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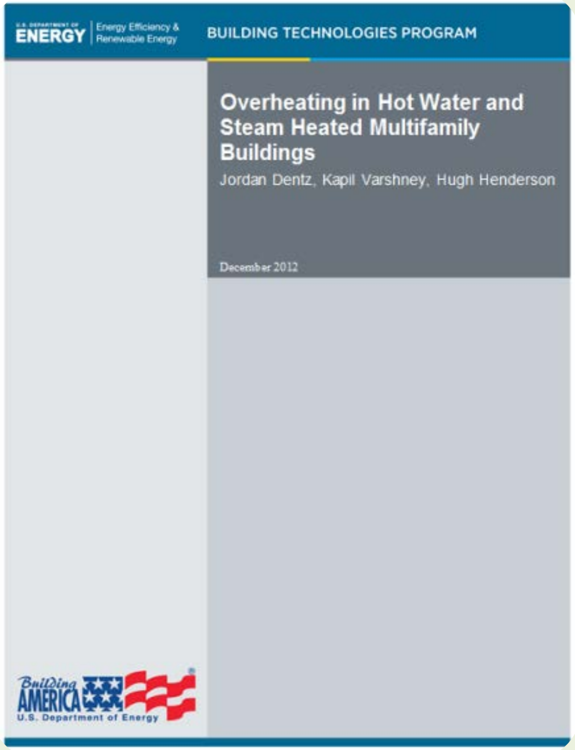
Advanced Residential Integrated Energy Solutions

Focusing on affordable housing including new and existing multifamily buildings

WHY IS THIS IMPORTANT?

- ~14 million units in the U.S. use steam or hot water heating
- Space heating the largest energy use in mixed and cold climate buildings
- Overheating study found nearly all apartments overheated most of the time: average heating season temp. 76.2°F



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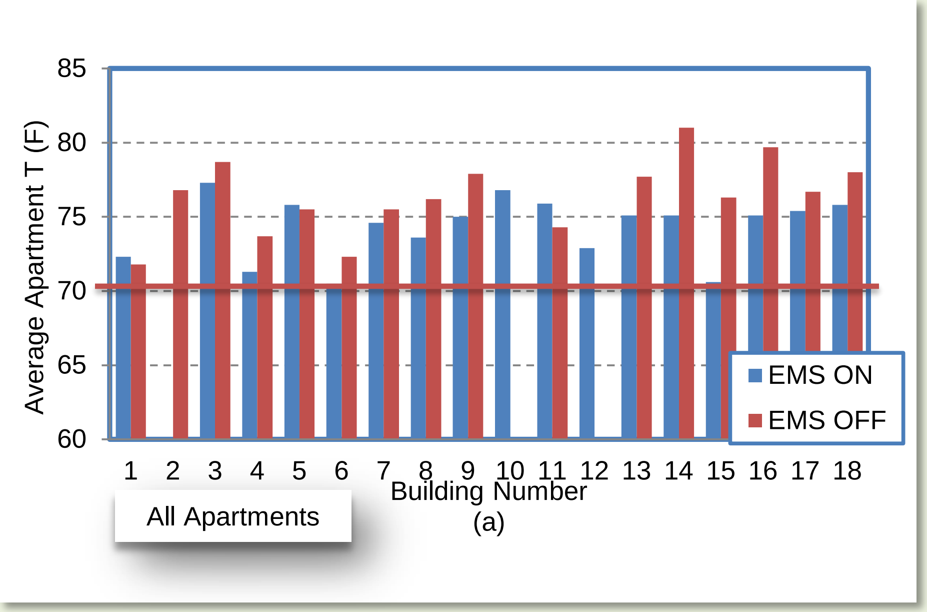
OVERHEATING IN HOT WATER AND STEAM HEATED MULTIFAMILY BUILDINGS

Long-term temperature data from ~100 apartments in 18 buildings:

- Almost all apartments overheated most of the time
- Average heating season temperature ~76.2°F
- EMS reduced but did not eliminate overheating
- Hot water and steam results similar



