Research Update:

Condensing Boiler Optimization

Duluth Energy Design Conference
2/22/2017

Rebecca Olson

Neighborhood Energy Connection

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Continuing Education

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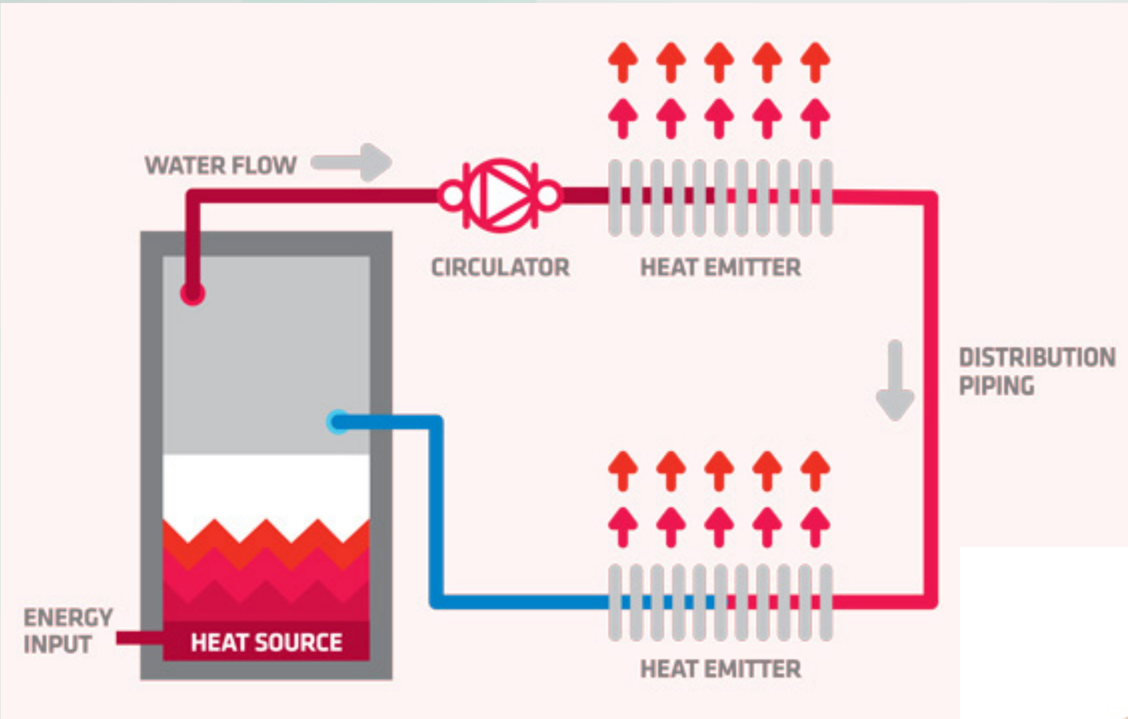
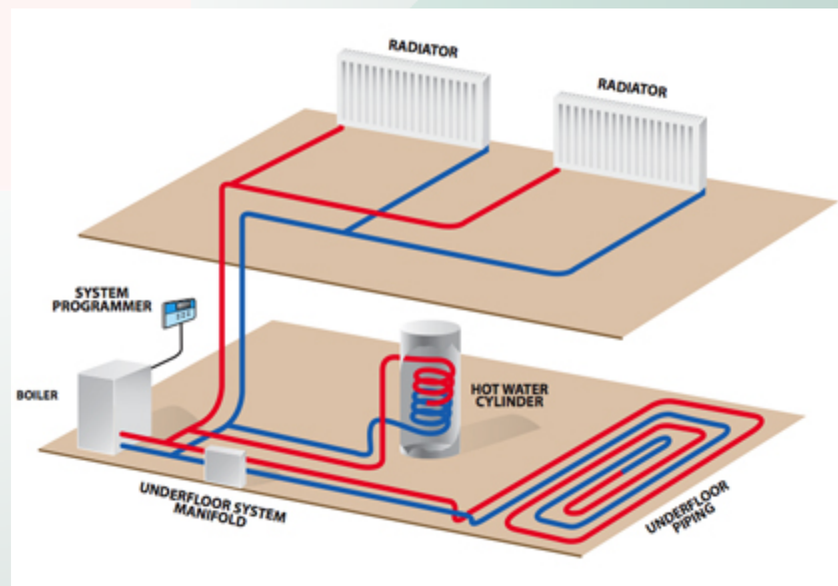
Objectives

- Understand how residential condensing boilers are being installed in MN
- Learn about HVAC contractor barriers and attitudes toward condensing boilers in residential applications
- Interpret data from monitoring of previously installed condensing boilers
- Learn which factors affect condensing boiler efficiency in single family homes
- Apply lessons learned from the research project into boiler installation practices
- Understand the overall goals of this research project
- Get updated on next steps of optimization project

Introduction to Hydronic Heating



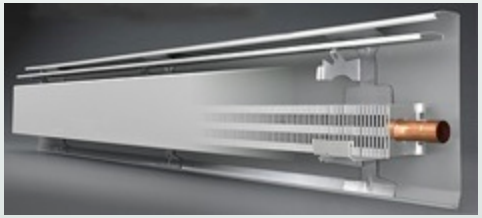


Introduction to Hydronic Heating

- Non-condensing vs. condensing
  - Conventional boiler: condensation of combustion gases can rust out heat exchanger
  - Condensing boiler: condensation of combustion gases is optimum for efficiency
- Difference in return temperature requirement
  - In order to get combustion gases to condense, the return water temperature needs to be below ~130°
- Radiator types
  - Radiator types and size play a significant role in the ΔT between supply and return temps.
- Issues with replacement from one to other
  - It's important to optimize efficiency when replacing a conventional boiler with a condensing boiler based on the above factors

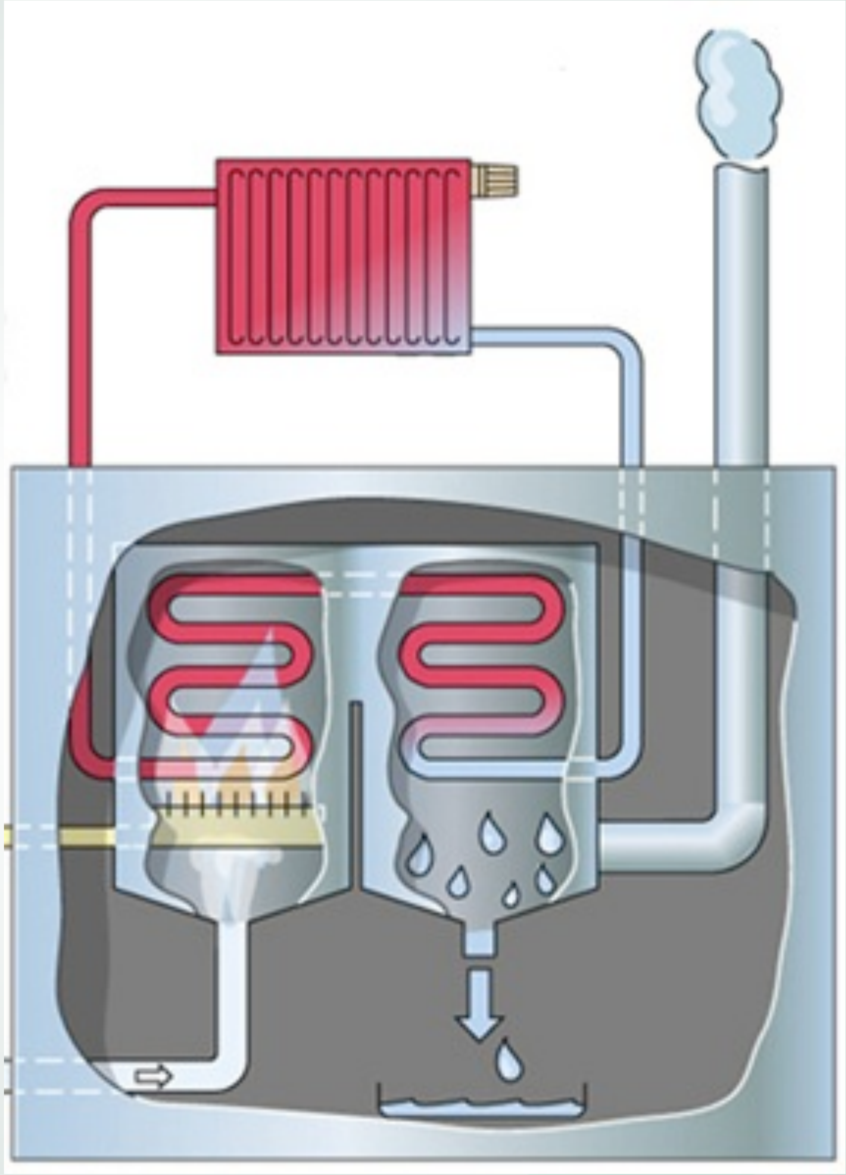
Hydronic Heating in MN

- Approximately 30% of MN homes are heated by a boiler
- Most of these are in older cities like St. Paul and Minneapolis
- Some in northern locations where central A/C is in less demand



Condensing Boilers

- How it works:
  - 2nd condensing heat exchanger
  - Less waste heat up the chimney
  - If return water temp is low, more heat is exchanged from the combustion gases to the boiler water: increasing efficiency
  - Supply temperature, flow rates and radiator type/size dictate return water temp.



