Real Life Air Source Heat Pumps

NESEA Building Energy Conference

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Outline

- Overview
- Some field research results
- Recent measurements and results
- Design and application resources and insights

Terminology

- COP = Coefficient of Performance

  = Energy Out / Energy In (like units)

  typical range 2~6 depending on conditions

- HSPF = rating of heating efficiency

  = Energy Out / Energy In (btu/watt)

  - this is a *seasonal model* based on lab test
  - *Like* a COP * 3.41 but it's not *measured*
  - *Many baked-in assumptions, minimal test points*

George Box (1919-2013)

"All models are wrong, but some are useful"

All **ratings** are wrong, but some are useful

CSA: EXP07 test procedure

Residential Air Source Heat Pumps

- 1980s – lots of ASHPs in northern climates
  - Duct leaks, air flow/charge problems
  - "blowing cold air" complaints
- Electric resistance heat compensates
  - Leading to low system efficiency / high cost
- **People believe ASHPs don't work in cold climates because of the climate**

Buying a DHP in 2012

- 2 Local contractors I tried to get bids from:
  - "It won't heat your house in Vermont… maybe if you were in Texas or Oklahoma."
  - "You should really get a 'geothermal' system… my dad and I installed lots of heat pumps in the '80s and they don't work that well..."
  - **Old myths die hard**…

Why heat pumps?

- Strategic electrification
  - Carbon reductions will require getting buildings off of fossil fuels
  - The grid can get "greener" over time
  - Heat pumps can get more efficient over time
  - PV on-site or off-site can provide electricity for individual heat pump(s) annually
  - Fossil fuel combustion will never be more efficient or have lower carbon emissions than it does now

DHP Residential Use Cases

- Offset existing heating source
  - Oil, LP, Electric resistance
  - 1-2 zones –through– complete replacement
- Exclusively heat low-load homes
  - Deep retrofit, new near/net zero
- Add HVAC to addition or new zone

Hidden in soffit or above ceiling

Field Studies - Brief Highlights

- 1990s, Ecotope (WA):
  - Heat pumps: more energy than electric resistance
  - less than electric furnaces
  - Big losses in ductwork, lack of zoning contributed
- 2003 (Ecotope):
  - 14 electric heat homes retrofitted
  - Single-zone, “standard” mini-splits
  - Saved average of 40% (*range* was very wide)

NEEP Meta-Study (EFG, 2014)

- BHE-EMT Heat Pump Interim Report 2013
- BPA- ACEEE Performance of DHP in the Pac. NW 2010
- BPA DHP Engineering Analysis (Res) 2012
- BPA DHP Retrofits Comm. Bldgs. 2012
- BPA Variable Capacity Heat Pump Testing 2013
- Cadmus DMSHP Survey Results 2014
- CCHRC ASHP Report 2013
- CSG DHP Performance in the NE 2014
- CSG Mini-split HP Efficiency Analysis 2012
- DOE DHP Expert Meeting Report 2013
- DOE DHP Fujitsu and Mitsubishi Test Report 2011
- DOER Renewable Heating & Cooling Impact Study 2012
- DOER Renewable Thermal Strategy Report 2014
- Ductless Mini-Split Heat Pump Customer Survey Results
- Eliakim's Way 3 Year Energy Use Report 2013
- EMaine Case Study (Andy Meyer) 2014
- Emaine EE Heating Options Study 2013
- Emaine LIWx Program Checkup 2014
- Emera Maine Ductless Heat Pump Pilot Program 2014
- KEMA Ductless Mini Pilot Study & Update 2009-2011
- Mitsubishi Heat Pump Market Data 2011
- Mitsubishi Indoor Unit Brochure 2011
- Mitsubishi M-series Features & Benefits 2011
- NEEA DHP Billing Analysis Report 2013
- NEEA DHP Evaluation Field Metering Report 2012
- NEEA DHP Final Summary Report 2014
- NEEA DHP Impact Process Eval Lab Testing Report 2011
- NEEA DHP Market Progress Eval 2 2012
- NEEA DHP Market Progress Eval 3 2014
- NEEP DHP Report Final 2014
- NEEP incremental cost study
- NEEP Strategy Report 2013
- NREL Improved Residential AC & Heat Pumps 2013
- Rocky Mountain Instit. DHP Paper 2013
- SCEC DHP Work Paper 2012
- Synapse Paper 2013 Heat-Pump-Performance
- VEIC Mini Split Heat Pump Trends 2014
- VELCO Load Forecast with Heat Pumps 2014

ENERGY FUTURES GROUP

ers energy & resource solutions

Recent Studies

- Building Science Corp (Building America) 2014
  - Long term monitoring in 8 low-energy homes
  - Predictable issues with indoor distribution
  - Big issue with “on/off” (*deep* setback = poor eff.)
- Steven Winter (Building America) 2015:
  - Measured 7 mini-splits retrofitted in homes
  - COP range from 1.1 – 2.3
  - Issues: low air flow, high inlet temperature, poor integration with central heat

Recent Studies

- Cadmus 2016 MA/RA impact evaluation:
  - 152, CC/NonCC, average rated HSPF 9-11
  - *Operating hours much lower than expected* (only running 19-27% of the time in winter)
  - Efficiencies somewhat lower than ratings
  - Net result: savings pretty small
- Issues: lack of use (many installed w/AC focus)
  - need better controls/thermostat placement
  - multi-zone had lower efficiency

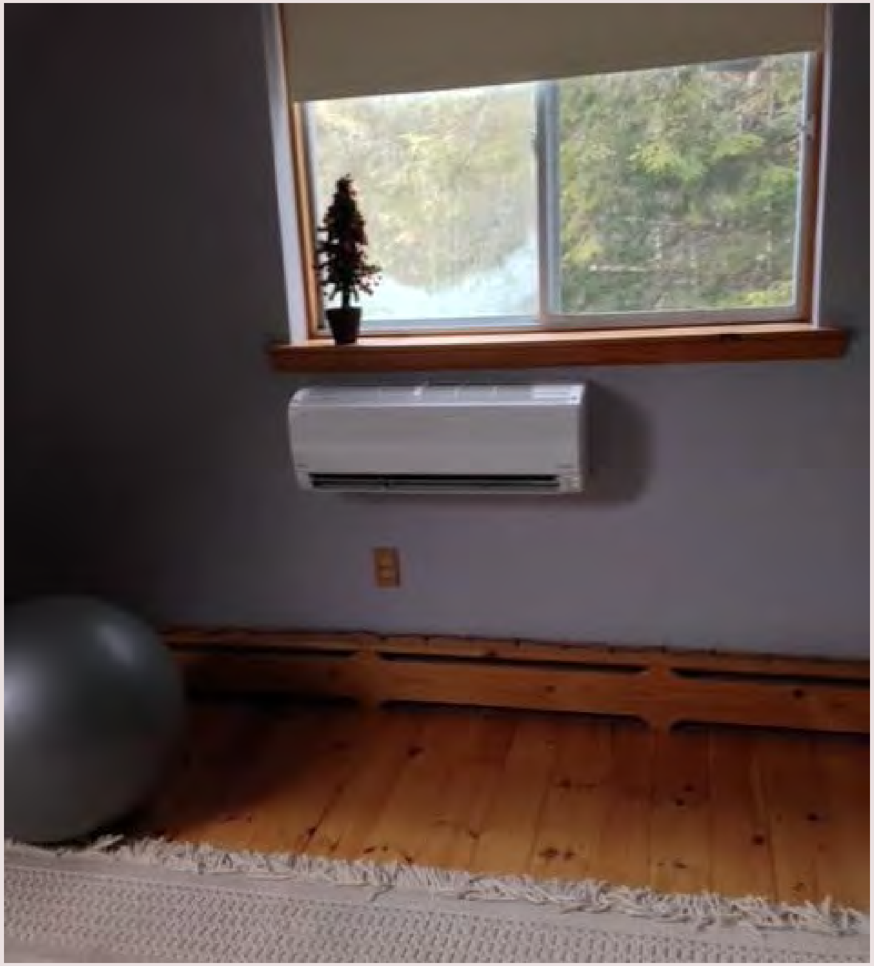
My Measurements

- Summary:
  - DHP Installation: Stamford, VT   July, 2012
  - Modestly efficient, 2400 SF house
  - 2 units, 3 zones
  - Monitored 9/2012-4/2014,
  - Co-heat test: resistance heat, 14 days

