Design and Operation of a Conditioning Energy Recovery Ventilator (CERV) for Passive Houses

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Motivation and Objectives

Combine our knowledge of HVAC systems with interest in energy efficient homes to create a niche product.

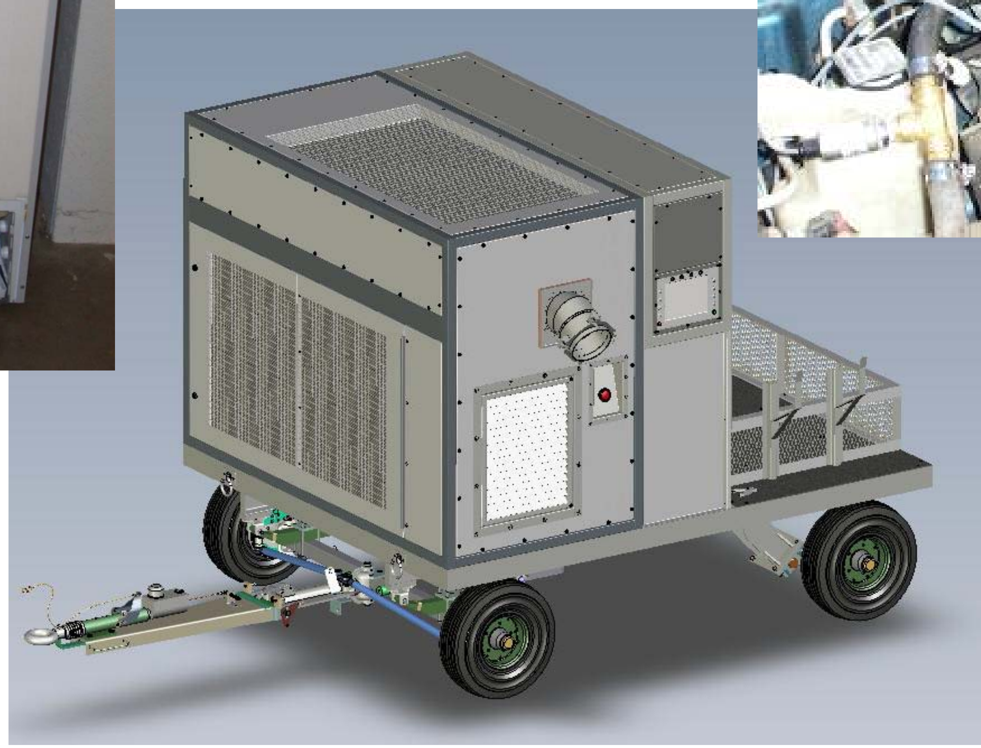
Coupled with highly efficient house construction (e.g., Passive House standards), efficient house conditioning systems lead to the ability to provide all home energy needs with solar energy in a cost effective manner.

The “CERV” is a primary component for efficient heating, cooling, and dehumidification of an energy efficient home.

Development of energy efficient house conditioning systems with the goal of constructing a “net zero energy” home for central Illinois and beyond.

Air Conditioning Experience

refrigerators



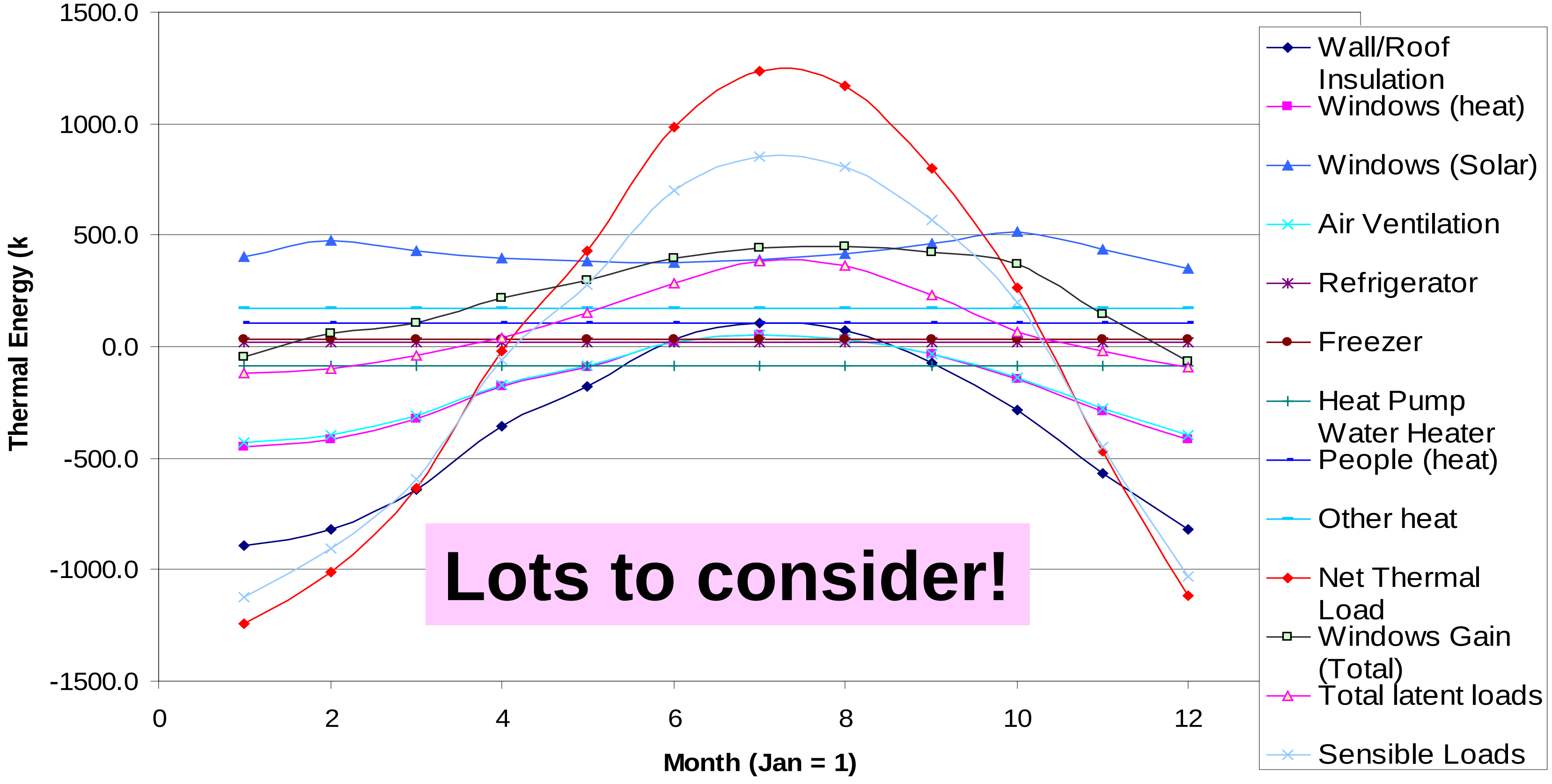
military aircraft cooling

automotive

Presentation Outline

- House Energy Characteristics
- Building Conditioning Requirements
- Conditioning Energy Recovery Ventilator Description
- CERV Operation and Performance

Keeping Comfortable



Building construction, outside conditions, Interior components, and activities

2007 Solar Decathlon House

- The 2007 University of Illinois Solar Decathlon “elementhouse” is a “Net Zero” house in which all house energy is supplied by solar energy (solar electric with PV panels)

- The UI 2007 Solar Decathlon House is also designed to supply up to 10,000 miles of electric vehicle transportation per year

•Zero energy house design significantly reduces the capacity requirements of its comfort conditioning system

•Ventilation and moisture management become very important

•While smaller, the comfort system must be more nimble and smarter than conventional systems

2000sq ft Home LifeCycleCost

Simple LifeCycleCost ~ $242,000

with 12 cm insulation = $20,500
and 27 m^2 PV = $20,200

Or, 10cm insulation = $17,100
and 29.5 m^2 PV = $22,100

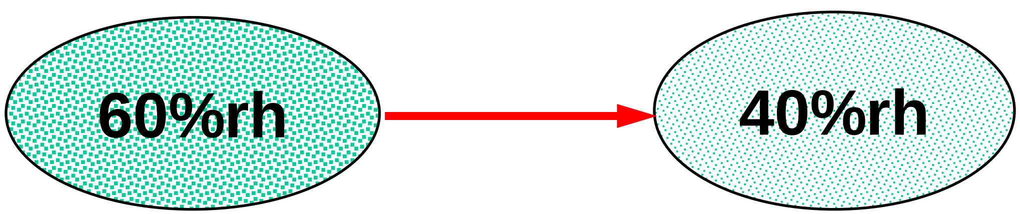
Or, 5 cm insulation = $8,500
and 45 m^2 PV = $33,800