Need for Condensing Boiler Research

- Lack of modulating condensing boilers in residential market
- Evidence that HVAC contractors and utilities have inconsistent confidence in products
- Prior research showing how important return temperature is on condensing boilers—commercial and hydronic air handler studies
- Need for quality installation protocol for utility savings and cost benefit confidence

Contractor Hesitance and Cost

- Cost of condensing units is generally high and variable
  - $6,500--$15,000 installation cost range
- Lack of confidence in operation at high efficiency
- Issues with early models and maintenance callbacks
- Confusion about supply set-temps and condensing rate optimization
- Not as many model options in this market as condensing forced air systems

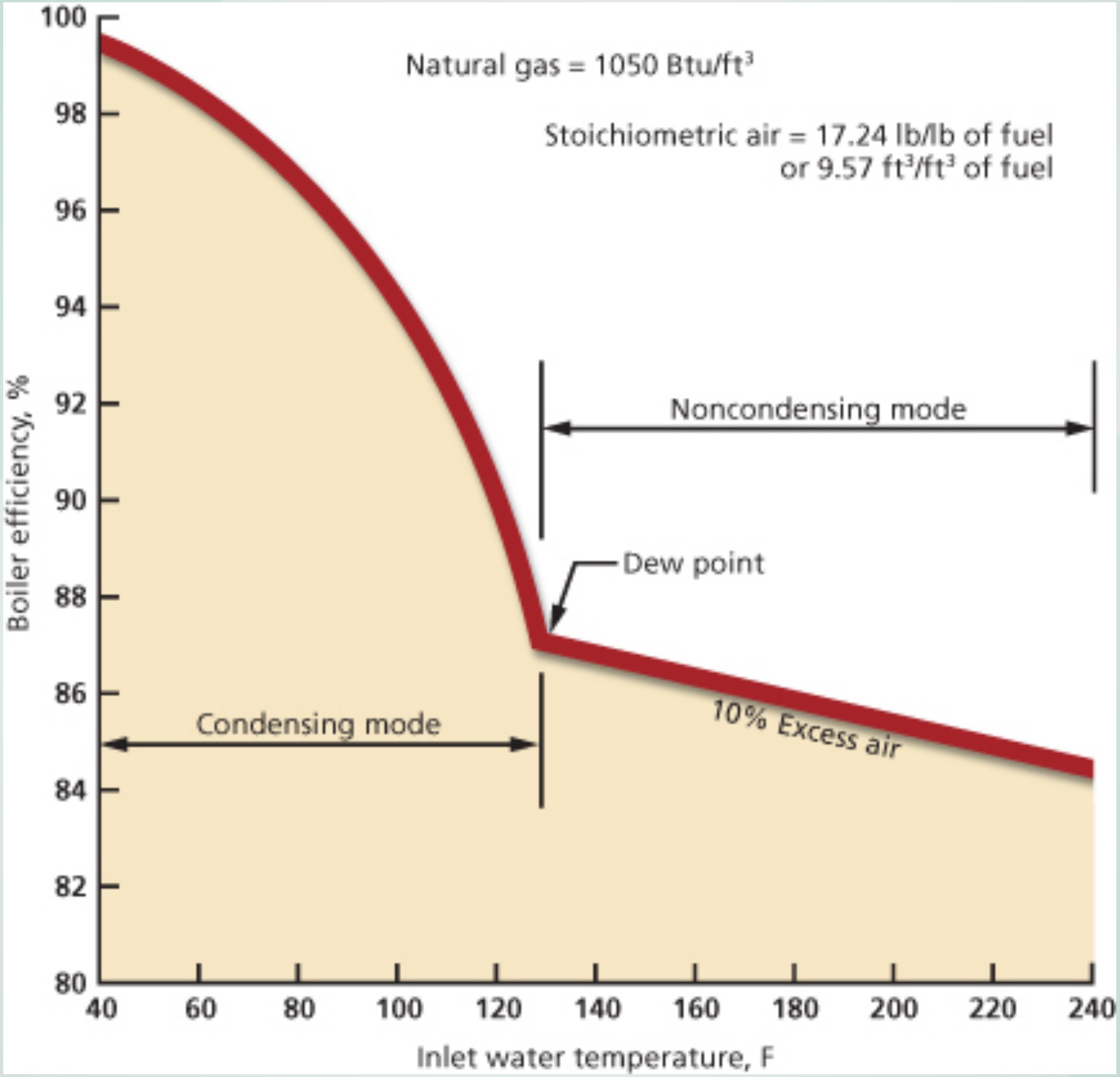
Condensing Boiler Rebates in MN

- Current rebates for condensing units are offered by:
  - Centerpoint Energy (91%+ AFUE=$500)
  - MN Energy Resources (90%+ AFUE=$200)
  - Great Plains Natural Gas (91%+ AFUE=$500)
  - Greater MN Gas (90%+ AFUE=$500)
  - New in 2017: Xcel Energy (90%=$300, 95%+=$400)
- 2017 Federal tax credit: TBD?

Prior Research and Information

- Conclusions:
  - Return water temp is a primary factor
  - Flow rates can influence return water temperature
  - Outdoor reset needs to be installed and set-up properly
  - Needed more info pertaining to MN housing stock, radiator types, and climate as well as more field implementation guidelines
- Building America—Butcher/Arena
- Commercial Boiler study—CEE Russ Landry
- ASHRAE Handbook

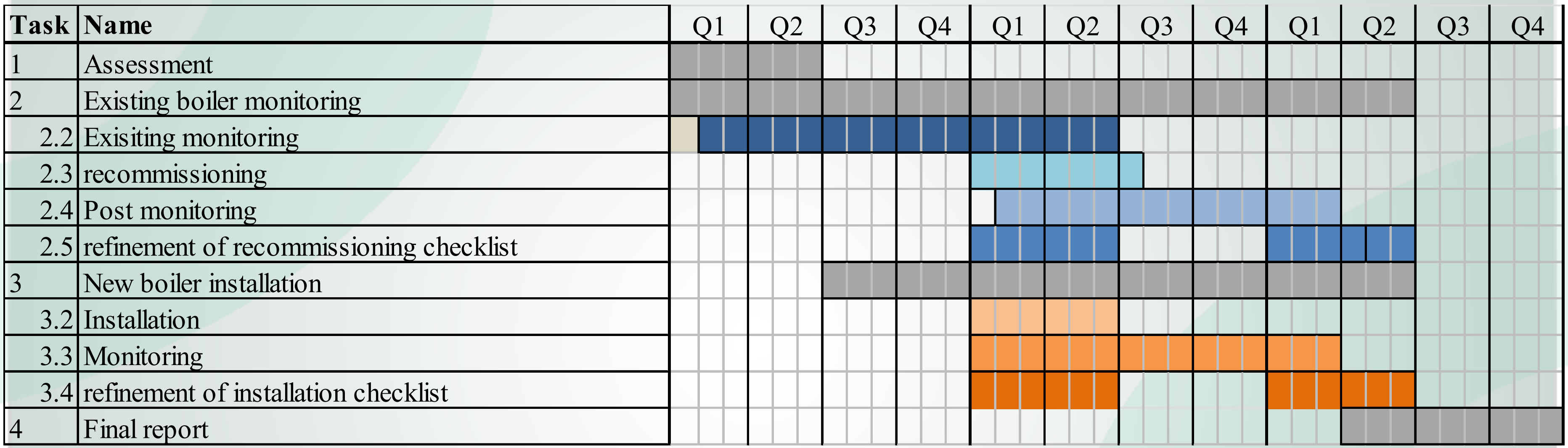
Prior Research and Information



Research Project Structure

- Field and Market research
- Existing condensing boiler monitoring
- Draft retro-commissioning activities
- Monitor savings after retro-commissioning
- Development of Quality Installation Protocol for Utility rebates based on savings from retro-commissioning
- Work with contractors to install condensing boilers in homes using QI protocol
- Information dissemination through webinars, presentations and published reports

Research Project Timeline



Market Research Structure

- Interview HVAC contractors about installation
  - Procedures
  - Pricing
  - Barriers
  - Incidence
- Interview homeowners about performance
  - Comfort
  - Maintenance
  - Issues
- Interview Utilities about rebate development and rationale

Early Market Research Results

- **Interview HVAC contractors about installation**
  - 6 companies interviewed so far including a supplier
  - Low volume of boiler replacements and even lower volume of condensing
  - Some hesitation on cost vs. performance
  - Costs seem to be inconsistent with equipment and labor details
- **Interview homeowners about performance of existing condensing Boiler**
  - Comfort is very high in existing sites
  - Maintenance does not seem to be an issue with any of the sites
  - Most sites relied on contractor to choose model
  - All 6 residents said they would recommend condensing system to others
- **Interview Utilities about rebate development and rationale**
  - Preliminary discussion with Xcel indicates they were worried about cost effectiveness.
  - They may be getting high installation cost estimates, and not have a lot of confidence in the efficiency

Field Research Phase I

- Characterization of Typical MN households
  - Based on aggregate consumption data from existing programs
- Participant solicitation/selection
- 6 sites chosen with existing modulating condensing boilers installed within the last 5 years
- Sites have varied heating loads and construction characteristics
- All homes have cast iron radiators
  - Some have other convector types, (i.e. baseboard, in-floor, low mass)
- 3 sites have indirect water heaters
- Monitoring
  - Gas usage
  - Supply and return water temperature
  - Flow rates
  - Condensation rate