1st Floor Unit - 12 HSPF

Outdoor Unit

Attic room - 2nd floor

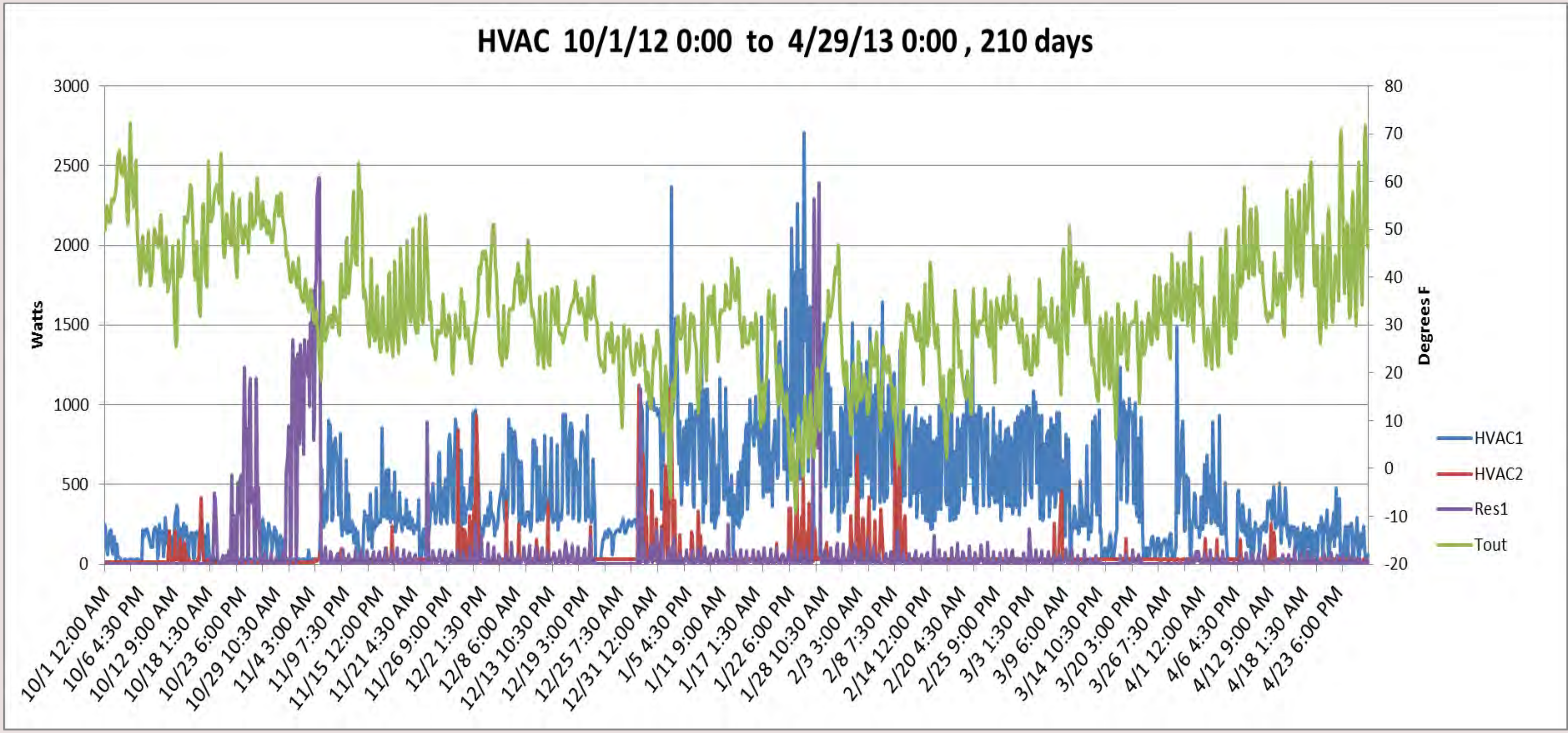


2-zone, 9 HSPF

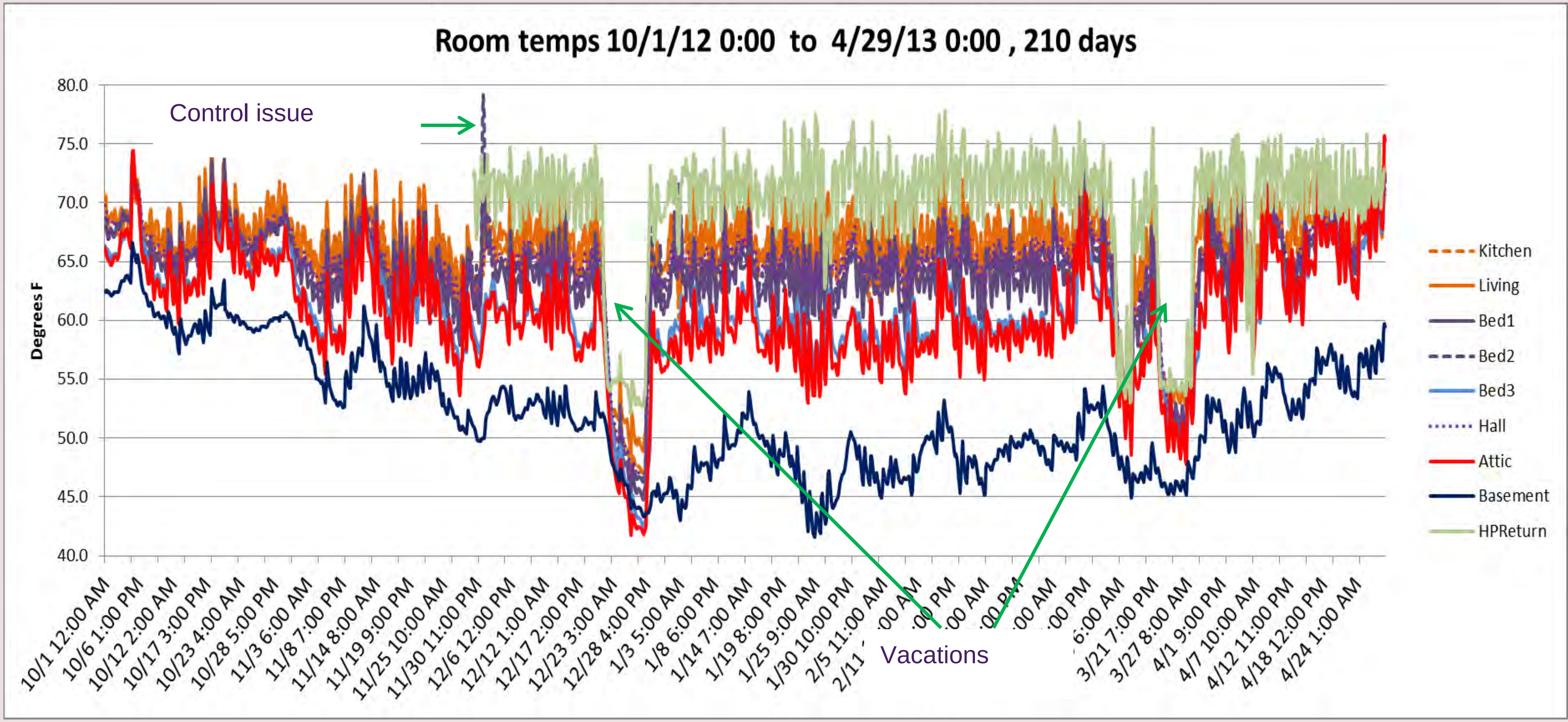
2nd Floor Air Handler – 3 rooms

- Return in hall, remote sensor in 1 room

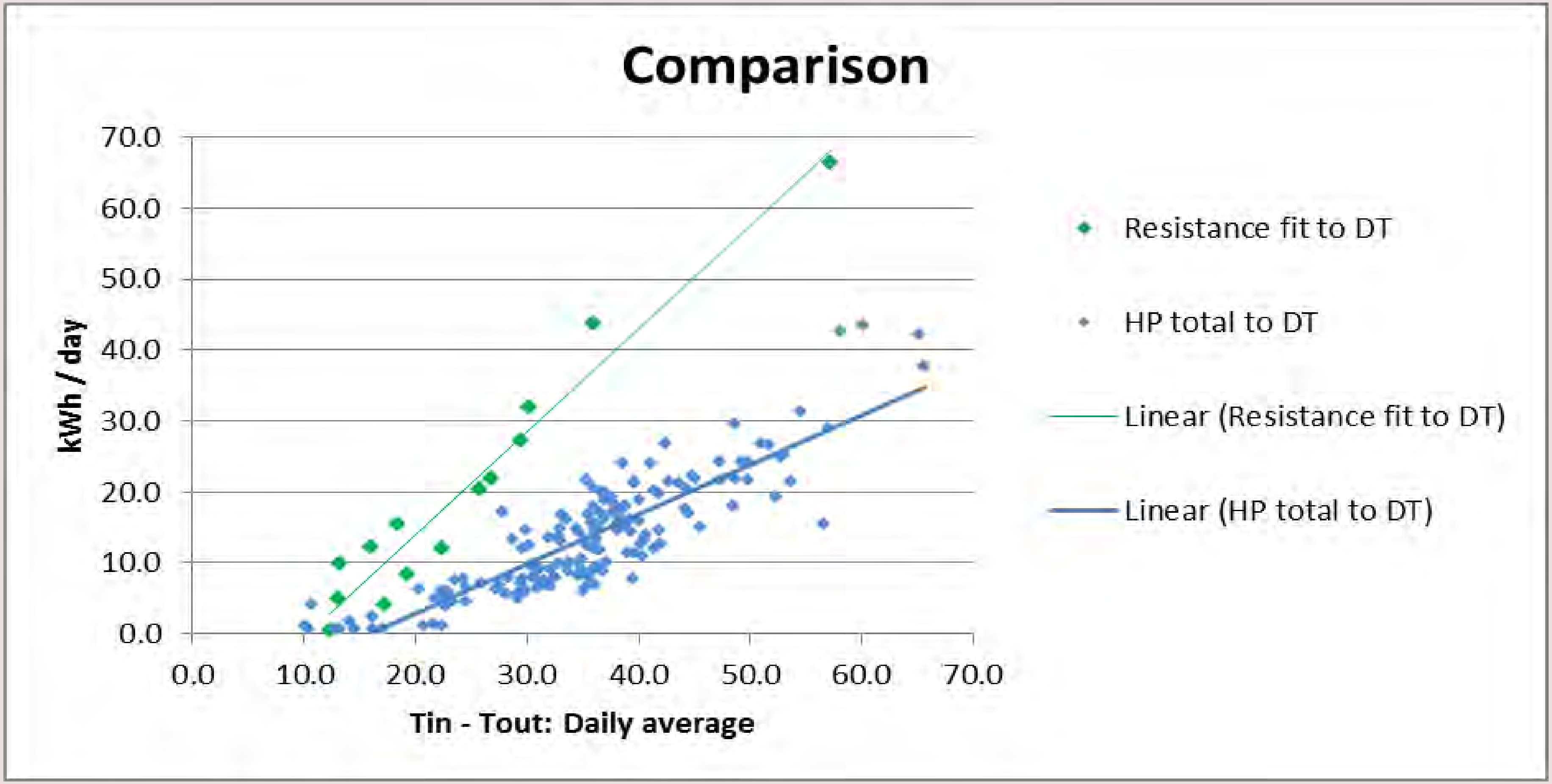
HVAC kWh and Tout



Room Temperatures



Resistance vs DHP



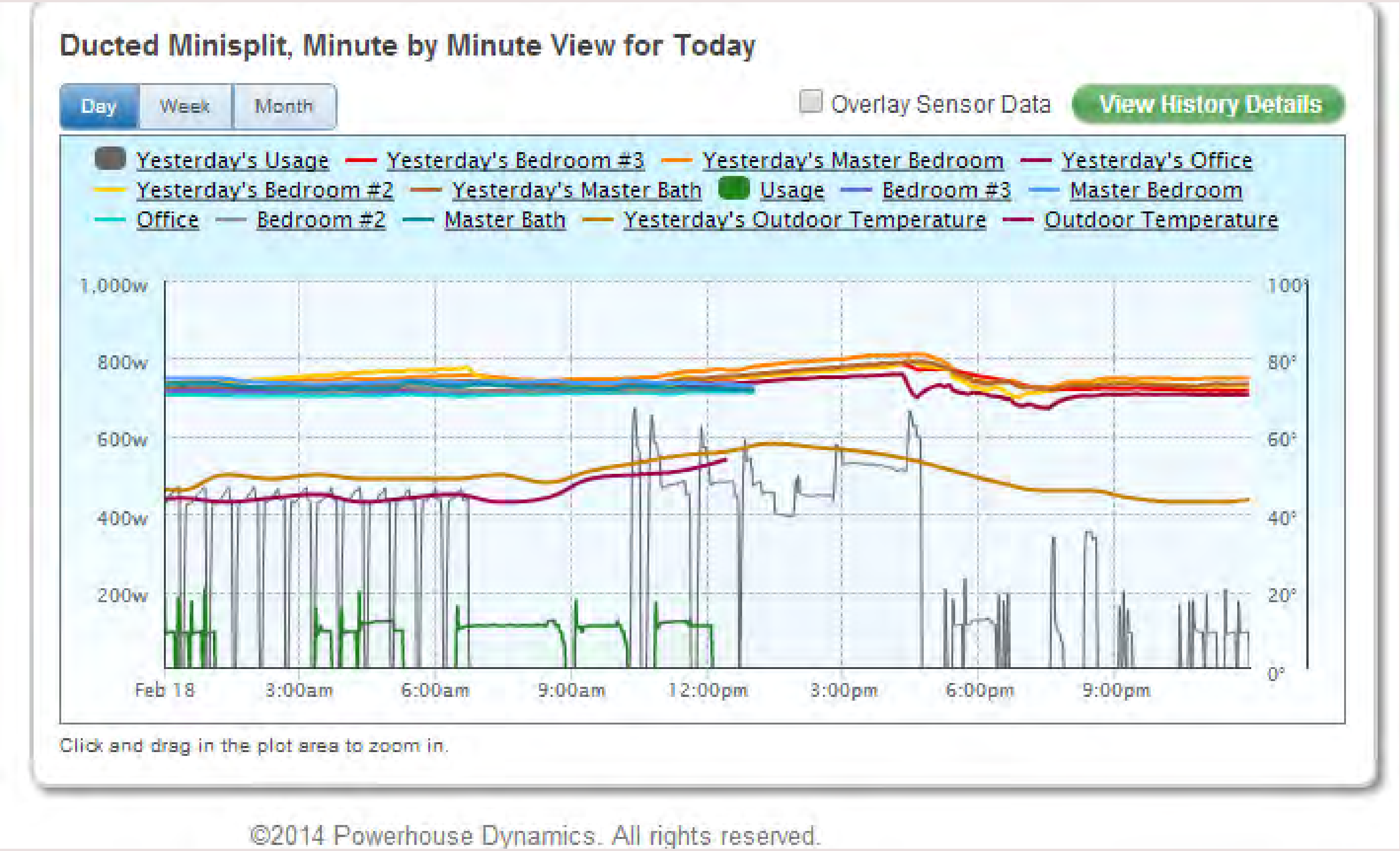
Some conclusions

- Fan Speed – “Low” is quieter
  - Started this way during our first winter
- “Auto” fan boosts capacity
  - Important in colder weather
  - Easier to leave in auto all the time
- *Don’t* use auto-changeover (H/C) setting