Optimal solution is fairly "flat"

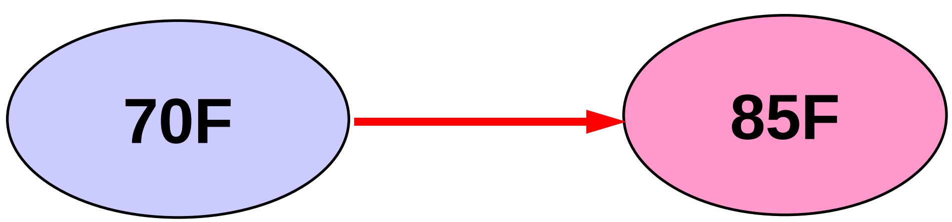
Sensible and Latent Heat

"Sensible" heat and "latent" heat refer to the transfer of energy into or out of a conditioned space where:

- Sensible refers to an energy transfer that you can "sense"
  - Temperature change of air
- Latent refers to an energy transfer that is hidden or not sensed
  - Moisture change of air



The energy needed to drop 70F air from 60%rh to 40%rh is the same as the energy to heat air from 70F to 85F



Conventional vs. Efficient

- Conventional homes are dominated by the exterior conditions
  - Leaky envelope means unwanted ventilation
  - Larger capacity required because of free air movement
  - Free exchange of conditioned/unconditioned air without recovery of energy
  - Little moisture control
- Efficient homes balanced more towards interior loads
  - Ventilation and moisture are controlled
  - Small energy loads make energy recovery significant

Typical House Conditioning System Illinois Weather

- Conventional home air conditioner ~3 “tons” (36,000 Btu/hr ~ 10,000 watts)
  - Designed for ~2/3 sensible and ~1/3 latent loads
- Conventional gas furnace ~80,000 Btu/hr ~ 22,000 watts
- Efficient capacity control of conventional systems difficult
  - Conventional construction requires large span of capacity control

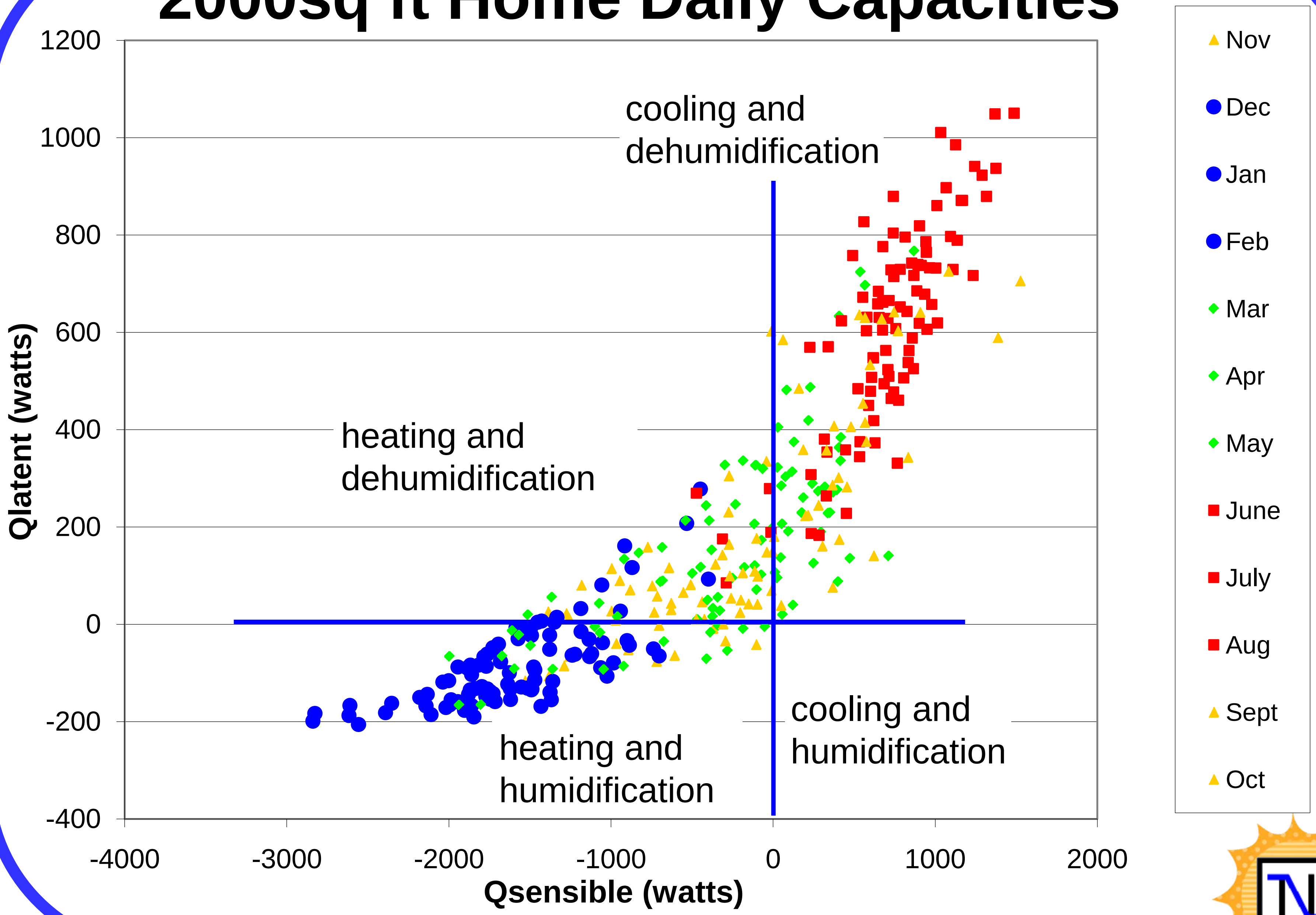
Base Case House

So, what capacity is needed to keep a high efficiency residence comfortable?
How many tons, BTUH, watts, liters per day…..?

