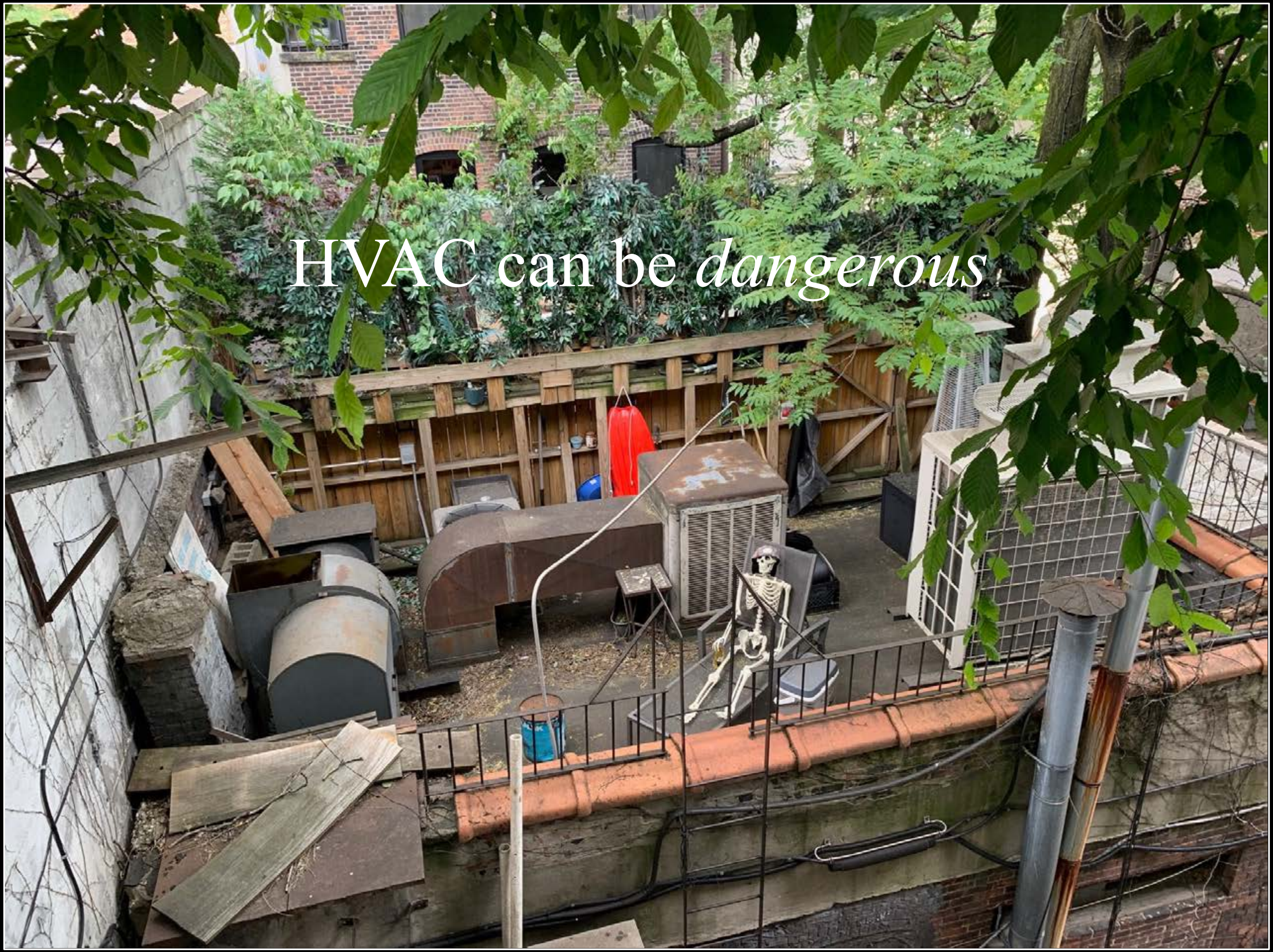
Fun With Monitoring - Using Data to Solve Problems From Design Through Occupancy

	DP(°F) : RTU In(return air/mixed air):1	DP(°F) : RTU Out(supply air):2	T(°F) : Theater	T(°F) : Outdoor Air	DP(°F) : Outdoor Air	T(°F) : Theater Floor	%RH : Theater Floor
min	61.30	58.80	66.20	69.50	67.30	67.80	82.20
max	70.60	71.20	73.00	85.10	76.00	70.10	92.20
diff	9.30	12.40	6.80	15.60	8.70	2.30	10.00

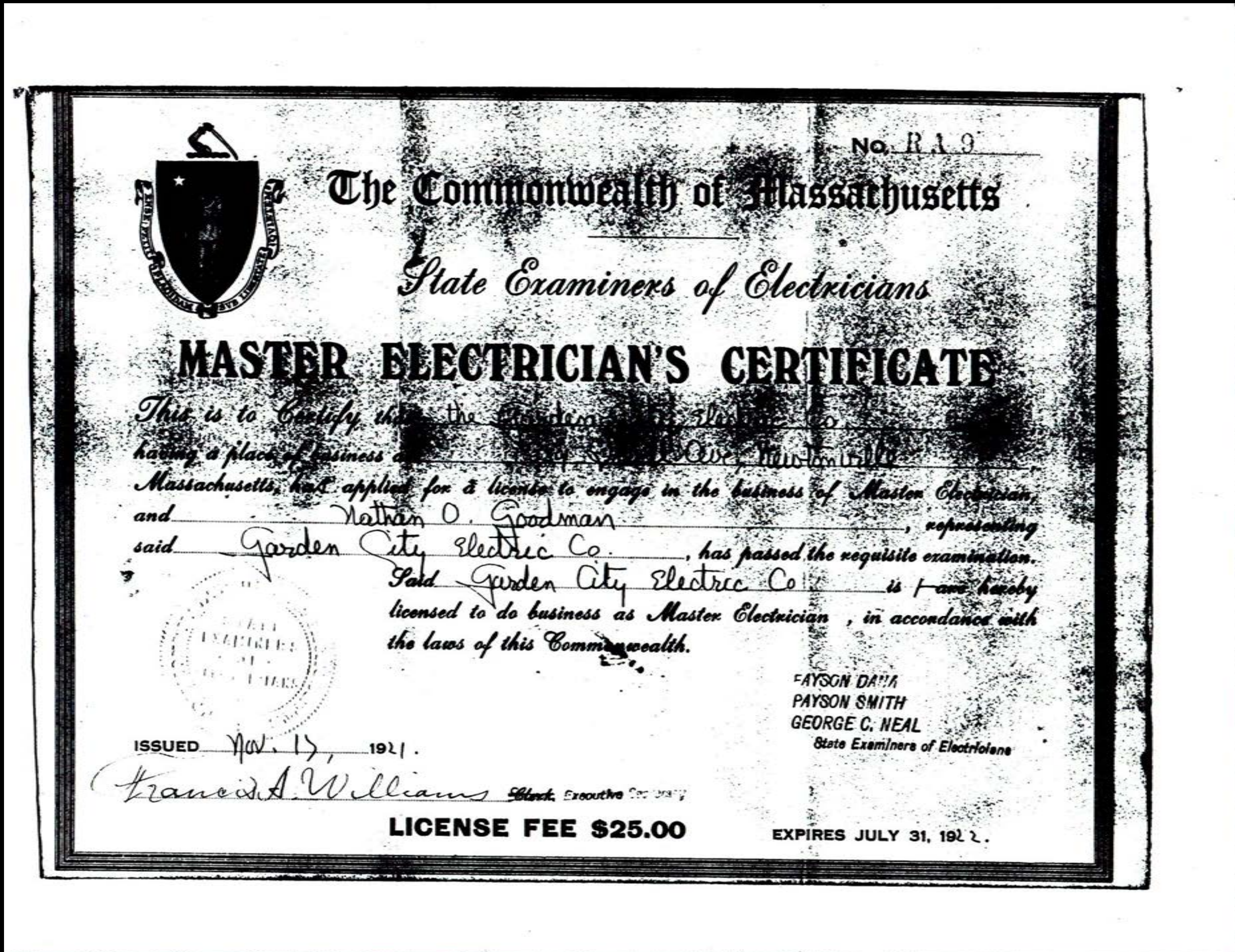
!25th! Westford Symposium - July 31, 2023

Marc Rosenbaum, PE, CPHC, MA CSL – Energysmiths – West Tisbury, MA

Mandatory AIA Warning Slide



How I Got Here


No. R 1 9

The Commonwealth of Massachusetts

State Examiners of Electricians

MASTER ELECTRICIAN'S CERTIFICATE

This is to Certify that the Garden City Electric Co. having a place of business at [illegible] Ave, Newtonville Massachusetts, has applied for a license to engage in the business of Master Electrician, and Nathan O. Goodman, representing said Garden City Electric Co., has passed the requisite examination. Said Garden City Electric Co. is ~~are~~ hereby licensed to do business as Master Electrician, in accordance with the laws of this Commonwealth.

PAYSON DANA
PAYSON SMITH
GEORGE C. NEAL
State Examiners of Electricians

ISSUED Nov. 17, 1921.

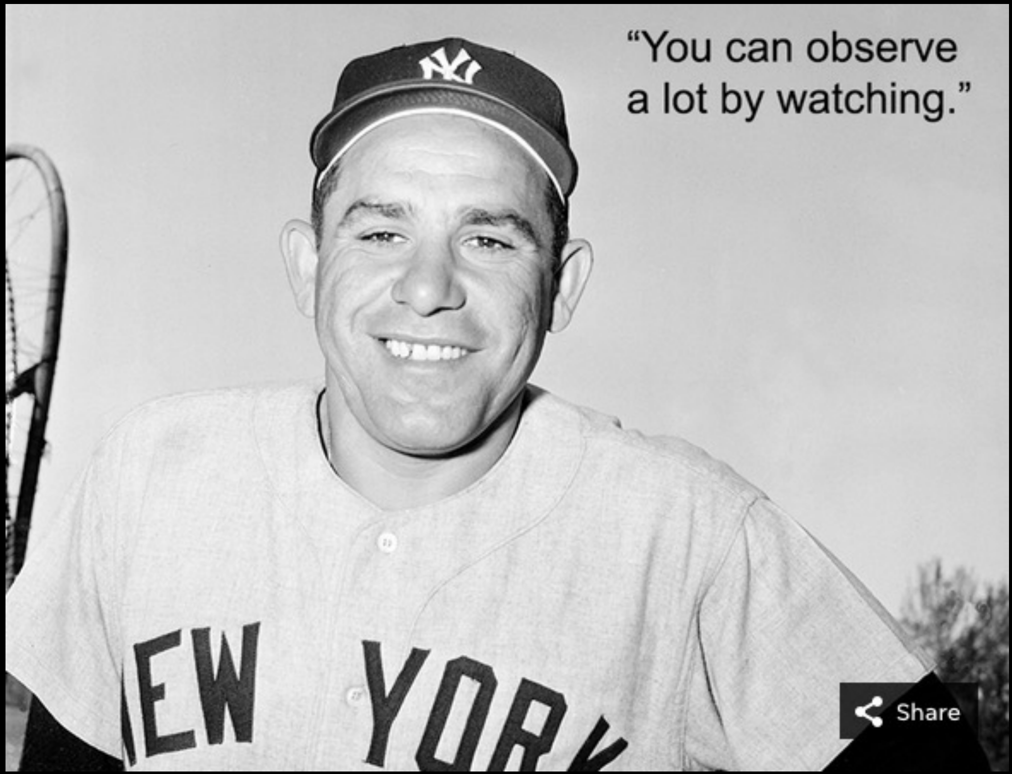
Francis A. Williams ~~Clerk~~ Executive Secretary

LICENSE FEE $25.00

EXPIRES JULY 31, 1922.