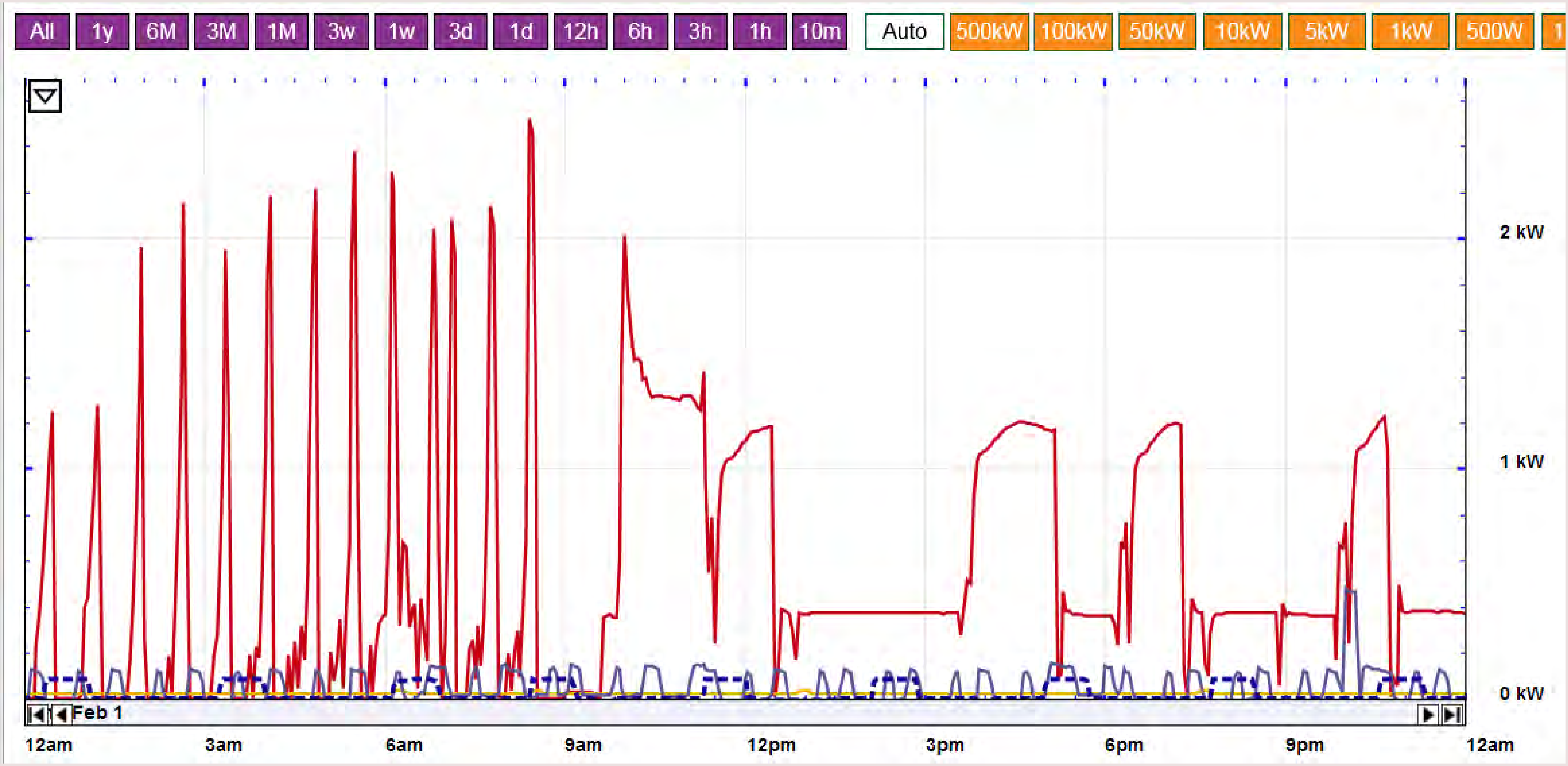
My house: Projected vs. Actual

	Projected	Actual
Load	7740 kWh	7358
Consumption	3067 kWh	2794
Cost	$460	$419
COP	**2.5**	**~ 2.8**

From NEEA research - cycling



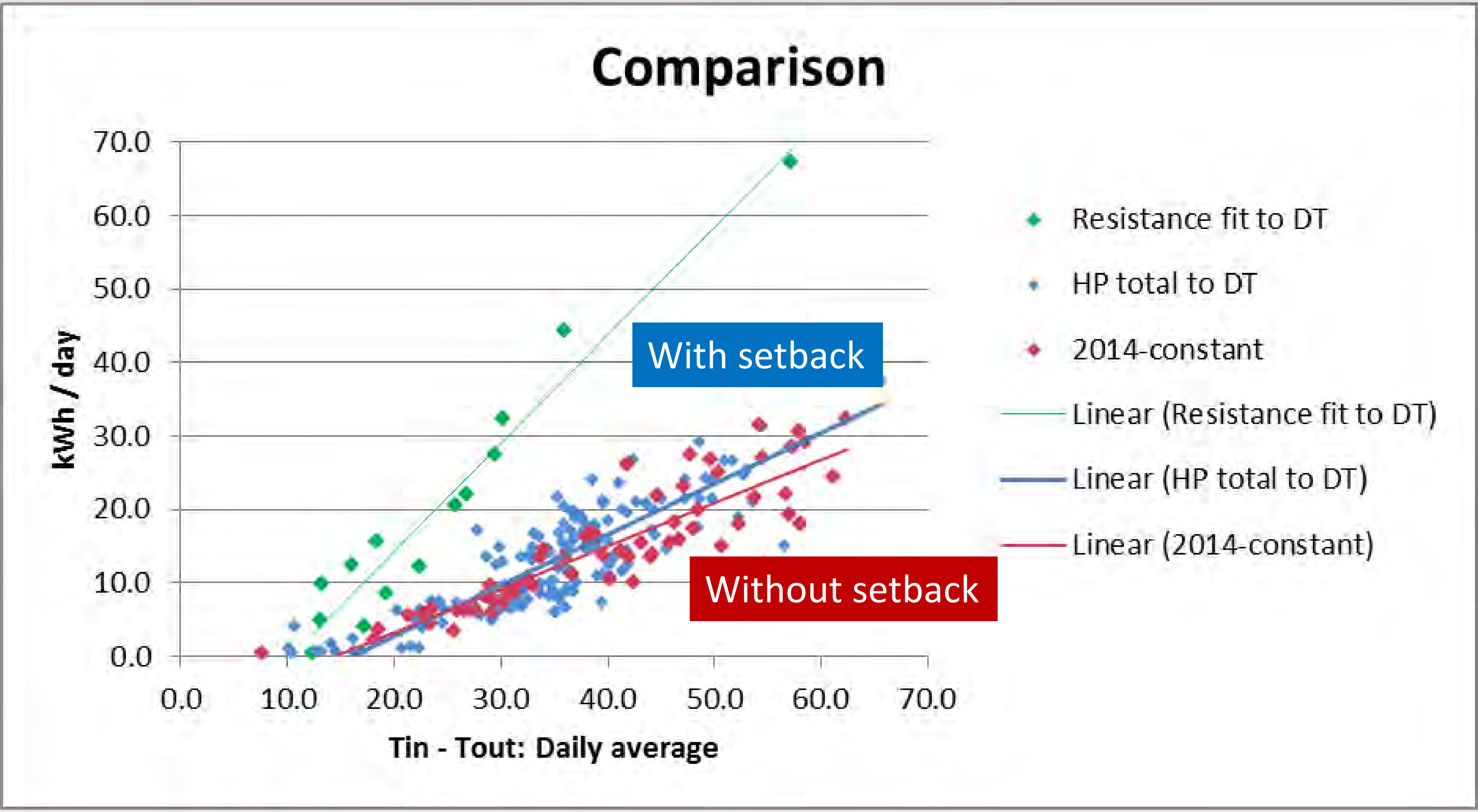
My house: 9 AM “high insulation” re-set



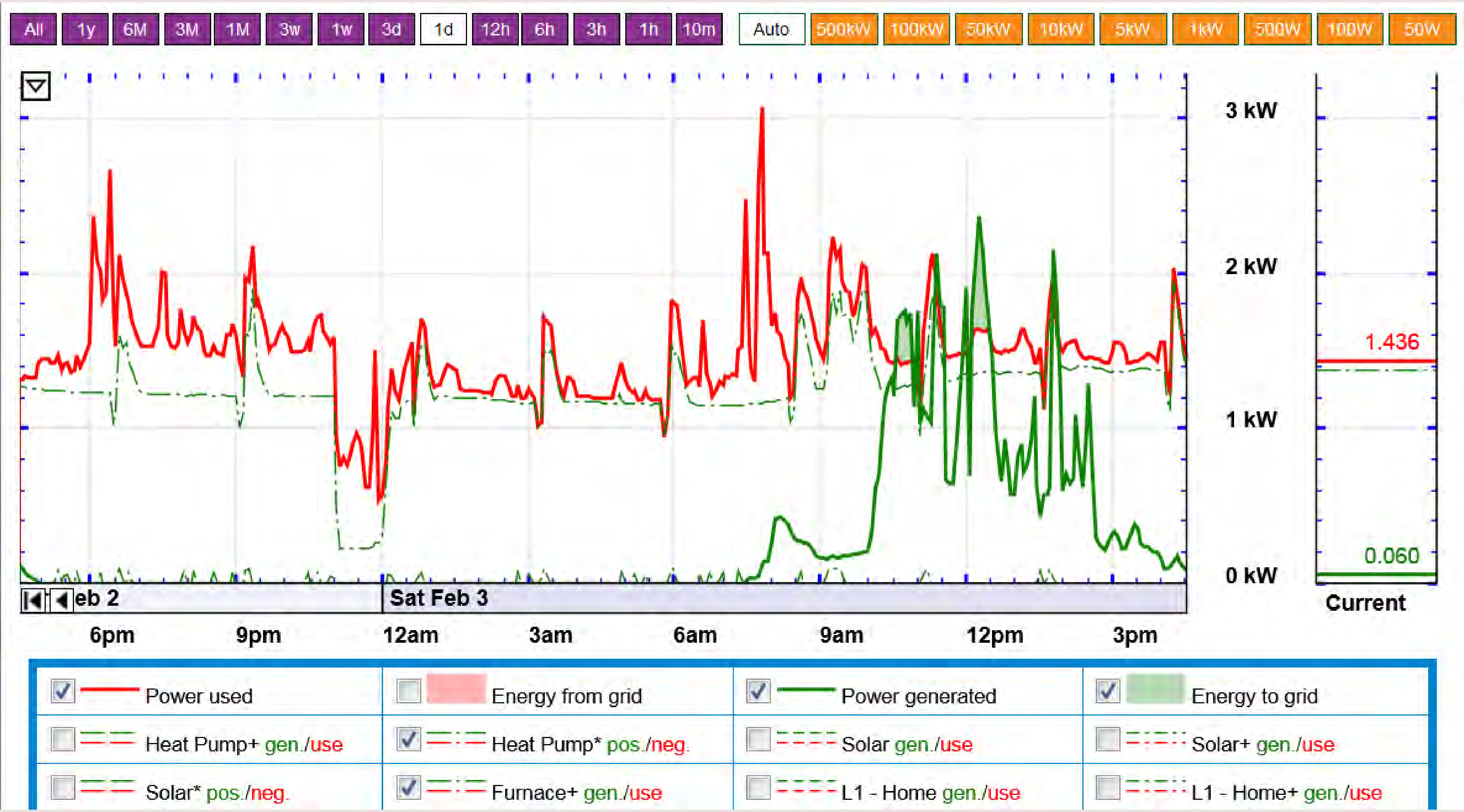
Temperature Setbacks

- For variable speed ASHP, don’t save much
  - Deep setback = long recovery, in high speed mode
  - Early morning recovery = lowest outdoor temps
  - Both of these = least efficient operation
- Better to “set it and forget it”
  - Use setback for > several days away
  - … but don’t expect fast recovery!