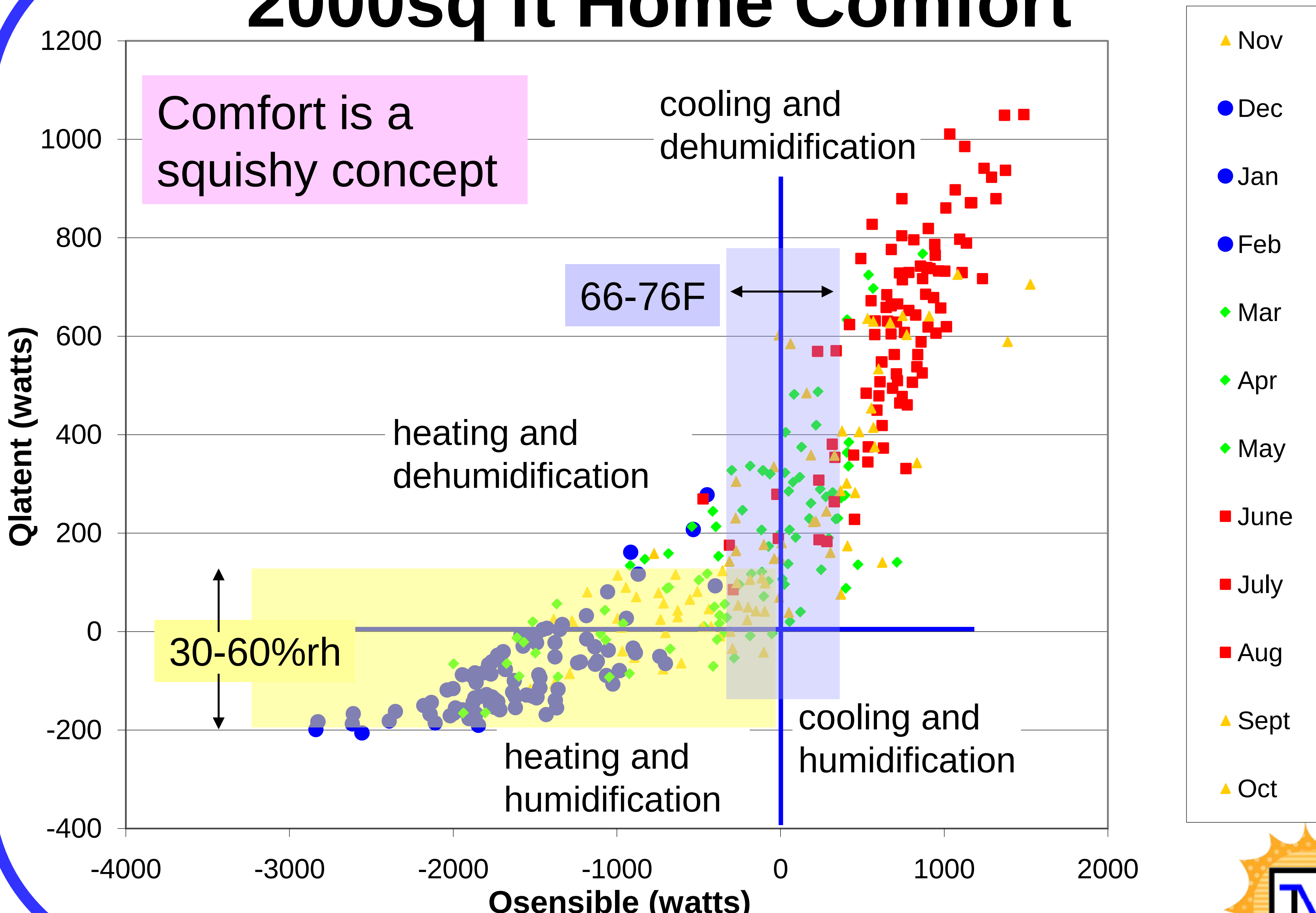
- 2000 sq ft, single story house (~45' x 45')
- 50 sq ft, south facing windows, $U=0.5 W/m^2\text{-}K$
  - High performance, triple/quadruple glazed
- UAwall + UAroof = 65W/K (~R22 wall, R44 roof)
- Ventilation = 50 cfm (0.2 ACH) => ASHRAE 62.2 standard
- 4 people (75W/person heat; 75W/person moisture)
- 200W internal generation (refrigerator, TV, computer, lights, etc)

ICF (insulated concrete form) home in Urbana IL

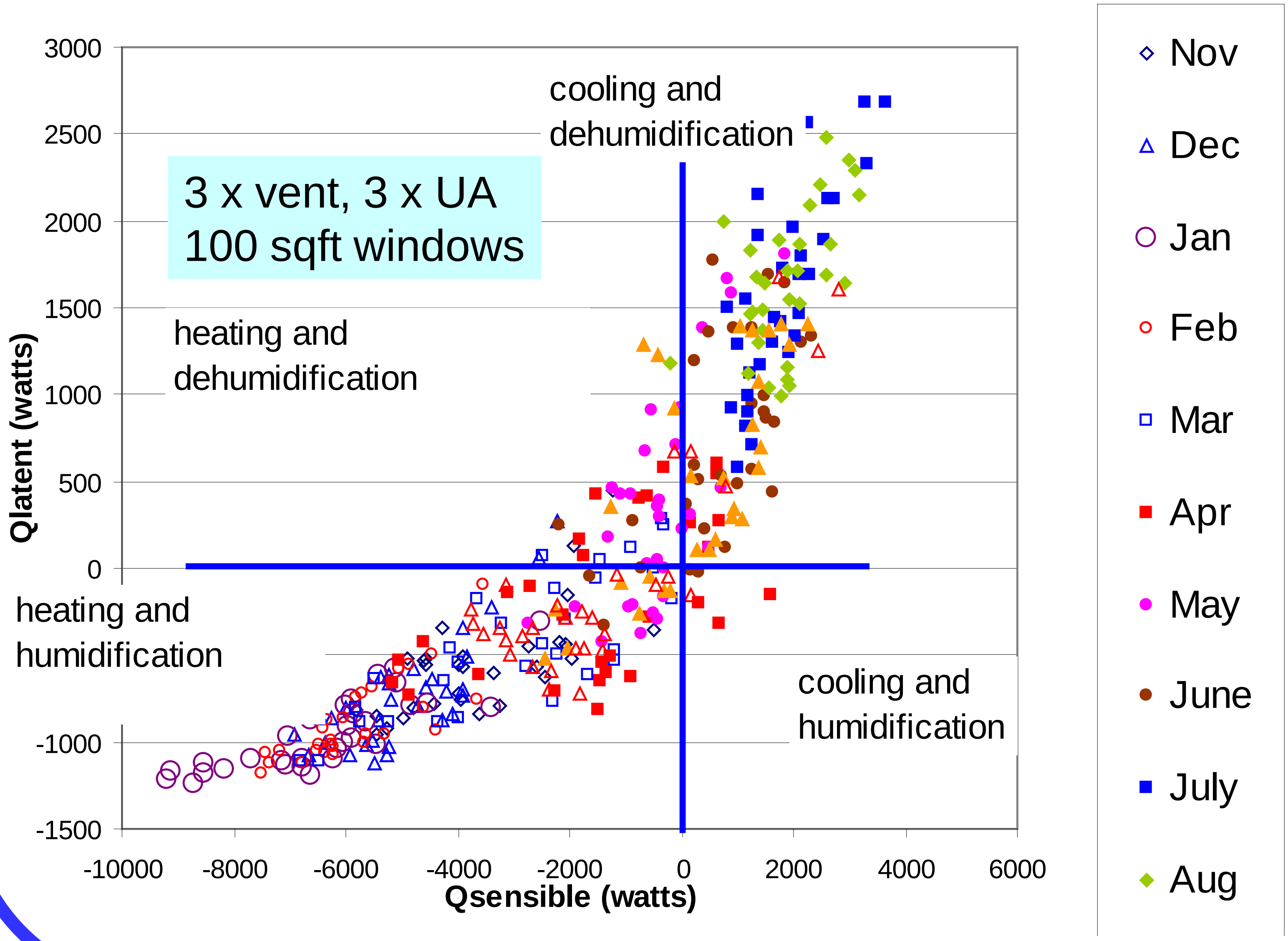
2000sq ft Home Daily Capacities



2000sq ft Home Comfort

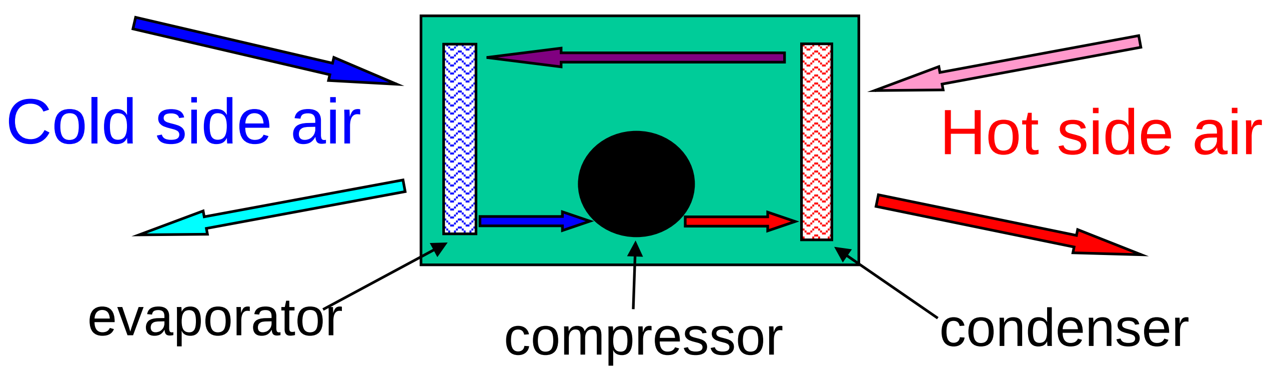


2000sq ft "Conventional" Home



CERV
Conditioning Energy Recovery Ventilator

Low temperature heat pump air conditioning system:



CERV Features

- Small capacity, self-contained, modular system
- Plug and play modules are added to reach required building capacity
- Air source heat pump with a variable speed compressor to adjust to load
- Provides heating, cooling, dehumidification, and ventilation