Field Research Phase I

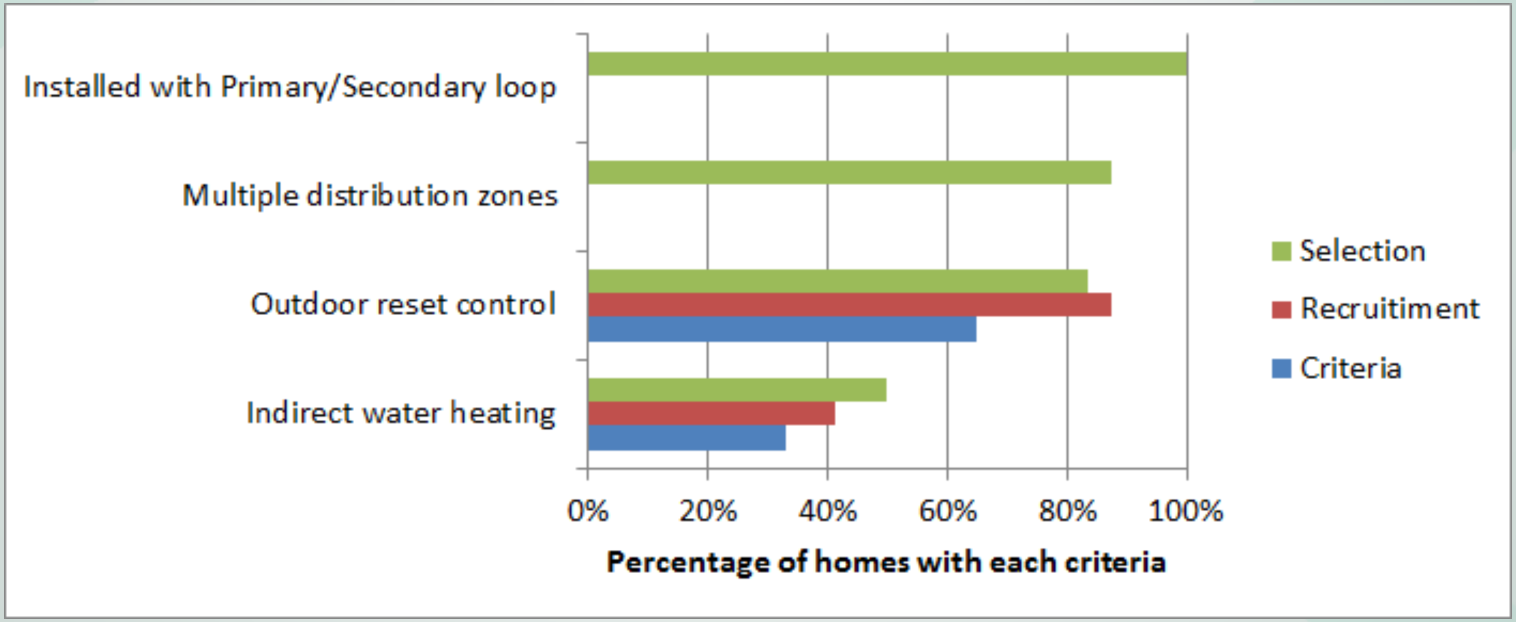
- 1st half of 2015/2016 heating season, monitored as installed
- Made minor changes to optimize efficiency
  - Adjusted supply temp
  - Optimized turn-down ratio
  - Attempted to change DHW supply temp and flow rate
- 2nd half of 2015/2016 heating season, monitored after adjustments
- Measured savings from 1st half to 2nd half
- Developed draft quality installation protocol

Site Selection Criteria

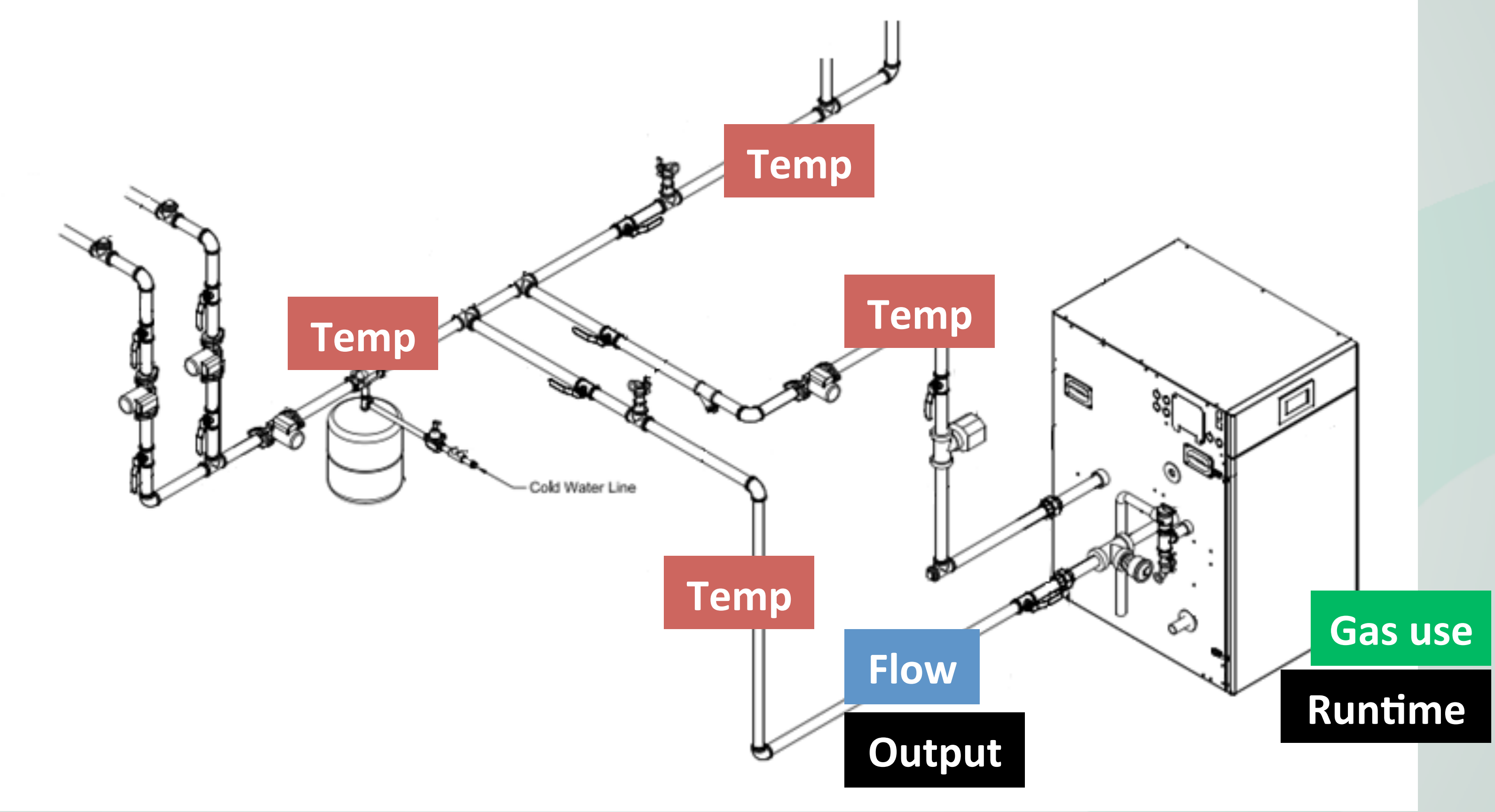
- At least 1 home per typical heating load quartile (420 to 700, 700 to 830, 830 to 1275, and >=1275 therms/yr)—based on MN aggregated residential utility program data
- At least 1 of each of the top 3 manufacturers—identified by utility rebate and local sales info
- A variety of installers
- MN program databases suggest between 30-36% of condensing boiler installs had indirect water heaters
- National Grid study found 30-40% of outdoor reset were not installed or installed poorly
- A variety of emitter types. Cast iron radiation, Low mass radiation, baseboards, and in-floor heating

Site Selection and Recruitment

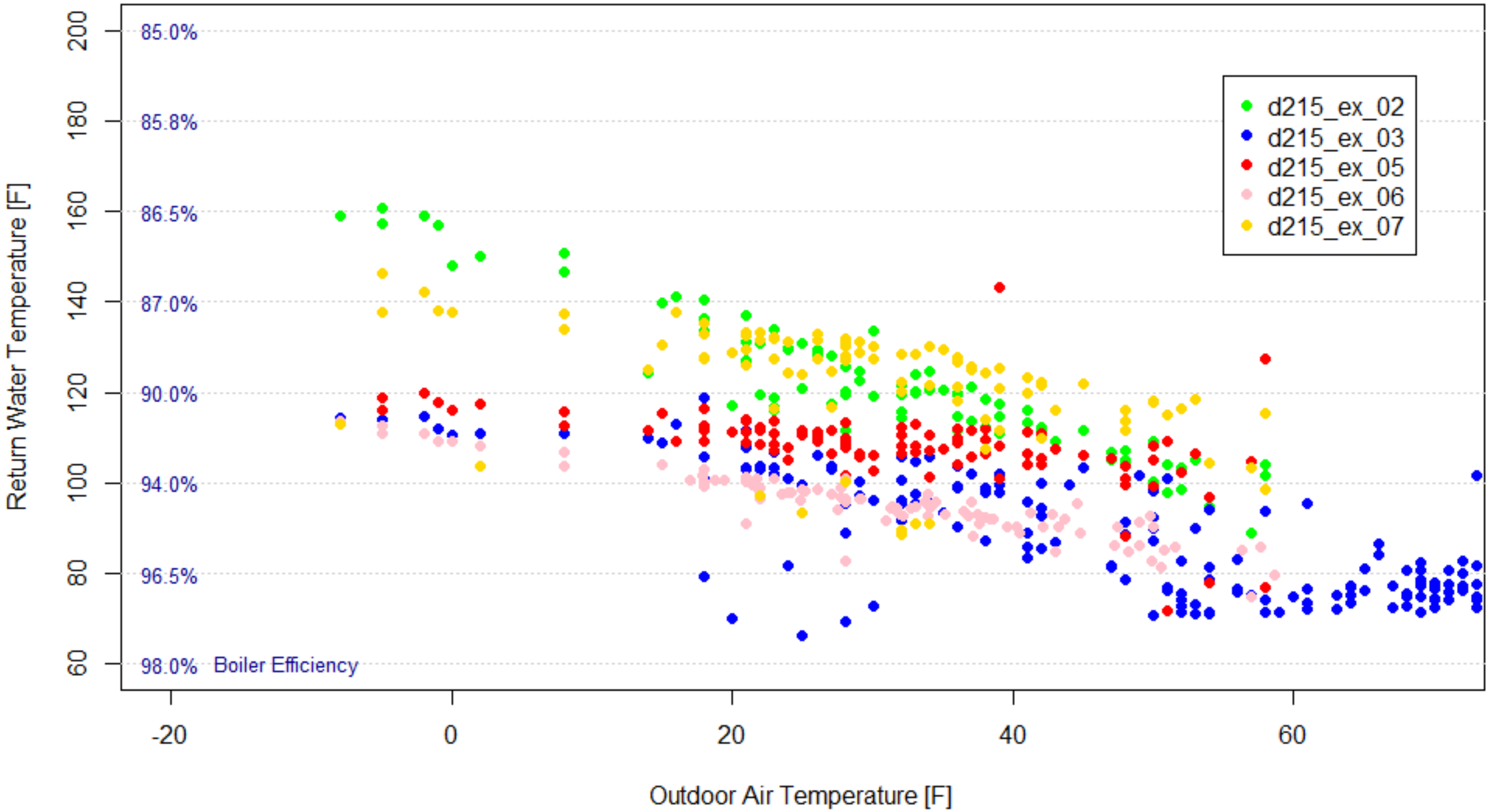
- **17 recruited homes had smaller loads than typical homes (Avg 720 therm/yr)**
  – In selected 6 sites, larger usage homes were slightly under represented
- **Identified 6 different manufacturers in recruitment.**
  – Top brands based on supplier and utility rebate data are represented in 6 selected sites
  – Triangle tube, Buderus, Bunham, Weil Mclain all included
- **11 different installers in recruited homes**
  – 5 different installers in selected sites