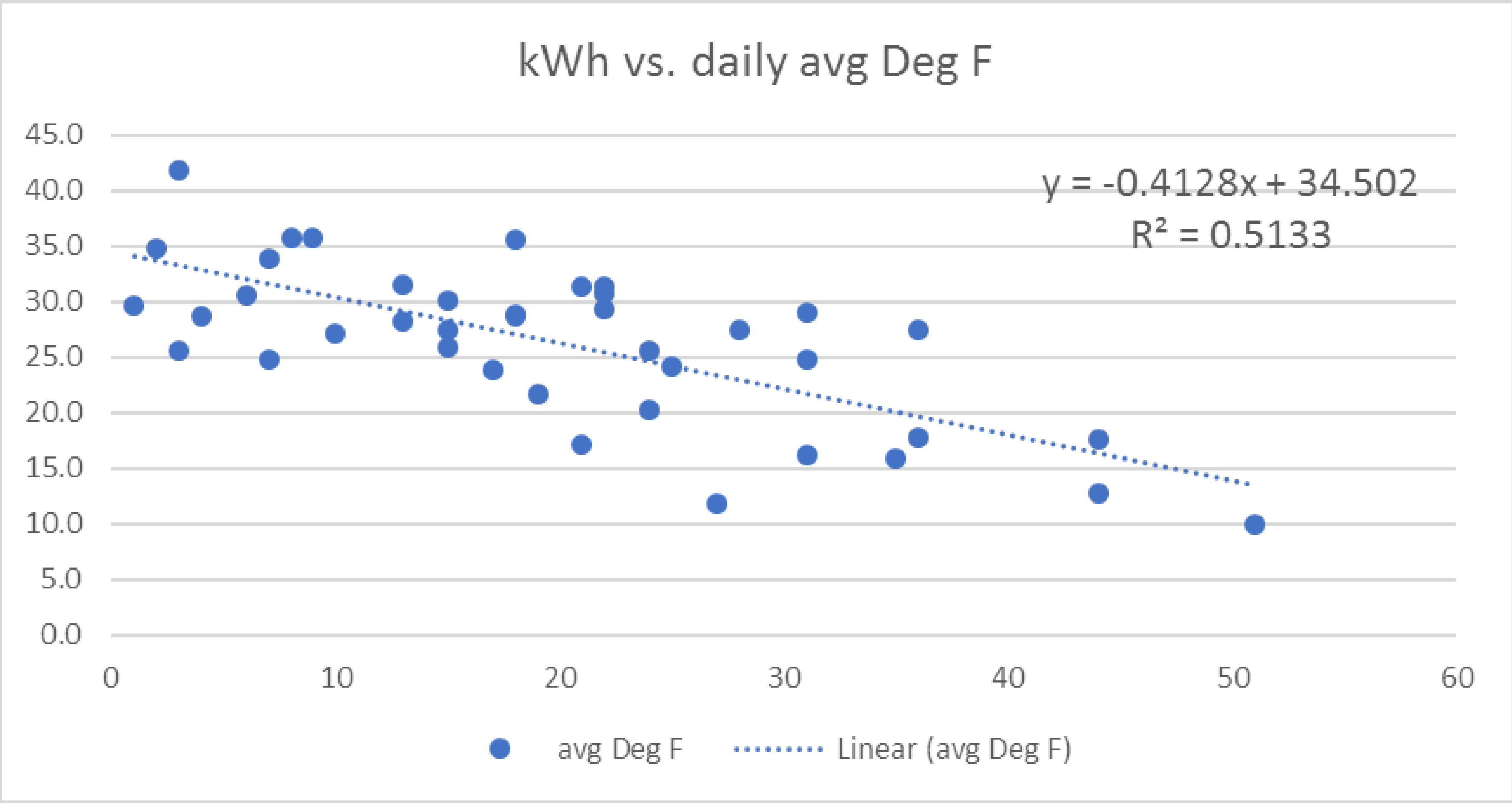
Feb-Apr 2014 added, no setback:



1 site from a current project:



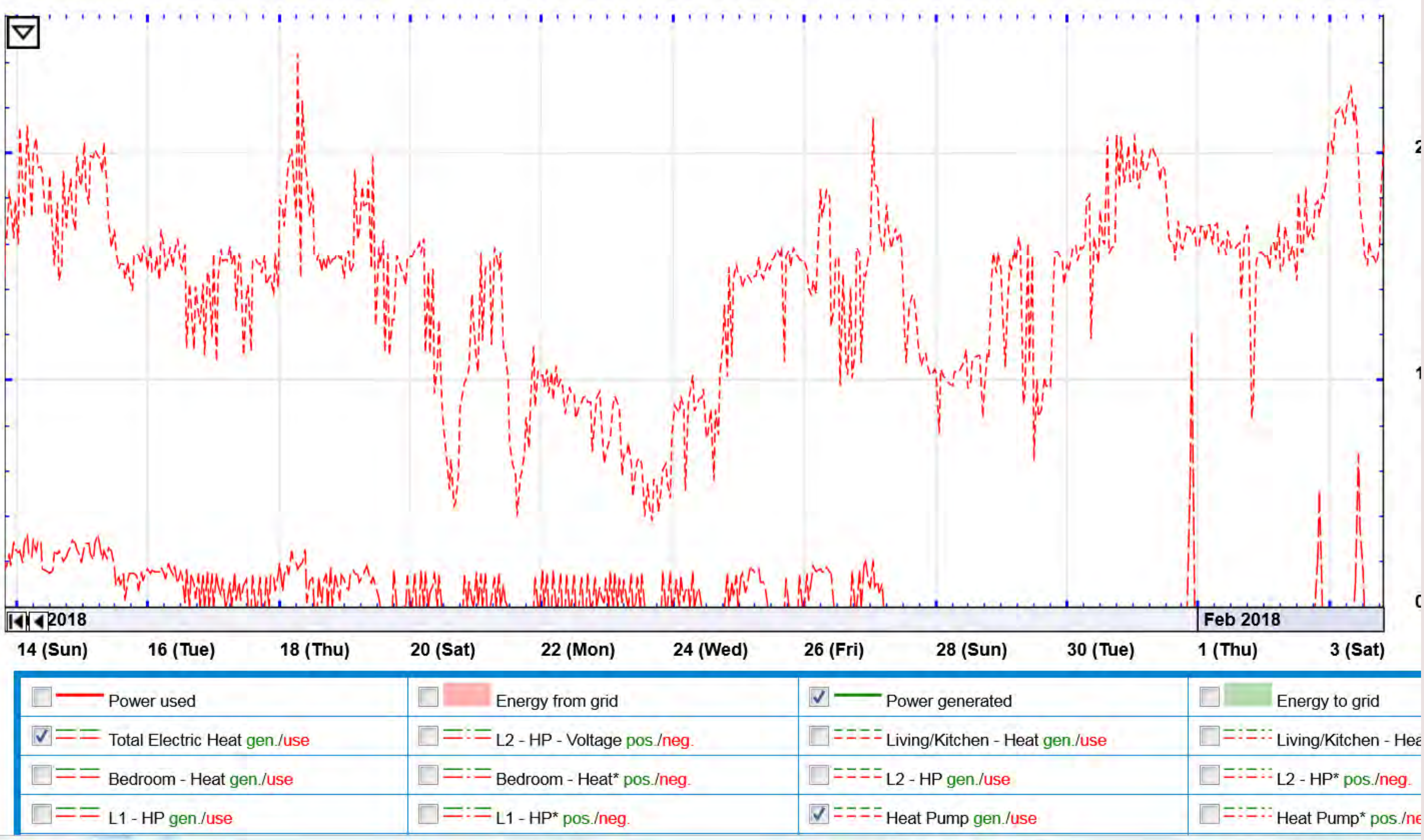
Daily data


kWh vs. daily avg Deg F
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
10
20
30
40
50
60
y = -0.4128x + 34.502
R² = 0.5133
avg Deg F
Linear (avg Deg F)

Gas Boiler, 1.5T Cold Climate HP

- 1500 SF ranch, 3 bedroom. Open floor plan
  - Separate gas DHW – conventional tank (new)
  - Moved boiler thermostat to master bedroom
  - Installed wall-mount thermostat opposite HP
- Savings: approx. 70% of gas heating
- Savings: approx. 60% of all gas
  - VERY preliminary: 2 months, imprecise gas data
  - M&V: CDH Energy for official results later

2nd site:

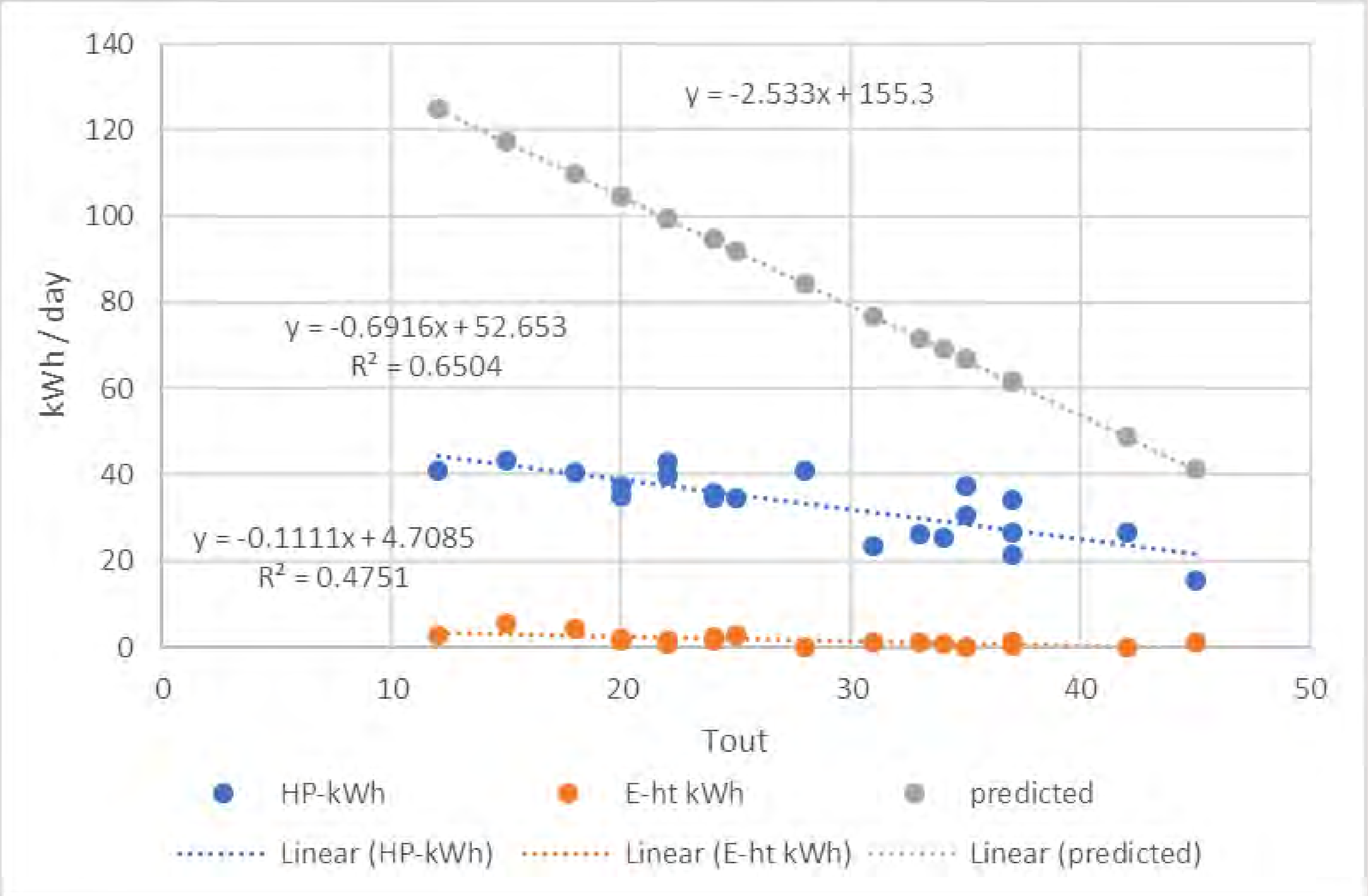


2018
Feb 2018
14 (Sun)
16 (Tue)
18 (Thu)
20 (Sat)
22 (Mon)
24 (Wed)
26 (Fri)
28 (Sun)
30 (Tue)
1 (Thu)
3 (Sat)
Power used
Energy from grid
Power generated
Energy to grid
Total Electric Heat gen./use
L2 - HP - Voltage pos./neg.
Living/Kitchen - Heat gen./use
Living/Kitchen - Hea
Bedroom - Heat gen./use
Bedroom - Heat* pos./neg.
L2 - HP gen./use
L2 - HP* pos./neg.
L1 - HP gen./use
L1 - HP* pos./neg.
Heat Pump gen./use
Heat Pump* pos./ne