Refrigerant Overview

Refrigerant	Systems	*ODP (Ozone Depletion Potential)	*GWP (Global Warming Potential)
R12	automotive	1	8100
R22	residential and light commercial air conditioning, refrigerators, and freezers	0.05	1700
R134a	residential and light commercial air conditioning, refrigerators, freezers, and automotive	0	1300
R410A	residential and light commercial air conditioning replacing R22	0	1890
R744 (CO2)	In development for automotive	0	1
HFO 1234 yf	Preliminary tests as a 134a "drop in"	0	4

- ODP – Ozone depletion potential compared to CFC-11 (1)
- GWP – contribution to global warming compared to same mass of CO2 (1)

Refrigerant and Regulations

- R12 banned in 1994 – replaced with R134a
- Montreal Protocol – international treaty to phase out ozone depleting substances – eliminates sale of R22 equipment starting in 2010, allocation of acceptable producers for service use of existing equipment
- European Union 2007 MAC (Mobile Air Conditioning) Directive: bans refrigerants with GWP > 150 from new vehicles in 2011 and all vehicles in 2017 – displacement of R134a

CERV Refrigeration System

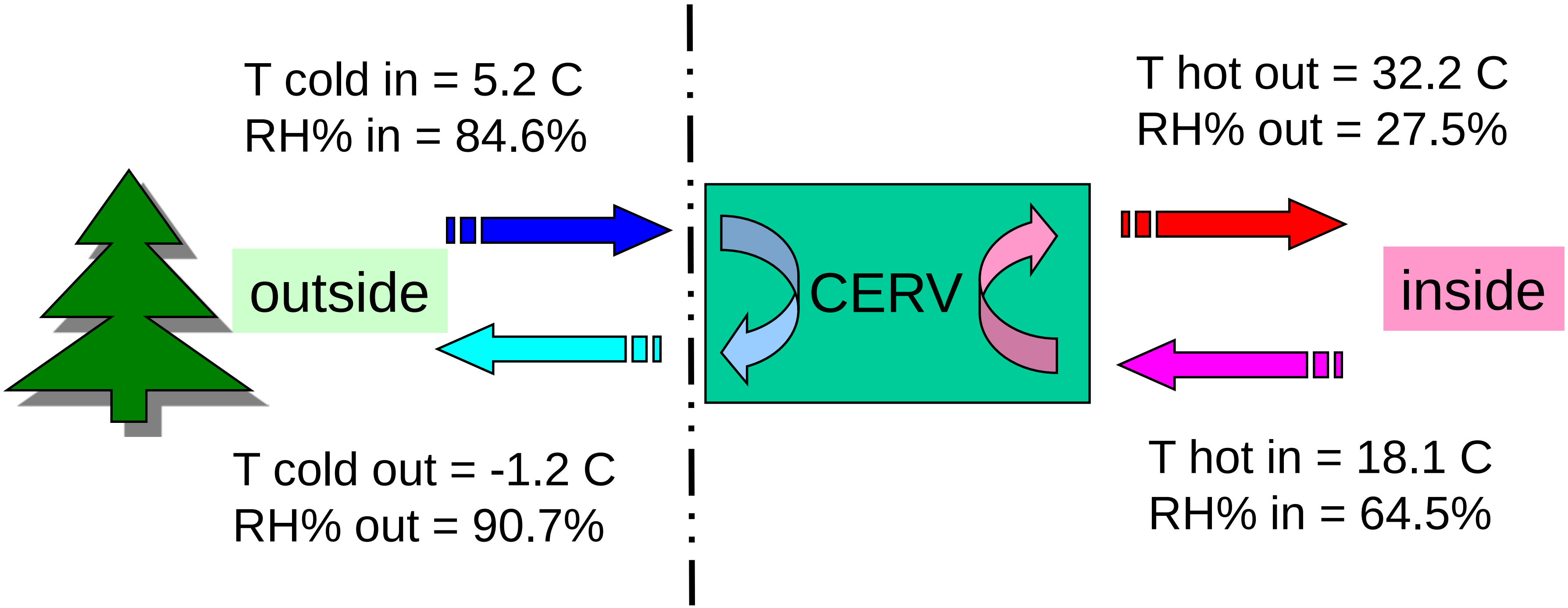
- Use 134a phase into 1234 yf as it becomes available
  - no ozone depletion
  - very low global warming potential
- Hermetically sealed system
  - small refrigerant charge
  - eliminates onsite charging, line sets, fittings
  - sealed for lifetime of unit
  - refrigerant can be recovered

CERV Modes of Operation and Test Results

- heating
- cooling
- heating with ventilation
- cooling with ventilation
- ventilation only

integrated controls to determine most efficient conditioning mode

Heating without ventilation:



