 Operation Modes

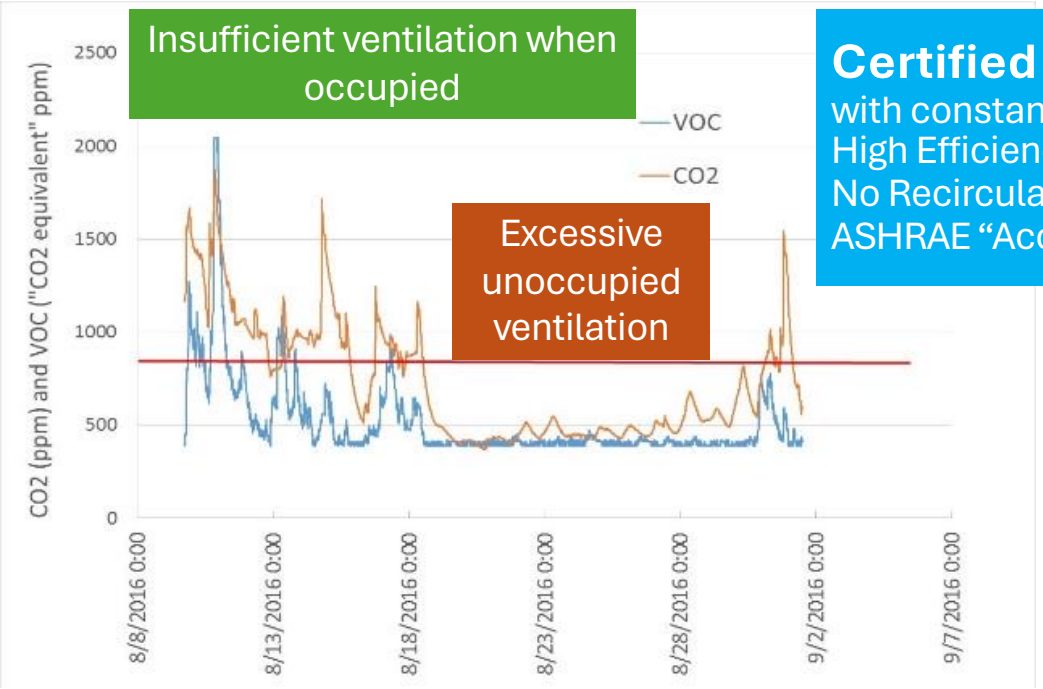


Want to open a window or door?

Go ahead, the CERV2/3 will sense and adjust

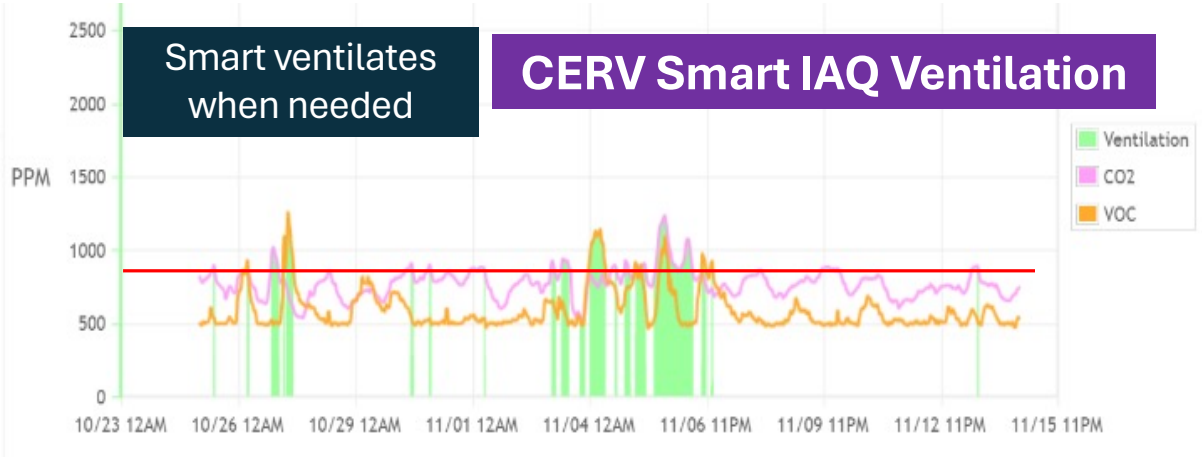
When it is “nice” outside, the CERV2/3 brings in fresh air automatically

Optional wireless, battery free window & door sensors allow CERV2/3 control comfort system operation (and to monitor status of door/window openings)



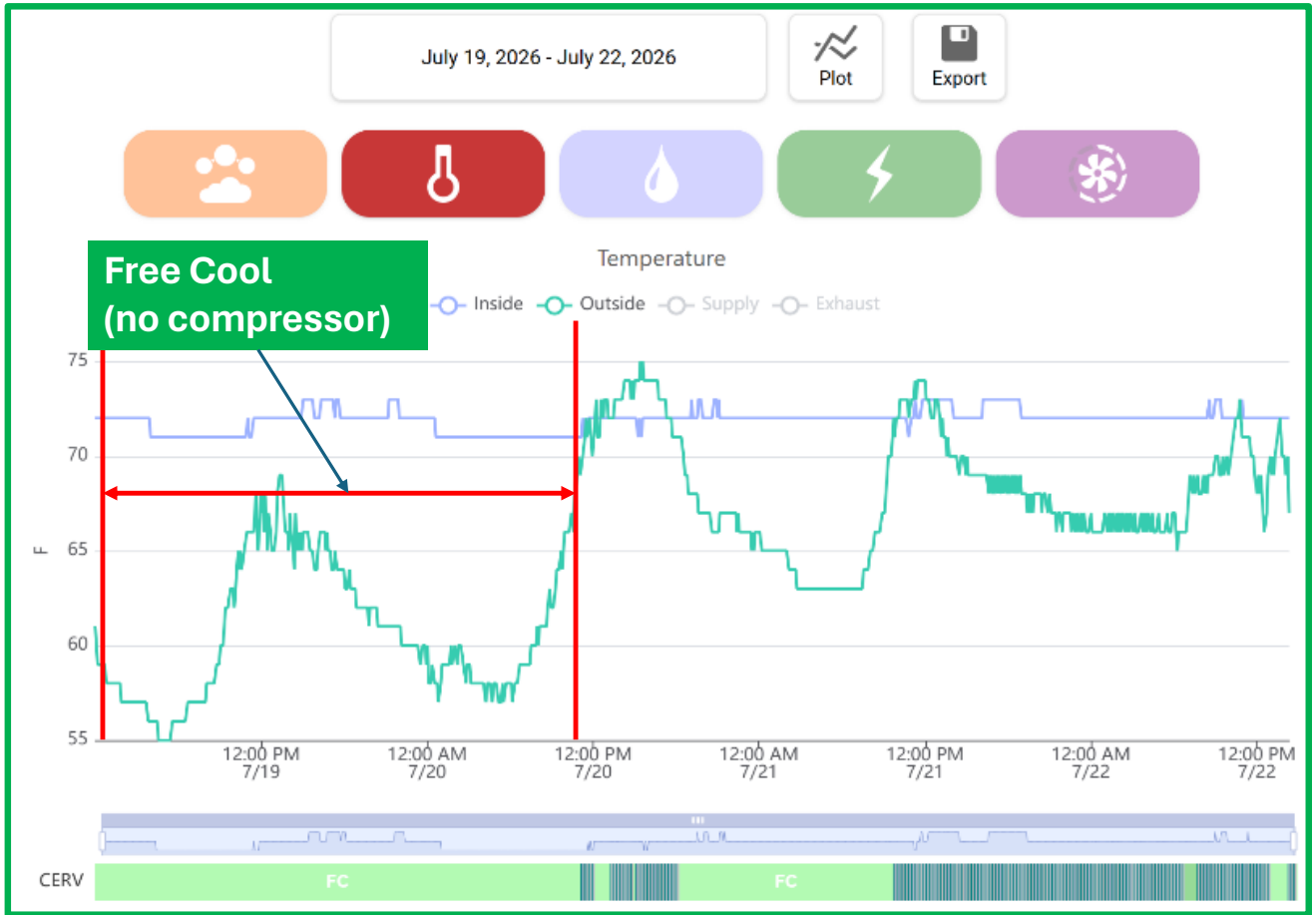
Certified Passive House
with constant flow ventilation
High Efficiency ERV (95%Sens; 75% Lat)
No Recirculation
ASHRAE "Acceptable" ventilation

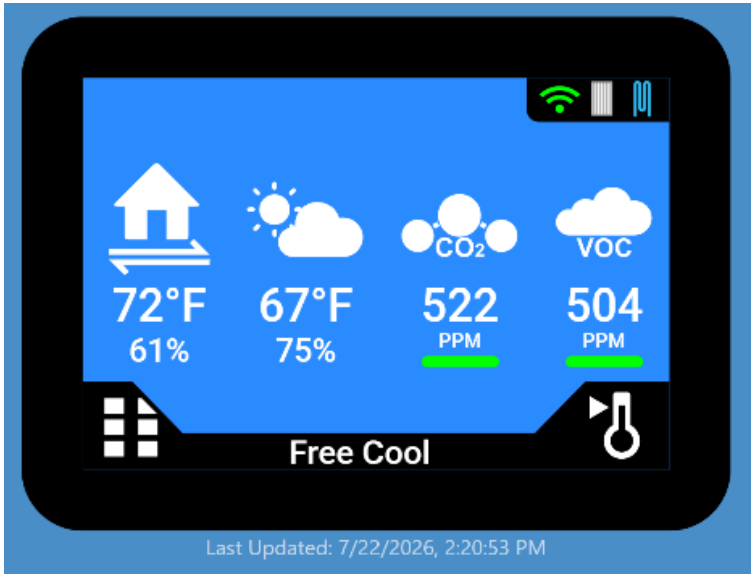
Comparison of PH Residence with Constant Ventilation and CERV Smart Ventilation



With today's sensors, automatic fresh air control improves our health and energy efficiency; allowing us to do the things we enjoy and not worry about IAQ

Free Cool - Montreal

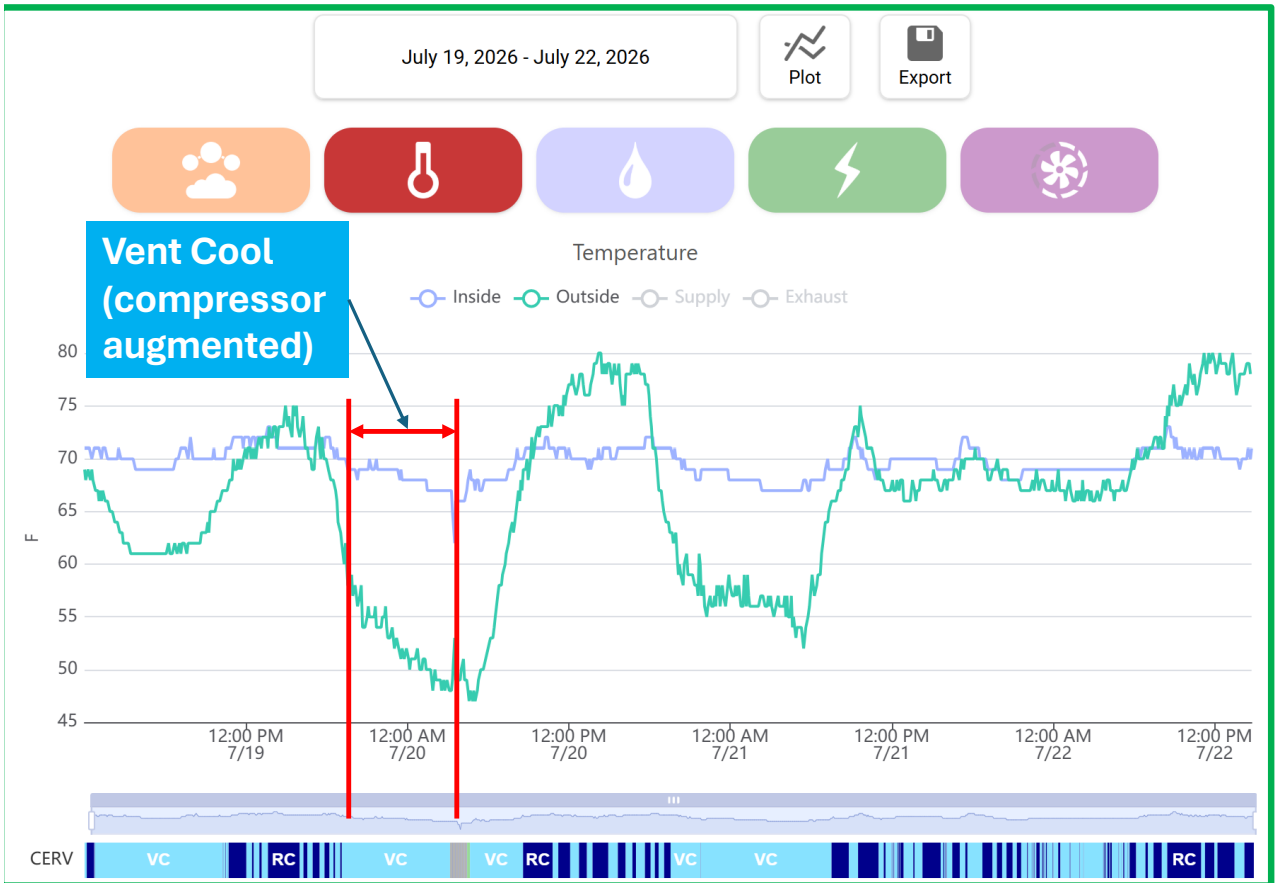


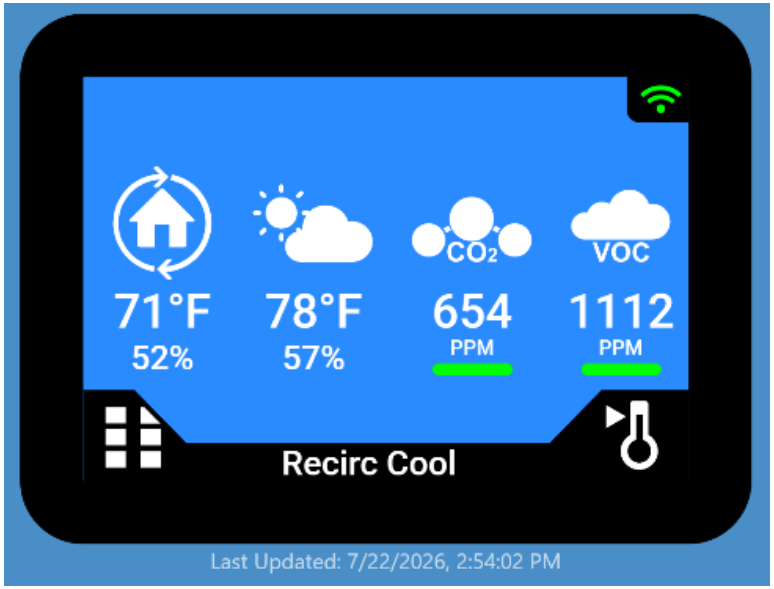


When outside is "nice" relative to indoors, CERV2 "free cools"