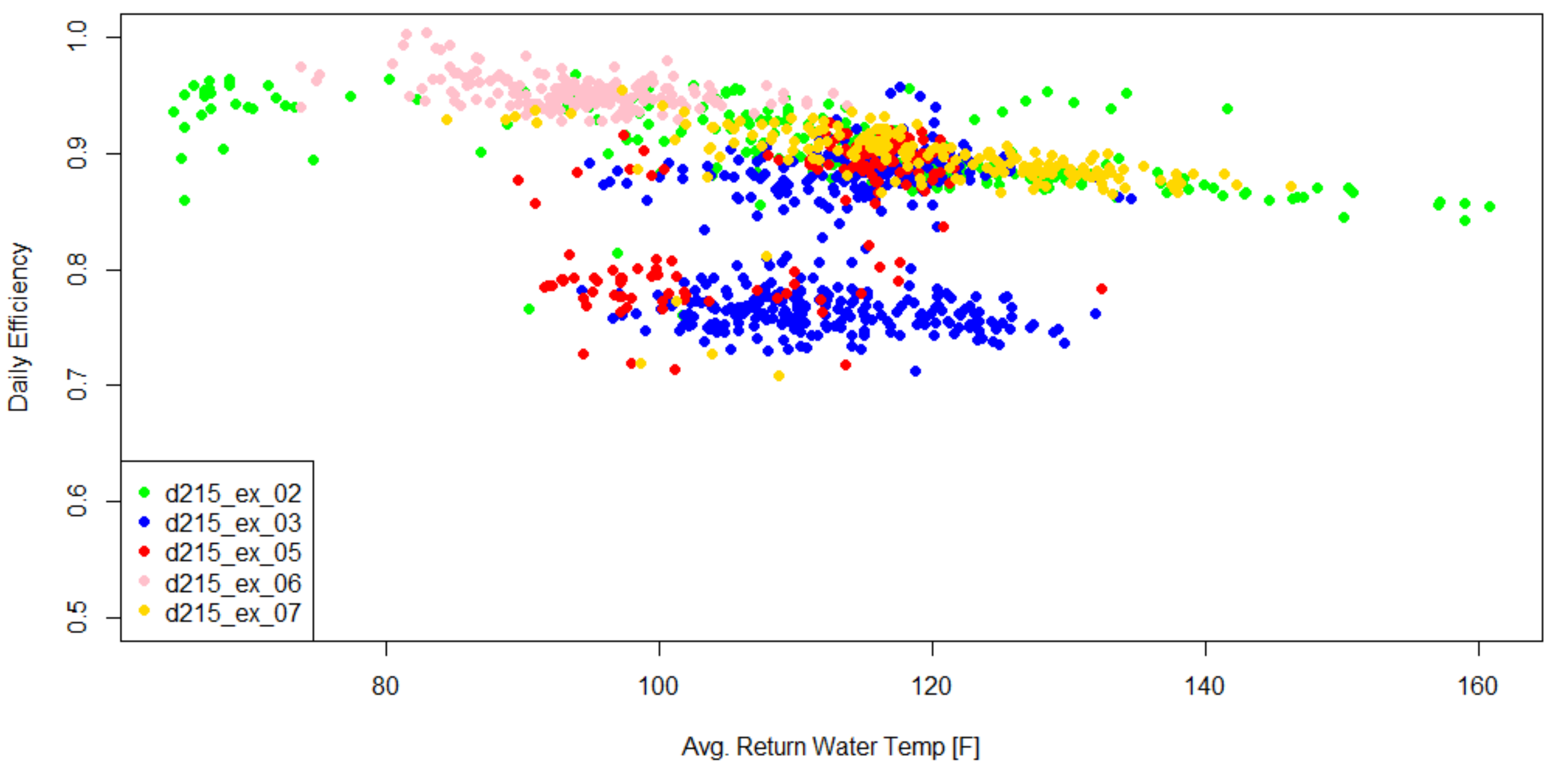
Monitoring Set-up



Phase I Pre Retro-commissioning Daily Measured Performance



Daily Measured Performance



Phase I: As-found performance

		Annual Energy Use		Annual Efficiency		
Site	Mode	Space Heating	DHW	Combined	Space Heating	DHW
		therms/yr	therms/yr			
d215_ex_02	As-found	**837**	na	na	**88.4%**	na
d215_ex_03	As-found	**536**	**112**	**88.0%**	**90.5%**	**76.1%**
d215_ex_05	As-found	**459**	**94**	**88.0%**	**91.6%**	**70.3%**
d215_ex_06	As-found	**669**	na	na	**95.1%**	na
d215_ex_07	As-found	**731**	na	na	**89.0%**	na

Retro-Commissioning Actions

- **Lowered Supply Temperature**
  - Determined reasonable level to still meet load, but lower return temp. to optimize efficiency
- **Adjusted overall Reset Curve**
  - Maximum supply temperature output at -12° vs. default of 0°
  - This will lower the slope of the curve making more points along the curve in the condensing mode
- **Adjusted DHW Supply when possible**
  - Based on lower efficiencies of indirect tanks as well as indications of unused capacity
  - This was either impossible, or didn't actually have an effect on the return temp because of heat exchange capability

Phase I Site Example (D215_ex_07)

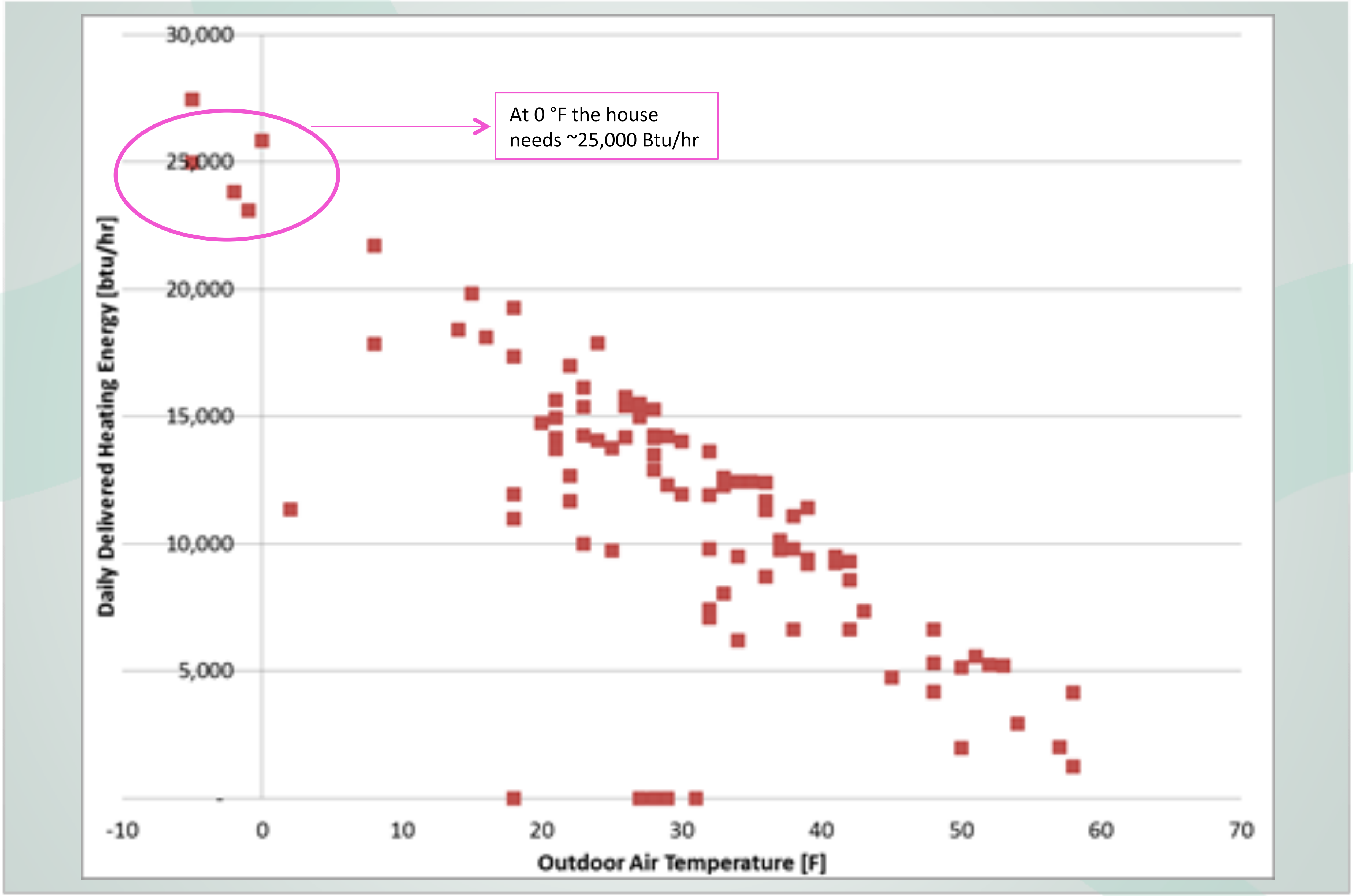
- Boiler for space heating only
- 6 Cast iron radiators
- 2 low mass radiators
- 3 zones w/ 3 t-stats

Capacity Estimates and Ratings (Btu/hr)		
Boiler Output	Min	Max
	28,500	99,000
Emmiters	at 140 Sup T	at 180 Sup T
	35,000	65,000
Design Heating Load (Bill Analysis)	at -12 F OAT	
	38,500	