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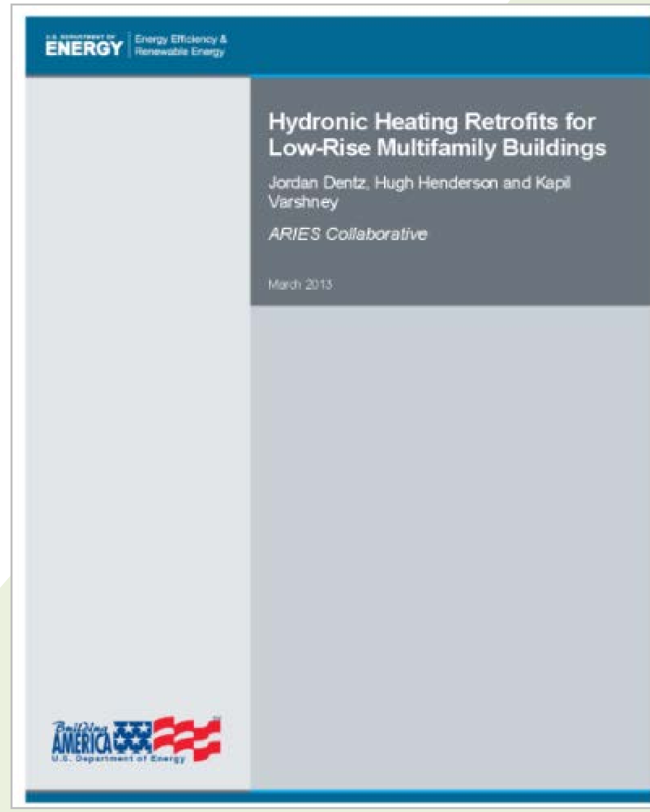
HYDRONIC HEATING CONTROL RETROFIT


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Hydronic Heating Retrofits for Low-Rise Multifamily Buildings

Jordan Dentz, Hugh Henderson and Kapil Varshney

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March 2013

Building America U.S. Department of Energy

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HYDRONIC HEATING RETROFITS FOR LOW-RISE MULTIFAMILY BUILDINGS

Goal: Quantify the effect of various multifamily boiler control strategies

Method: In three similar buildings assess the impacts of:

- Outdoor reset improvements
- Indoor cut-off
- Night-time setback

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SITE DESCRIPTION

- Three buildings in Cambridge, MA
- Hydronic heat
- 9 to 18 apartments per building
- 2 or 3 Weil-McLain boilers per building
- TRVs on convectors – many failed
- Existing outdoor reset boiler control

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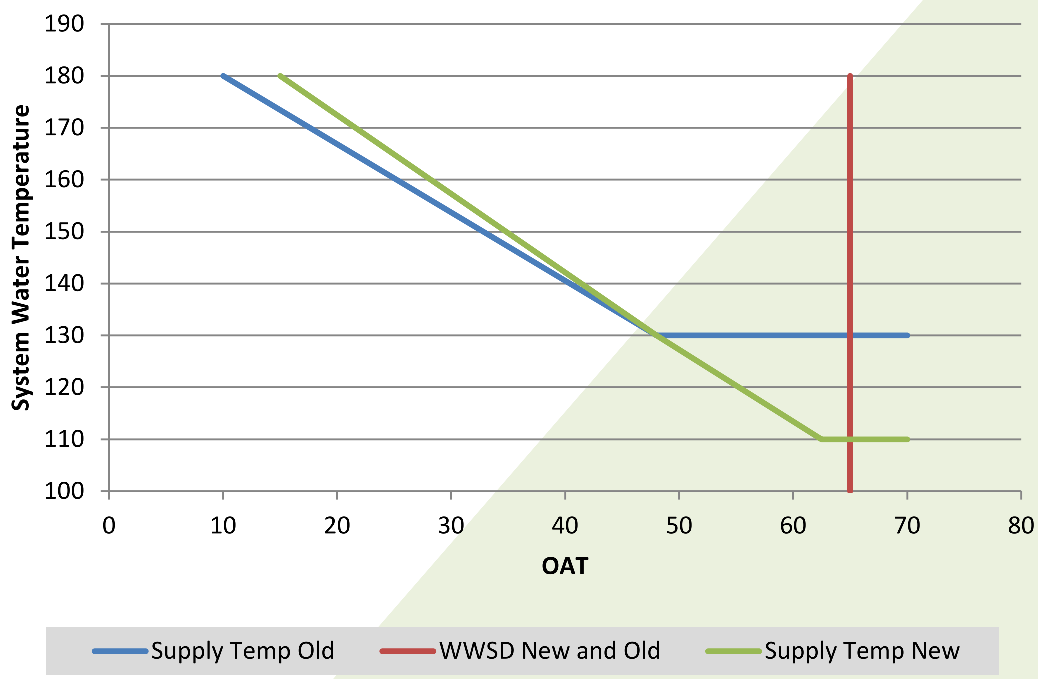
OUTDOOR RESET: BUILDING 4