- **Automated window opening….whether you're awake or asleep, home or away**
- **Unlike opening a window, fresh air is filtered!**
- **Fresh air can be "stored"! ….delaying or eliminating venting when not-so-nice outside**

Vent Cool – Habitat Home Vermont

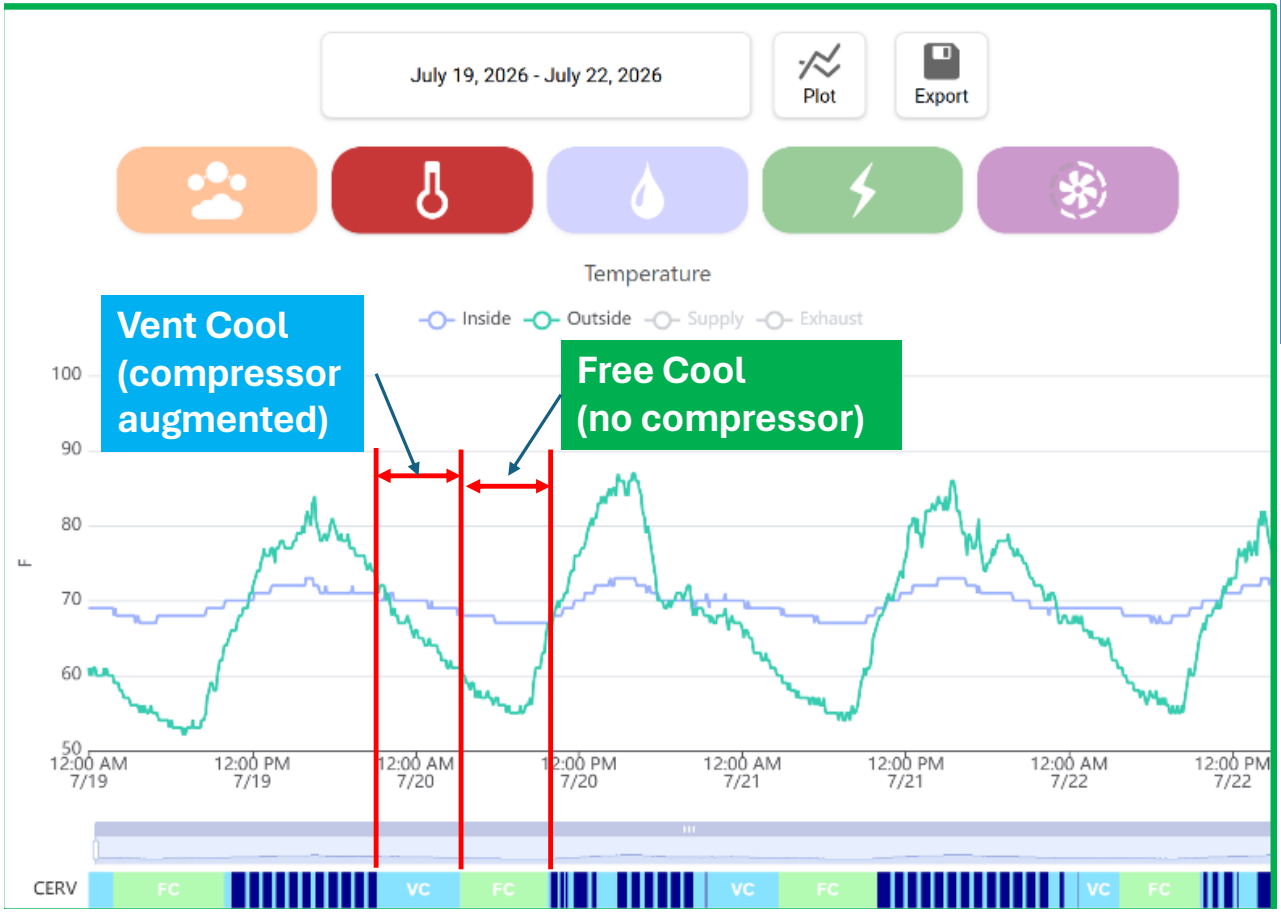


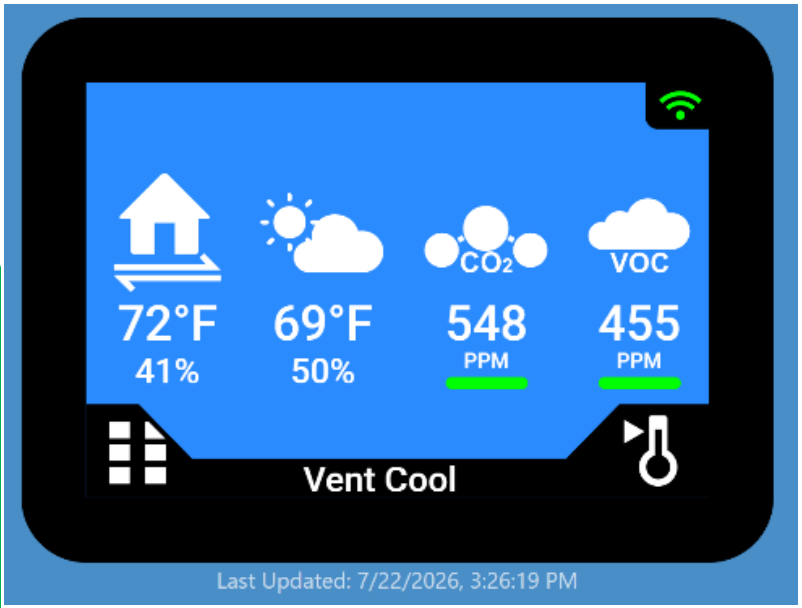


When outside is "nicer" than indoors, CERV2 "vent cools"

- Vent cool occurs when indoor temperature deviates from thermostat setting, requiring higher cooling capacity
- Outdoor air more energy efficient to cool than indoor air
- House pollutants lowered

Vent & Free Cool - Colorado





CERV2 moves seamlessly and automatically from one mode to another mode

Energy Comparison

Stanton Home:
Architect: Katrin Klingenberg
Built 2009
East of Urbana Illinois

- Owner replacing ductless minisplit head every other year
- Ultimate Air ERV with geoloop heat exchanger
  - 95% sensible
  - 75% latent
- Early certified North American Passive House

RecoupAerator® 200DX
Energy Recovery Ventilator

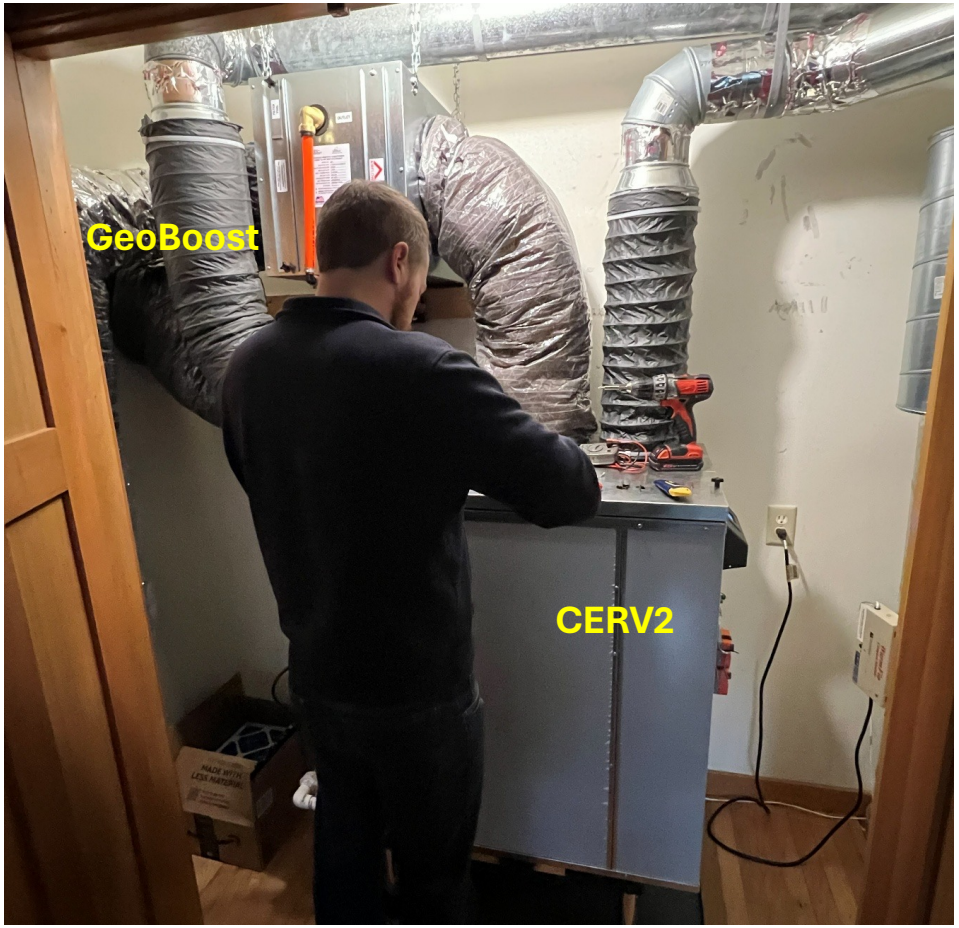
Owner's Manual
&
Installation Guide

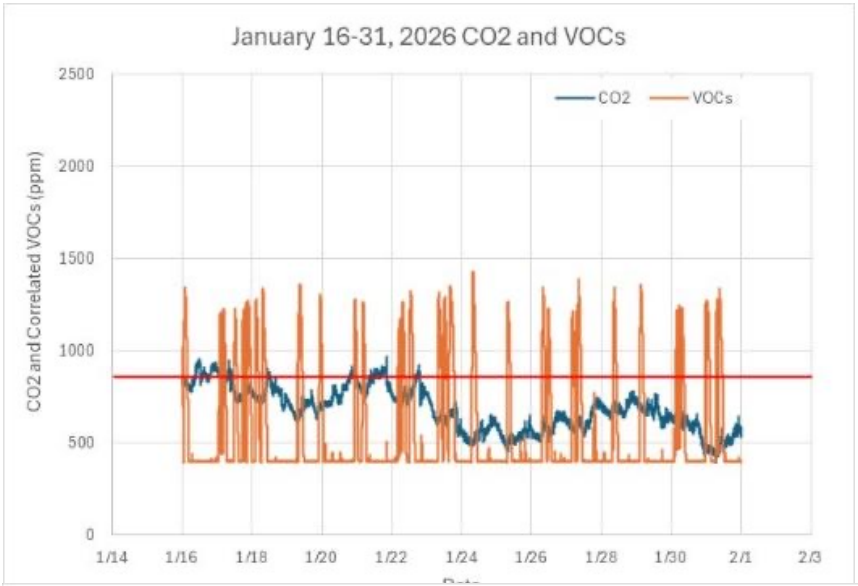
UltimateAir®

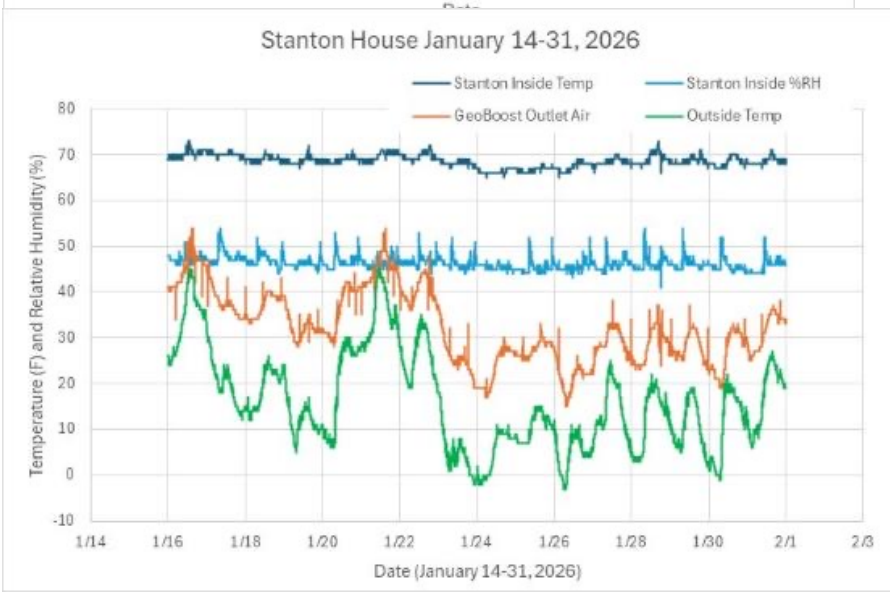
Specifications

Model	RecoupAerator 200DX Energy Recovery Ventilator (ERV). Includes pre-filters, patented energy transfer/filtration material, fans, controls, and motors.
Airflow Capacity	~70 – 210 CFM
Sensible Apparent Efficiency	95%
Heat Exchange Type	Patented rotary random matrix polymer
Filtration	Energy transfer/filtration material 95% effective at 1.8 microns (MERV 12), replaceable, with washable aluminum pre-filter

Stanton Home
CERV2 November 2025







Homeowner Comments

Gregory Fri, Jan 9, 11:15 AM

to me

Hi, this is Greg Stanton. First I want to say how glad I am that we installed the Cerv2. Considering it has already been tested in subzero weather and outperformed the old system - better distribution of heat, steady maintenance of set temperature and, greater efficiency/lower energy costs based on kWh comparison of the same time period between last year and this one. (Although I still want to see another months comparison to be sure).