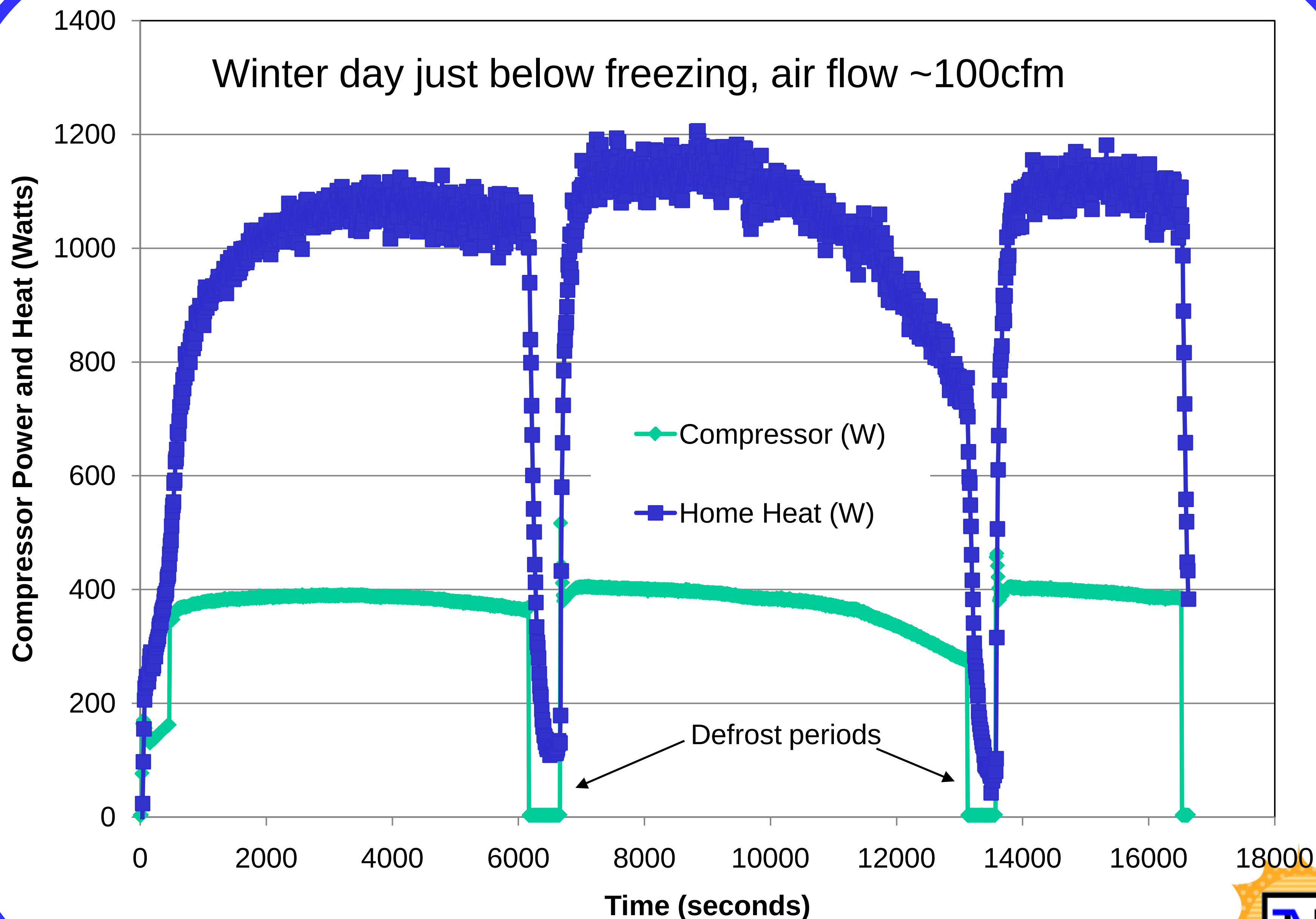
compressor power = 377 W

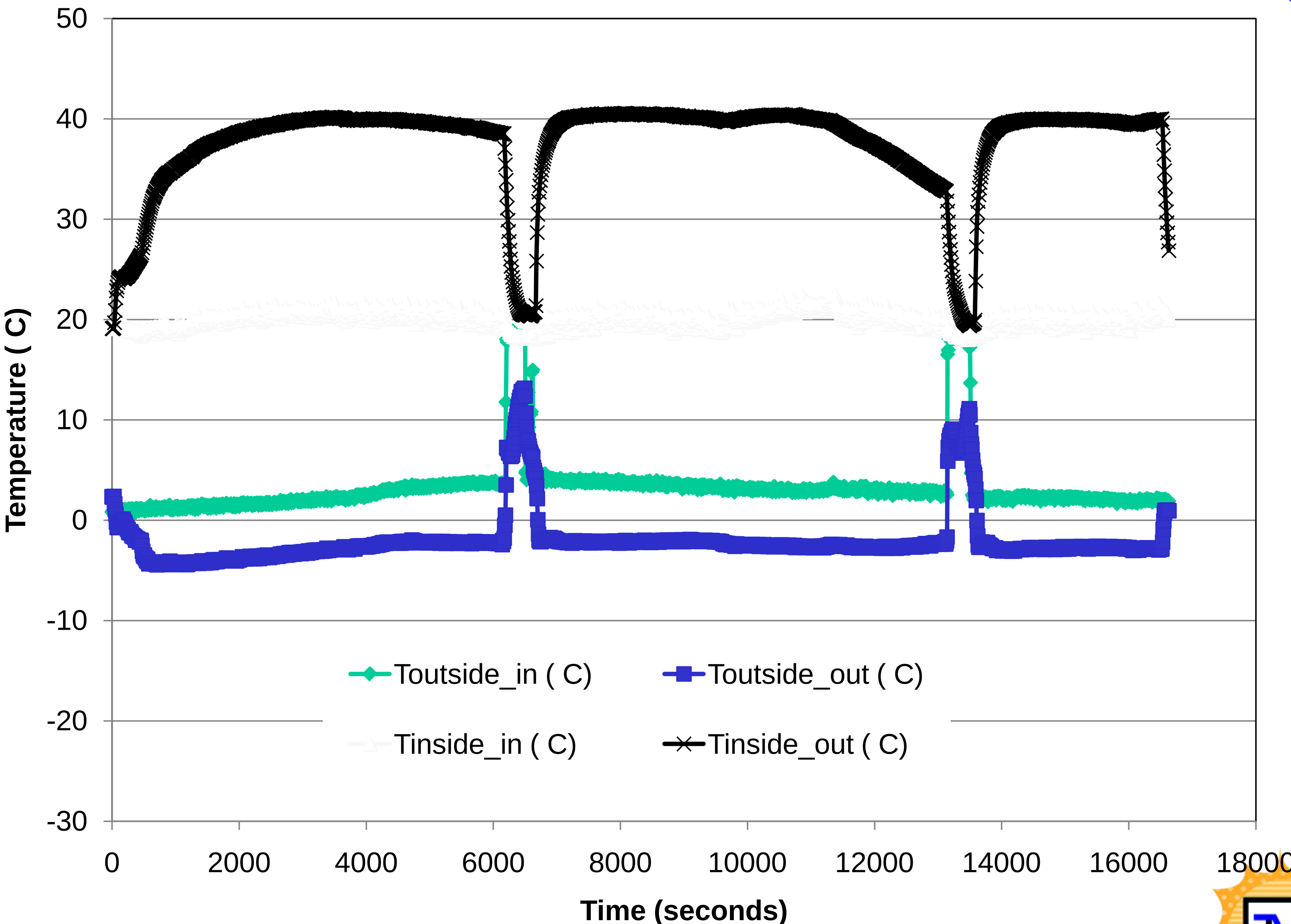
total heating capacity = 1165 W

COP = 3.1

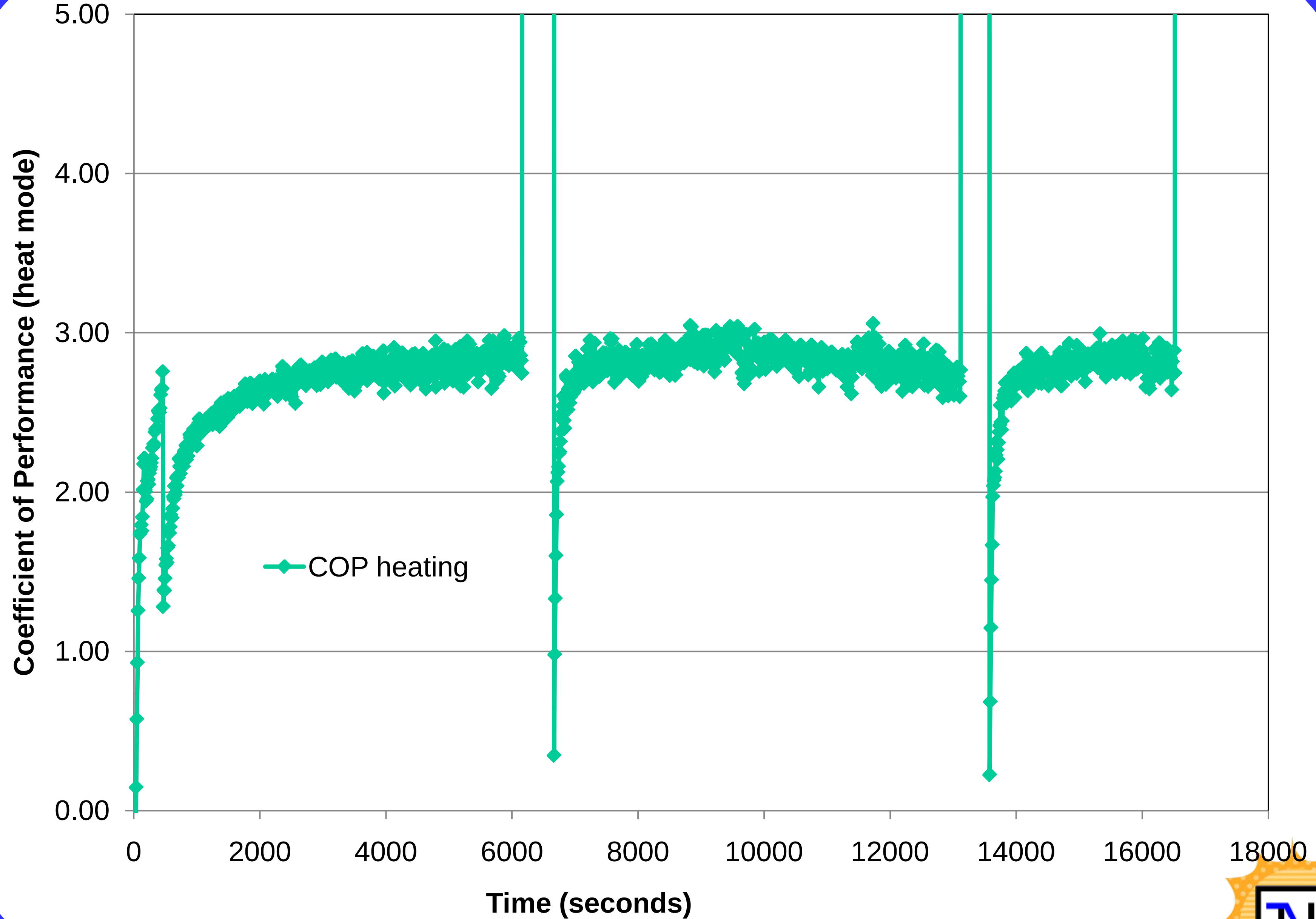
EER = 11.1 Btu/W-hr

Energy Efficiency Ratio


Winter day just below freezing, air flow ~100cfm
Compressor Power and Heat (Watts)
Time (seconds)
Compressor (W)
Home Heat (W)
Defrost periods
0
200
400
600
800
1000
1200
1400
0
2000
4000
6000
8000
10000
12000
14000
16000
18000