Why Bother?

- Measure the performance of a building or system
- Solve a problem – identify cause(s)
- Identify a problem heretofore unnoticed
- Demonstrate the cause of a problem to a skeptic
- Determine proper inputs for design
- Understand cause and effect
- Learn something! Curiosity is its own reward ☺



Types of Monitoring

- Long term, leave in place
- Short term, solve a problem
- Instantaneous, measure one data point

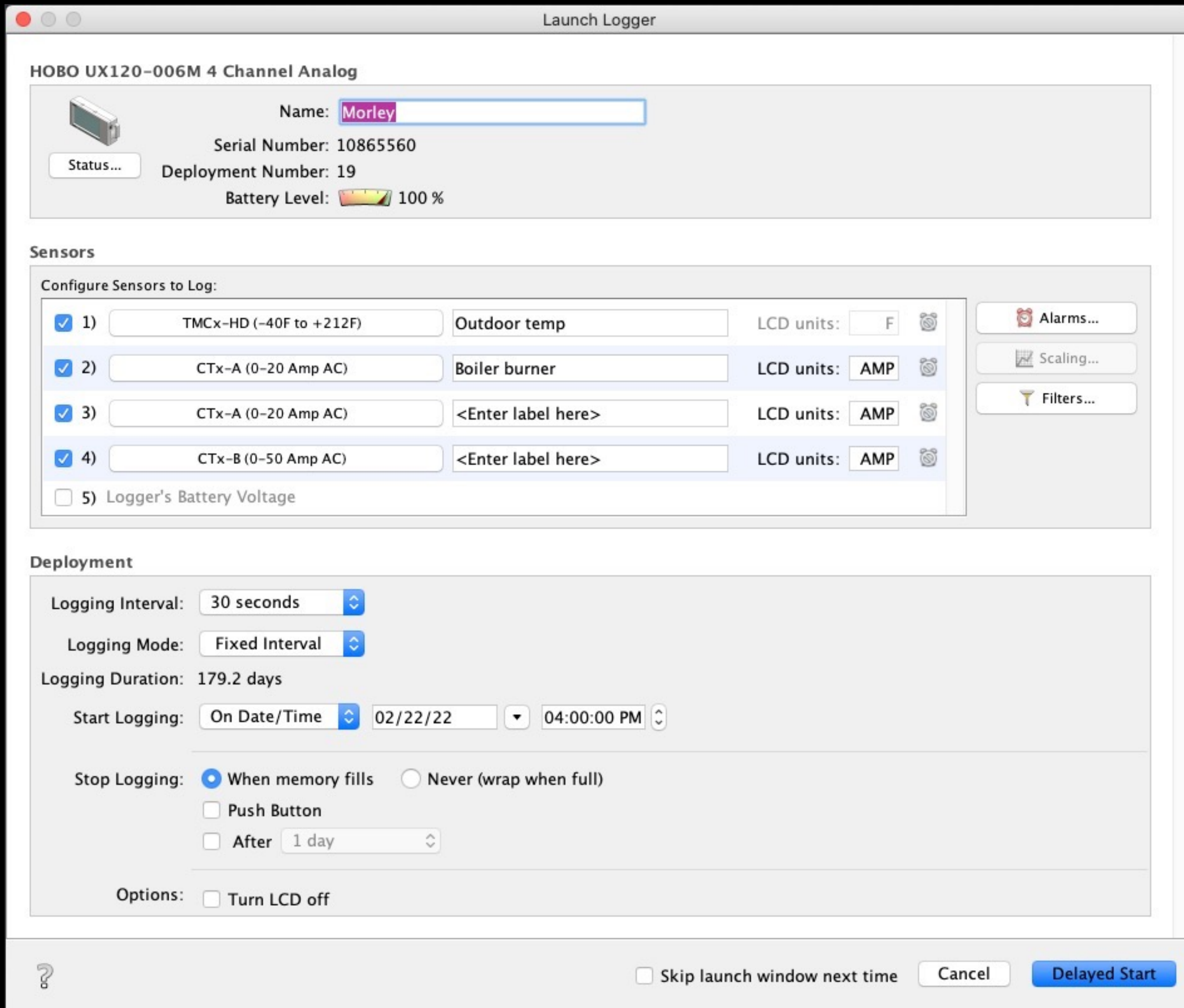
Onset Computer

Onset Computer Hobos

- Old style multi-channel with 2 external channels and internal T, RH
- Multi-channel with 4 external channels, LCD, more data storage
- 50A current transformer (CT)
- 50 ft indoor/outdoor temperature sensor

These older units require a laptop and a cable to launch and read out – newer ones are Bluetooth. More money gets WIFI capability.

Hoboware


Launch Logger
HOBO UX120-006M 4 Channel Analog
Name: Morley
Status...
Serial Number: 10865560
Deployment Number: 19
Battery Level: 100 %
Sensors
Configure Sensors to Log:
1) TMCx-HD (-40F to +212F)
Outdoor temp
LCD units: F
2) CTx-A (0-20 Amp AC)
Boiler burner
LCD units: AMP
3) CTx-A (0-20 Amp AC)
<Enter label here>
LCD units: AMP
4) CTx-B (0-50 Amp AC)
<Enter label here>
LCD units: AMP
5) Logger's Battery Voltage
Alarms...
Scaling...
Filters...
Deployment
Logging Interval: 30 seconds
Logging Mode: Fixed Interval
Logging Duration: 179.2 days
Start Logging: On Date/Time 02/22/22 04:00:00 PM
Stop Logging: When memory fills
Never (wrap when full)
Push Button
After 1 day
Options: Turn LCD off
Skip launch window next time
Cancel
Delayed Start

Digital Multi-meter

- Instantaneous measurement, although logging ones are available
- Amps, AC voltage, DC voltage, Ohms

Digital Thermocouple

- This one has two channels
- Thermocouple is slender, reacts quickly

Kill-A-Watt

- For 120 VAC loads
- Plug into receptacle, plug device into it
- Available in logging version to aggregate kWh usage as well as wattage drawn

CO2 Sensor

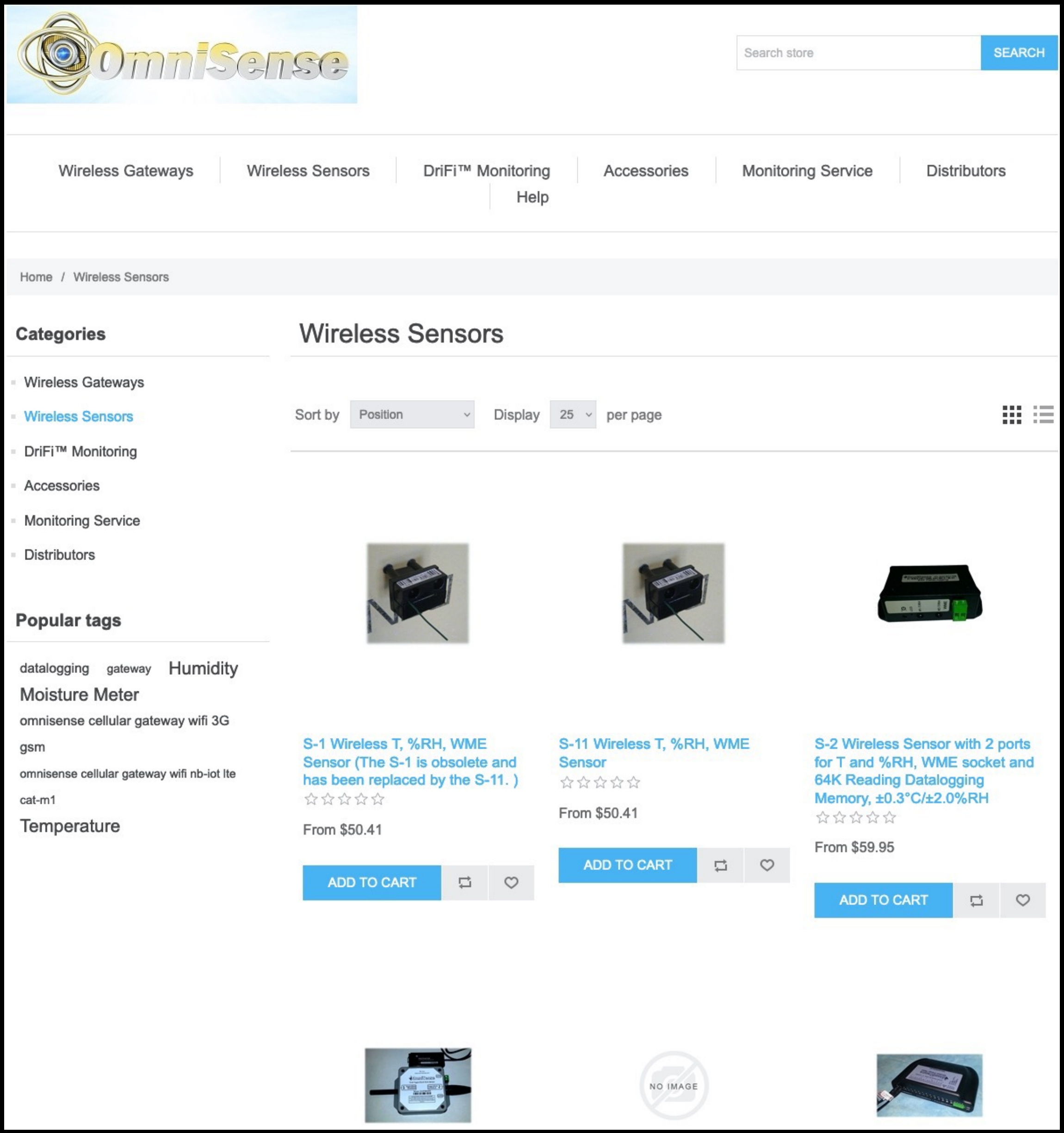
- Use with a Hobo logger
- Onset has dedicated sensor/loggers
- Self-calibrating – I put it outdoors periodically to check