Greg Sat, Feb 28, 11:48 AM

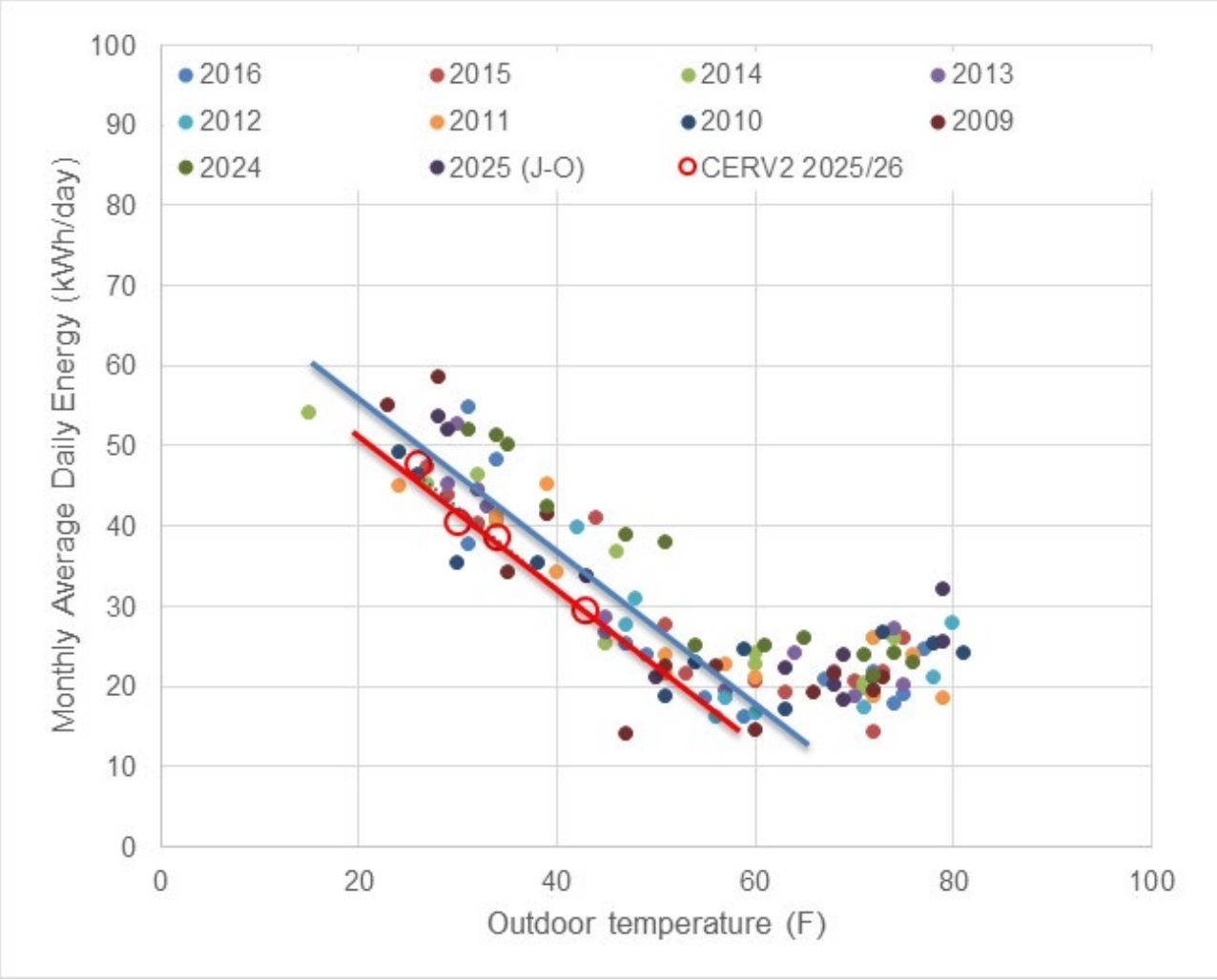
to me

I did a comparison of the power bills from the last three months and the year before (all billing periods the same) and we have conserved KWh each month since CERV2 was installed even though two months were 2 and 5 degrees colder (I'm sure there was some benefit from the solar hot water system too which has been running for past two months). So, that's the good news. The bad news is that my electrical bills have increased $21, $27, $17 from a year ago. Good deeds are punishable and I worry about the possibility of hidden demands from large Data Center Power Sponges

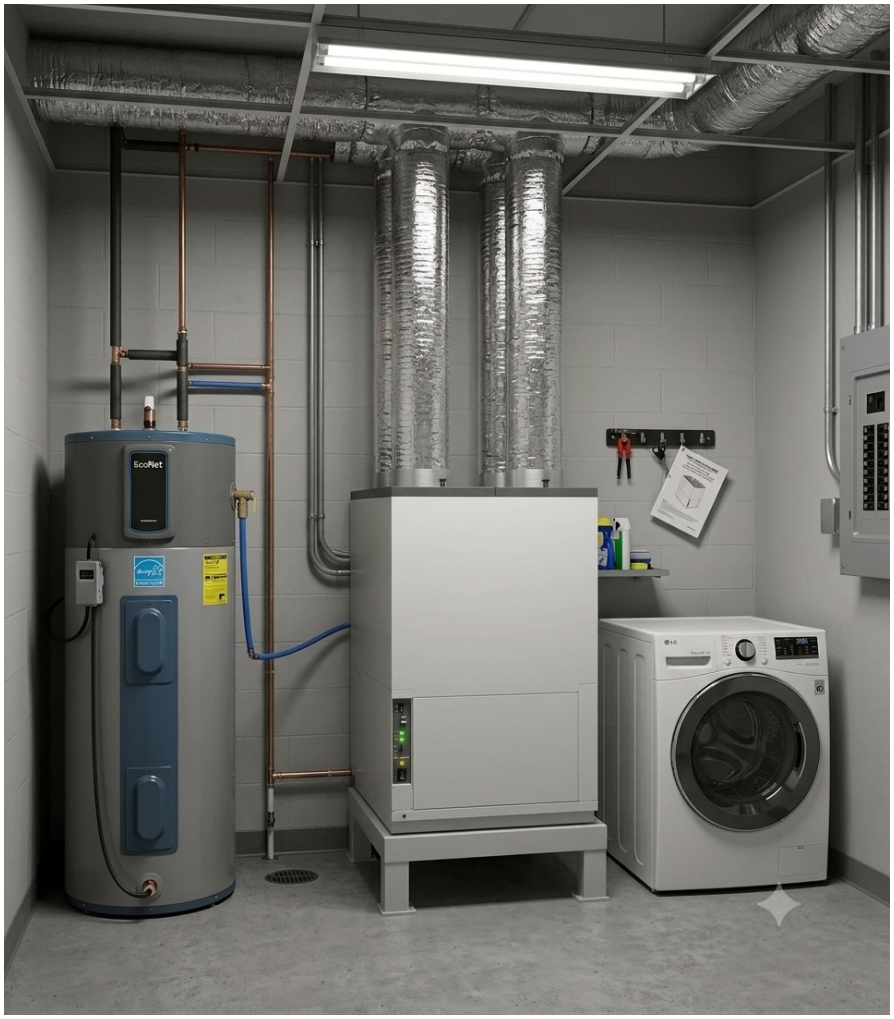
CERV2: Less Energy, Better Air Quality

- CERV2 ~10-12% more energy efficient with better air quality than 95% efficient ERV
- Champaign-Urbana IL winter ~6000 F-days (approximately 60% of year in heating mode with average temperature of 40F)

- Stanton home annual energy ~11,000kWh/year
- Before CERV2, winter ~6460kWh (adjusting DD from 65F to 60F reference)
- After CERV2, winter ~5640kWh
- Annual savings ~800kWh/y .... About 3000 miles of EV driving!



CERV3 – Smart Air Quality & Comfort Management



CERV3 is designed for all climates now and future climate changes

- 6sqsft floor area
- Manages HPWH (heat pump water heater) conditioning
- Individually meter each residence utilities
- Online administrative & maintenance dashboard included for monitoring, control & diagnostics

CERV3®

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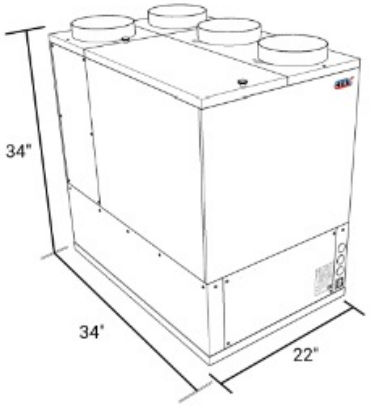
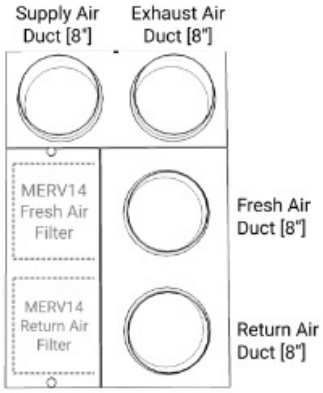
CERV3 Physical Parameters

Cold Climate Heat Pump | Fresh Air Ventilation | Air Pollutant Removal | Dust & Allergen Defense | Ultraviolet Germ Shield | Indoor Air Quality Monitoring | Low GWP Refrigerant

System	
Input Power	120 VAC 60hz (15A)
Dimensions	34" x 22" x 34"
Weight	140 lbs
Max Airflow	300 cfm
Filter Size	10" x 20" x 1"
Filter Type	MERV 14
Duct Openings	8" Round
Drain Outlet	3/4" PVC
Warranty	5 Years (1st Year Parts & Labor; Years 2-5 Parts Only)





- Hermetically sealed heat pump (nominal ¾ ton comfort capacity)
- "R32" low GWP (global warming potential) refrigerant
- No refrigerant connections or remote condensers
- Online administration and maintenance dashboard included (no service fees)
- Standard 10"x20" low cost MERV14 filters

CERV3 Performance

Recirculation Heating & Cooling		
Outdoor T	**Capacity**	**Efficiency**
95°F (35°C)	9,200 BTU/h	3.3 (COP)
82°F (28°C)	10,100 BTU/h	3.5 (COP)
47°F (8°C)	10,200 BTU/h	3.0 (COP)
35°F (-2°C)	8,000 BTU/h	2.6 (COP)
17°F (-8°C)	7,200 BTU/h	2.0 (COP)
5°F (-15°C)	6,100 BTU/h	1.76 (COP)

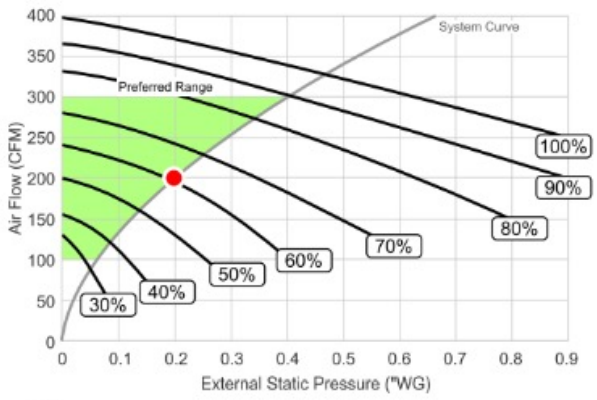
Heating and cooling capacity relative to indoor conditions.
Excludes variable speed fan power.