Electric Resistance Heat

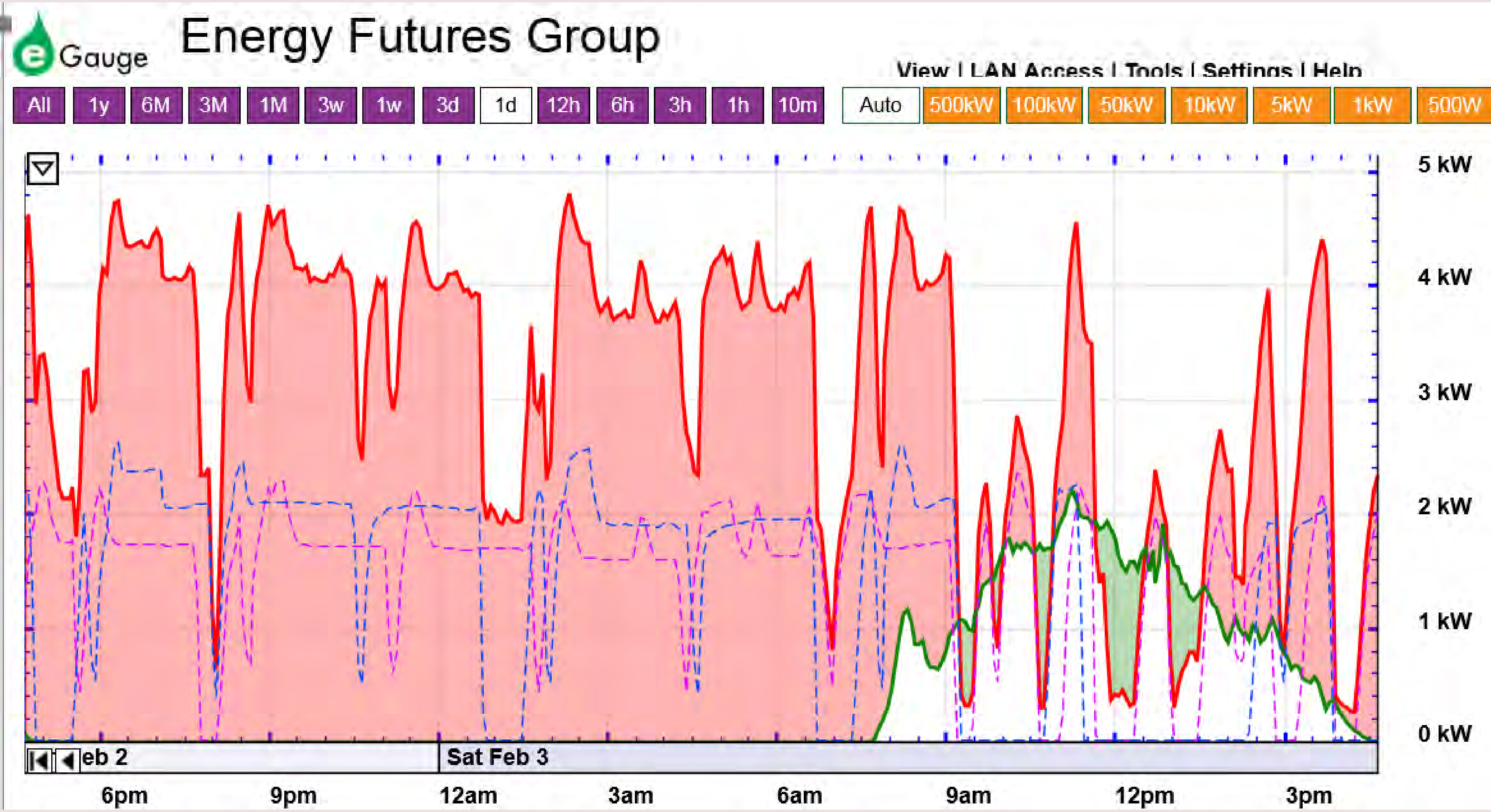
- 2-story, 1 ½ bedroom
- Pre-heat pump billing data
- 21 days of logger data:

Net COP (incl. "aux")	**2.4**
COP - HP only	**2.5**
Savings	**59%**
would have used kWh:	1752
Actually used kWh	1025
kwh/day saved	49

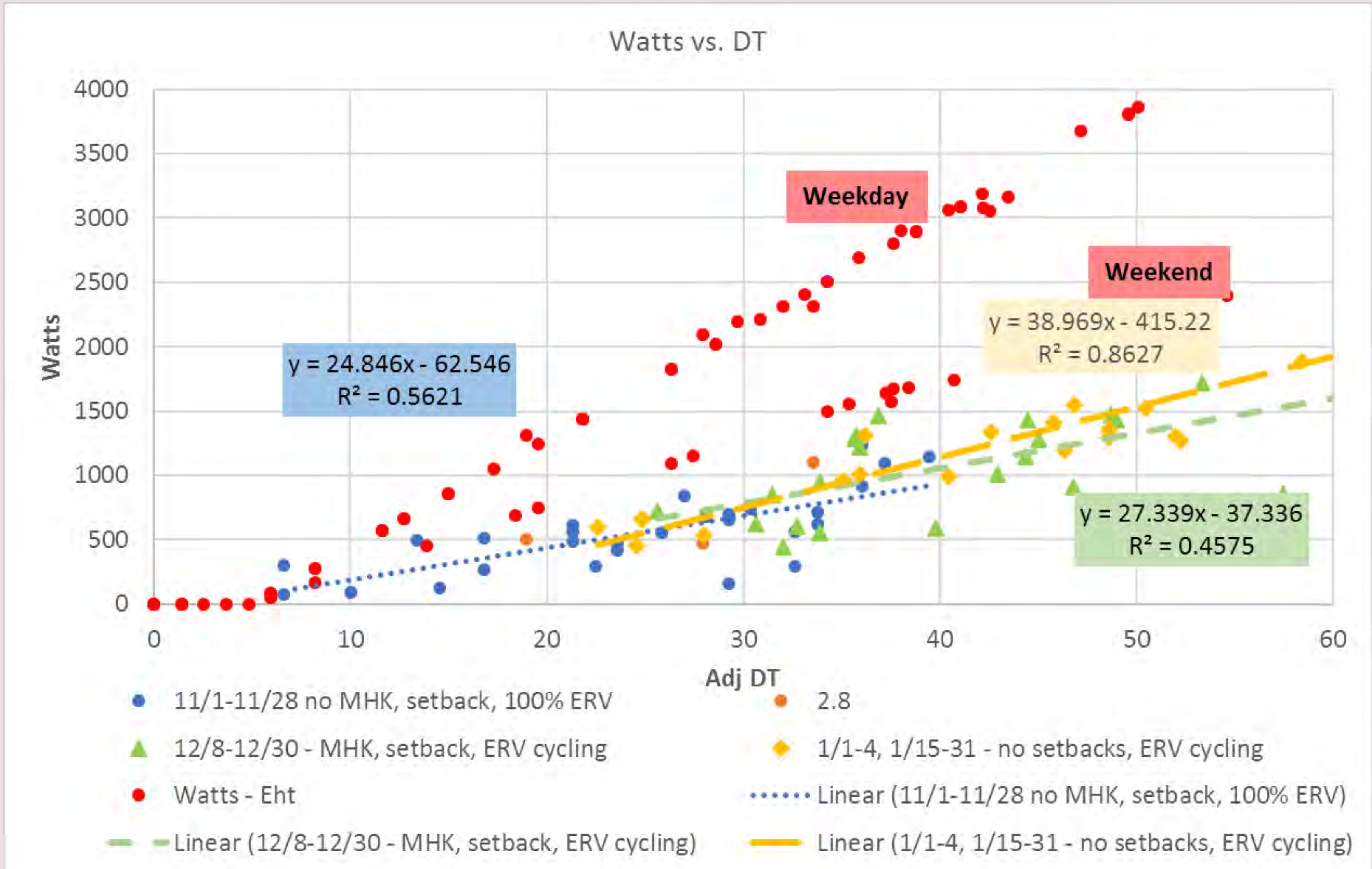


140
120
100
80
60
40
20
0
kWh / day
y = -2.533x + 155.3
y = -0.6916x + 52.653
R² = 0.6504
y = -0.1111x + 4.7085
R² = 0.4751
0
10
20
30
40
50
Tout
HP-kWh
E-ht kWh
predicted
Linear (HP-kWh)
Linear (E-ht kWh)
Linear (predicted)

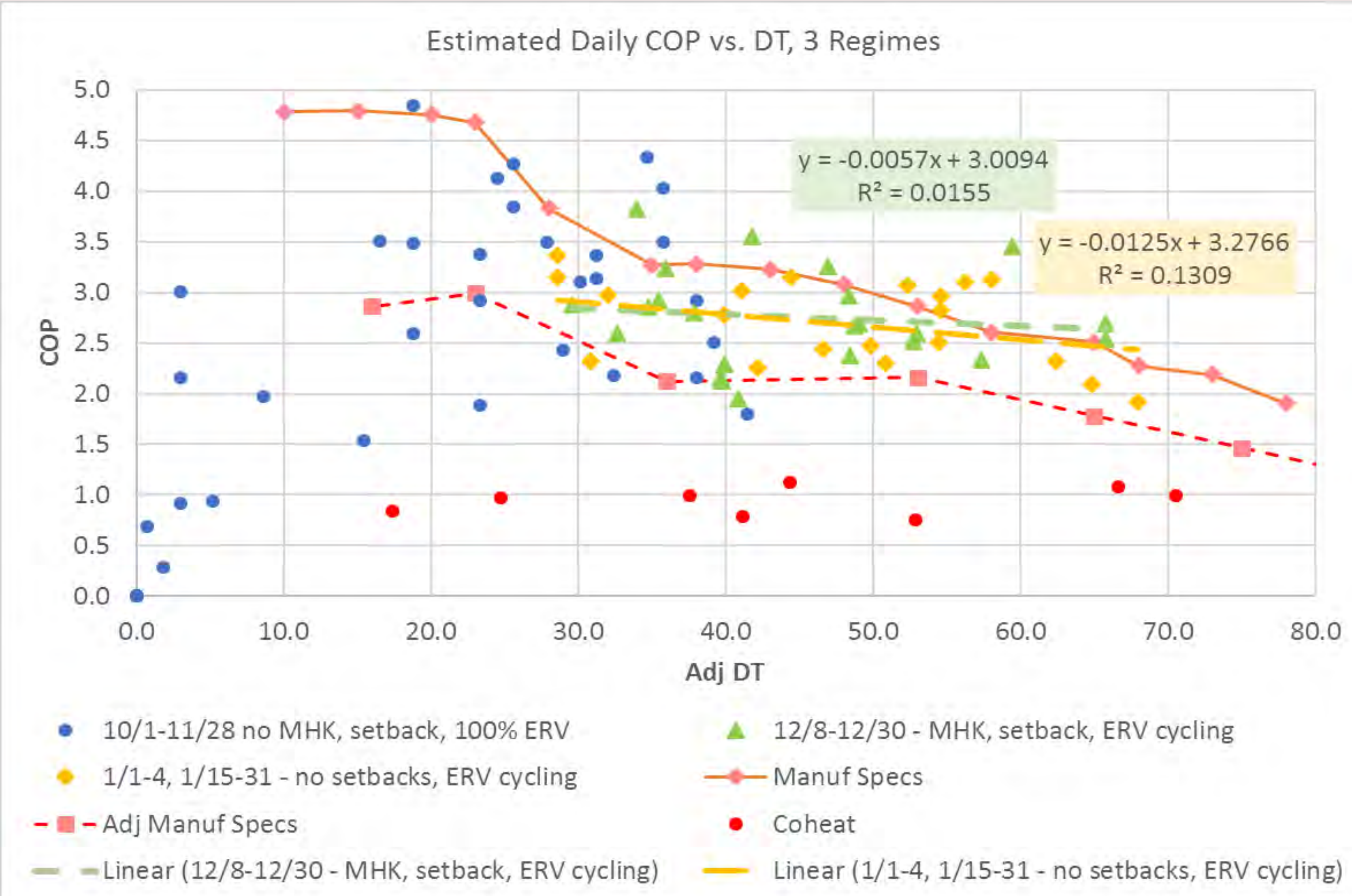
EFG Office (2, 2-zone ASHP)