Reset schedules

- **Original:** supply temperature of 180°F at 10°F outdoor temp., decreasing to 130°F at about 48°F. Minimum boiler supply temperature 130°F
- **New:** Supply temperature of 180°F at 10°F outdoors (increased to 15°F partway through the first winter). Minimum boiler supply temperature 140°F and reduced to 110°F over the course of the season.



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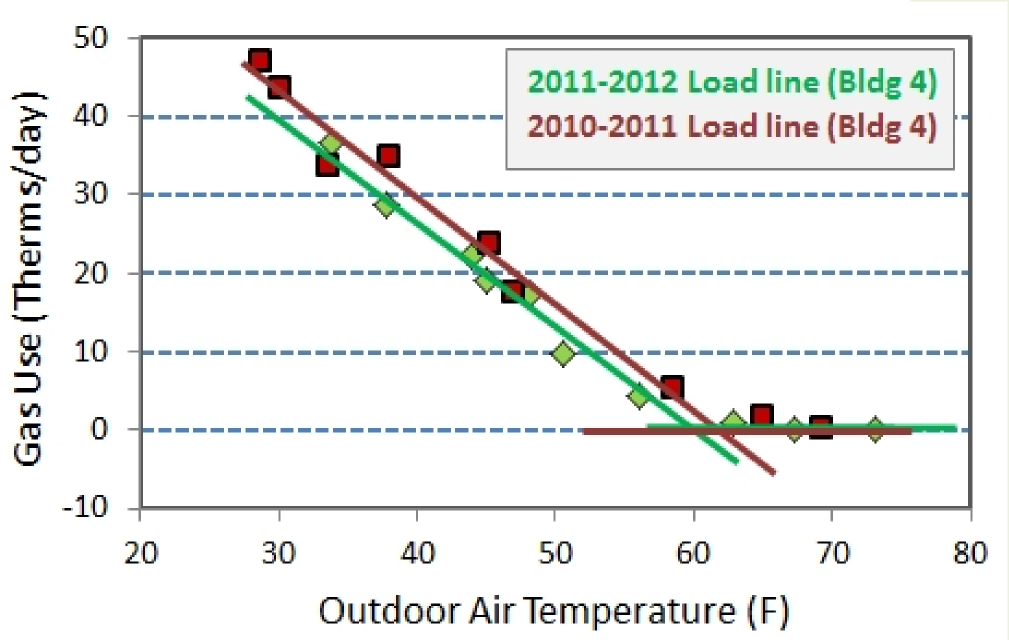
LOAD LINE