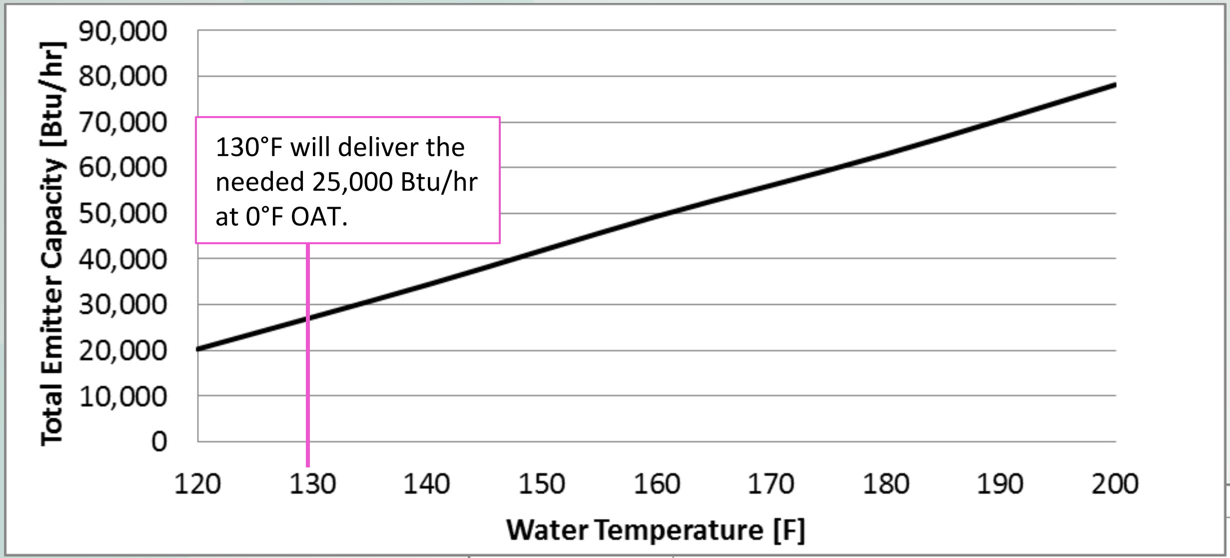
Supply Temperature Optimization

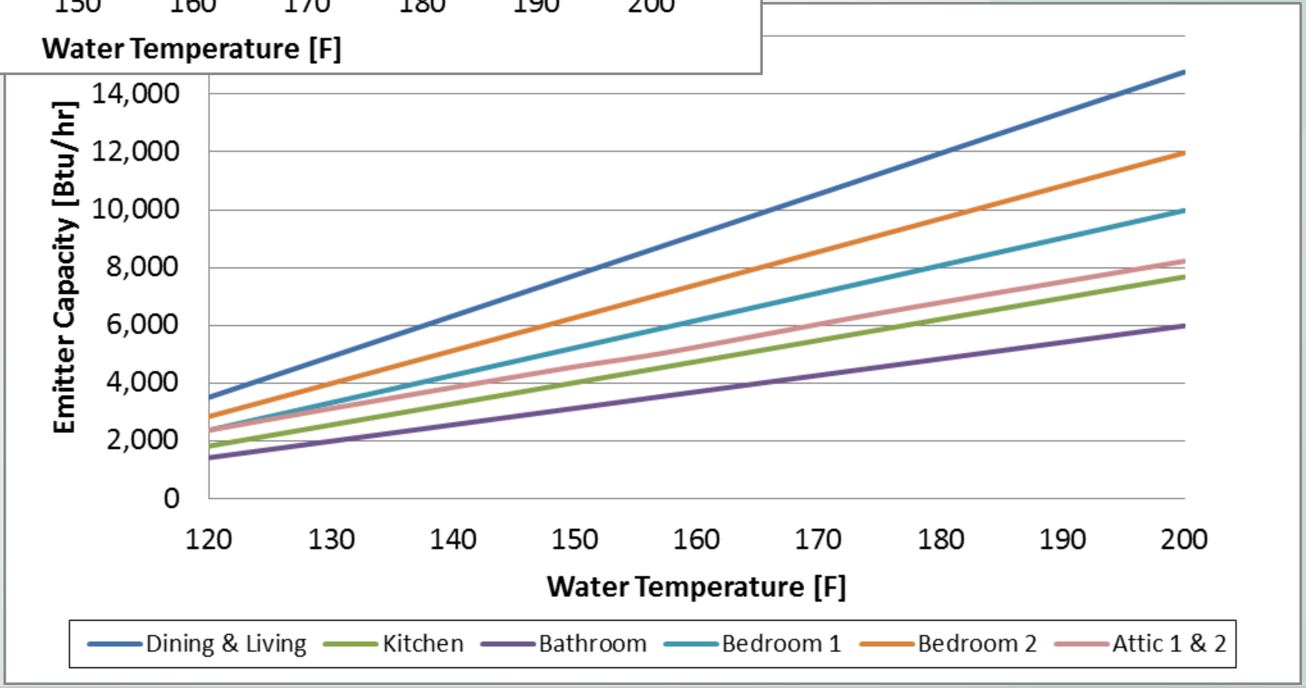
- Calculate or estimate the home heating load
- Calculate or estimate the emitter capacity
- Minimize the supply water temperature so that the house load can still be met

Phase I Site Example (D215_ex_07)