ASHP & Resistance Watts vs DT



COP vs. Temp Diff



EFG Co-Heating Test Results

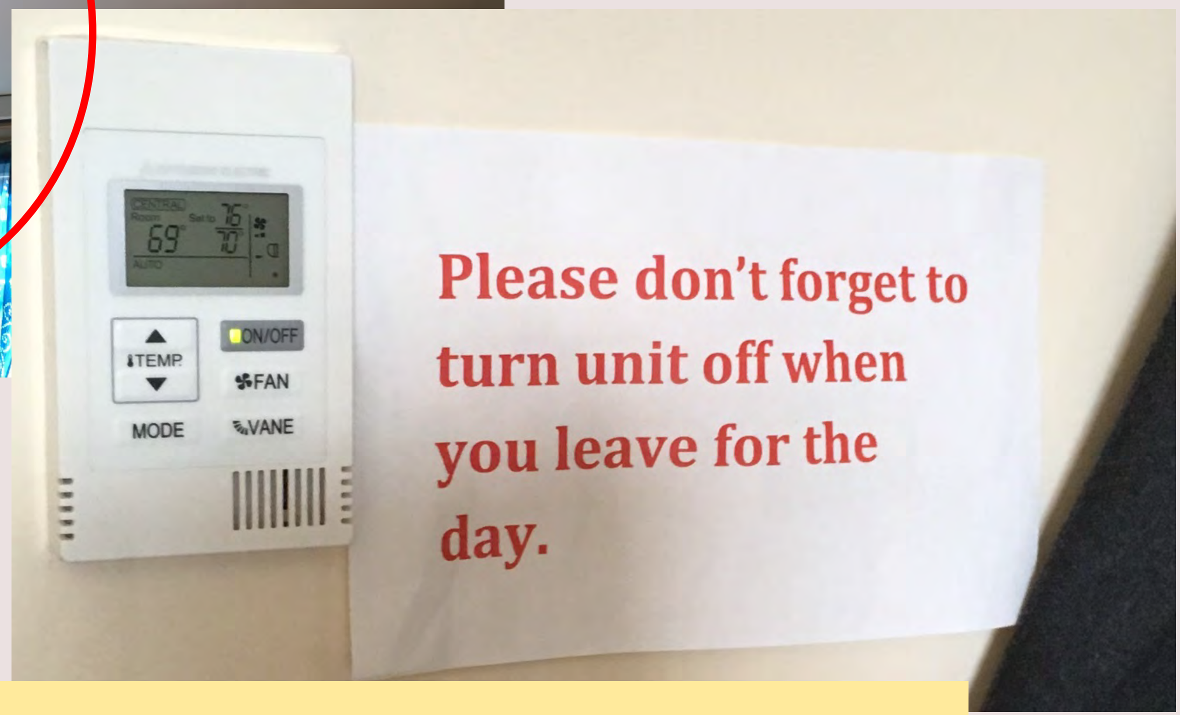
- Very preliminary – need more data

Tout avg.	COP	No sun COP	Rated COP	Condition
51	3.4	3.7	4.8	10/1-11/28 no MHK, setback, 100% ERV (higher uncertainty-less comparable)
21	2.9	2.8	3.0	12/8-12/30 - MHK, setback, ERV cycling
22	2.8	2.6	3.1	1/1-4, 1/15-31 - no setbacks, ERV cycling
38	3.0	2.9	3.5	All recorded since 11/01/17

7000 SF – office/classroom

Manual override (“service disconnect”) used frequently in meeting/classroom spaces

Discomfort – fan set to continuous run

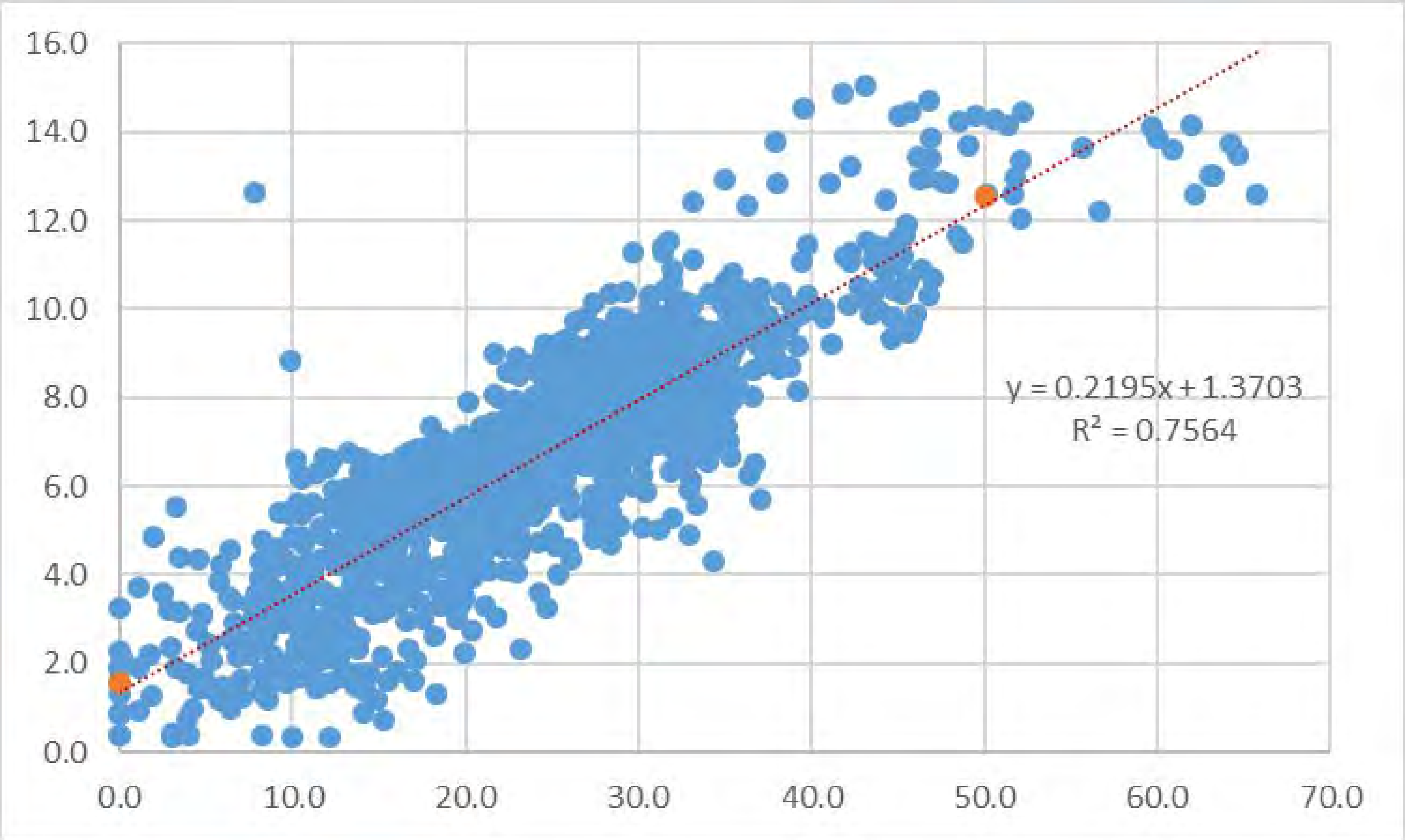


Misguided efforts to conserve

Fixes…

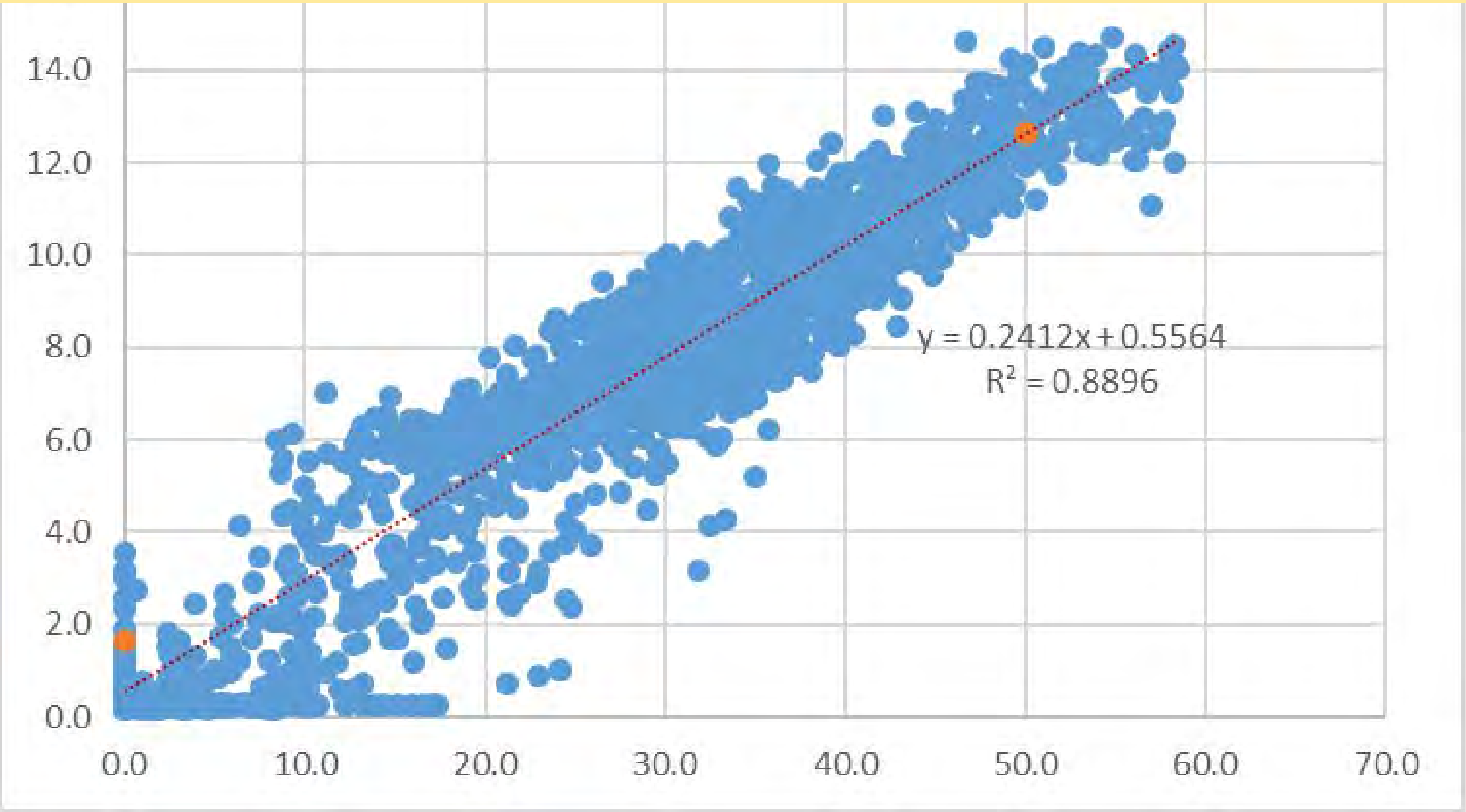
- Changed programing to allow occupant fan control
- Told people to leave temp settings constant
  - And reset at night even if they turn it off
- Results:
  - Base energy: modest decrease
  - Heating energy: virtually the same
  - Happier, more comfortable people!