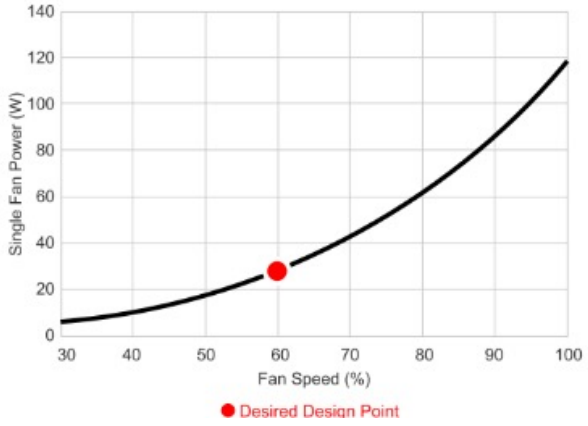
Dehumidification			
Indoor T	**Indoor RH**	**Capacity**	**Efficiency**
74°F (23°C)	50%	28.0 L/Day	1.54 L/kWh
74°F (23°C)	60%	37.3 L/Day	2.02 L/kWh

Energy Recovery			
Outdoor T	**Indoor T**	**Airflow**	**Efficiency**
95°F (35°C)	75°F (24°C)	100 CFM	1.0 TRE
32°F (0°C)	68°F (20°C)	100 CFM	1.1 SRE

Meets and exceeds Energy Star Cold Climate requirements.
May qualify for state or utility rebates for purchase and installation costs.

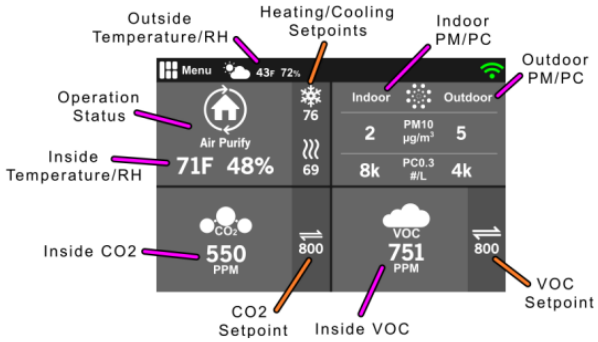
Fan Performance

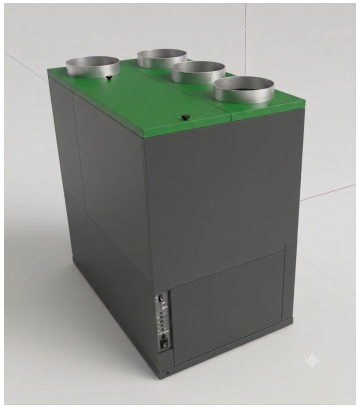




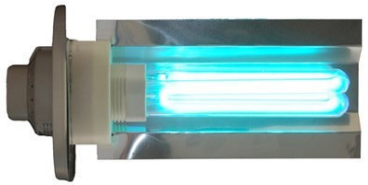
- **Cold ambient operation**
- **Hot and humid cooling with high latent (dehumidification) capacity**
- **Seamless electric backup (3kW duct heater)**
- **300cfm air flow capacity for pollutant management**
- **Efficient energy recovery during cold and hot weather**
- **“Free” conditioning when outdoor is “nicer” than indoor**

CERV3 IAQ Management





CERV-UV
ULTRAVIOLET AIR PURIFICATION

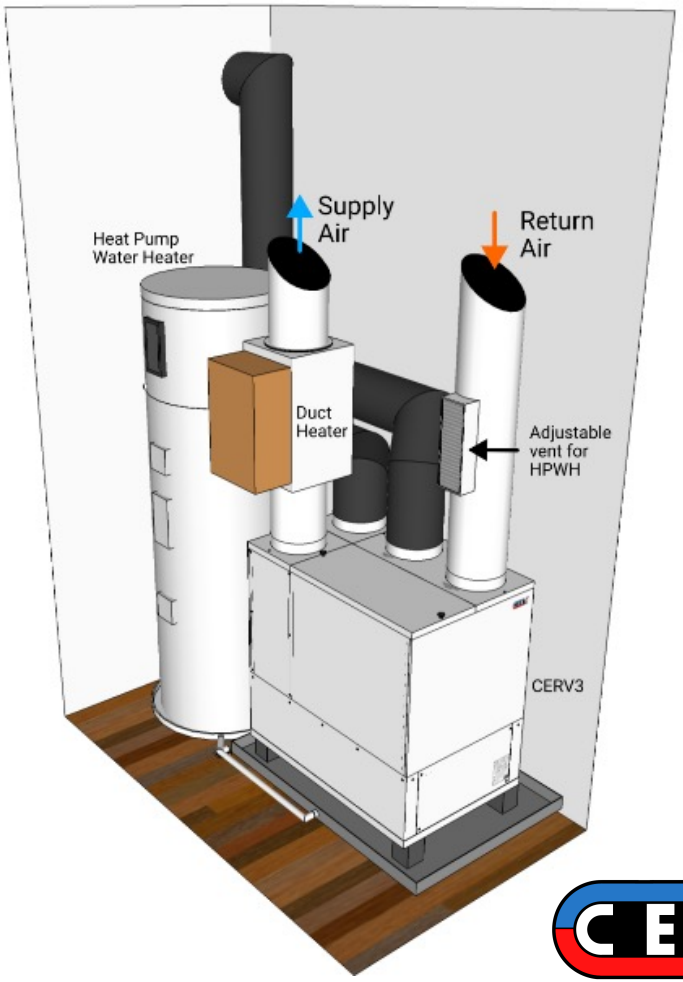


- Cold ambient operation
- Hot and humid cooling with high latent (dehumidification) capacity
- Seamless integration of aux components, sensors & actuators; eg, electric backup, bath vent switches, remote T/RH/CO2, humidifier, etc
- 300cfm air flow capacity for pollutant management
- Efficient energy recovery during cold and hot weather
- “Free” conditioning when outdoor is “nicer” than indoor

PARTICULATE DEFENSE

MADE IN AMERICA
SOLAR POWERED BUSINESS

CERV3 IAQ & HPWH & Backup Electric Configuration



- Pairing a heat pump water heater (HPWH) with CERV3 provides efficient water heating coupled with HPWH
- HPWH can be placed in a confined space with CERV3; return air keeps HPWH operating efficiently
- HPWH and CERV3 can share condensate drain
- HPWH adds to dehumidification
- In-residence ventilation, comfort conditioning and water heating allow apartment utility and water usage metering
- Backup electric duct heater (3kW) seamlessly controlled by CERV3
- Approximately 10sqft required for CERV3 (6sqft) and HPWH (4sqft)
- CERV3 fresh air and exhaust ducts ~8” to 10” diameter. Inlet & exhaust can be adjacent (single opening)

Moisture

This proud, old Brooklyn building (1013 Grand St) was the first air conditioned building in the world. Willis Carrier designed the air conditioning system in 1906. **The AC system was needed for humidity control, not cooling!** The SackettWilhelms Lithography company had been unable to operate printing machines during NYC's humid summers.

What is a CERV3?
Heat pump…yes
Dehumidifier….yes
Energy recovery….yes

How should it be rated?
Whole house IAQ, comfort & energy

AHRI Heat Pump

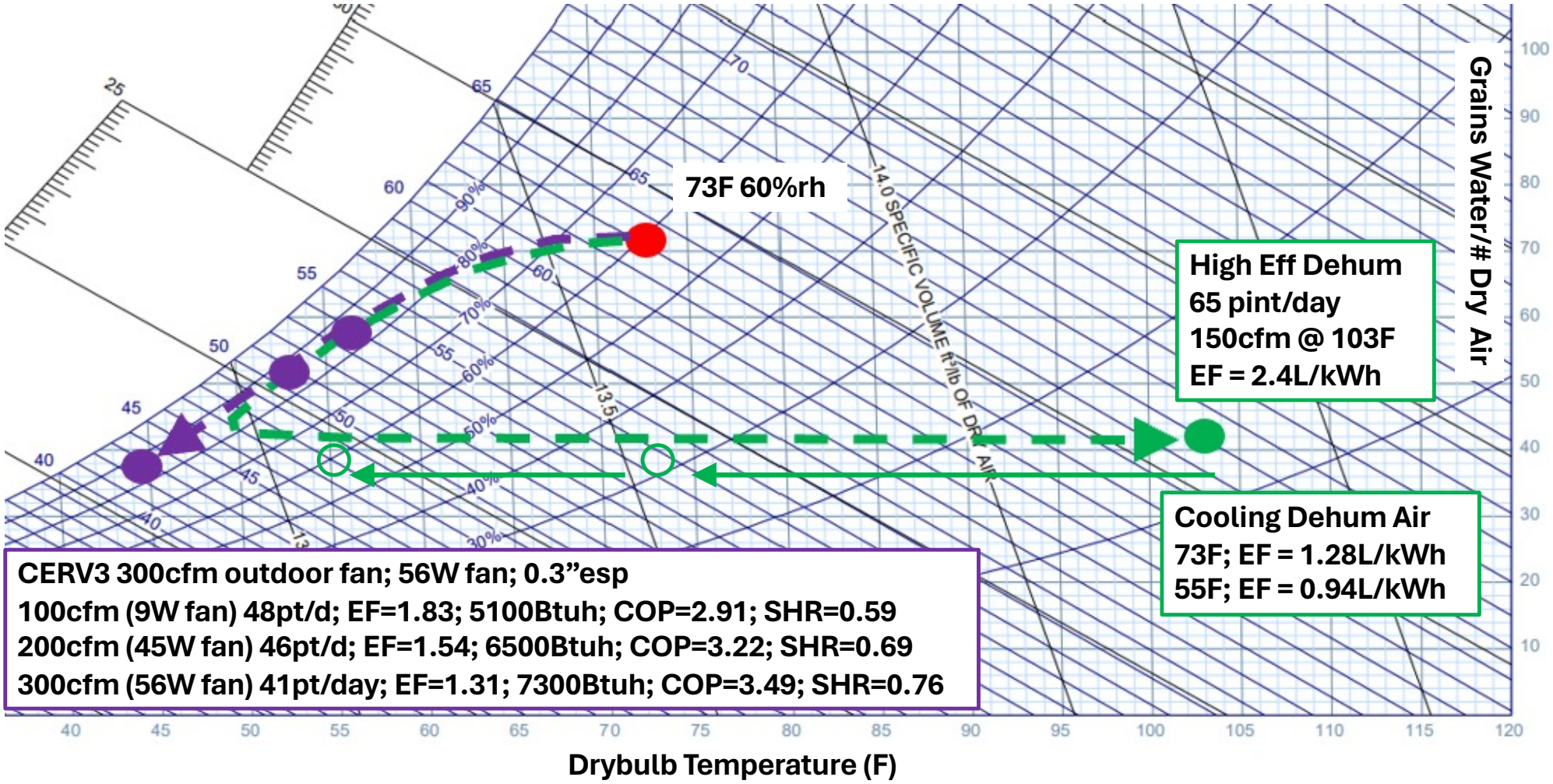
AHAM Dehum

HVI HRV/ERV

CERV HP Dehum ERV

Coffee shop in Amherst MA
"Drip" coffee!

CERV3 Dehumidification



Energy Exchange (Warm Humid)

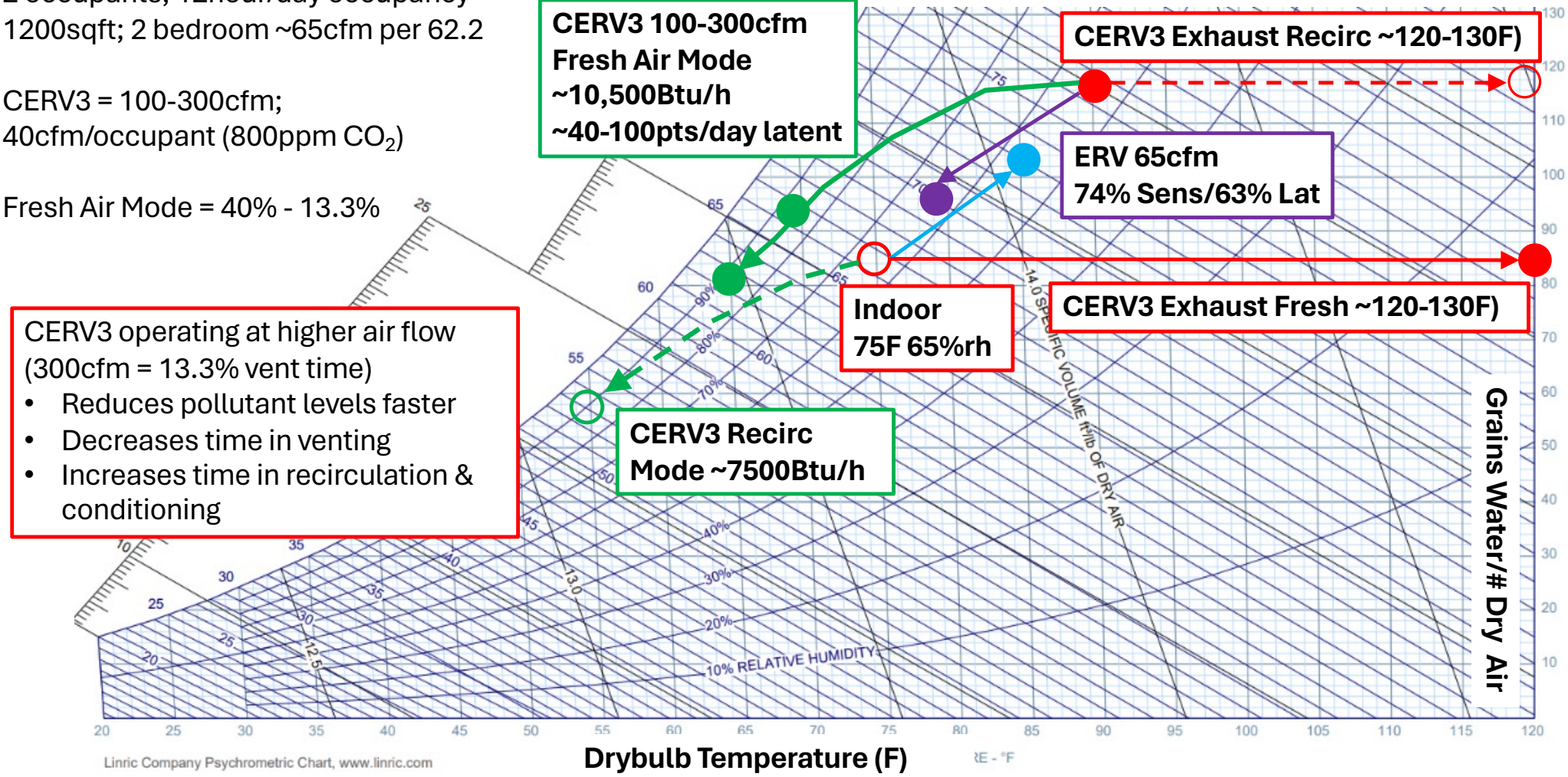
2 occupants; 12hour/day occupancy
1200sqft; 2 bedroom ~65cfm per 62.2