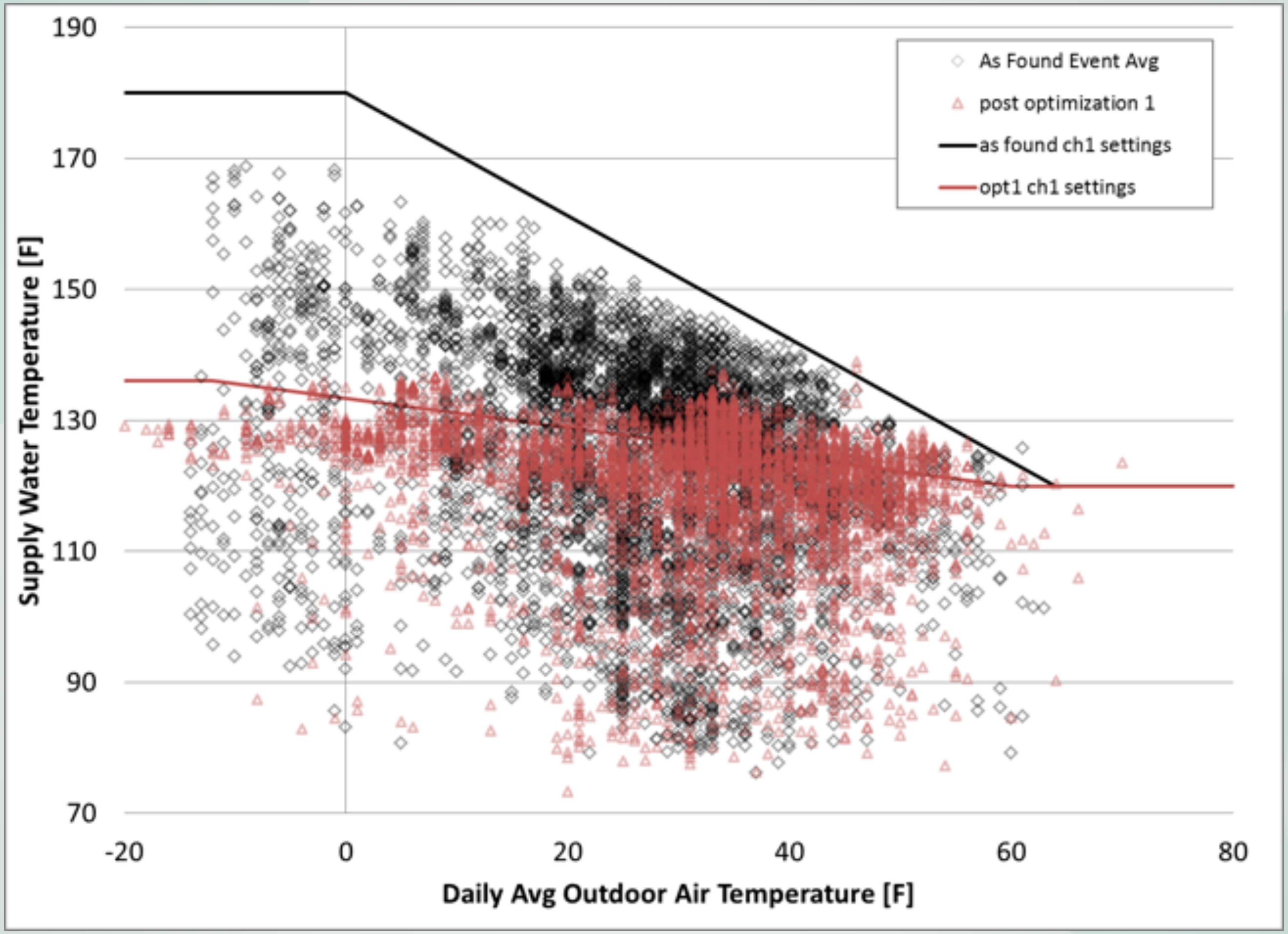


Site Example(D215ex07)Emitter Capacity

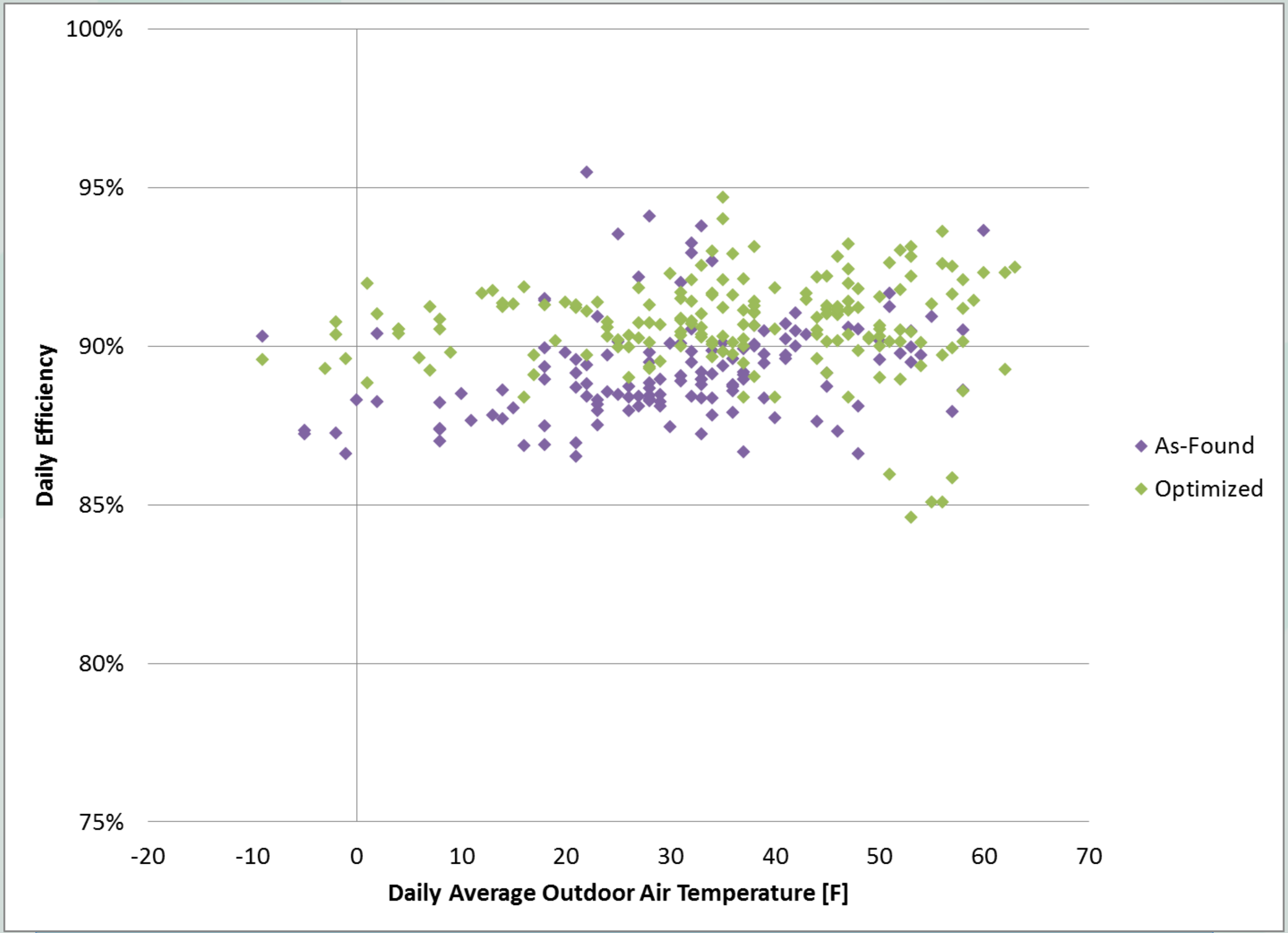




Site Example(D215ex07) Improvement



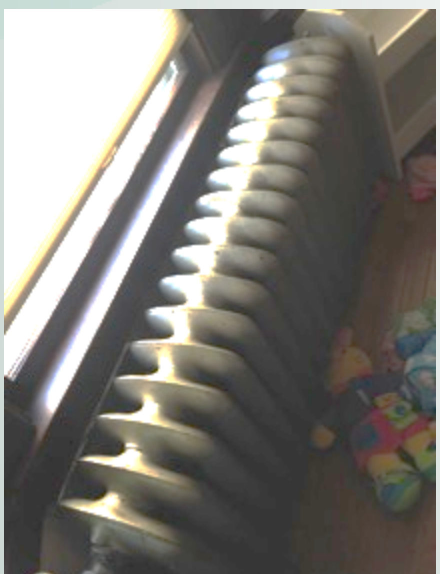
After retro commissioning performance



As-Found Annual Efficiency: 89.0% **Optimized Reset 90.5%**

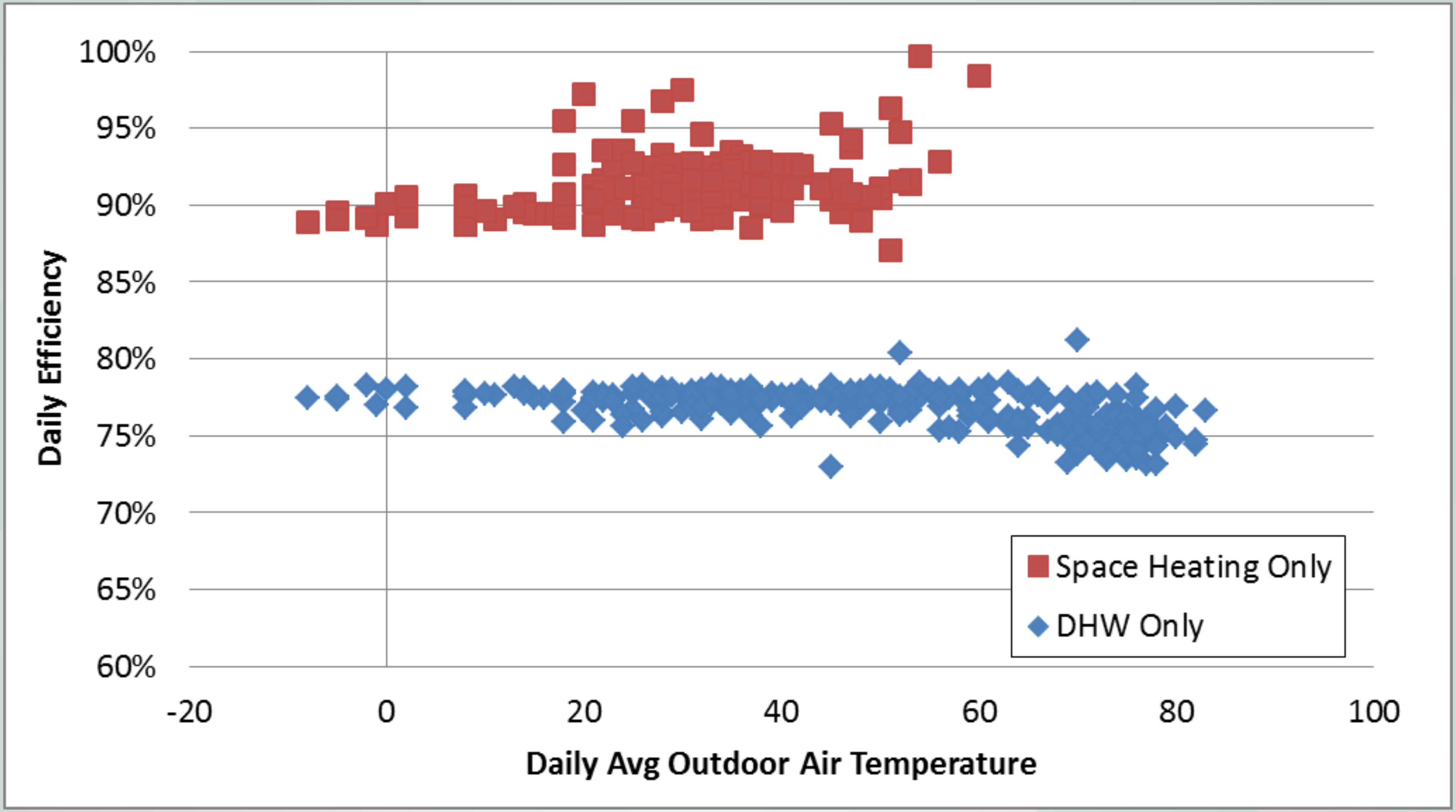
Site Example (D215_ex_03) - DHW

- Boiler and indirect water heater
- 6 Cast iron radiators
- 41 Gal WH set at 130°F



Capacity Estimates and Ratings (Btu/hr)		
Boiler Output	Min	Max
	22,745	75,200
Emmiters	at 140 Sup T	at 180 Sup T
	22,234	41,997
Design Heating Load (Bill Analysis)	at -12 F OAT	
	28,925	

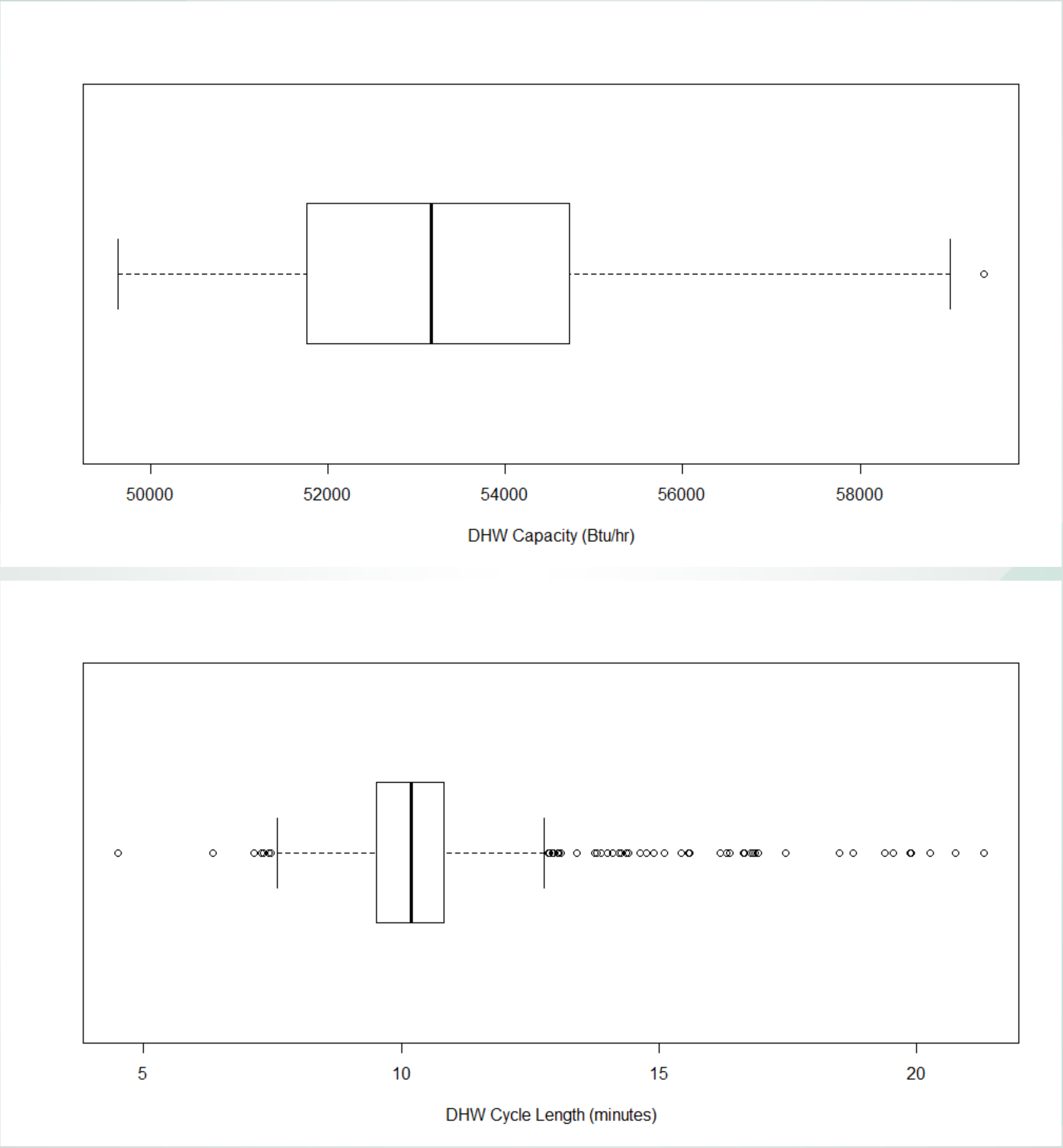
Site Example (D215 ex 03)