Radon

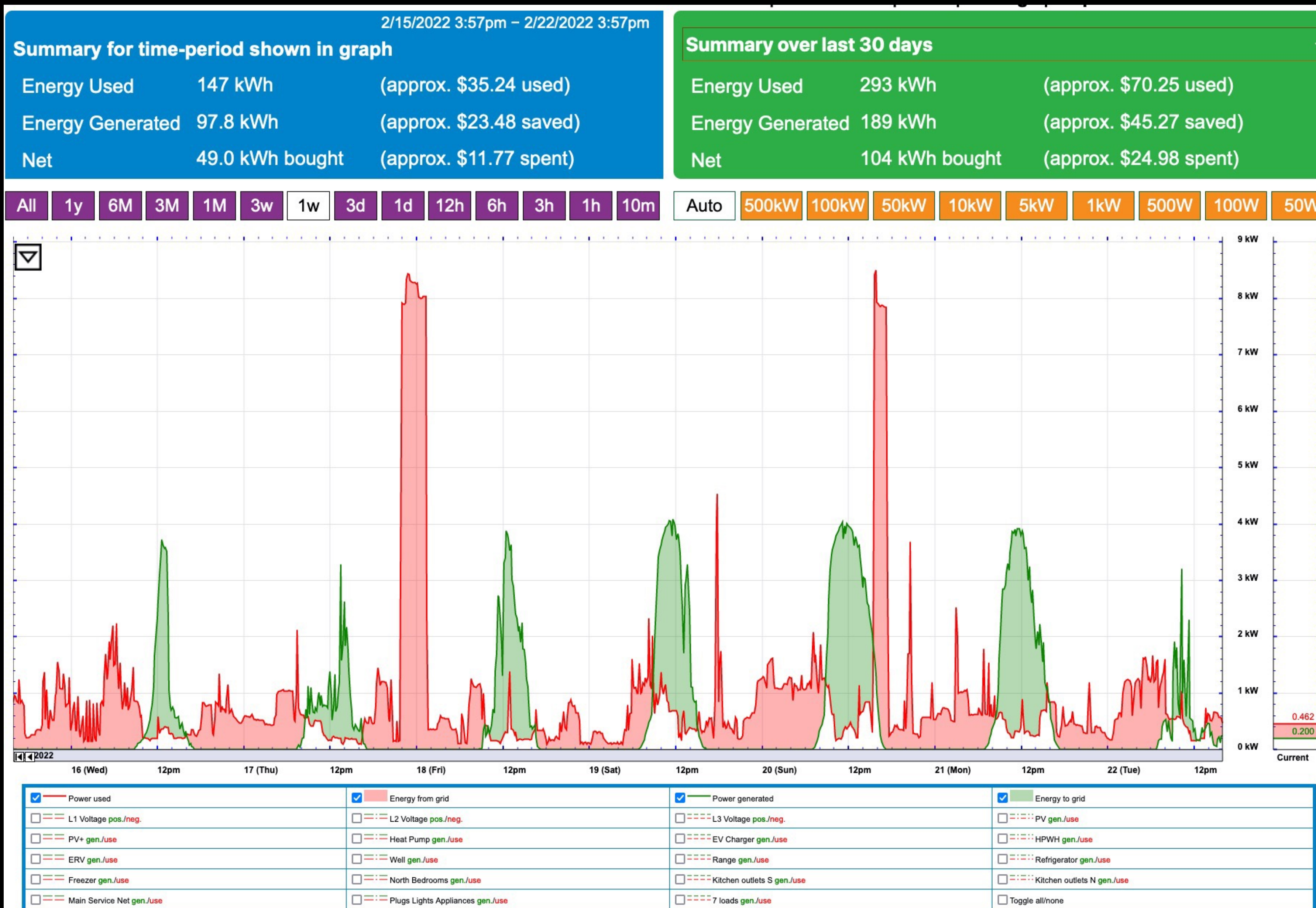
- Hourly readings
- Download via Bluetooth to phone

Omnisense

- Web-accessible monitoring
- Temperature, RH, dewpoint, CO2, moisture content,…..

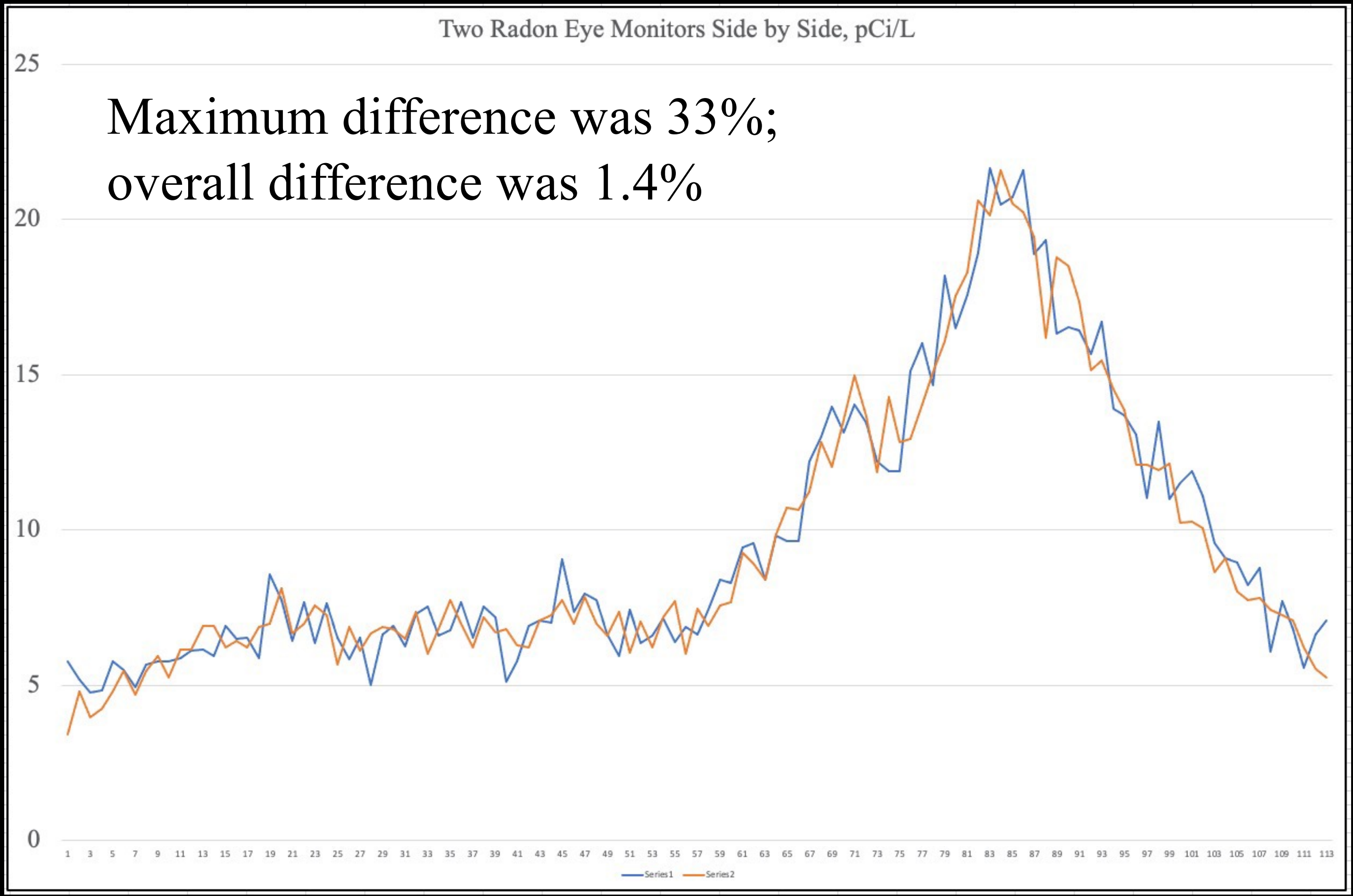


Circuit by Circuit Monitors



Calibration

- Can the instrument be calibrated to a known standard?
- Can sensors of the same type be calibrated to each other?
- Is each measurement critical or can the results be averaged?



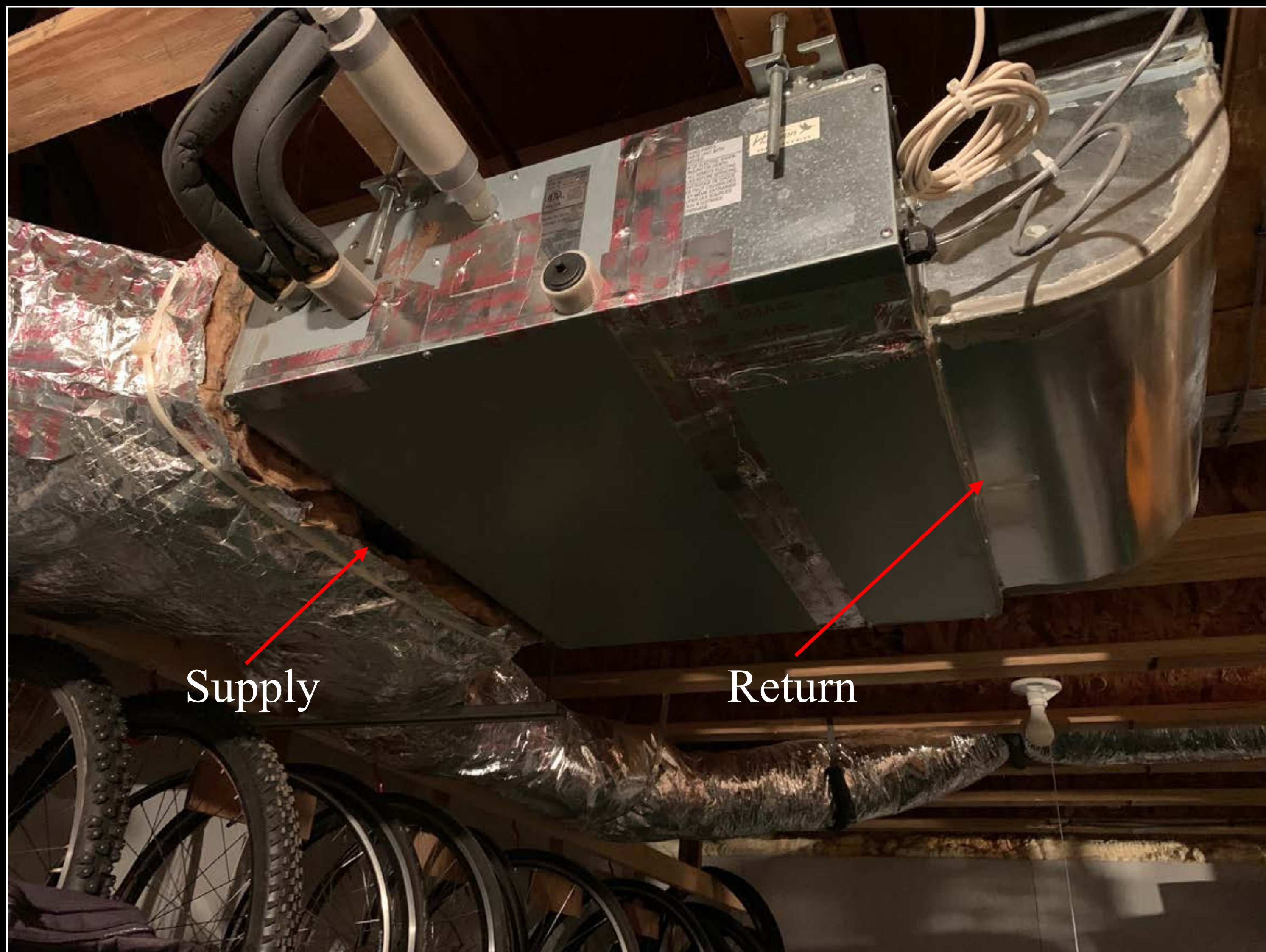
Accuracy vs. Precision

- Accuracy of a set of measurements is how close they are to the true value
- Precision of a set of measurements is how close they are to each other (repeatable)

- *How accurate do the measurements need to be to be useful?*

Accuracy – Use One Sensor?

- Example – measure the temperature rise across a ducted heat pump.