CERV3 = 100-300cfm;
40cfm/occupant (800ppm CO_2)

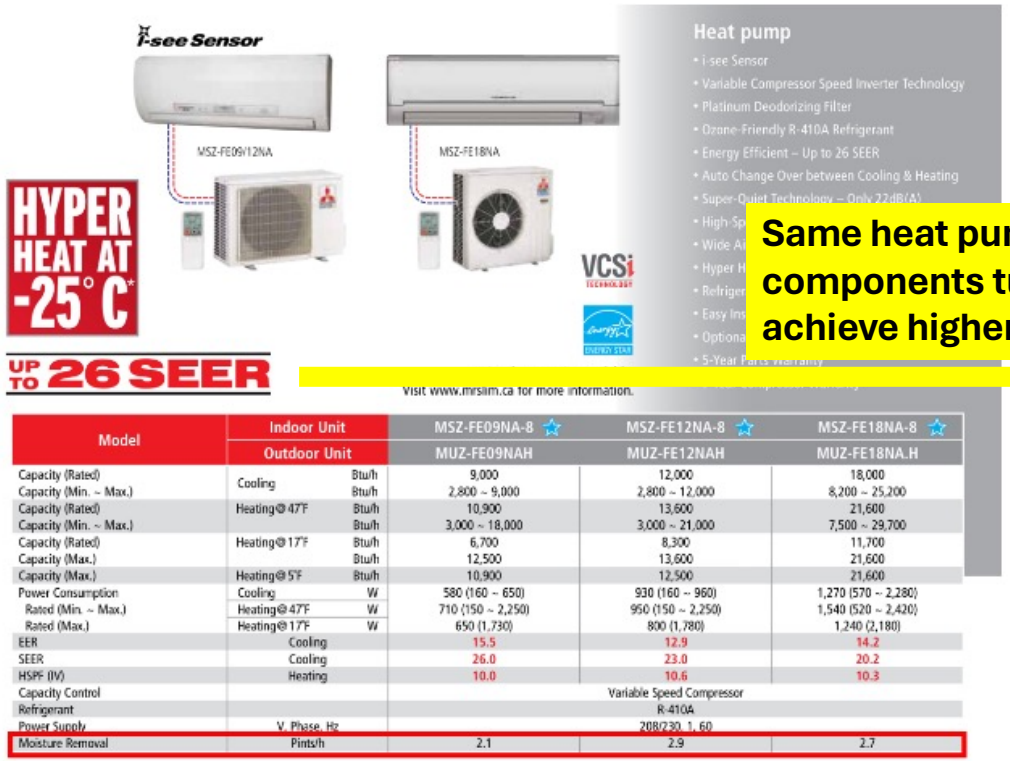
Fresh Air Mode = 40% - 13.3%

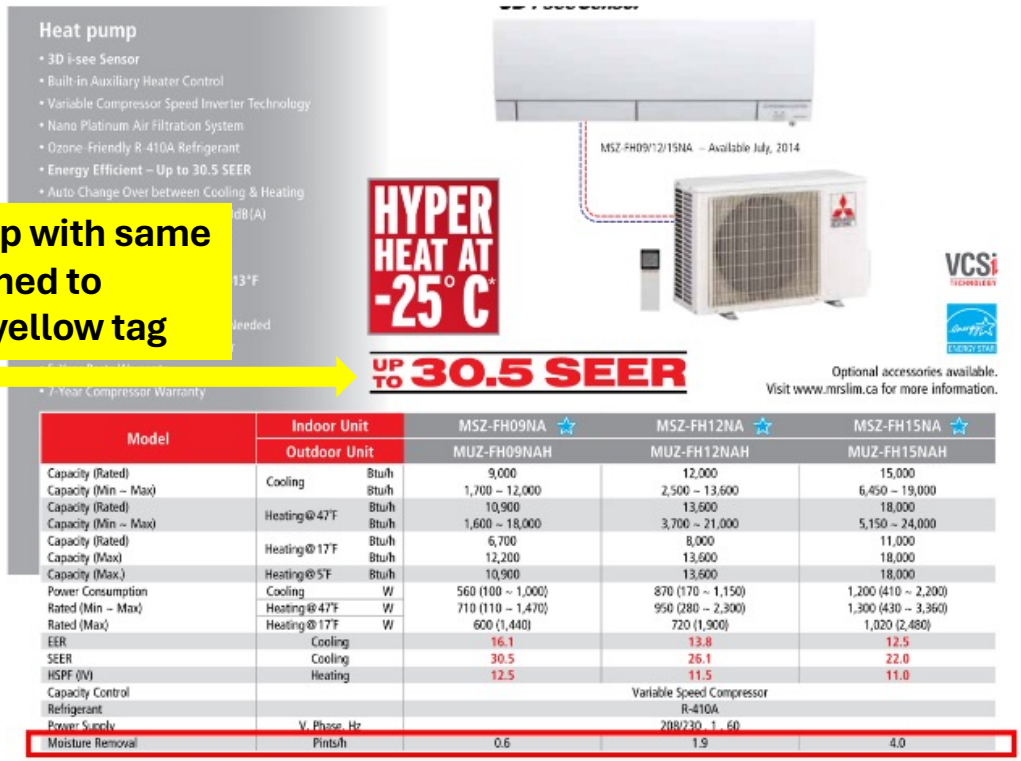
CERV3 operating at higher air flow (300cfm = 13.3% vent time)

- Reduces pollutant levels faster
- Decreases time in venting
- Increases time in recirculation & conditioning



Yellow Tags – Inhibiting Innovation & Performance?





Same heat pump with same components tuned to achieve higher yellow tag

Model	Indoor Unit		MSZ-FE09NA-8	MSZ-FE12NA-8	MSZ-FE18NA-8
	Outdoor Unit		MUZ-FE09NAH	MUZ-FE12NAH	MUZ-FE18NA.H
Capacity (Rated)	Cooling	Btu/h	9,000	12,000	18,000
Capacity (Min. ~ Max.)		Btu/h	2,800 ~ 9,000	2,800 ~ 12,000	8,200 ~ 25,200
Capacity (Rated)	Heating@47°F	Btu/h	10,900	13,600	21,600
Capacity (Min. ~ Max.)		Btu/h	3,000 ~ 18,000	3,000 ~ 21,000	7,500 ~ 29,700
Capacity (Rated)	Heating@17°F	Btu/h	6,700	8,300	11,700
Capacity (Max.)		Btu/h	12,500	13,600	21,600
Capacity (Max.)	Heating@5°F	Btu/h	10,900	12,500	21,600
Power Consumption	Cooling	W	580 (160 ~ 650)	930 (160 ~ 960)	1,270 (570 ~ 2,280)
Rated (Min. ~ Max.)	Heating@47°F	W	710 (150 ~ 2,250)	950 (150 ~ 2,250)	1,540 (520 ~ 2,420)
Rated (Max.)	Heating@17°F	W	650 (1,730)	800 (1,780)	1,240 (2,180)
EER	Cooling		15.5	12.9	14.2
SEER	Cooling		26.0	23.0	20.2
HSPF (IV)	Heating		10.0	10.6	10.3
Capacity Control			Variable Speed Compressor		
Refrigerant			R-410A		
Power Supply	V, Phase, Hz		208/230, 1, 60		
Moisture Removal	Pints/h		2.1	2.9	2.7

Model	Indoor Unit		MSZ-FH09NA	MSZ-FH12NA	MSZ-FH15NA
	Outdoor Unit		MUZ-FH09NAH	MUZ-FH12NAH	MUZ-FH15NAH
Capacity (Rated)	Cooling	Btu/h	9,000	12,000	15,000
Capacity (Min ~ Max)		Btu/h	1,700 ~ 12,000	2,500 ~ 13,600	6,450 ~ 19,000
Capacity (Rated)	Heating@47°F	Btu/h	10,900	13,600	18,000
Capacity (Min ~ Max)		Btu/h	1,600 ~ 18,000	3,700 ~ 21,000	5,150 ~ 24,000
Capacity (Rated)	Heating@17°F	Btu/h	6,700	8,000	11,000
Capacity (Max)		Btu/h	12,200	13,600	18,000
Capacity (Max.)	Heating@5°F	Btu/h	10,900	13,600	18,000
Power Consumption	Cooling	W	560 (100 ~ 1,000)	870 (170 ~ 1,150)	1,200 (410 ~ 2,200)
Rated (Min ~ Max)	Heating@47°F	W	710 (110 ~ 1,470)	950 (280 ~ 2,300)	1,300 (430 ~ 3,360)
Rated (Max)	Heating@17°F	W	600 (1,440)	720 (1,900)	1,020 (2,480)
EER	Cooling		16.1	13.8	12.5
SEER	Cooling		30.5	26.1	22.0
HSPF (IV)	Heating		12.5	11.5	11.0
Capacity Control			Variable Speed Compressor		
Refrigerant			R-410A		
Power Supply	V, Phase, Hz		208/230, 1, 60		
Moisture Removal	Pints/h		0.6	1.9	4.0

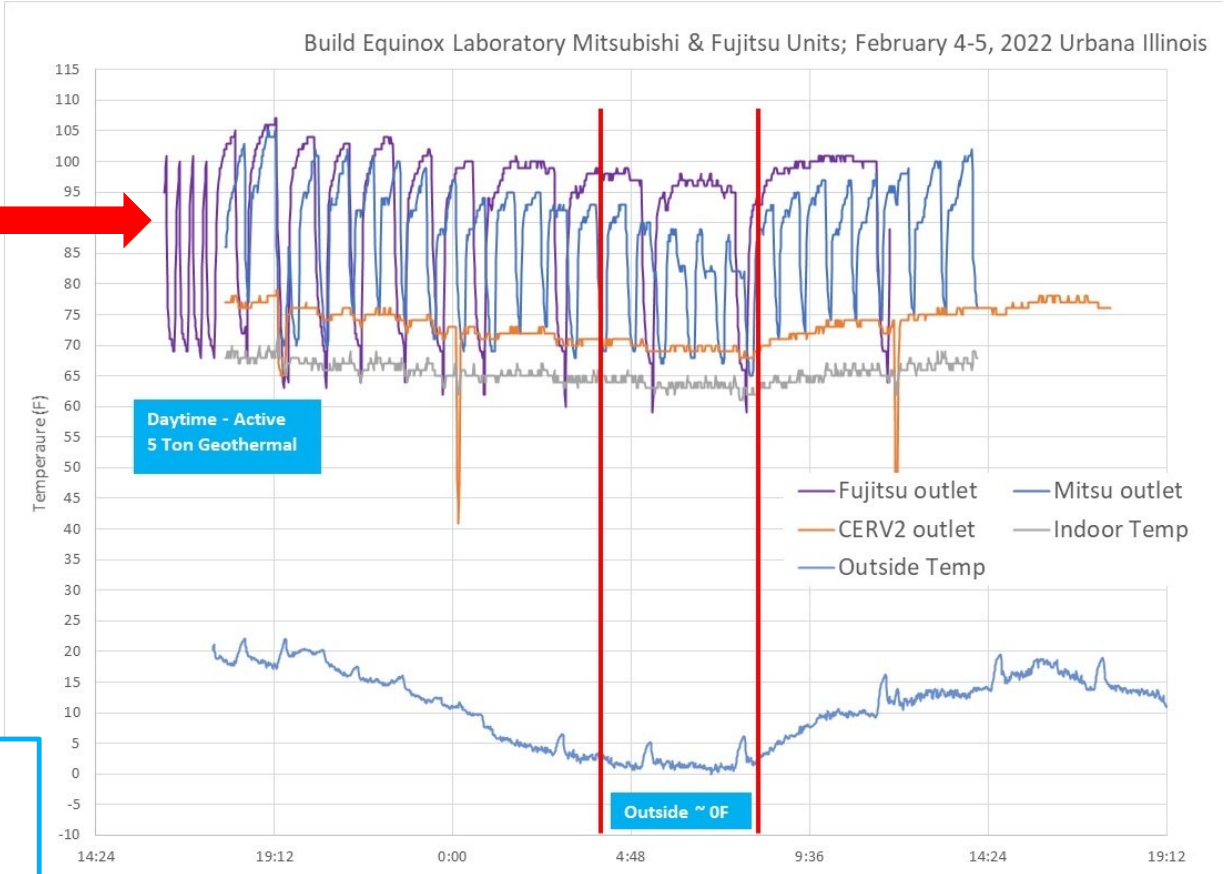
Manufacturers design to "yellow tag" rather than actual need, reducing latent capacity for SEER gain

9000Btu/h 2.1pt/h (50pt/day) reduced to 0.9pt/h (22pt/day)

12000Btu/h 2.9pt/h (70pt/day) reduced to 1.9pt/h (46pt/day)

Yellow Tags

- 1 ton Mitsu and Fujitsu **ducted** minisplits with similar yellow tag performance
- Temperatures below 5F (lowest AHRI test point for Energy Star), Mitsu drops to low stage with half hour defrosting
- Note: “smart” defrosting becomes less frequent at cold temperatures (see CERV defrost cycle)



Residential Humidity Control

Ducted Heat Pump vs. Multisplit Heat Pump

BY NELSON FUMO, PH.D., MEMBER ASHRAE; MANOJ BHANDARI; JASON LEROY, MEMBER ASHRAE

Although ducted systems remain prevalent in North America, ductless multisplit systems are emerging as an option. For hot-humid and mixed-humid climate zones, humidity control is as important for comfort as space temperature control. We present results of the comparison of a zoned traditional ducted variable speed heat pump and a multisplit heat pump in a test home located in U.S. Climate Zone 3.