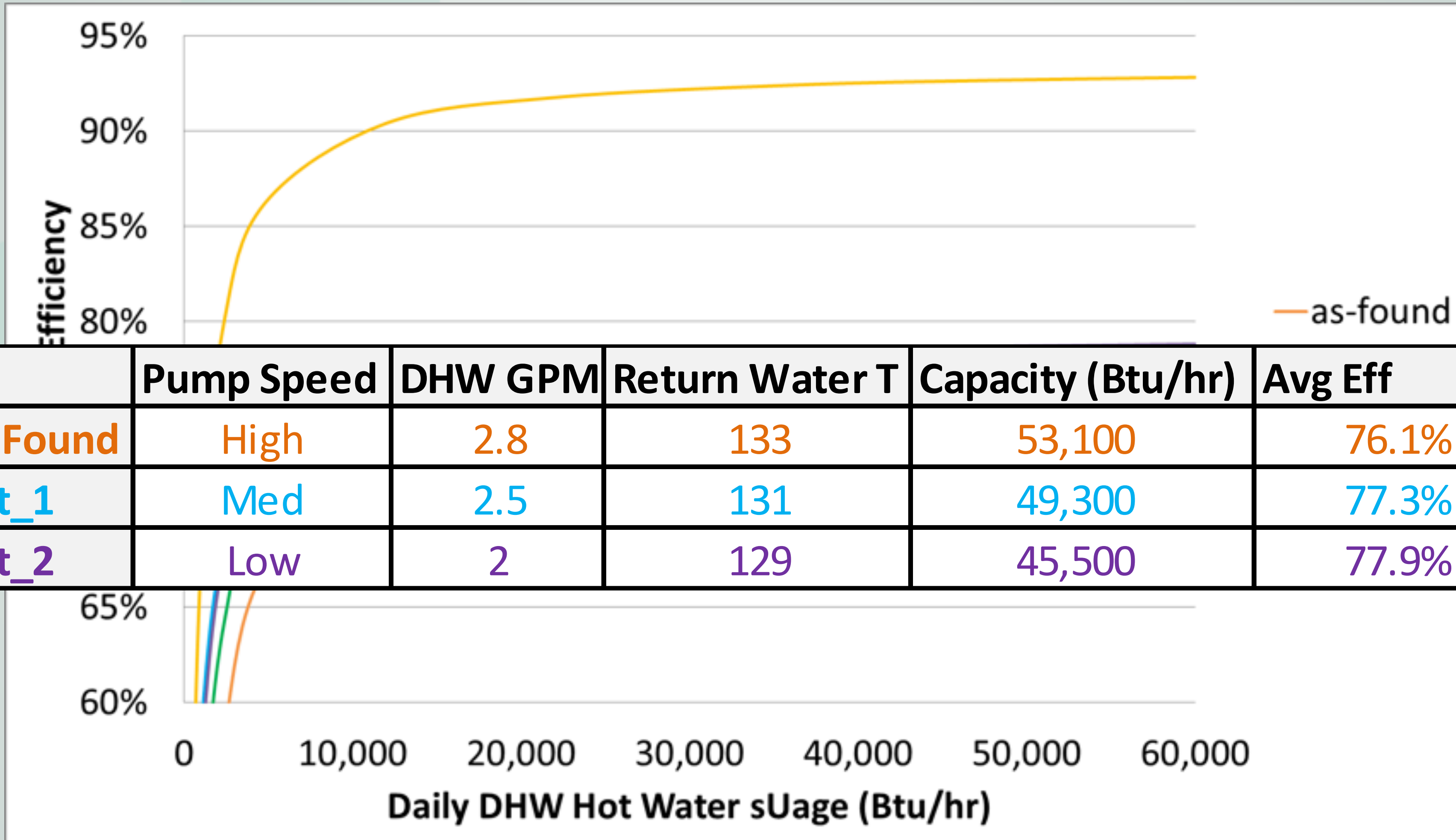
DHW Optimization

- Does the current DHW capacity meet load?
- Minimize the supply water temperature
  - Many older boilers fix the DHW temperature
    - d215_ex_03
- Minimize the DHW loop flow rate
  - Manual pump adjustment
  - Or boiler settings

Site Example (D215 ex 03)



After retro commissioning performance



	Pump Speed	DHW GPM	Return Water T	Capacity (Btu/hr)	Avg Eff
As-Found	High	2.8	133	53,100	76.1%
Opt_1	Med	2.5	131	49,300	77.3%
Opt_2	Low	2	129	45,500	77.9%

Comparison Chart

Site	Mode	Annual Combined Eff	Annual Space Eff	Annual DHW thermal Eff
d215_ex_01	As-found	82.6%	86.2%	62.6%
d215_ex_01	Opt - OAT Curve	Analysis On-going		
d215_ex_02	As-found	na	88.4%	na
d215_ex_02	Opt - OAT Curve	na	90.2%	na
d215_ex_03	As-found	88.0%	90.5%	76.1%
d215_ex_03	Opt- Clean	88.2%	90.5%	77.1%
d215_ex_03	Opt - DHW 1	88.4%	90.5%	77.3%
d215_ex_03	Opt - DHW 2	88.6%	90.5%	77.9%
d215_ex_05	As-found	88.0%	91.6%	70.3%
d215_ex_05	Opt- NA	No Optimization to be Done		
d215_ex_06	As-found	na	95.1%	na
d215_ex_06	Opt - NA	No Optimization to be Done		
d215_ex_07	As-found	na	89.0%	na
d215_ex_07	Opt - OAT Curve		90.4%	

Conclusions Optimization

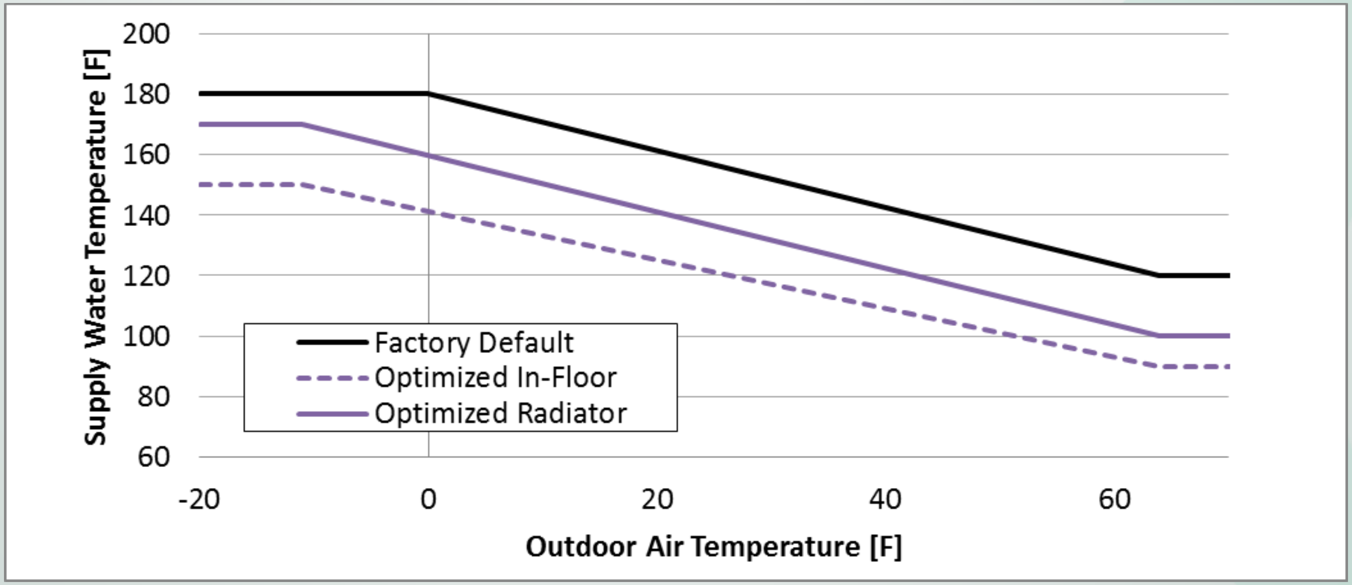
- Enabling recommended OAT reseat curve will achieve majority of savings
  - Further optimization is possible, but not typically cost effective
- Water heating has room for improving efficiency
  - However the system must be designed for low water temperatures (which appears to be uncommon)