Case #1

Measure the performance of a building or a system

Heat Pump COP @ -7˚F

- Temperature rise across the air handler = 39.8 ˚F
- Flow rate 368 CFM (Duct Blaster measurement)
- Input power 2.09 kW
- 39.8 x 368 x 1.08 / 3,412 BTU/kWh = 4.64 kW
- COP = 4.64/2.09 = 2.22

- How much energy goes to the basement?
- Average ΔT across the supply registers and the return grille was 35.4 ˚F
- (39.8 – 35.4) / 39.8 = 11%

Each measurement – temperature, power, flow rate - has potential error, so total uncertainty of the result is increased

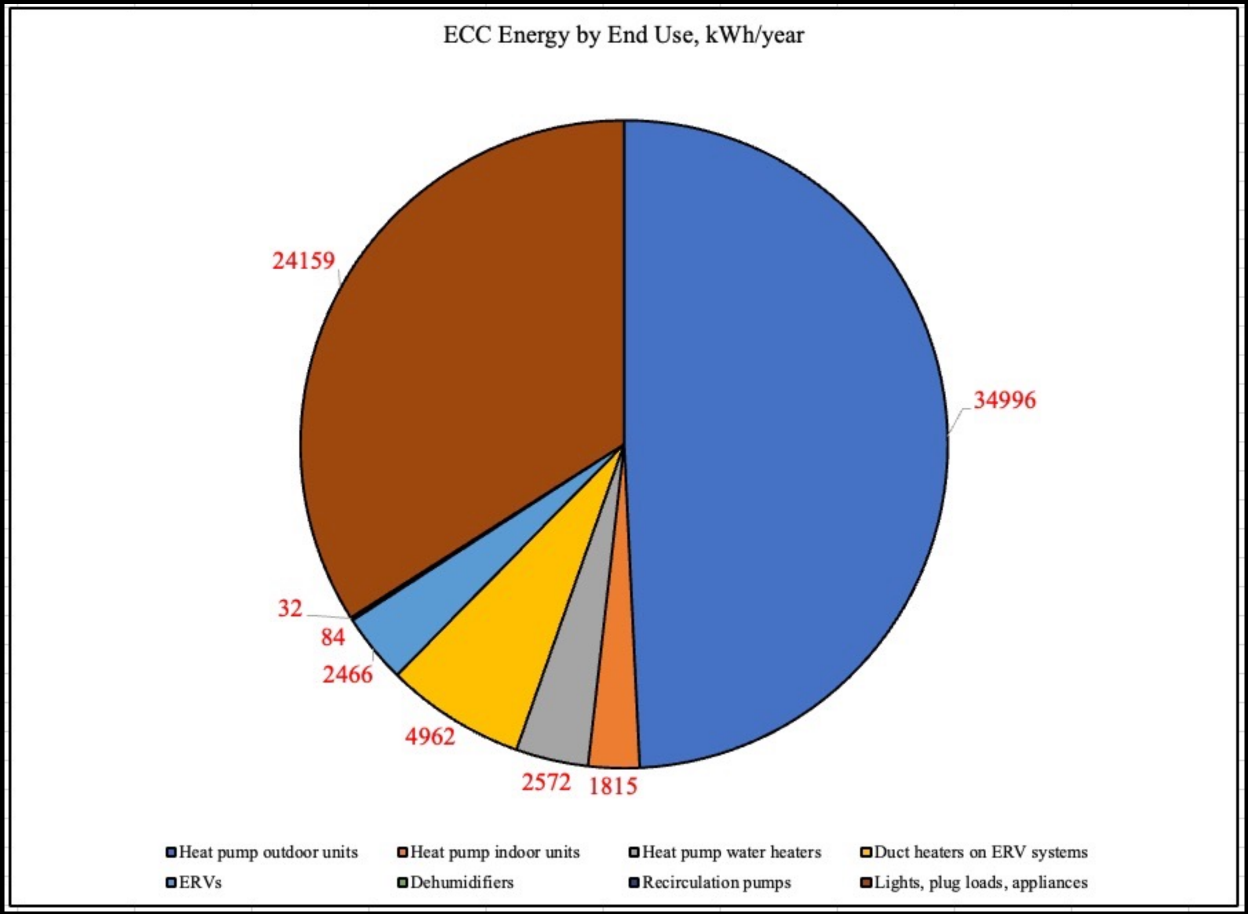
Case #2

Measure the performance of a building or a system

The Case of the VRF Heat Pumps

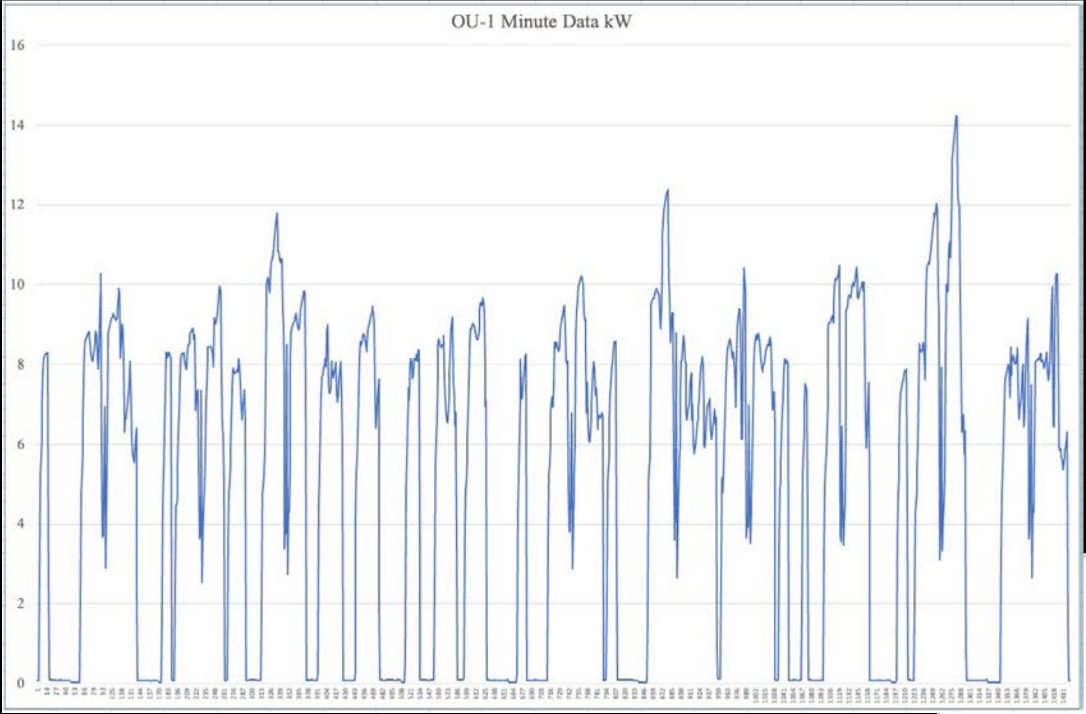
- 9,600 sf daycare center
- R-27 slab, R-30 walls, R-50 roof, R-6 windows, R-2.5 skylights, 0.04 CFM75/ssf
- Two 10 ton heat recovery VRF air-air heat pumps, 18 indoor units
- Seven ERVs totalling 2,400 CFM, CO_2 demand control

VRF Heat Pumps

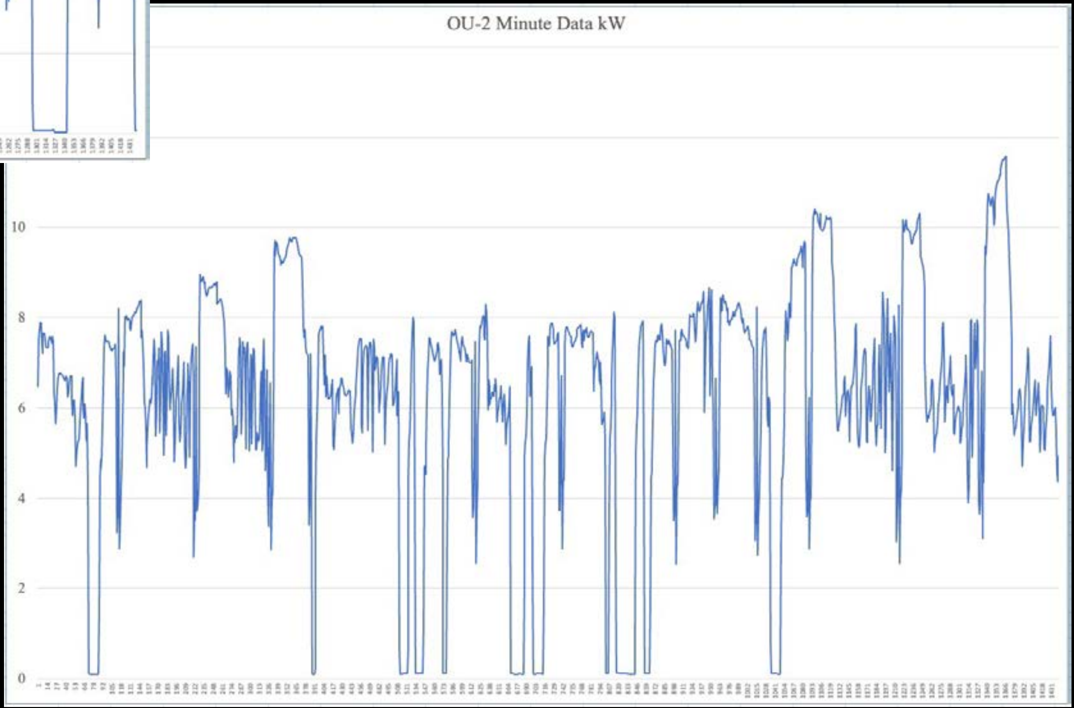


- Site EUI 7.42 kWh/sf/yr (25 kBTU/sf/yr)
- HP EUI 3.84 kWh/sf/yr
- Summer months are the highest usage

One Cold, Cloudy, Unoccupied Day



- Outdoors 20˚F, indoors 70˚F
- ERVs off
- 324 kWh total building use
- 276 kWh HP use
- Calculated net load 15 kW
- HPs 11.4 kW
- COP +/- 1.3
- Uncorrected COP Data is 2.58



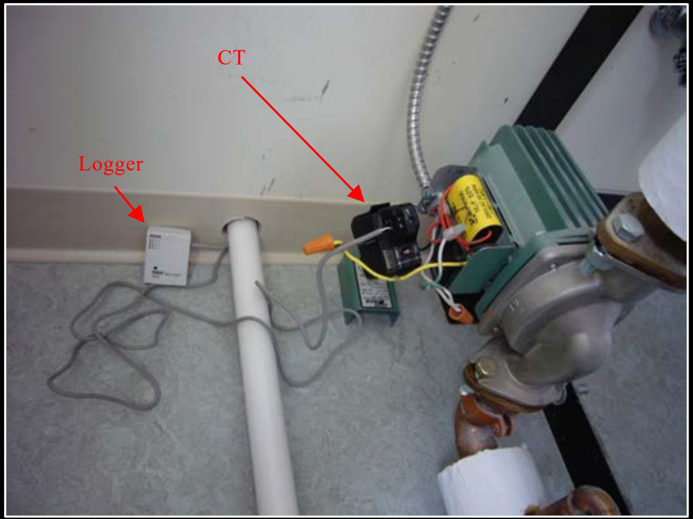
- Minute data
- One unit turns on and off