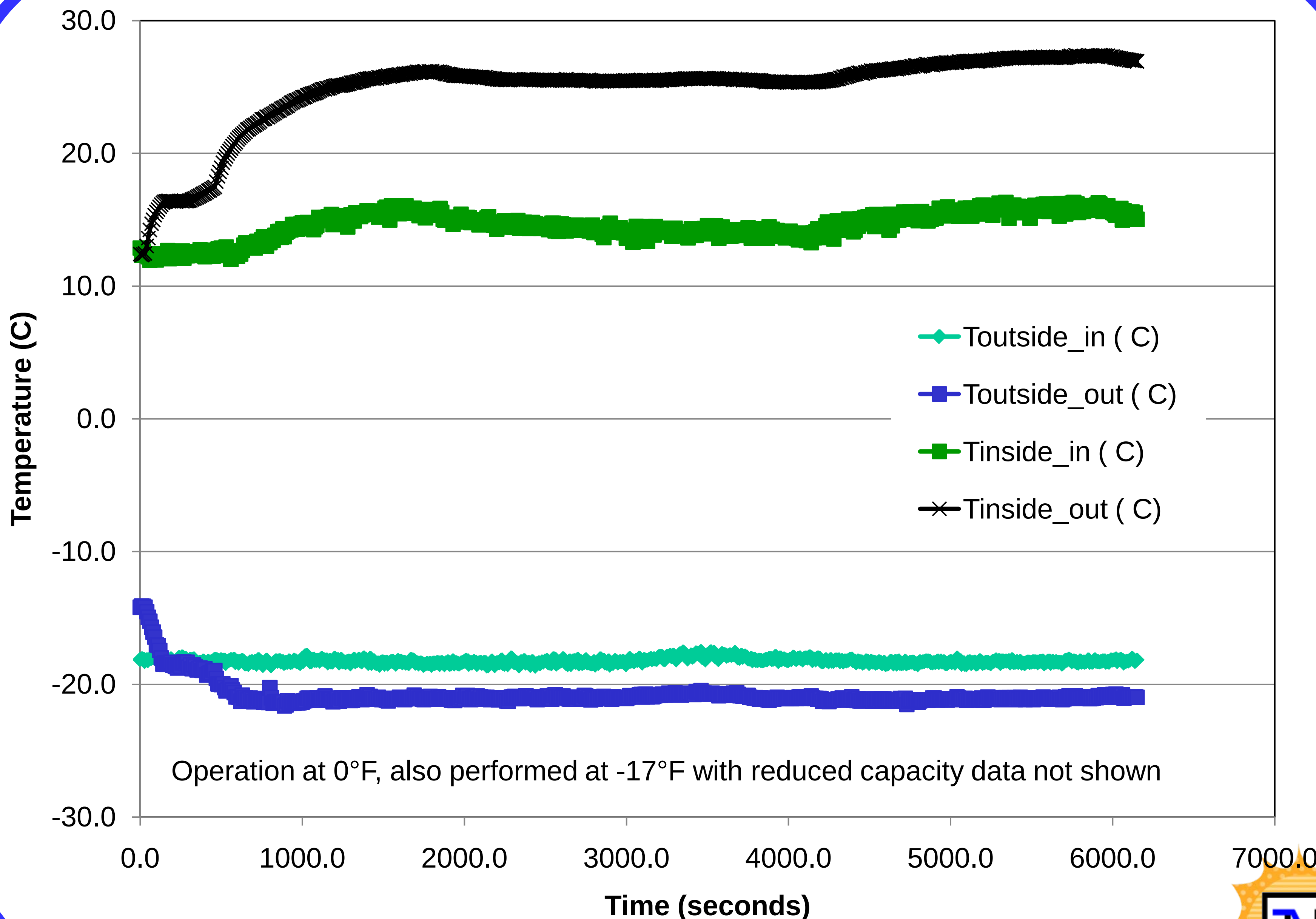
50
40
30
20
10
0
-10
-20
-30
Temperature (C)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Time (seconds)
Toutside_in (C)
Toutside_out (C)
Tinside_in (C)
Tinside_out (C)

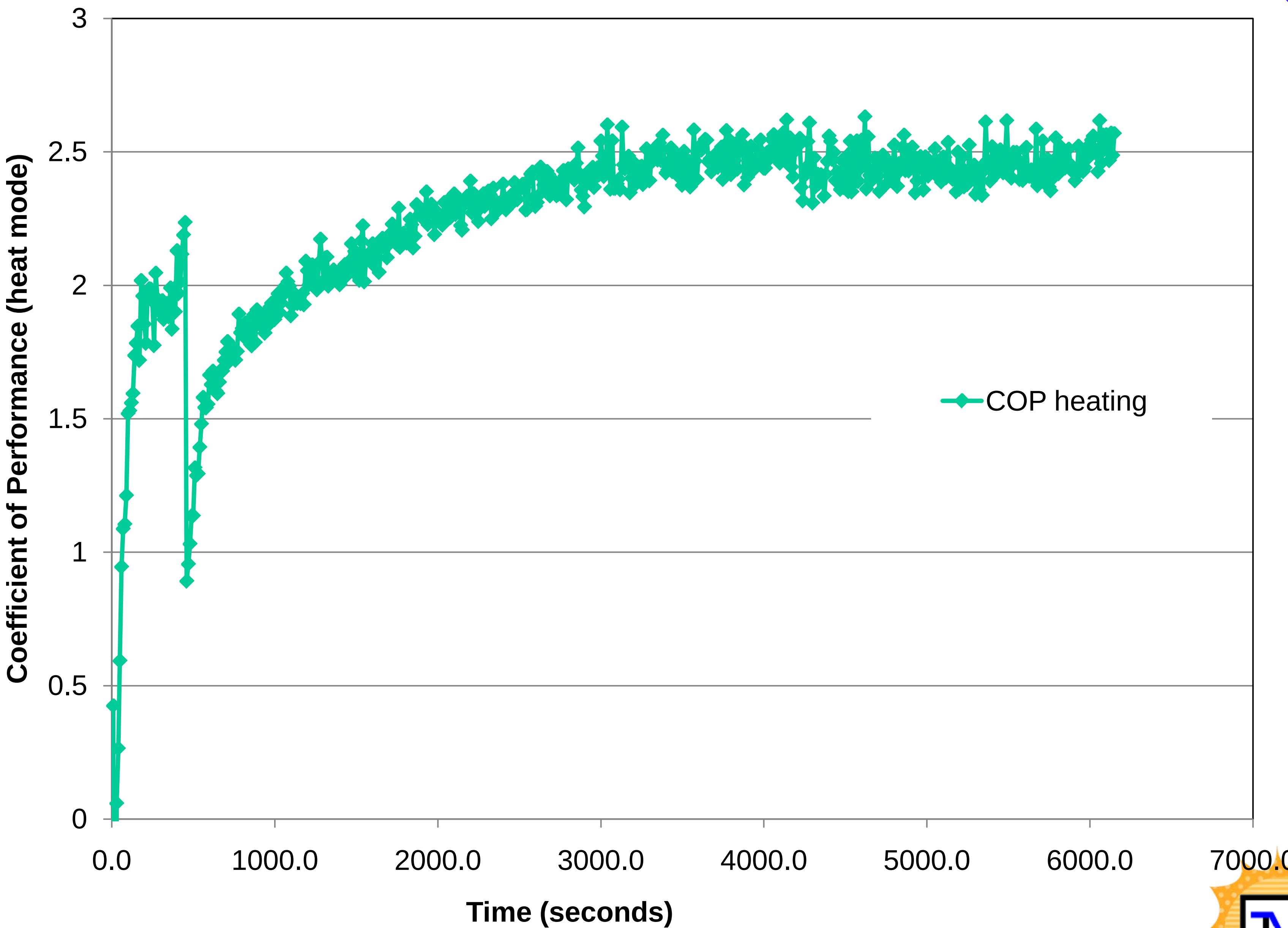


Coefficient of Performance (heat mode)
5.00
4.00
3.00
2.00
1.00
0.00
COP heating
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Time (seconds)