ASHRAE J, July 2024

Two heat pumps with same yellow tags tested in same house during Tyler Texas cooling season. Traditional “split system” heat pump used 30% less energy with much better humidity control than multi-head minisplit

Multi-Family CERV3 IAQ & Comfort Control

- Administrative dashboard for monitoring
  - Remote diagnostics
  - Maintenance checks
  - Filter & UVGI bulb replacement scheduling
- Online control by management & residents
- OTA (Over-the-Air) Upgrading
- Coordinated control
  - Utility time-of-day scheduling
  - Building peak demand control possible
- Convenient, remote new tenant ID reset
- CERV operation independent of WiFi
- All IAQ & comfort (temperature & humidity) data archived
- CERV3 – 3rd generation smart HVAC:
  - Provides comfort conditioning, displacing need for separate heat pump
  - Low GWP refrigerant (R32)

CERV3®

Multi-Family Ventilation & Comfort Control

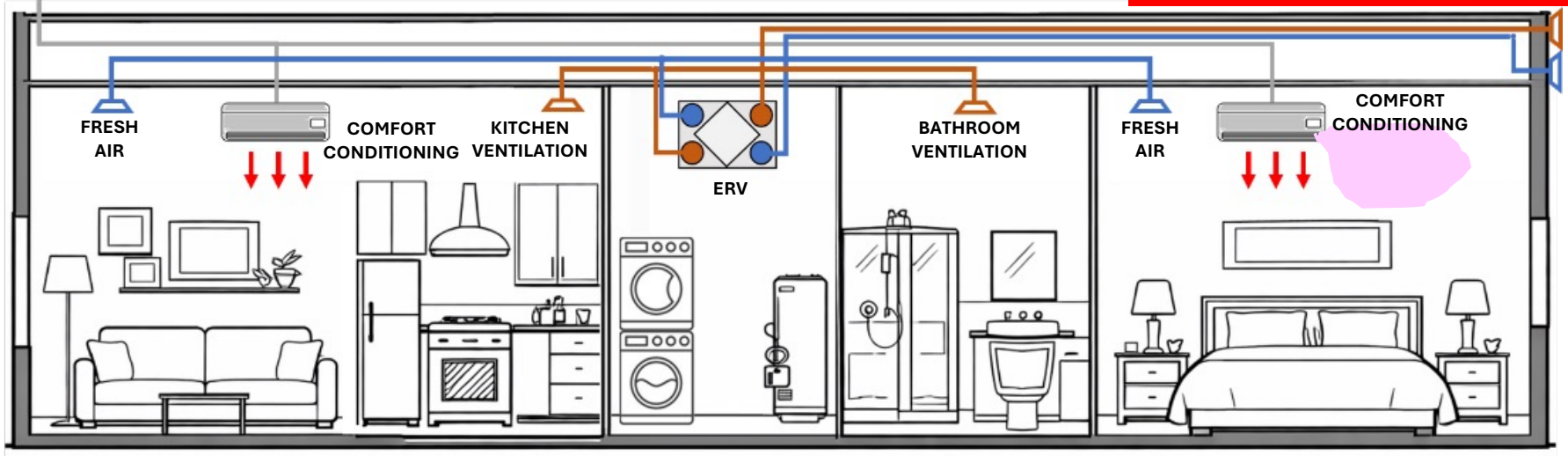
Conventional “One-n-Done”
ERV/HRV Ventilation Setup

DUCTLESS OR DUCTED
MINIPLIT HEAT PUMP
Annual Head Washing

Poorly filtered cassette heads must be cleaned!

ERV PER APARTMENT OR ONE ERV SERVING MULTIPLE APARTMENTS
Central unit balancing difficult
No recirculation filtering
Unable to match IAQ needs

Refrigerant leakage due to cassette head corrosion



Multi-Family Ventilation & Comfort Control

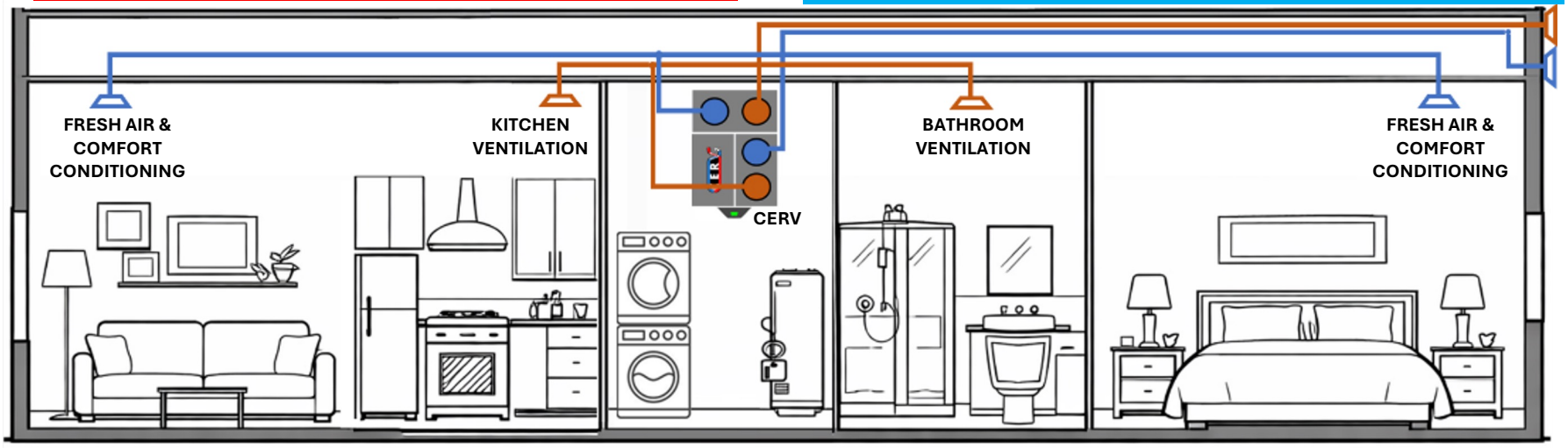
Frees Roof for additional solar PV for utility cost reduction

NO OUTDOOR UNIT

Build Equinox CERV3 Smart IAQ & Comfort Management

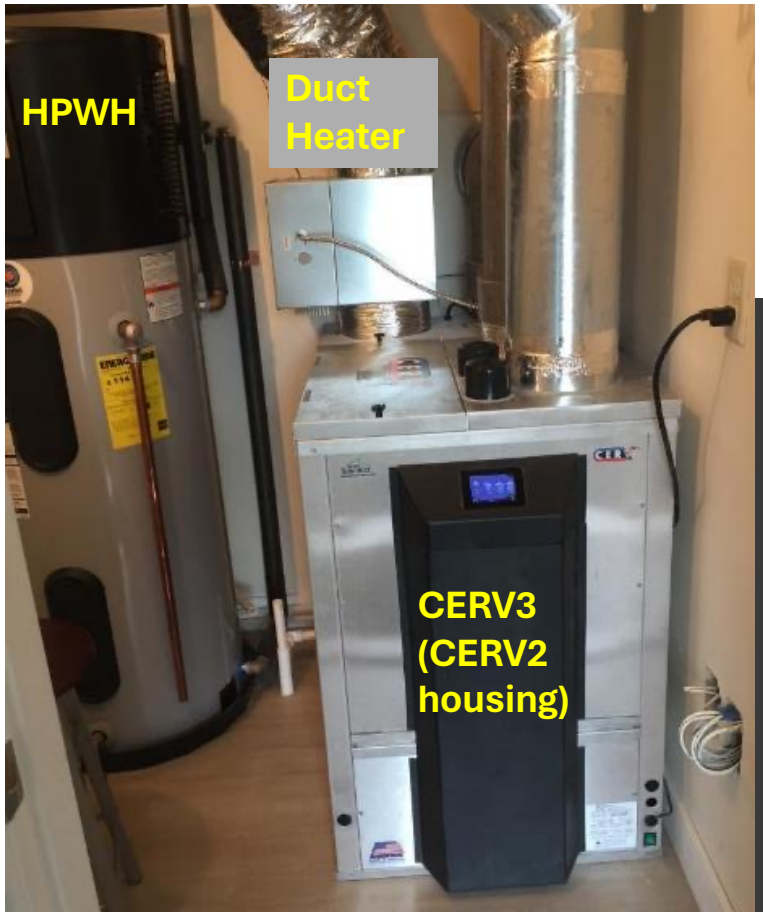
CERV3 < half minisplit refrigerant charge
Corrosion resistant design; MERV14 filtered air, all aluminum xchanger & ducting
Can detect leaks (VOCs) and ventilate

CERV3 PER APARTMENT
(PACKAGED UNIT)
Integrated IAQ and Comfort Management
No head cleaning
Provides recirculation filtering



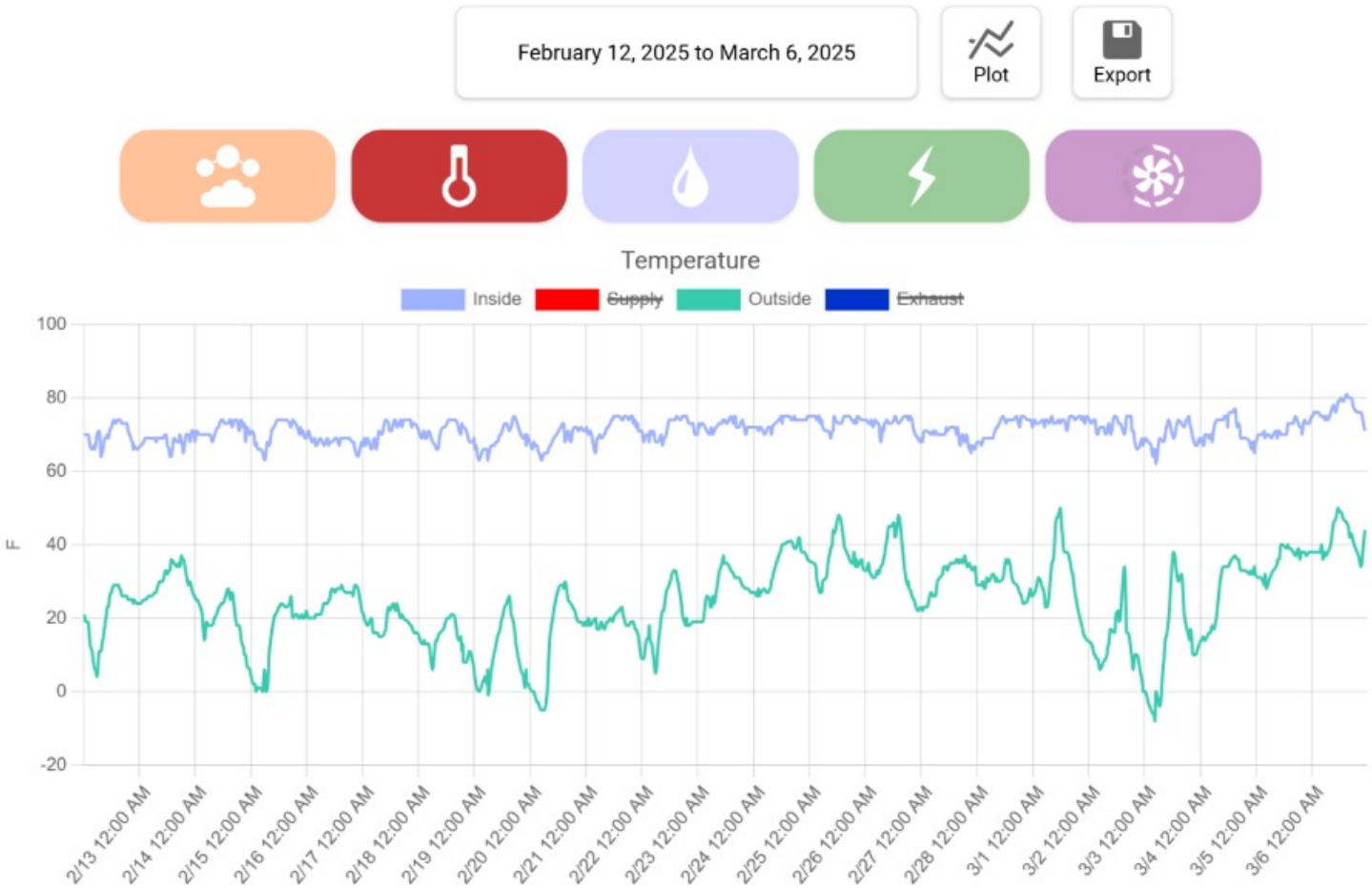
CERV3 Field Demonstration-White River Jct Vermont