Case #3

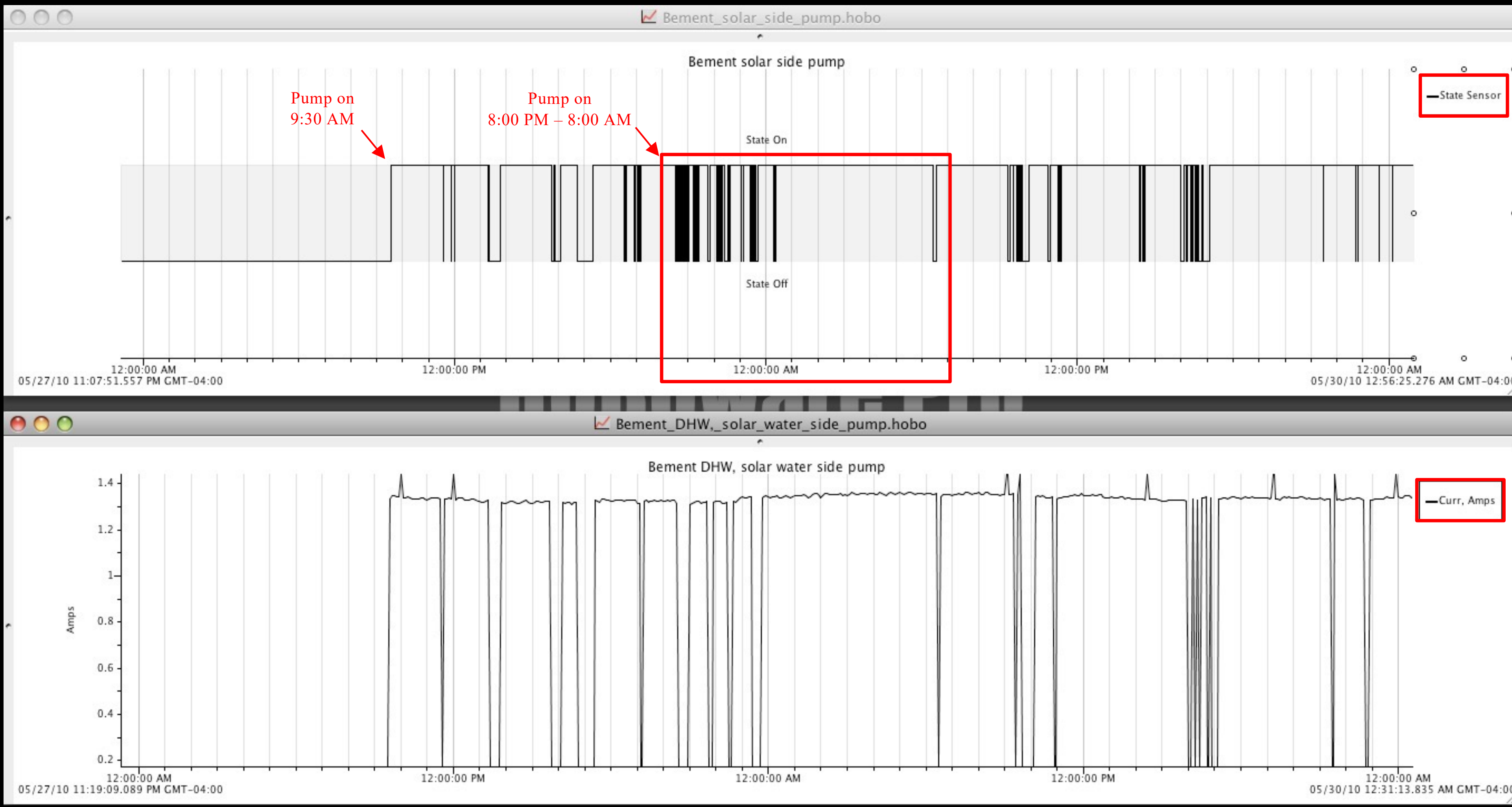
Identify and solve a problem

The Case of the High Hot Water Energy

- 10,000 sf dorm – 4 faculty apartments, 10 double dorm rooms – 28 occupants
- 240 sf drainback SDHW system – two 120 gallon solar storage tanks with 120 gallon electric back-up
- Monitoring showed that back-up electric energy was higher than expected, while DHW usage was in line with modeled usage
- Installed Hobo dataloggers with current transformers on the solar array pump and on the potable side pump, as well as on the heating elements in the back-up tank



The Case of the High Hot Water Energy



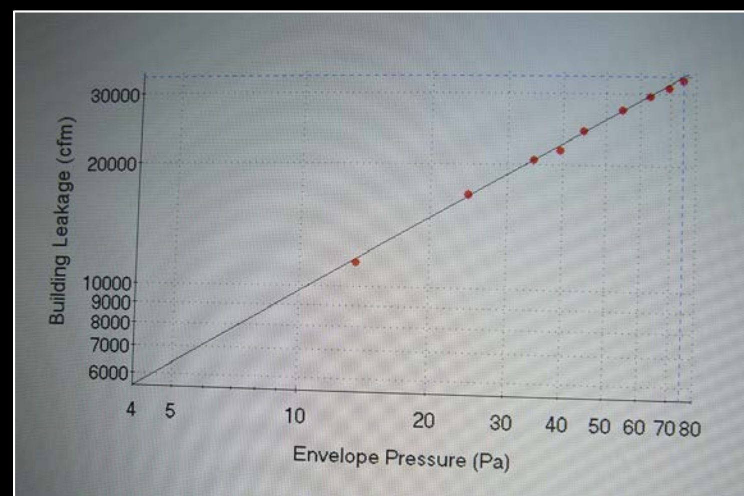
The pumps were running at night – controller was faulty.

These are not *lunar* hot water systems

Case #4

Identify and solve a problem

The Case of the High Average Energy Use



- 226,500 sf university building
- Excellent peak load performance (1,100 sf/ton)
- Annual energy performance less stellar

The Case of the High Average Energy Use

- Data both peak and usage was available
- Peak electrical use was 1.75 W/sf
    - Lighting 0.55 W/sf
    - Plug loads 0.28 W/sf
    - Other 0.92 W/sf (NB: 178,400 sf underground parking garage, commercial kitchen)
- Average electrical load was 1.15 W/sf – 66% of peak – seemed high
- I asked MIT to look for something that was running all the time
- Kitchen hood was 6,000 CFM but variable speed based on cooking intensity
- Speed control uses an electric eye across the hood to sense opacity of exhaust (smoke), ramping up the exhaust fans as opacity increases
- Investigation showed that the hood was running at full speed 24/7
- Further investigation showed that fire suppression system piping *blocked* the electric eye, sending the false signal that exhaust opacity was always maximum
- MIT Director of Engineering estimated energy use impact as an additional 30% annually

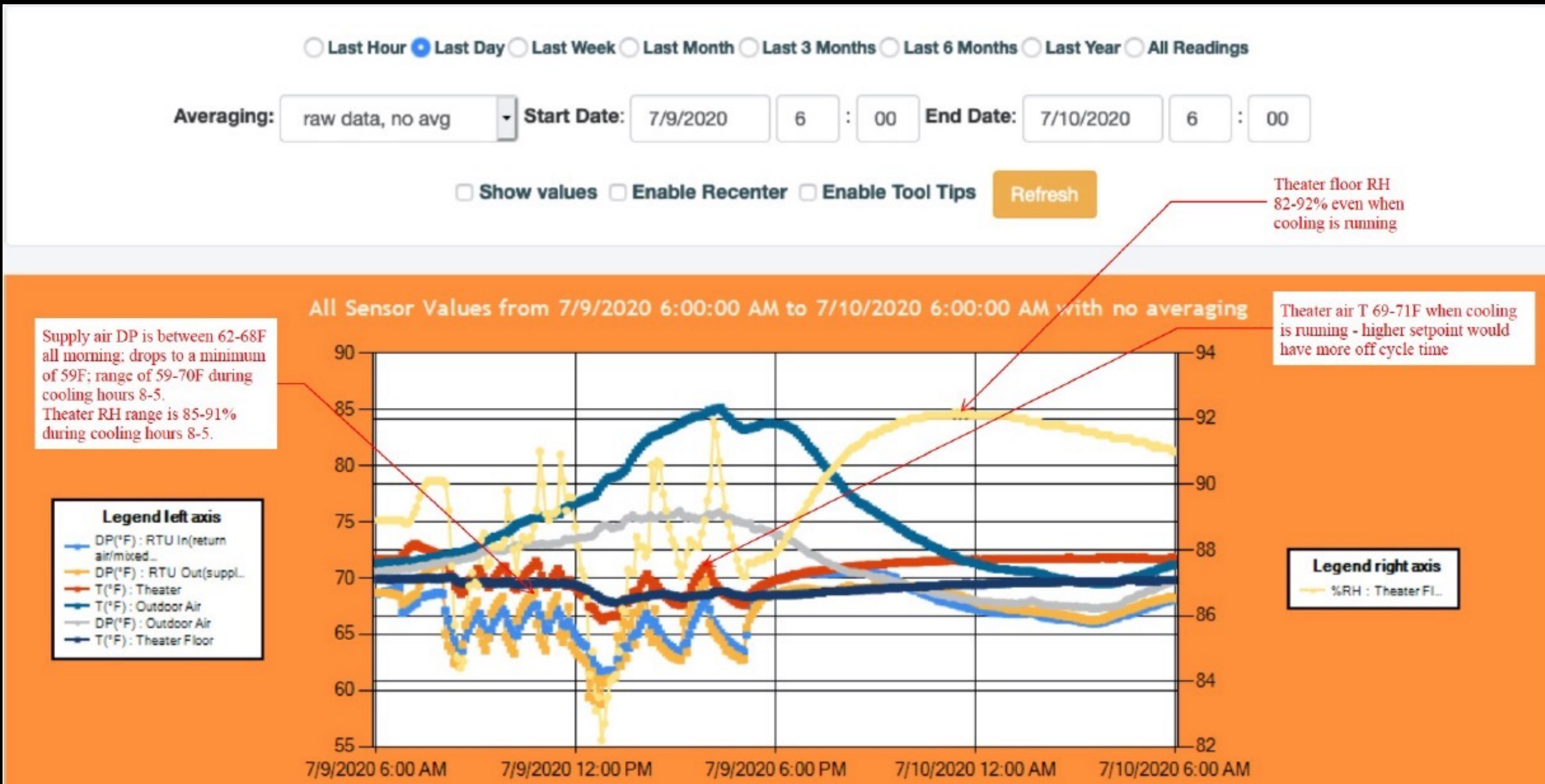
Case #5

Demonstrate the cause of a problem to a skeptic

The Case of the Moldy Theater

- 270 seat black box theater in coastal MA – 3 year old building
- Mold on seats and stage curtain
- RH over 80% in cooling season
- Facilities staff working with design ME were stymied
- 10,000 CFM constant volume air handler with 4 stages of compressor modulation available
- Outdoor air was set to a maximum of 2,850 CFM and a minimum of 540 CFM with no energy recovery.
- To avoid over-cooling, the compressors are controlled by space temperature, so as the cooling load decreases, coil temperature and the discharge air temperature of the air rises. Dehumidification capacity falls off rapidly.
- Peak dehumidification load from occupants and ventilation air was 10-13 tons.
- Equipment dehumidification capacity was 3.8 tons.
- An Omnisense datalogging system was installed with the following points:
    - Theater air near floor
    - Theater air high
    - Outdoor air
    - Mixed air (return air/outdoor air) into the air handler coil
    - Discharge air from the air handler