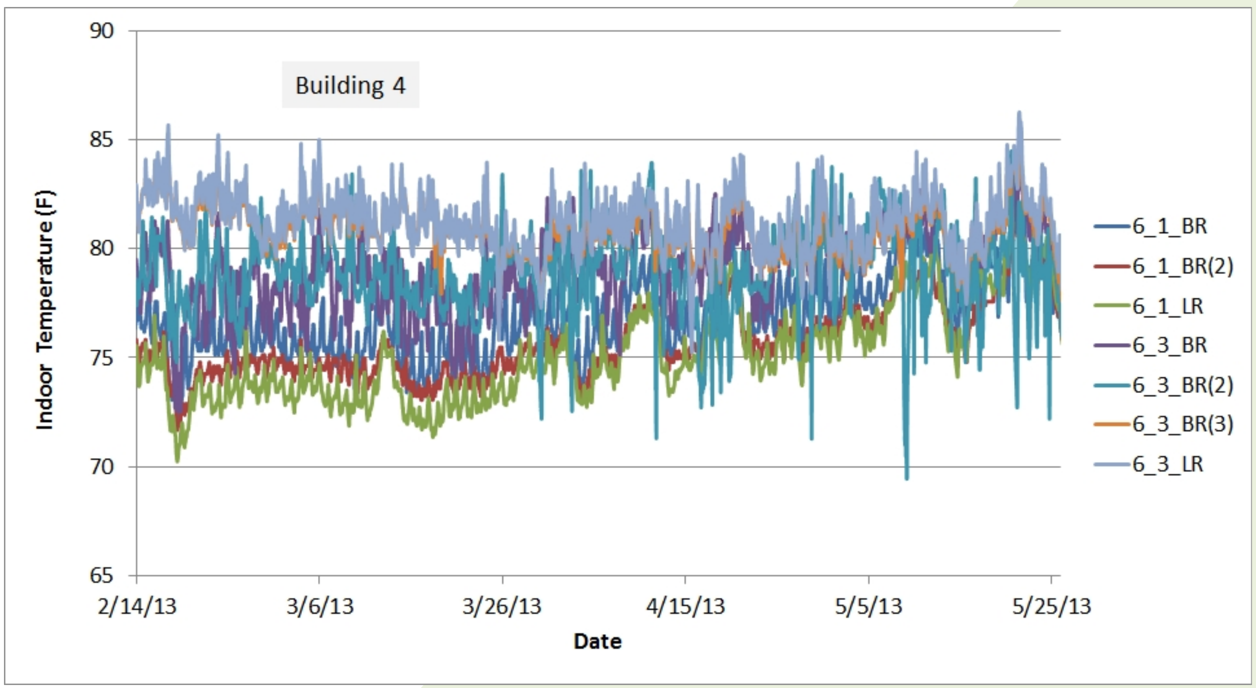
- Monthly gas bill data for the pre-retrofit season (May 2010 to May 2011) compared to the post-retrofit season (June 2011 to May 2012) weather-normalized with weather data for the 2010–2011 season.
- Dependence of space heating energy consumption on outdoor air temperature.
- Three parameter change point linear regression model.



RESULTS

- Heating energy use decreased 10%
- Indoor temperatures well above 70°F
- Opportunity for further savings by lowering the reset curve

	Heating
Pre-Retrofit (2010–2011)	6,800
Post-Retrofit (2011–13) (Normalized With 2010–2011 OAT)	6,100
Total Reduction	700
% Reduction	10.1%