Before (hourly Oct-Dec ’16)



Jan-Apr '17 – no setbacks or fan-on

Standby >1 to 0.6kW, virtually same slope (2.4 kW/°F



Resources: Equipment Selection

- NEEP Cold Climate Listings (neep.org)
  - High heating efficiency rating: HSPF >10
  - High efficiency in cold weather: COP > 1.75
    - at 5°F outdoor temperature
- Also look for
  - High capacity (output) at low outdoor temps
  - **Rated operation at -5°F, -15°F, or lower**
  - Max capacity is expected when it’s cold!

NEEP ccASHP Listings

DISCLAIMER- Some of the performance values reported as part of the Cold-Climate ASHP Specification are NOT derived from industry standard test procedures or third-party tested/v

Products added to list since previous update highlighted in pink

General Information

Updated: March 9, 2017

Manufacturer	Brand (if applicable)	AHRI Certificate No.	Outdoor Unit Model	Indoor Unit Model(s)	HSPF (Region IV):	SEER	EER (@ 95°F)	ENERGY STAR Certifie	Ductless or Ducted	If Ductless, Multi-zone or Single-zone
Daikin		3208521	RXG09HVJU	FTXG09HVJU	11	26.1	15.8	Yes	Ductless	Single-zone
Daikin		3208522	RXG12HVJU	FTXG12HVJU	10.55	24.2	14	Yes	Ductless	Single-zone
Daikin		3208523	RXG15HVJU	FTXG15HVJU	10	21	12.9	Yes	Ductless	Single-zone
Mitsubishi		4217888	MUZ-FE18NA	MSZ-FE18NA	10.3	20.2	14.2	Yes	Ductless	Single-zone
Mitsubishi		4908219	MUZ-FE09NA	MSZ-FE09NA	10	26	15.5	Yes	Ductless	Single-zone
Mitsubishi		4934170	MUZ-FE12NA	MSZ-FE12NA	10.5	23	12.9	Yes	Ductless	Single-zone
Fujitsu		5063325	AOU9RLS2	ASU9RLS2	12.5	27.2	16.1	Yes	Ductless	Single-zone
Fujitsu		5063326	AOU12RLS2	ASU12RLS2	12	25	13.8	Yes	Ductless	Single-zone
Daikin		5265753	RXS09LVJU	FTXS09LVJU	12.5	24.5	15.3	Yes	Ductless	Single-zone
Daikin		5265755	RXS12LVJU	FTXS12LVJU	12.5	23	12.8	Yes	Ductless	Single-zone
Daikin		5265756	RXS15LVJU	FTXS15LVJU	11.6	20.6	14.4	Yes	Ductless	Single-zone
Daikin		5265757	RXS18LVJU	FTXS18LVJU	11	20.3	12.7	Yes	Ductless	Single-zone
Daikin		5265758	RXS24LVJU	FTXS24LVJU	10.6	20	12.5	Yes	Ductless	Single-zone
Nortek Global	Maytag	5597453	PSH4BG024K	B6VMAX024K-B	10	19	13.9	Yes	Ducted	N/A
Nortek Global	Maytag	5597457	PSH4BG036K	B6VMAX036K-B	10	19	12.9	Yes	Ducted	N/A
Fujitsu		5751311	AOU9RLFC	AUU9RLF	13	24	14.5	Yes	Ductless	Single-zone
Fujitsu		5751312	AOU9RLFC	ARU9RLF	12.2	21.5	14.5	Yes	Ductless	Single-zone
Fujitsu		5751313	AOU12RLFC	AUU12RLF	12.2	21.9	12.8	Yes	Ductless	Single-zone
Fujitsu		5751314	AOU12RLFC	ARU12RLF	11.5	20	12.8	Yes	Ductless	Single-zone
LG		5859619	LUU187HV	LCN187HV	10.1	20	15	Yes	Ductless	Single-zone
LG		6236101	LSU240HSV3	LSN240HSV3	10.2	20	12.5	Yes	Ductless	Single-zone
American Standard		6749789	4A6V0024A1	*AM8C0B30V21	10	19.25	13.75	Yes	Ducted	N/A
American Standard		6749791	4A6V0048A1	*AM8C0C48V41	10	19.25	12.5	Yes	Ducted	N/A
Trane		6749942	4TWV0024A1	*AM8C0B30V21	10	19.25	13.75	Yes	Ducted	N/A
Trane		6749944	4TWV0048A1	*AM8C0C48V41	10	19.25	12.5	Yes	Ducted	N/A
American Standard		6750232	4A6V8036A1	*AM8C0C36V31	10	18	13	Yes	Ducted	N/A
American Standard		6750233	4A6V8048A1	*AM8C0C48V41	10	18	12.5	Yes	Ducted	N/A

Current Product List (3.9.17) | Delisted (on 1.1.17)

NEEP Guides

- Sizing/selection guide and installation guide
- neep.org, “Initiatives/air source heat pumps”, “Air-Source Heat Pump Installer Resources” link on right side
- Also, “Cold Climate Air Source Heat Pump” link at right to cold climate list
- Updates coming in 2018, + consumer’s guide

Sizing and Selecting Guide

Application Sheets

Guide To Sizing & Selecting Air-Source Heat Pumps in Cold Climates

A companion to NEEP's Guide to Installing Air-Source Heat Pumps in Cold Climates

Heating (or Heating & Cooling) Displacement

Application Description	
Suggested ASHP System Configuration (Single/Multi-Zone Ductless, Mini-Duct, Centrally Ducted)	
Suggested Treatment of Existing HVAC System	
Sizing Strategy Overview	
Load Calculation	
Equipment Selection Considerations	
Oversizing Concerns / Tradeoffs	

Further Guidance

Guide To Sizing & Selecting Air-Source Heat Pumps in Cold Climates

A companion to NEEP's Guide to Installing Air-Source Heat Pumps in Cold Climates

Full Heating System Replacement

Application Description	
Suggested ASHP System Configuration (Single/Multi-Zone Ductless, Mini-Duct, Centrally Ducted)	
Suggested Treatment of Existing HVAC System	
Sizing Strategy Overview	

Guide To Sizing & Selecting

A companion to NEEP's Guide to Installing Air-Source Heat

Isolated Zone

Application Description	One room or zone that is otherwise thermally isolated … a newly finished basement room, build out above gara… had poor thermal comfort.

Installation Guide

Guide To Installing Air-Source Heat Pumps in Cold Climates

A Companion to NEEP's Guide to Sizing & Selecting Air-Source Heat Pumps in Cold Climates

Introduction

High-quality installations of air-source heat pump (ASHP) systems generate referrals, increase sales, reduce callbacks and improve customer comfort and satisfaction. Installation practices also have a major impact on efficiency and performance of an ASHP system. Efficient ASHPs have seen significant sales growth in colder climates in recent years. The recent generation of cold-climate ASHPs, combined with insights from large-scale installation programs and installers, has led to a better understanding of the full range of practices to ensure maximum system performance and customer satisfaction. This guide provides a list of these best practices, as well as homeowner education and system setup guidance, to help ensure efficient air-source heat pumps and happy customers in cold climates.

Heat pumps should always be installed by licensed, trained professionals. Always follow manufacturer's specification and installation instructions, and all applicable building codes and regulations. All installers should attend a manufacturer's training or preferred installer program.

ASHPs come in a number of configurations, and in some cases the following guidance may be specific to one or more of those system types. There are many variations and terms used, but these guidelines will focus on the following broad categories: "ductless ASHP" refers to any non-ducted cassette type indoor unit (including wall-mount air handlers, floor mounted consoles, in-ceiling cassettes, etc.); "mini-duct ASHP" refers to remote air handlers that are typically designed for compact, concealed-ceiling or short-duct configurations; and "centrally ducted ASHP" refers to whole-house systems with central air handlers. The icons shown here are used below to indicate when guidance is specific to a certain system type. All items without icons are generally applicable to all ASHP configurations.

Applies to: Ductless ASHP | Mini-Duct ASHP | Centrally ducted ASHP

Access/Use of Guides

- Guides developed to be shared/used broadly
- Guides posted on NEEP's public website, available to download
- Guides available to co-brand
- Seeking opportunities to disseminate resource
- Please send ideas about key venues to share the Guides

Issues

- Design
  - Multi-zone
  - Sizing
- Installation
  - Snow/ice / drip / drain pan heat
- Utilization
- Controls / firmware / settings
  - Wall mount thermostat
  - Temp sensing / air handler
  - Constant fan
- Setbacks

Design (Retrofit)

- 1st floor unit primary heating for 2-story house
  - 2nd floor unit great for cooling 2-story house
    - Ducts help upstairs—low load rooms
- **Most** savings from first heating unit
  - Sometimes 2-3 heads for cut-up floor plans
- More: increased comfort, convenience
  - Higher cost and lower efficiency

Design

- Don’t use HSPF “as-is” to estimate or even compare performance
  - Adjust for climate using bin analysis for actual equipment and application
  - Be careful about what manufacturers specs you use
    - Typically run at max capacity at low temperatures
    - NEEP guide is really helpful

Design - Sizing

- Focus on the application
  – Sole heating source: cold weather performance/ capacity is critical
  – Retrofit to offset oil/LP/resistance heat: overall performance matters more
- Conventional sizing may not be relevant for some uses
  – Smaller seems to be better – as long as load is met

Sizing – New Con / DER

- Make sure to do actual load calculations
- Use equipment spec's *at design conditions*
- Zoning: Avoid oversizing many small zone
  - Use zones strategically
  - Slim/horizontal duct systems for 2-4 bedrooms
  - Most single family homes: 2-3 zones; condos: 1-2
- Isolated room – separate zone