The Case of the Moldy Theater



75˚F, 50% RH = 55˚F DP; ASHRAE limits DP to 60˚F

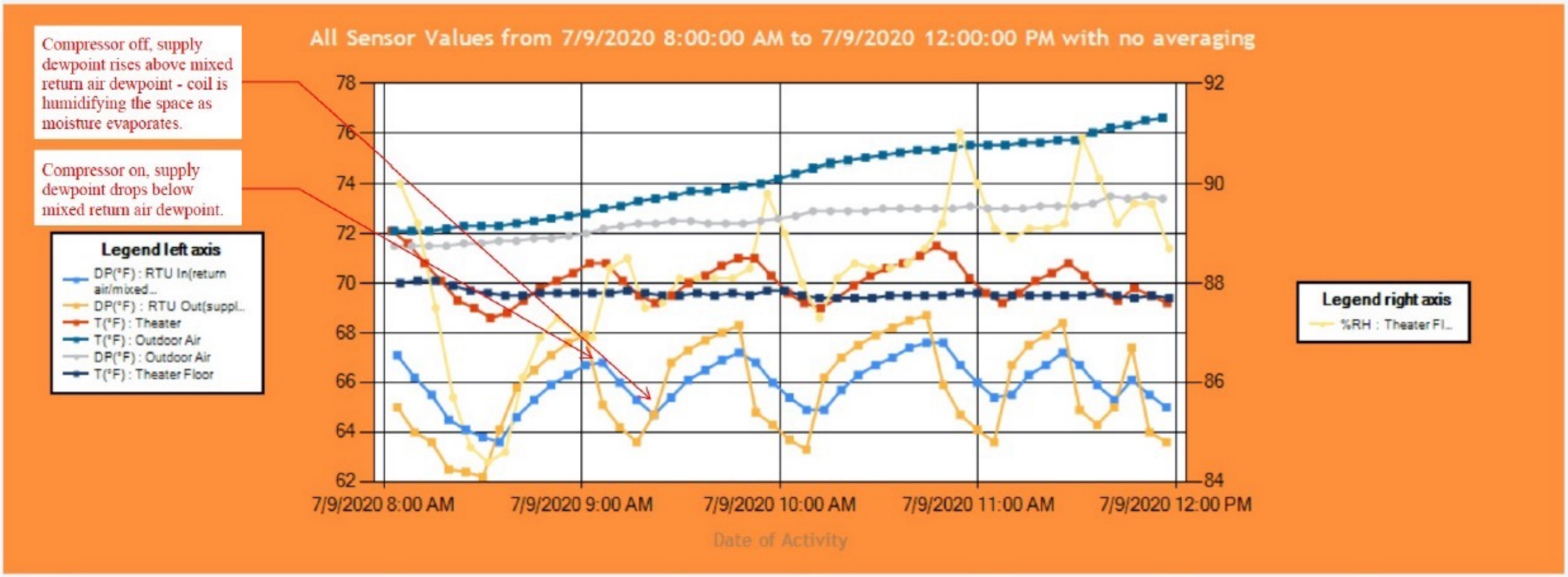
	DP(°F) : RTU In(return air/mixed air):1	DP(°F) : RTU Out(supply air):2	T(°F) : Theater	T(°F) : Outdoor Air	DP(°F) : Outdoor Air	T(°F) : Theater Floor	%RH : Theater Floor
min	61.30	58.80	66.20	69.50	67.30	67.80	82.20
max	70.60	71.20	73.00	85.10	76.00	70.10	92.20
diff	9.30	12.40	6.80	15.60	8.70	2.30	10.00

The Case of the Moldy Theater

Last Hour · Last Day · Last Week · Last Month · Last 3 Months · Last 6 Months · Last Year · All Readings

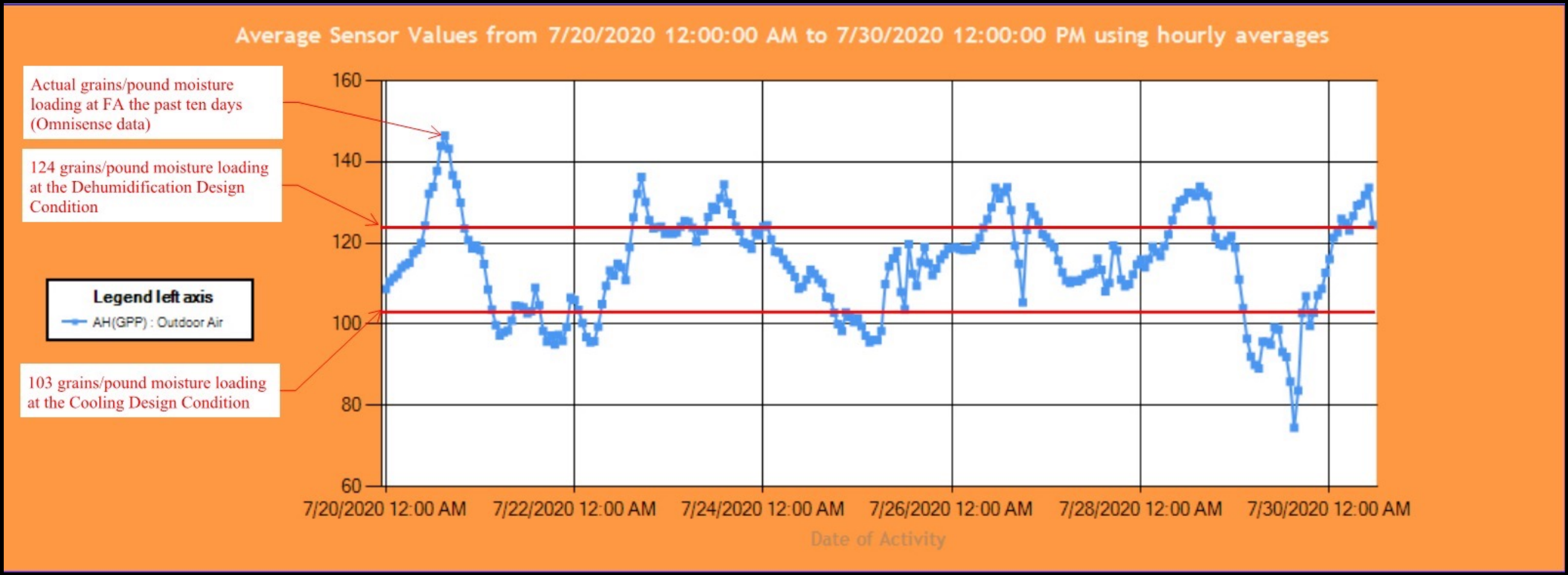
Averaging: raw data, no avg **Start Date:** 7/9/2020 8 : 00 **End Date:** 7/9/2020 12 : 00

Show values · Enable Recenter · Enable Tool Tips · Refresh



	DP(°F) : RTU In(return air/mixed air):1	DP(°F) : RTU Out(supply air):2	T(°F) : Theater	T(°F) : Outdoor Air	DP(°F) : Outdoor Air	T(°F) : Theater Floor	%RH : Theater Floor
min	63.60	62.20	68.60	72.10	71.50	69.40	84.40
max	67.60	68.70	72.10	76.60	73.50	70.10	91.00
diff	4.00	6.50	3.50	4.50	2.00	0.70	6.60

The Case of the Moldy Theater



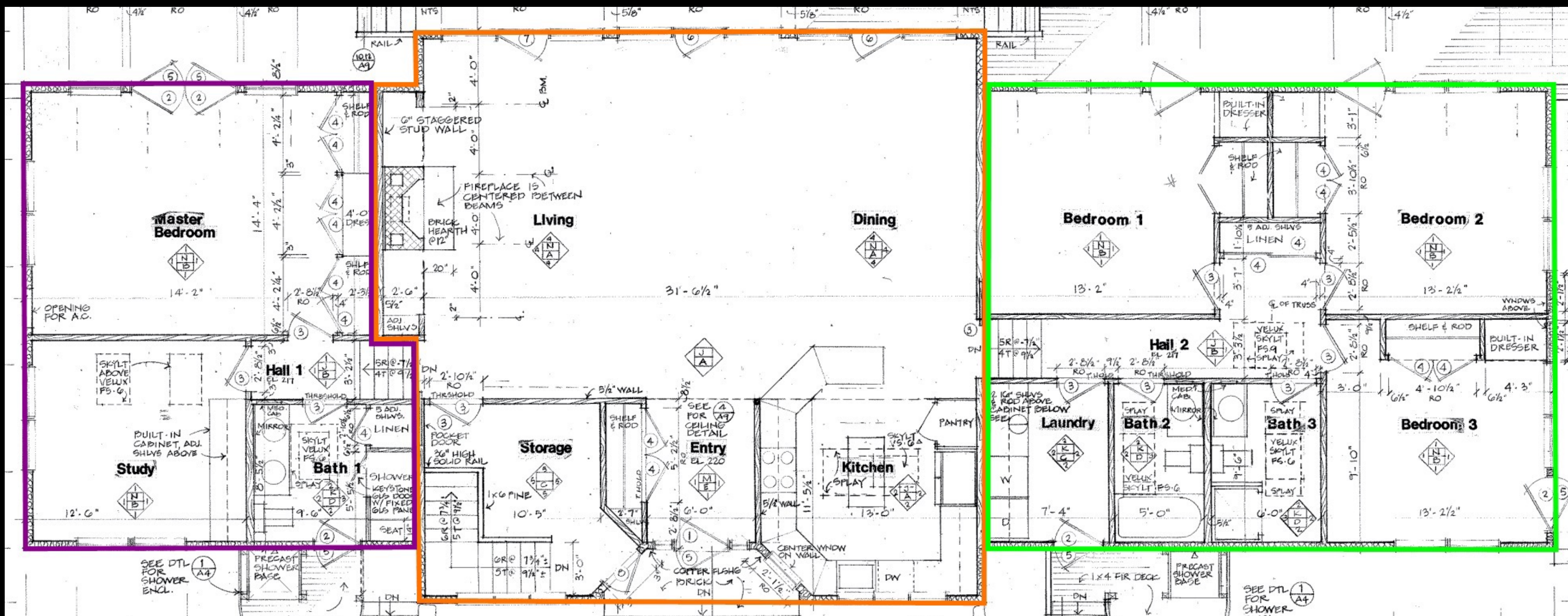
Design for Dehumidification moisture load of outdoor air is 20% higher than the Cooling Design moisture load. Peak moisture load observed was 19% higher than Design for Dehumidification load, and 44% higher than Cooling Design load.