Very cold day ~2°F, long operation, no defrost needed

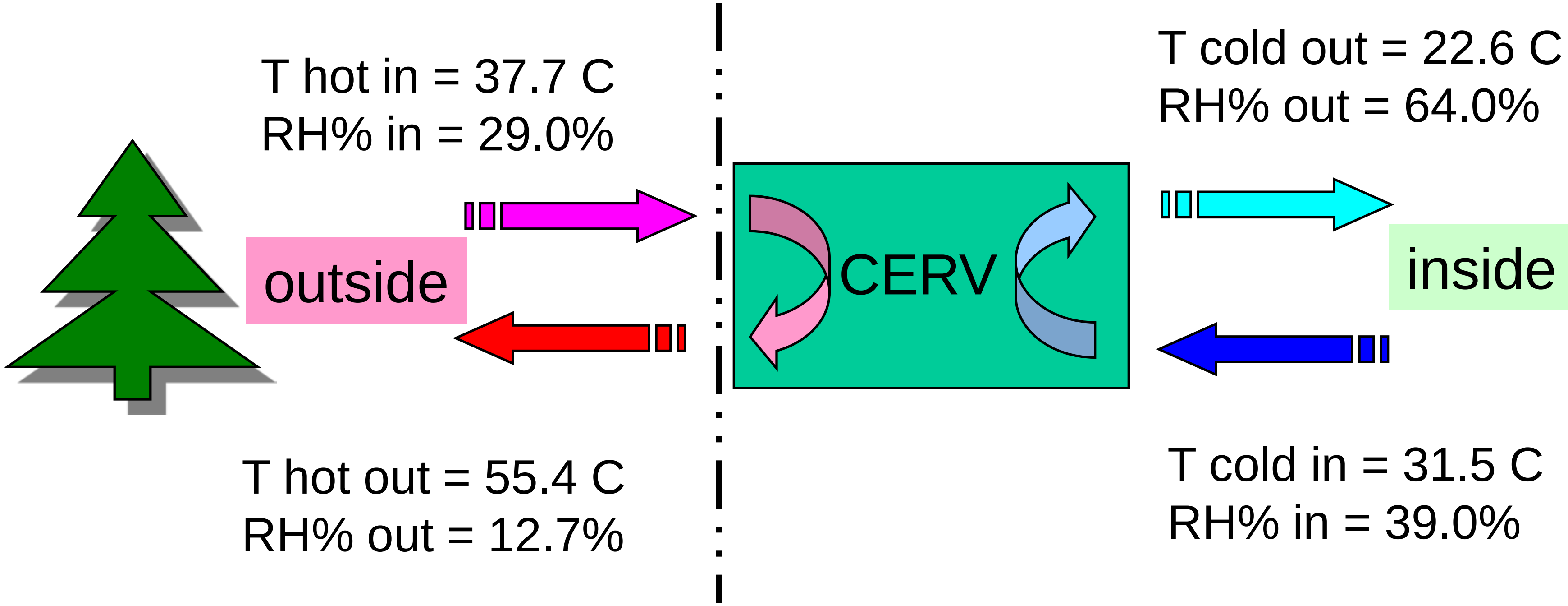
“drop in” mode lowers comp power


30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
Temperature (C)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
6000.0
7000.0
Time (seconds)
Toutside_in (C)
Toutside_out (C)
Tinside_in (C)
Tinside_out (C)
Operation at 0°F, also performed at -17°F with reduced capacity data not shown



3
2.5
2
1.5
1
0.5
0
Coefficient of Performance (heat mode)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
6000.0
7000.0
Time (seconds)
COP heating

Cooling without ventilation:



compressor power = 450 W

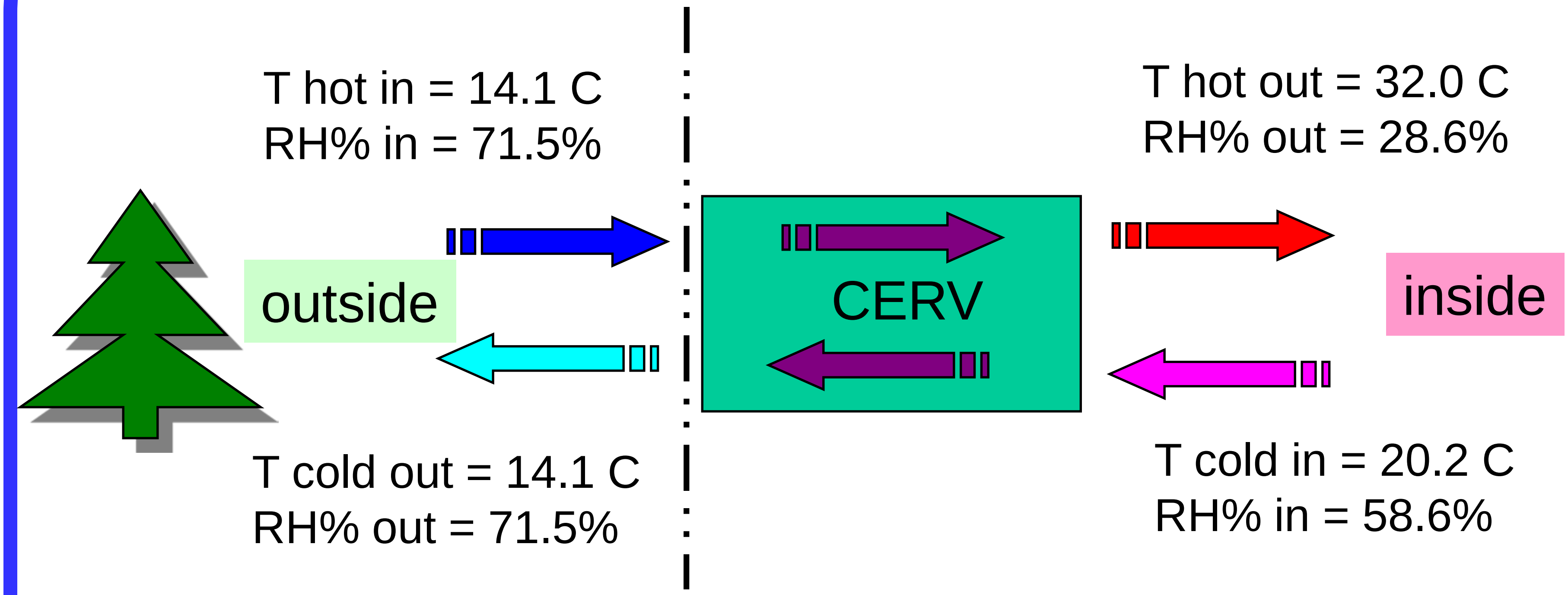
total cooling capacity = 1079 W

COP = 2.4

EER = 8.6 Btu/W-hr

lat. = 133 W
sens. = 947 W

Heating with ventilation:



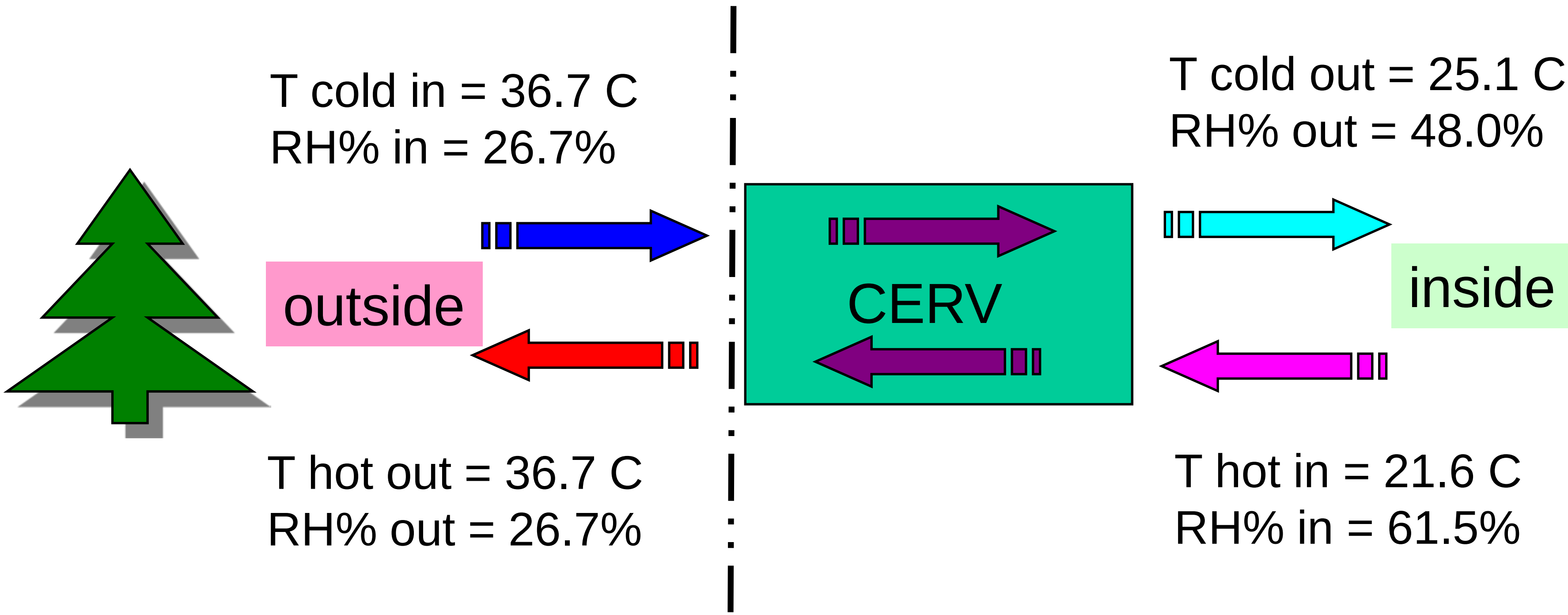
compressor power = 335 W

total heating capacity = 1803 W

COP = 5.4

EER = 19.3 Btu/W-hr

Cooling with ventilation:



compressor power = 381 W

total cooling capacity = 1342 W

COP = 3.5

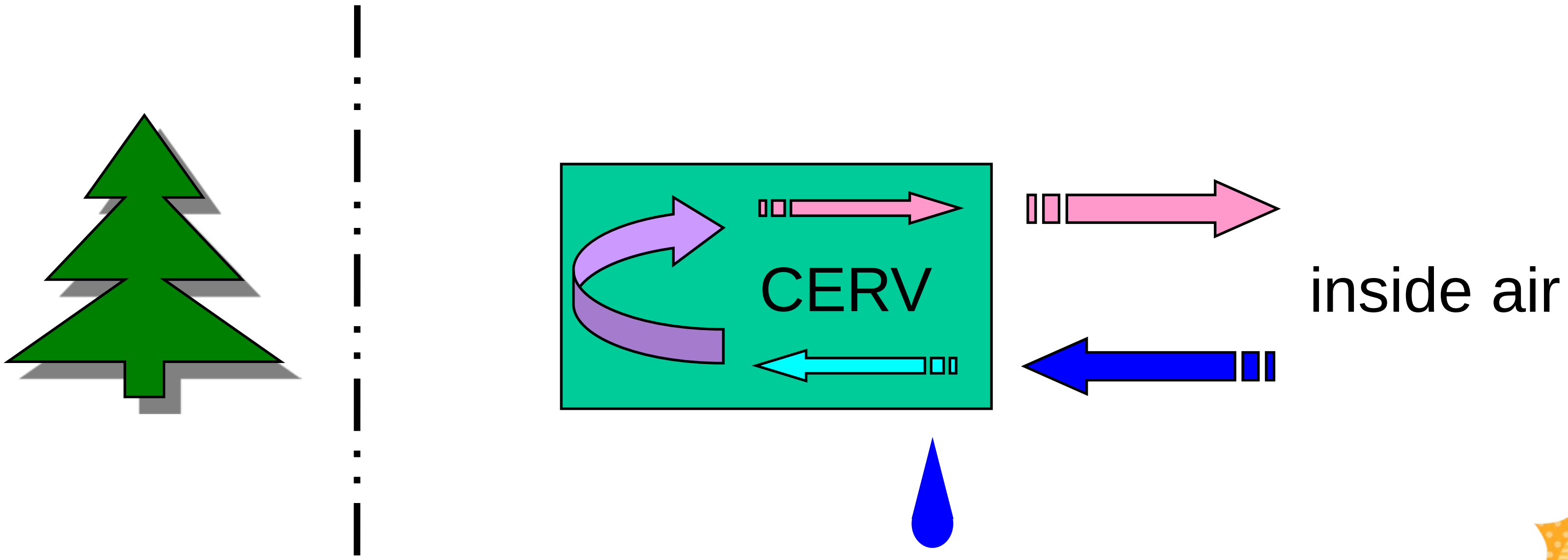
EER = 12.7 Btu/W-hr

lat. = 231 W
sens. = 1110 W

Ventilation only:

CERV in dehumidification mode

- tests show water removal rate of 0.5 liters/hr
- with compressor power of 300 W gives 1.5 l/kW-hr
- EnergyStar dehumidifier standard for this size is >1.0 l/kW-hr
- could be coupled with a ventless clothes drier



Future Testing

Many initial tests have been performed,
but ...many remain.

Test matrices quickly expand!

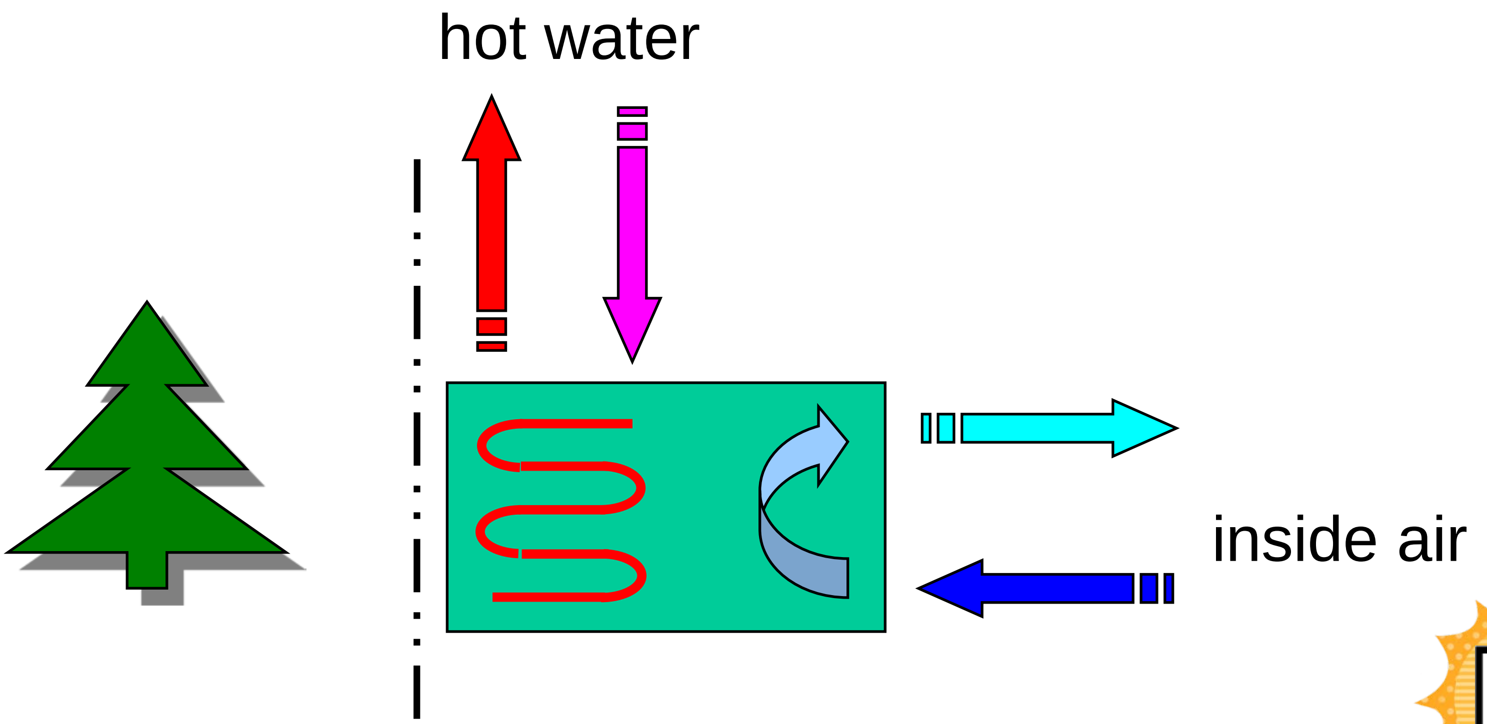
4 temperatures x 4 air flows x 4 humidities x 4 compressor speeds
= 256 points

results look promising so far

Additional Future Options:

CERV with heat pump water heater

- heats water with a COP of 2-3 (electric water heater COP is 1
- added benefit of cooling and dehumidifying house
- with COP of 3 and 15% efficient PV panels = 45% efficiency equivalent to solar thermal without added complexity



Other Considerations

- Evaporator Defrosting
  - Frost buildup on air source heat pump when heating in cold weather
- Condensate removal
  - can possibly be used to improve condenser efficiency
- moisture/mold/odor prevention
- end of life recycle ability

Thanks

Questions?