Design / Install

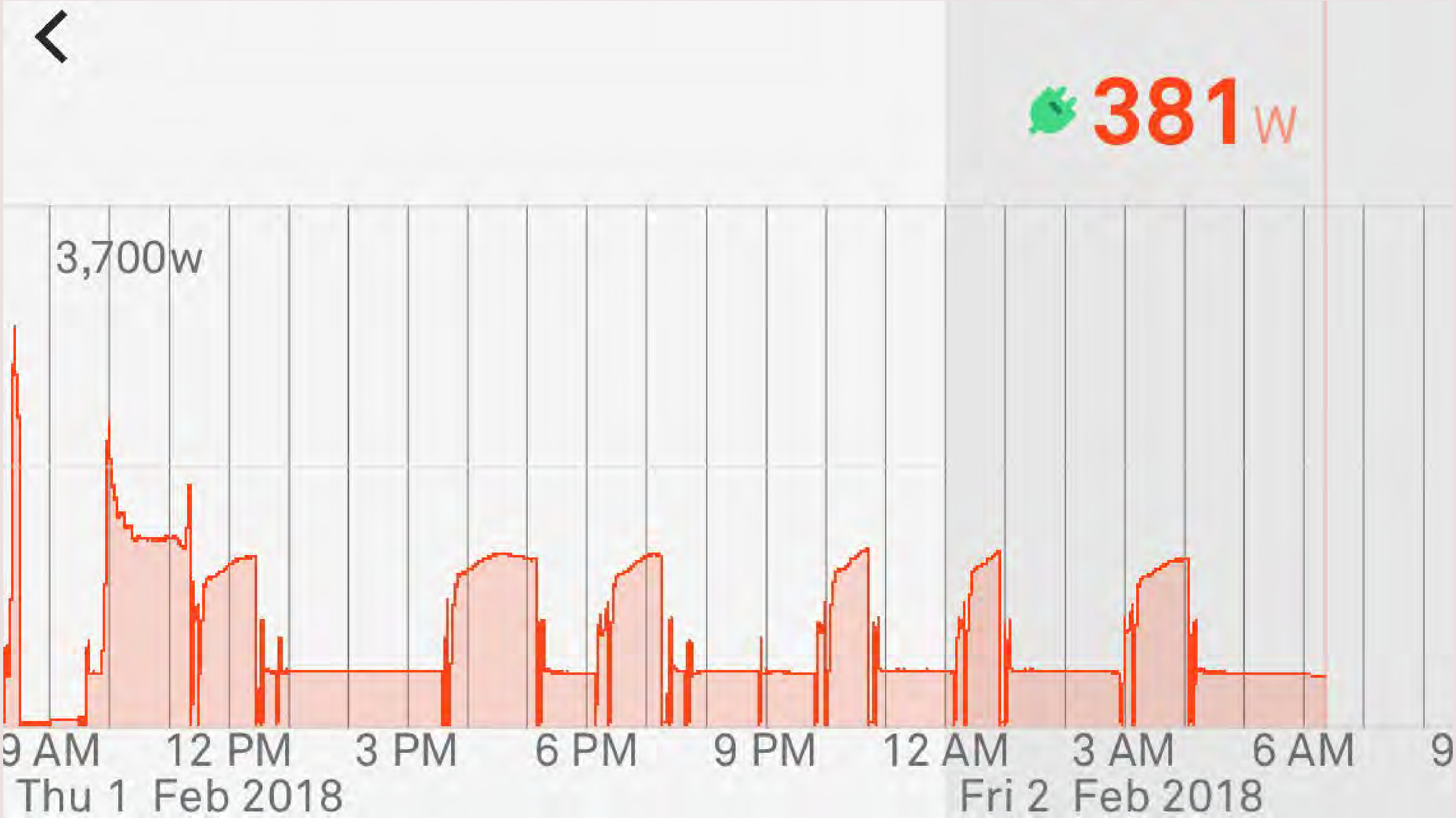
- In heating climate: indoor unit low on wall
  - Window sill height provides balance between heating and cooling performance in cold climate
  - Or use floor mounted system
  - Or ducted system with floor registers if space is available

“Floor mount” good for larger spaces

- Better heat distribution, esp. first/lower floor

- Or, ducted system with floor registers

Got Monitoring?



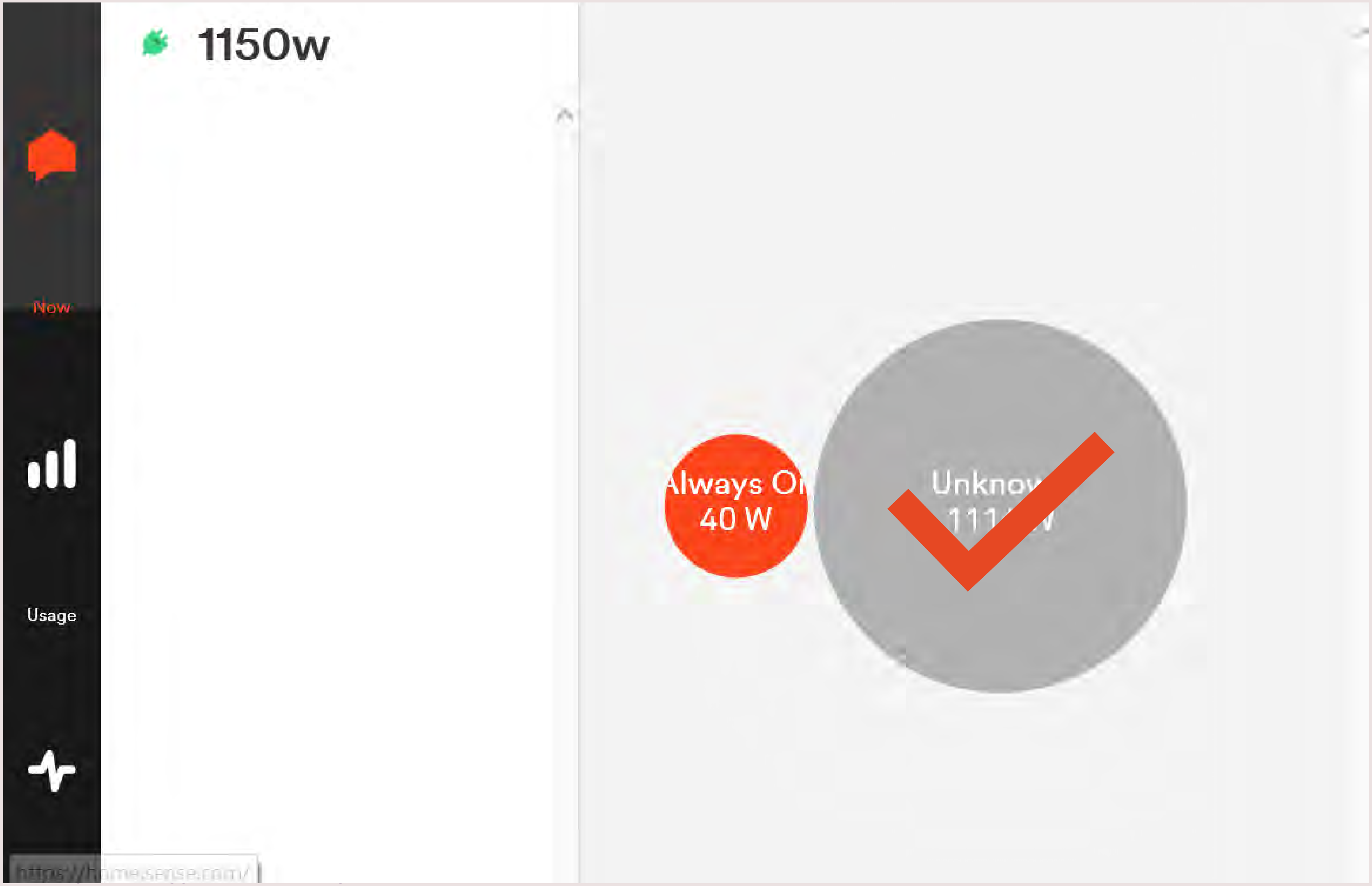
Monitoring is *really* good to have

- See what's happening… but adds $300-1500+
- eGauge – flexible, configurable, geeky
  - No subscription fee (need to backup data in case of failure)
- eMonitor – more consumer friendly
  - Have to pay for data storage
- Sense – Can't "sense" variable-speed heat pump unless you put it on JUST the HP circuit

Sense – cheaper, but imperfect:

Bruce

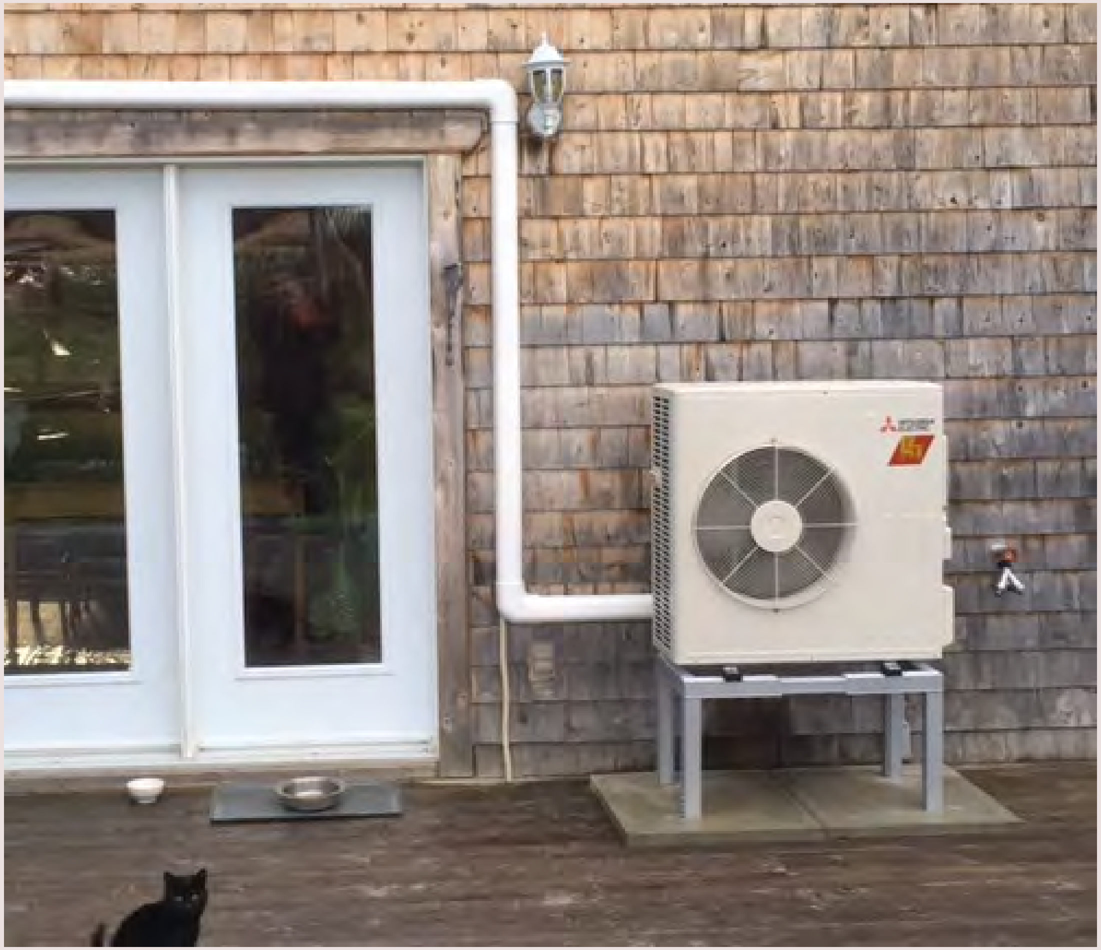
Connect only to the heat pump:



Care In Installation

- Follow manufacturers instructions carefully
  - Refrigerant charge adjustments if needed
  - Flare fittings, purge system, start-up process
- Keep above snow line – wall brackets
  - Best if mounted to foundation
  - (or wall in less noise-sensitive area)
- Surge protector at service disconnect
- Rodent-proof entry

Wall mount or stand:



Beware frost heave w/stands

Drip Diverter

- Avoid eave drip, or use diverter
- Sheltering from above is good – don’t obstruct air flow (follow instructions for clearances!)

Surge protector helps avoid this:

Rodent-proofing line set entry

Controls / Settings

- Use Wall-mounted controls
  - Sense temperature *at control, not in return air*
- Fan Speed: Auto, avoid constant-fan settings
- Avoid "Auto" heating / cooling setting
- Override fan temp sensing control for air handlers in unconditioned space
- Retrofit: the heat pump needs to operate
  - Set ASHP warmer than backup heat!
  - Control location – ASHP as primary, central as backup

Thanks!

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