-1200sqft High Performance Home



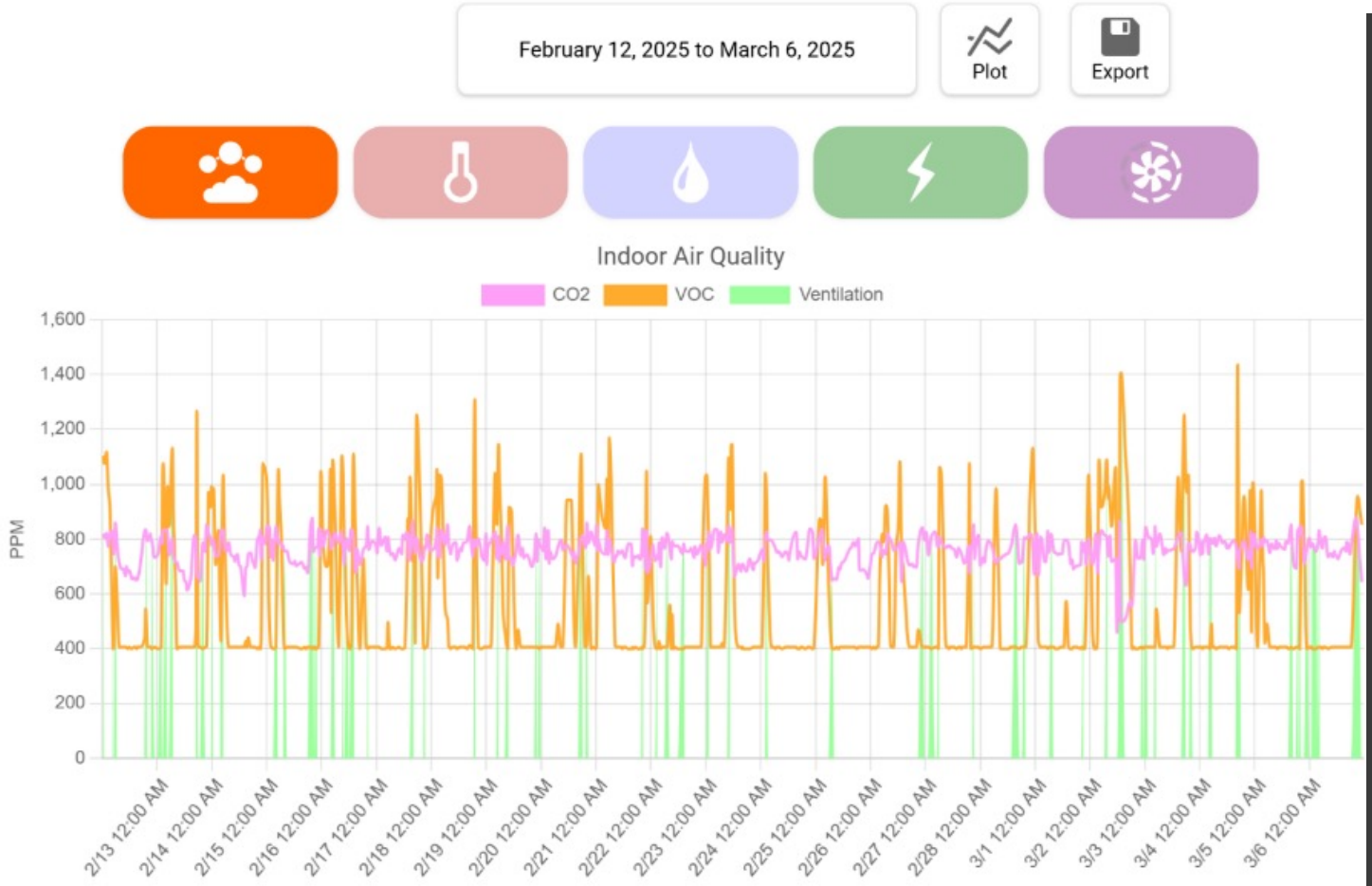
- 2024-2025 CERV3 field demonstration
- 1200sqft Vermod manufactured home located in White River Jct VT
- 3 occupants
- CERV3, 3kW backup duct heater (CERV3 controlled) and HPWH
- Winter & Summer data

1200sqft Manufactured Home – White River Junction VT -Winter Temperatures



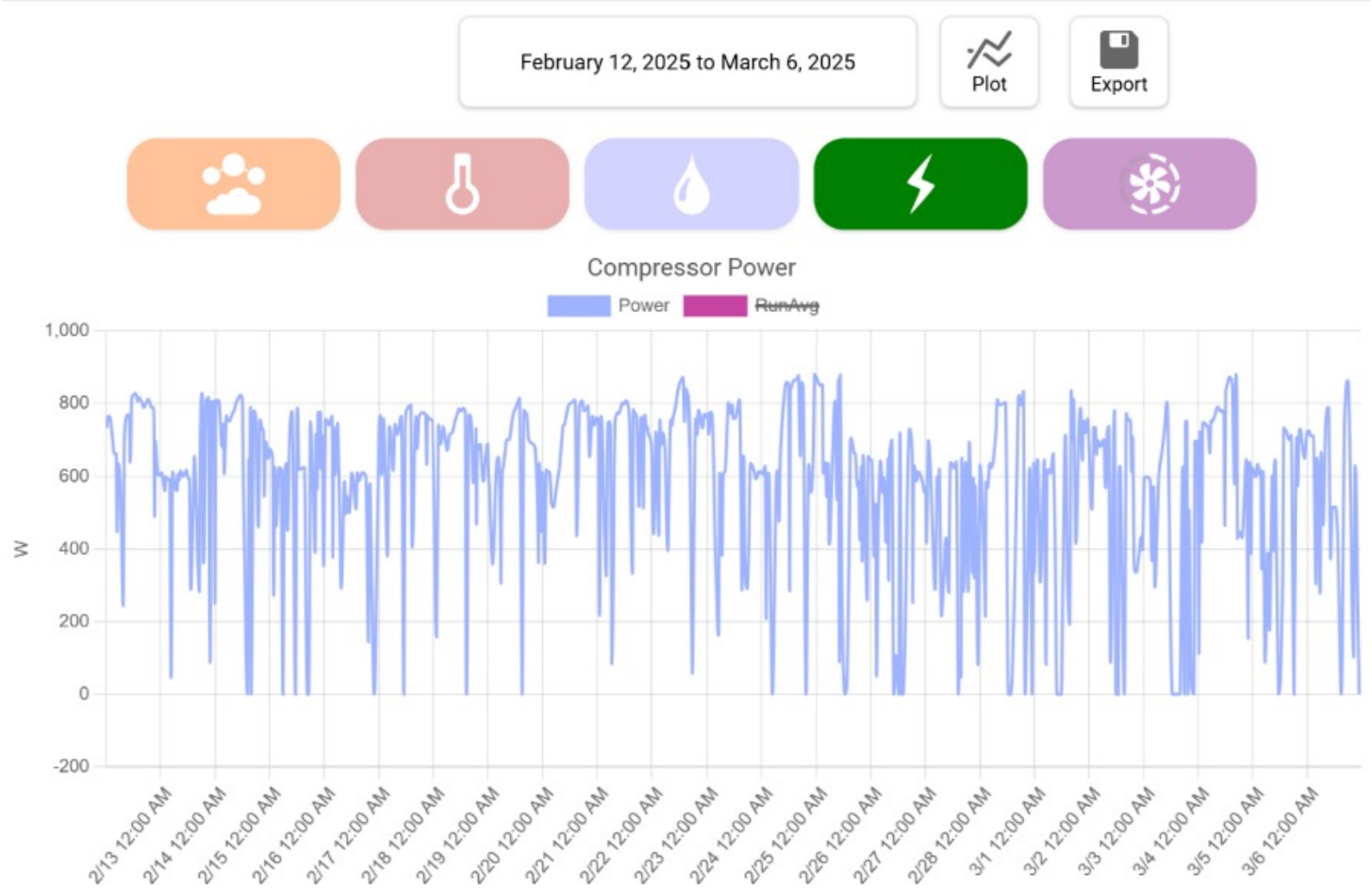
- **CERV3 maintained comfort through winter extremes**

1200sqft Manufactured Home – White River Junction VT -Winter Indoor Air Quality (CO_2 & VOCs)



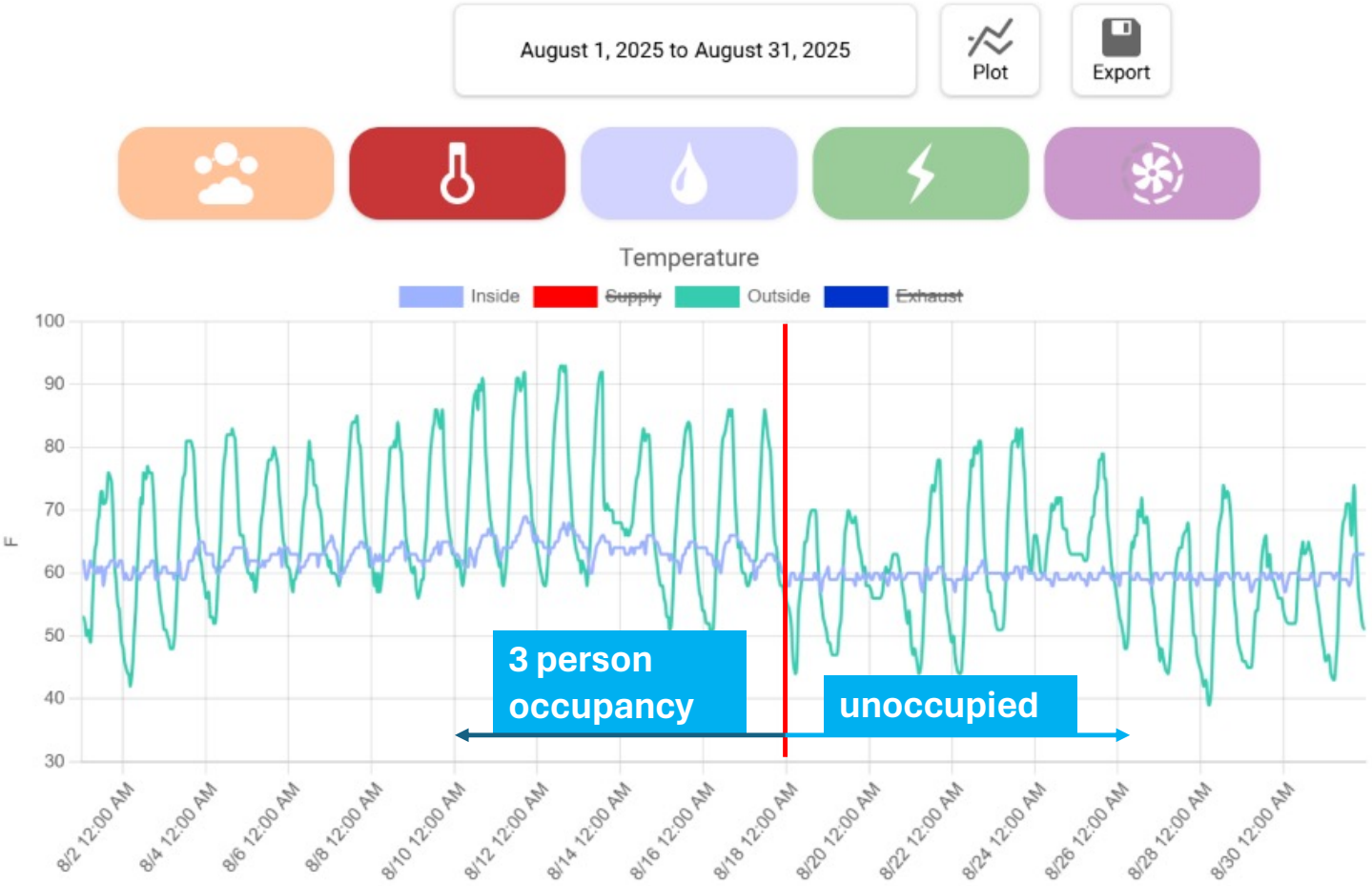
- 3 occupants
- CERV3 does not sacrifice air quality and occupant health during winter extremes
- 800ppm CO2 indicates very healthy air with more than twice today's inadequate ventilation standard
- Green bars indicate fresh air venting
- Recirculation during non-venting periods removes particulates and manages comfort