Case #6

Demonstrate the cause of a problem to a skeptic

The Case of the Hot Basement

- 2,400 sf House, oil furnace, three zones with motorized zone dampers



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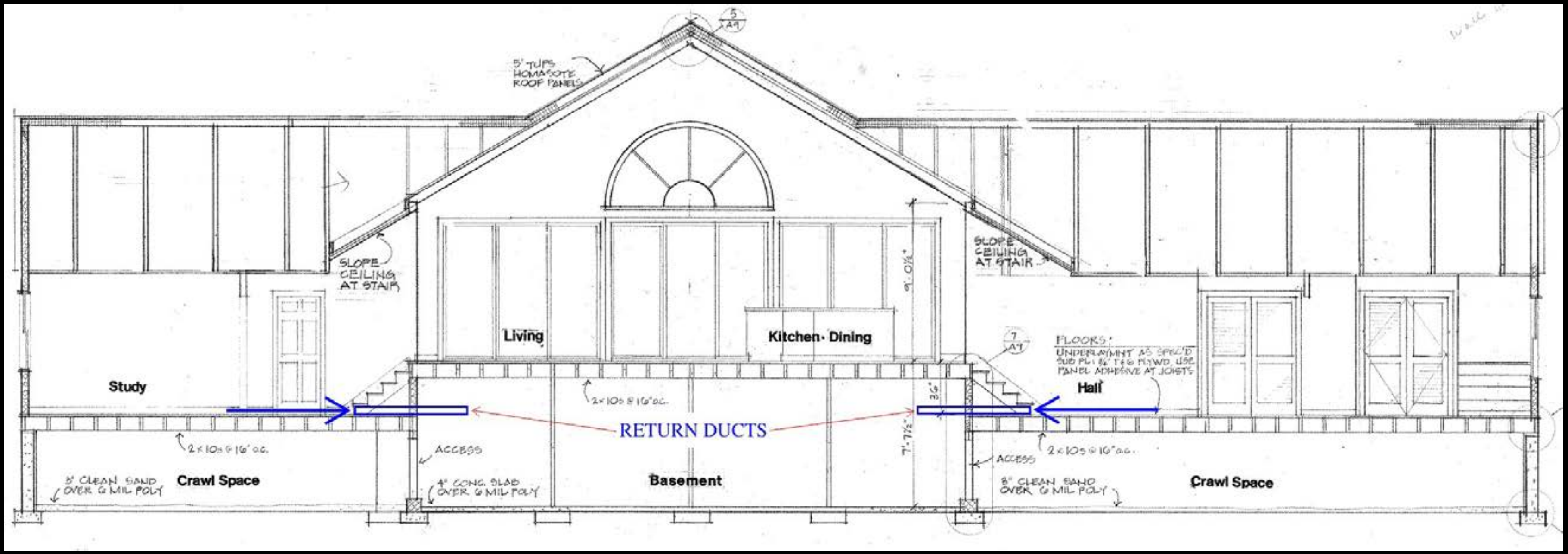
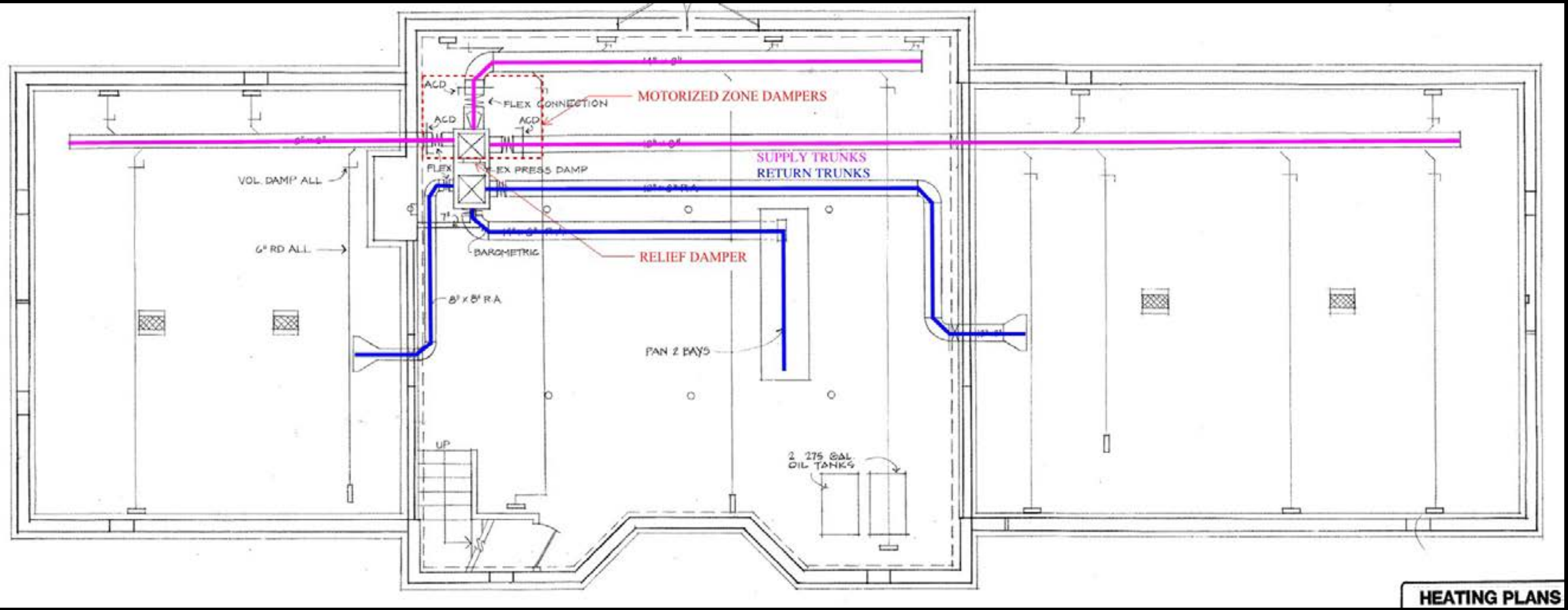
The Case of the Hot Basement





The Case of the Hot Basement

These are the ONLY returns in the house – the returns in the bedroom wing stair risers shown on the plan ARE NOT THERE

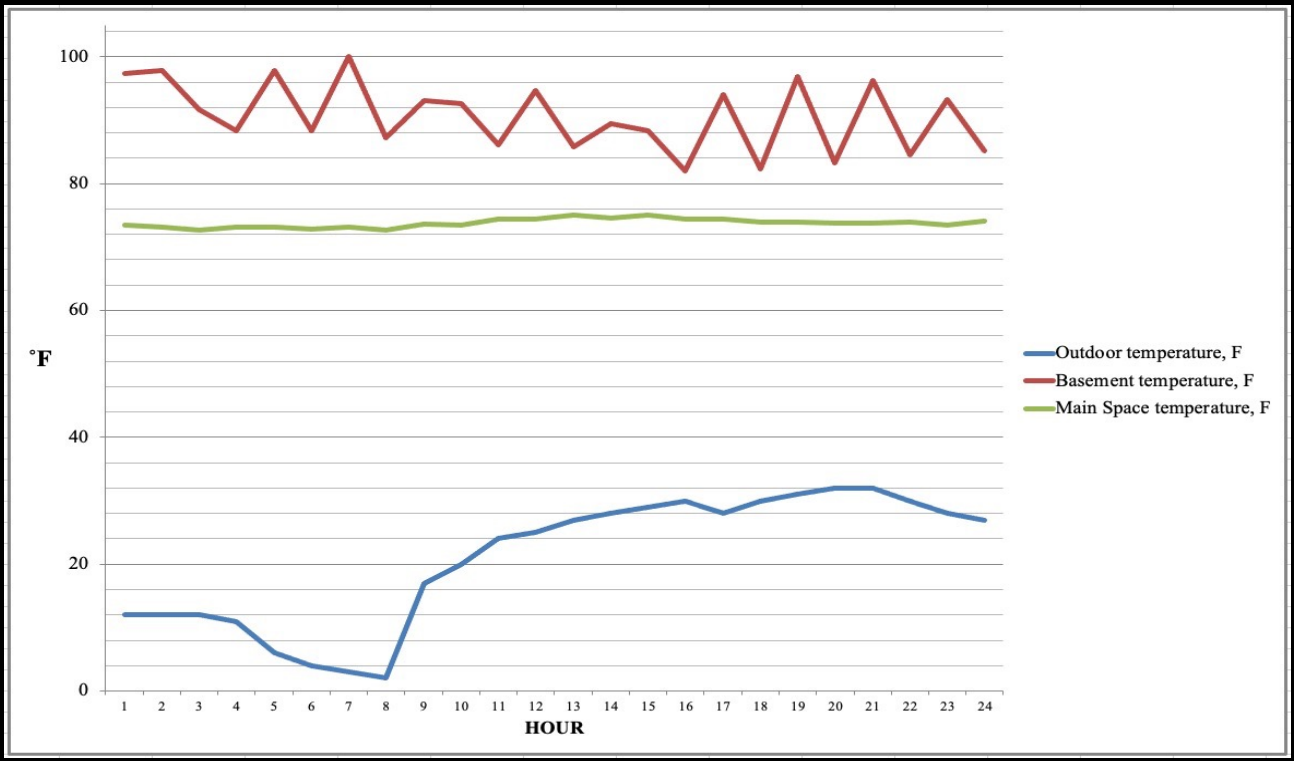
The Case of the Hot Basement

The gravity relief damper opens when zone dampers are closed, because the furnace has a constant flow fan and the air must go somewhere

The Case of the Hot Basement

Individual T/RH loggers in the main living space zone and outdoors, and a multi-channel logger with temperature sensors in each crawl space and the basement, as well as a current transformer on the oil burner to track burner run time

The Case of the Hot Basement



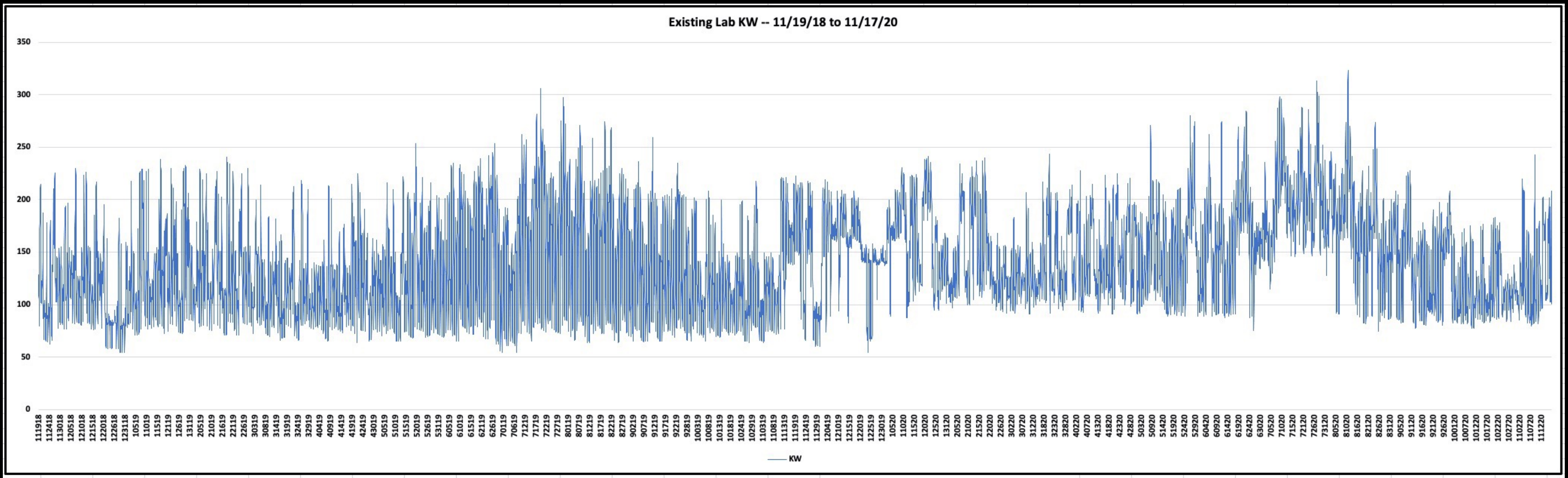
- One 24 hour period - outdoor temp drops to 2˚F
- Bedroom wing zone thermostats are *never satisfied* due to inadequate CFM, so those zone dampers are open continuously
- Basement reaches 100˚F because most of the supply air comes out the relief damper – main living space damper is always closed
- Main living space is always warm enough – heated by the unintentional radiant floor ☺ - slight warming due to solar gain 10 AM – 4 PM