Field Research, Phase II

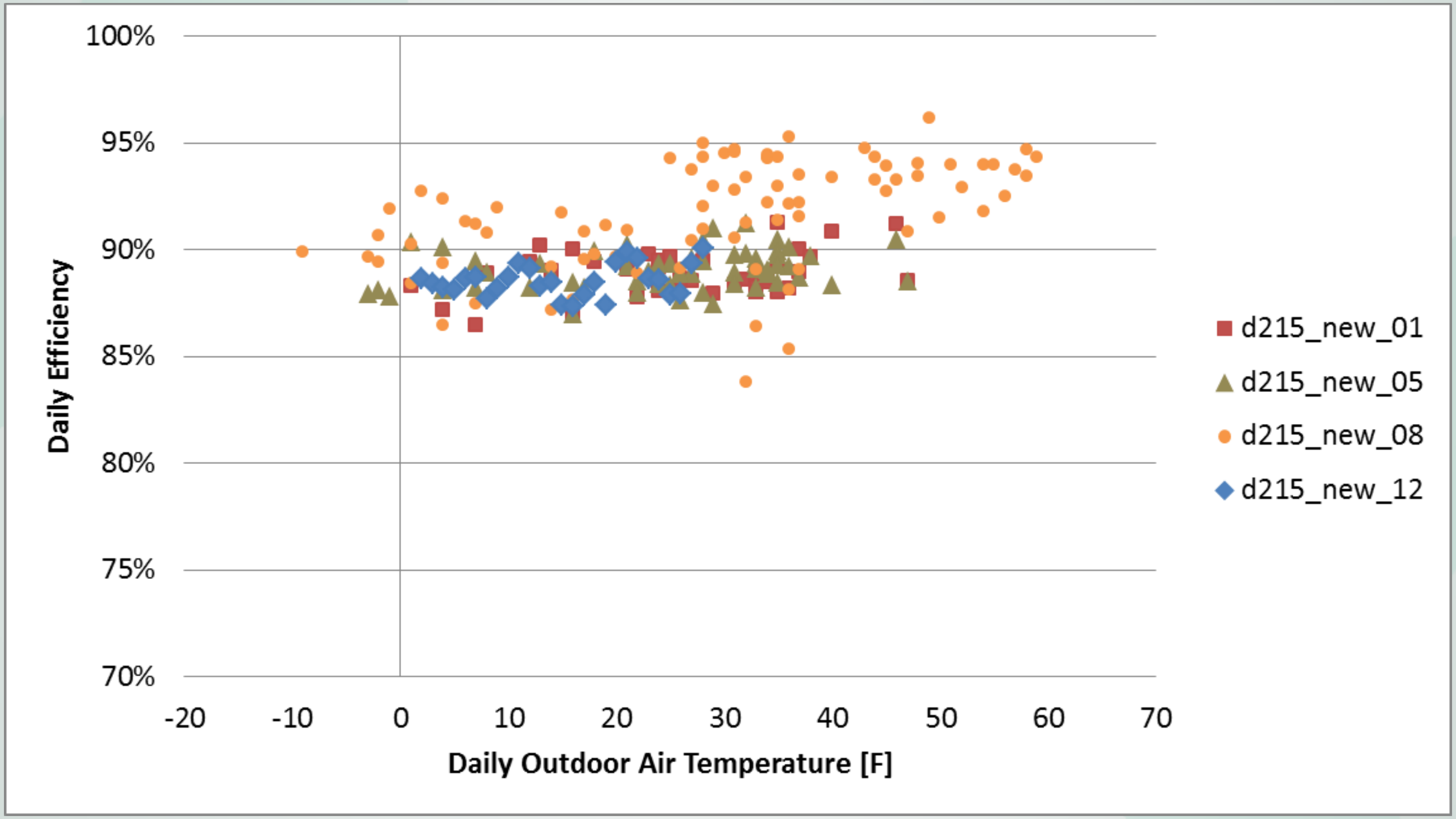
- Selected 7 homes looking to replace non-condensing boiler with condensing boiler
- Used similar solicitation and selection criteria to Phase I
- Worked with 4 contractors to install new boiler in accordance with draft QI protocol in selected sites
- Monitoring (same as existing sites)
  - Gas usage
  - Supply and return water temperature
  - Flow rates
  - Condensation rate
- Measure efficiency and compare to Phase I to estimate potential savings associated with QI protocol

Phase II Set-up Procedure leading to QI guide

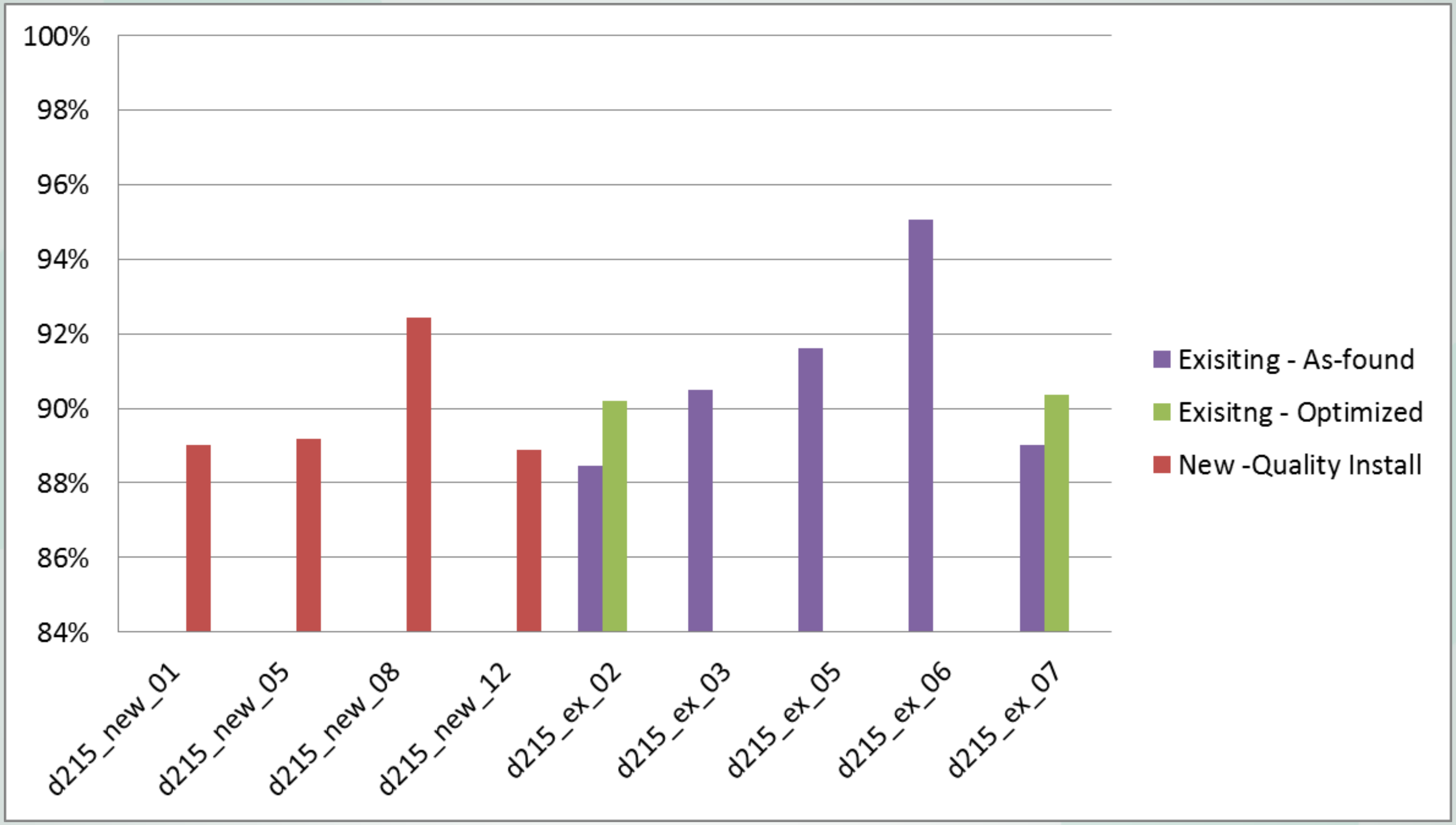
- Boiler sized according to manual J
  - Ensure minimum firing rate is as low as possible
- Ensure outdoor reset is installed and meets manufacturer specifications.
  - Ex. Not located in sunny location or in exhaust path
- Set appropriate reset curve



Comparison Chart Phase II



Comparison of Annual Space Heating Efficiency



- On average condensing boilers saved 14% annual space heating costs over 80% AFUE boilers.
- Indirect water heaters were equivalent to a 0.70 EF power vent WH

Preliminary Conclusions

- Condensing equipment meet expected savings
  - Even boilers with non-aggressive reset curves are efficient because set temp is reached before supply water temp gets to high limit
  - 1-3% savings potential based on intensive set-up procedure—emitter capacity measurement
  - Not cost effective
- DHW performance is more aligned with Power vented water heater than condensing
  - Not recommending unless cost competitive with power vent

Dissemination Plan

- Hold several webinars and live presentations about project findings
- Work with contractors involved in interviews as well as installations to adopt QI protocol and hone in on pricing
- Work with WX agencies to determine assessment protocol for condensing boiler work scope
- Work with gas utilities not currently offering rebates for mod cons to implement rebate with QI protocol required
- Publish final research report and send out with DER newsletters etc.

Future plans

- Analyze cost effectiveness
- Finalize optimized reset curve recommendations
- Communicate with utilities about Basic set-up protocol
- Get information out based on Dissemination plan
- Publish final research report and send out with DER newsletters etc.

Thank You!

Rebecca Olson

Residential Energy Program Director, Neighborhood Energy Connection

rebeccao@thenec.org

651-789-5705

Project Partners:

Ben Schoenbauer

Senior Research Engineer

Center for Energy and Environment

bschoenbauer@mncee.org

612-244-2413

Dave Bohac

Director of Research

Center for Energy and Environment

dbohac@mncee.org

612-802-1697

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