1200sqft Manufactured Home – White River Junction VT -Winter Electric Power



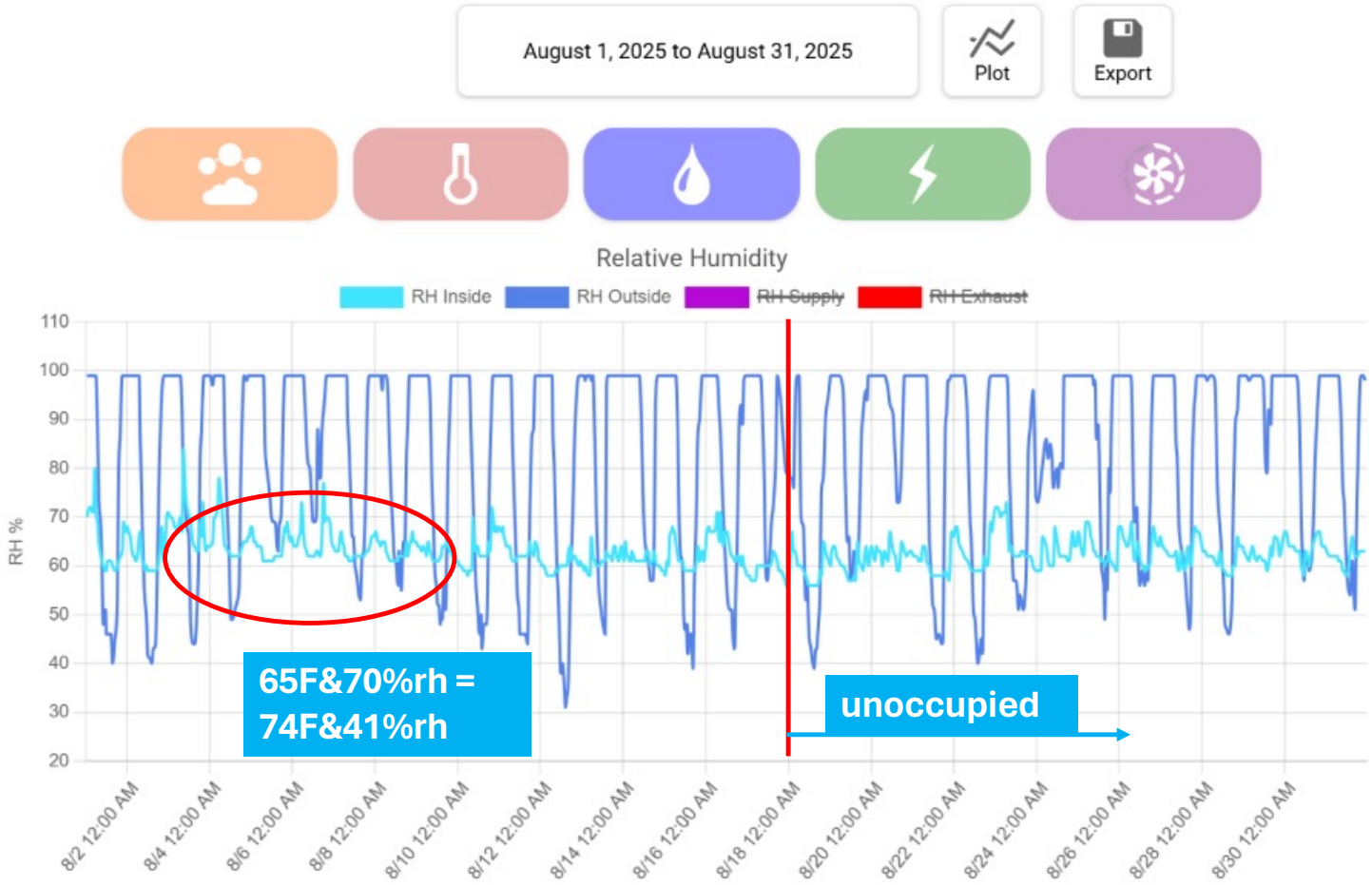
- **Energy efficient, low power heat pump**
- **Each residence in multifamily can be metered individually for energy consumption**

1200sqft Manufactured Home – White River Junction VT -Summer Temperatures



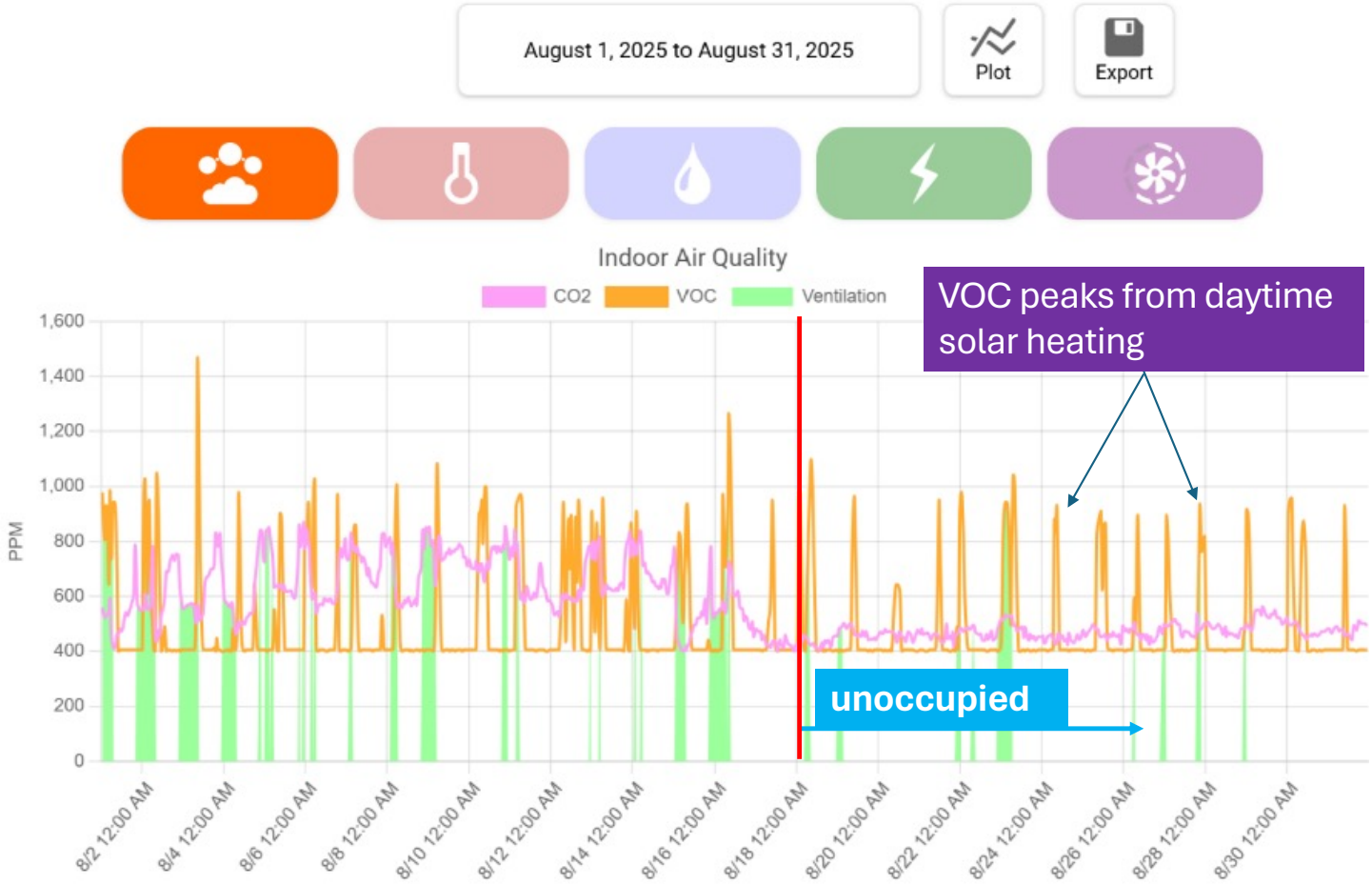
- Family preferred very cool summer indoor temperatures (<65F)
- Occupied and unoccupied periods show impact of occupancy on indoor temperature levels
- Unoccupied maintained steady at 60F…74F more typical of summer indoor temperature

1200sqft Manufactured Home – White River Junction VT -Summer Humidity



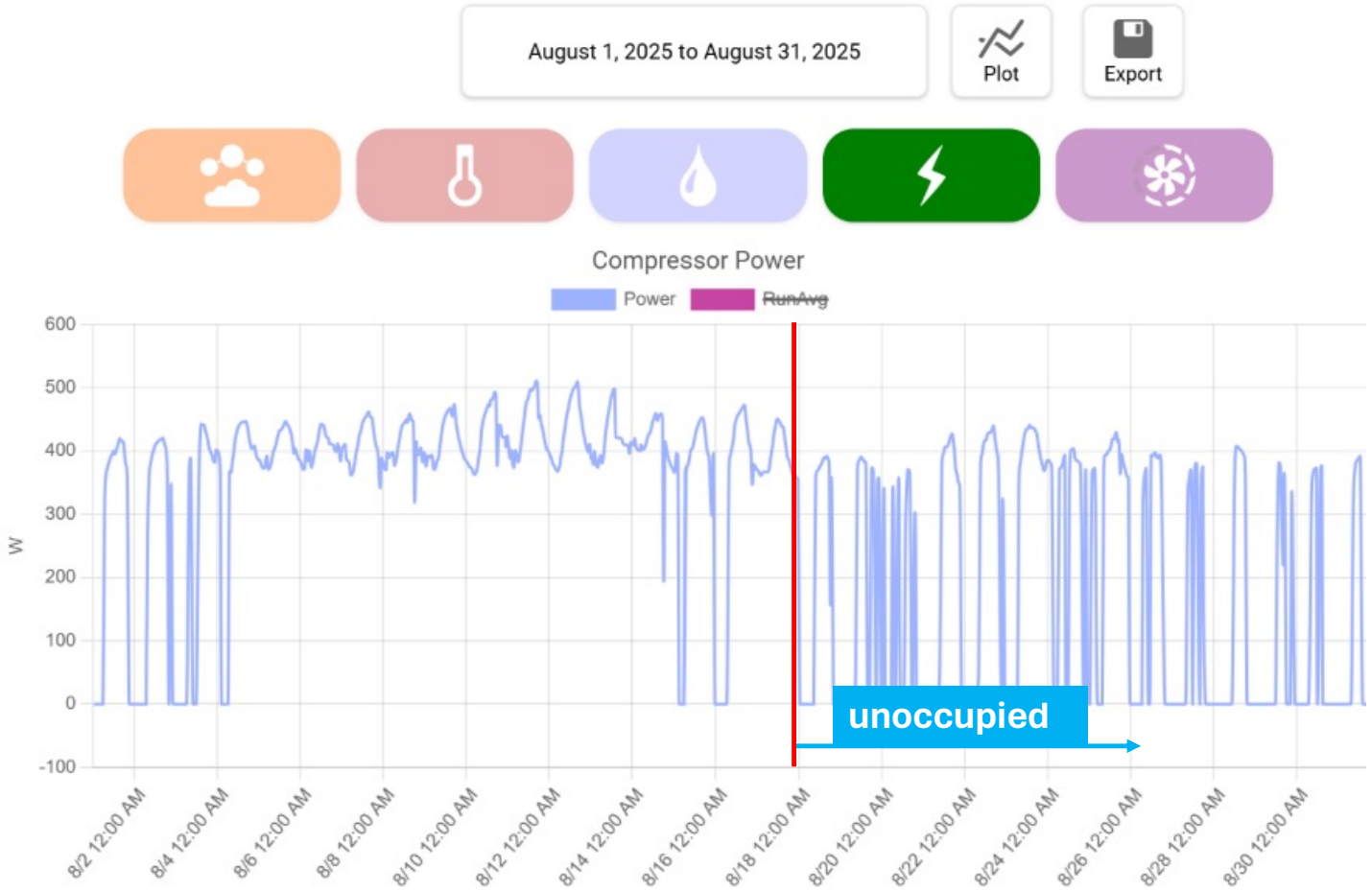
- CERV3 incorporates high dehumidification capacity
- Note that 65F and 70%rh is very low humidity.....if indoor air warmed to 74F, indoor humidity would be 41%rh
- Outdoor humidity is consistently high
- Note Admin&Maintenance can remotely monitor vacant residences to ensure humidity/mold problems not developing

1200sqft Manufactured Home – White River Junction VT -Summer Indoor Air Quality (CO_2 & VOCs)



- CERV3 automatically vents when pollutants (CO2/VOCs/PM/PC) exceed setpoints
- Ventilation automatically reduced during unoccupied period
- Unoccupied periods may experience elevated pollutant such as VOCs released from materials by daytime solar heating

1200sqft Manufactured Home – White River Junction VT -Summer Electric Power



- Very efficient, low powered cooling and dehumidification
- 500Watts electrical power for occupied cooling & dehumidification = 12.5kWh per day
- ~$2.50/day with $0.20/kWh electricity

"...our tools are better than we are, and grow better faster than we do. They suffice to crack the atom, to command the tides. But they do not suffice for the oldest task in human history: to live on a piece of land without spoiling it."

Thank you!

Professor Aldo Leopold
University of Wisconsin
1938 speech