Case #7

Determine proper inputs for design

The Case of the (Imaginary) Internal Gains

- Existing 22,000 sf lab building with planned 30,000 sf addition
- HVAC engineer's calculated cooling load for the addition was 323 tons – which works out to *38W/sf,* much of which was modeled as lab internal gains
- 2 years' worth of 15 minute electricity data for the existing facility showed a peak draw of 323 kW, or *15W/sf* – this includes chiller energy and exhaust fan energy (two large users that don't contribute to internal gains)
- Careful examination of the electricity data outside of the cooling season led to the engineer accepting that internal gains likely were between 5 and 7 W/sf
- The revised cooling load was under 100 tons

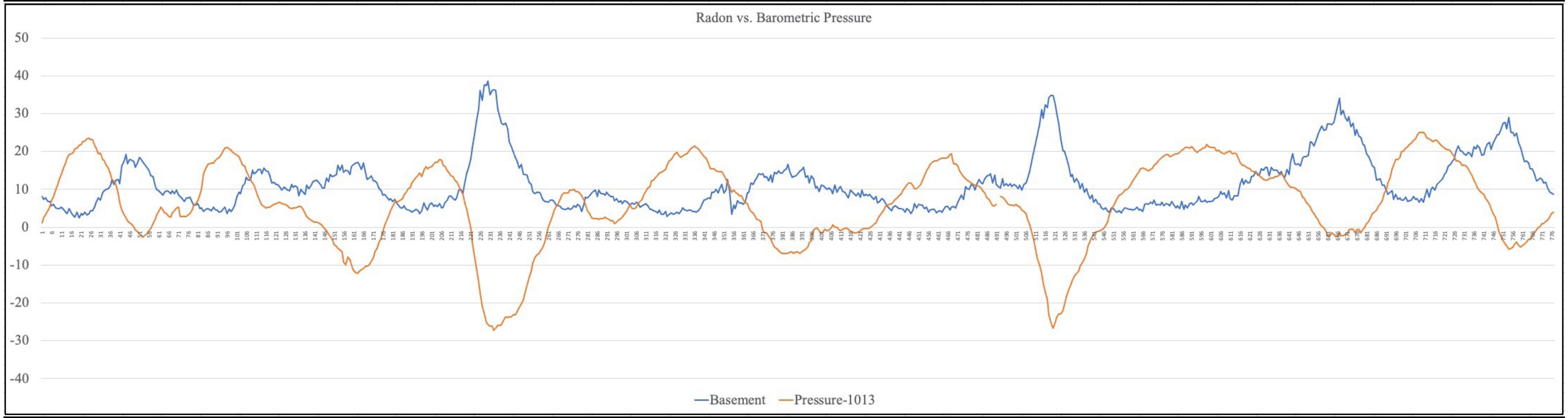


Case #8

Understand cause and effect

The Case of the Varying Radon Levels

I've been trying to understand what causes the radon level in my basement to vary so much. I have correlated it with ΔP between indoors and outdoors, outdoor temperature, and now barometric pressure. I get hourly barometric pressure from the Web, and measure radon with the RadonEye. The low pressure events are storms, so the cause may be rain soaking the ground rather than barometric pressure itself.



Pressure is plotted as (Barometric Pressure – 1013 millibars)

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Case #9

Understand cause and effect

The Case of The Mystery CO2

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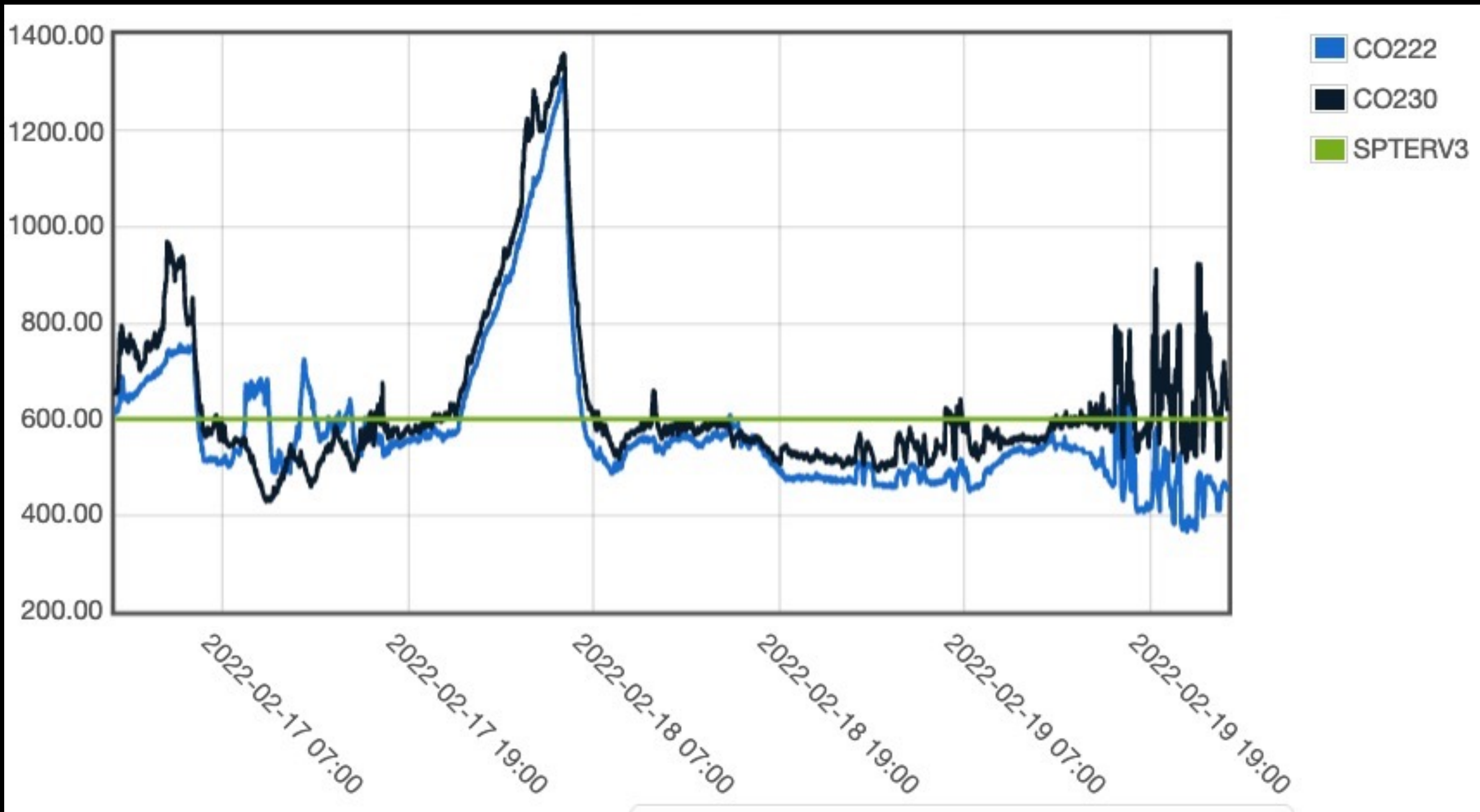
The Case of The Mystery CO2

Marc Rosenbaum, PE – Energysmiths – West Tisbury, MA

The Case of The Mystery CO_2

- New 9,600 sf Early Childhood Center on Martha's Vineyard
- Demand controlled ventilation with Renewaire ERVs based on CO_2
- Mitsubishi VRF ASHPs with heat recovery for heating and cooling
- Ducted UltraAire dehumidifiers for separate humidity control
- ERVs are enabled 5 am – 10 pm
- Dehumidifiers are enabled 10 pm – 5 am and use the same duct work
- eGauge monitoring system
- Watching the building as it was occupied in late Fall, we noticed that CO_2 was rising in the rooms on some nights when the ERVs were off and there were no people in the building
- We put a Telaire CO_2 sensor and a Hobo logger in place, first in a mechanical attic to see if the CO_2 was offgassing from open cell foam

The Case of The Mystery CO2



The Case of The Mystery CO2

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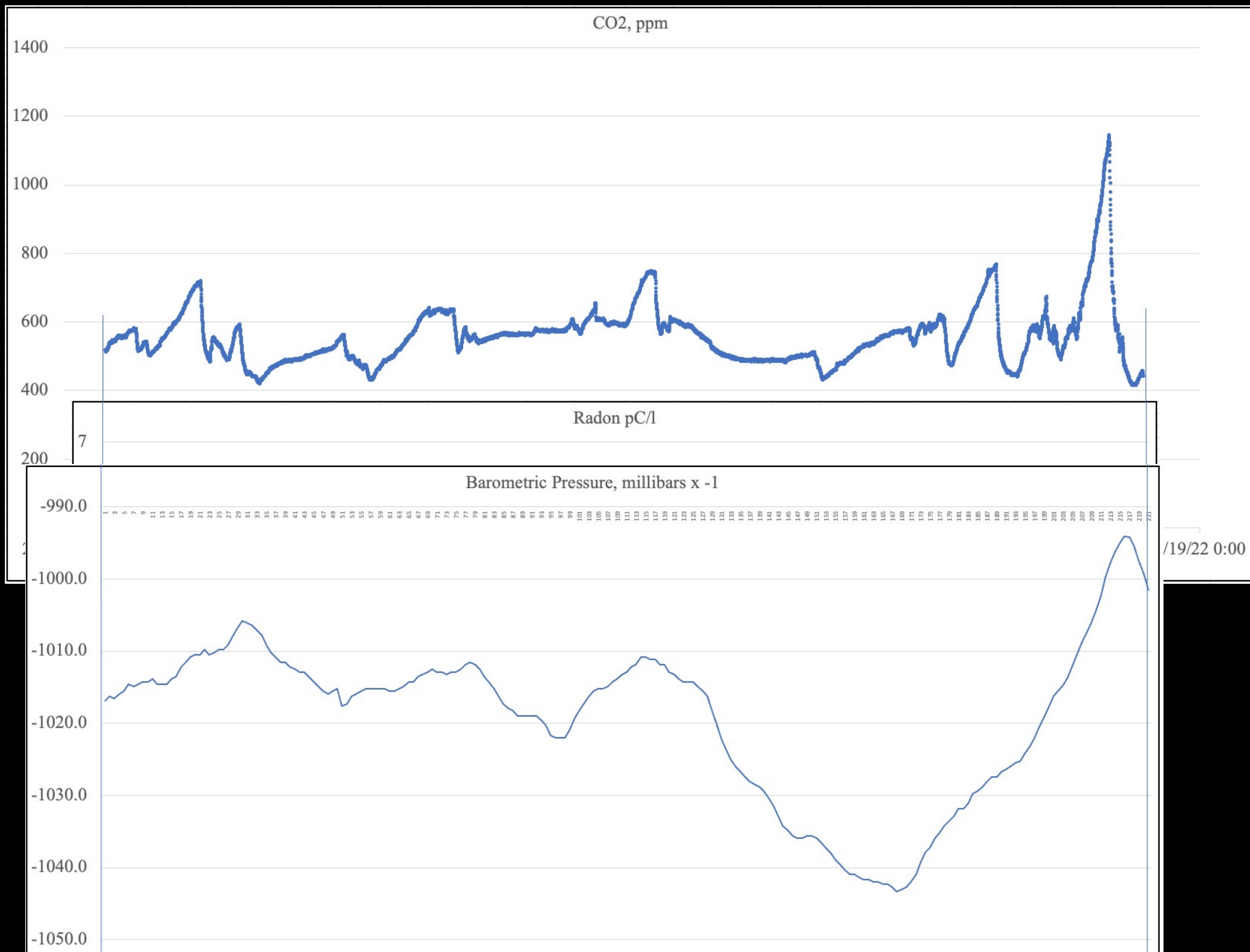

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