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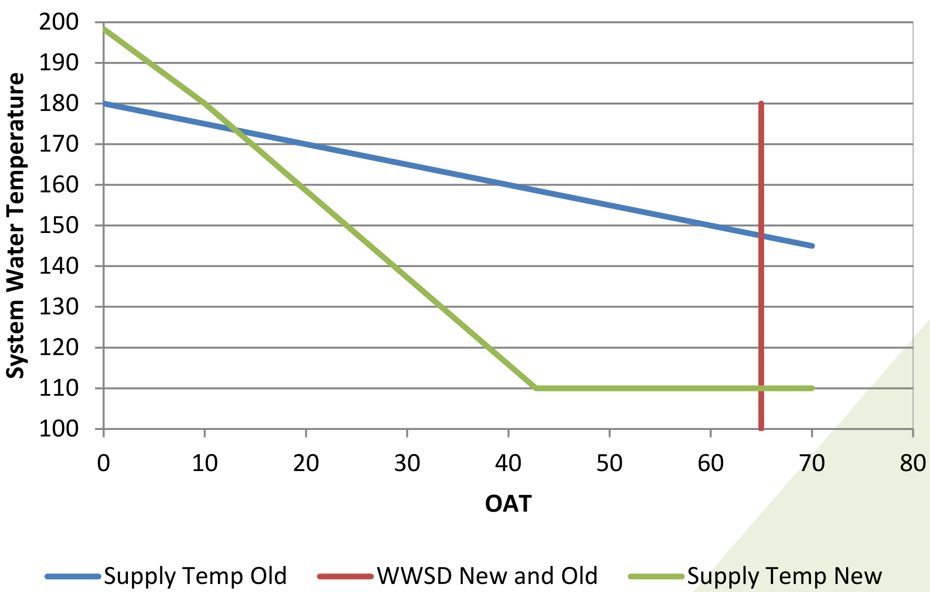
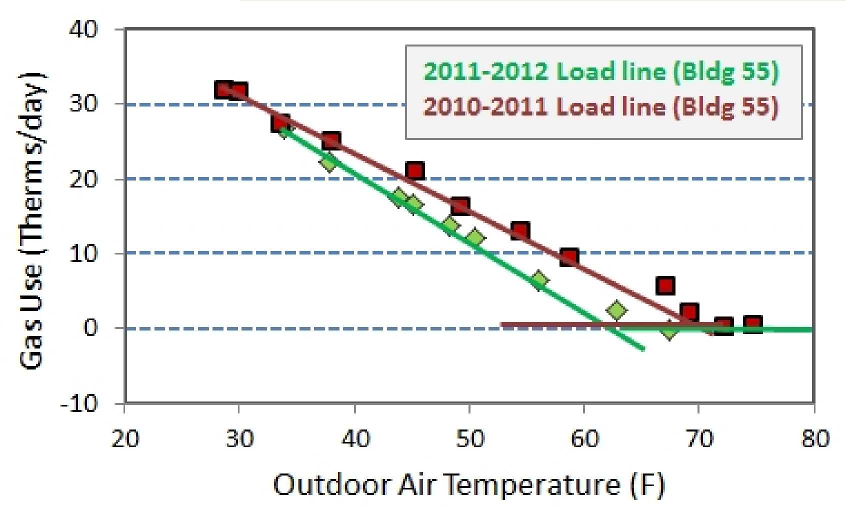
OUTDOOR RESET: BUILDING 55

Reset schedule

- **Original:** Supply temperature of 180°F at 0°F outdoor temperature, decreasing to 145°F at 70°F
- **New:** 180°F at 10°F outdoor temperature, decreasing to 70°F at 70°F outdoors with a minimum boiler supply temperature of 110°F. 5°F night-time setback
- **Results:** 15.5% heating energy savings





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INDOOR CUT-OFF: BUILDING 3

- Three single-stage boilers
- One temperature sensor in each apartment
- Wireless network
- Provide average space temperature to controller
- Controller cuts off boiler when average indoor space temperature exceeds threshold (indoor temperature cut-off)
- When average indoor temperature is below the threshold, outdoor reset control is active

Floor						
3	Apt. 9_5 69	Apt. 9_6 82.5	Apt. 5_5 71.5	Apt. 5_6 76	Apt. 3_5 75.5	Apt. 3_6 73.5
2	Apt. 9_3 83.5	Apt. 9_4 75.5	Apt. 5_3 75.5	Apt. 5_4 76.5	Apt. 3_3 70	Apt. 3_4 76
1	Apt. 9_1 62.5	Apt. 9_2 67.5	Apt. 5_1	Apt. 5_2 69	Apt. 3_1 68	Apt. 3_2 74

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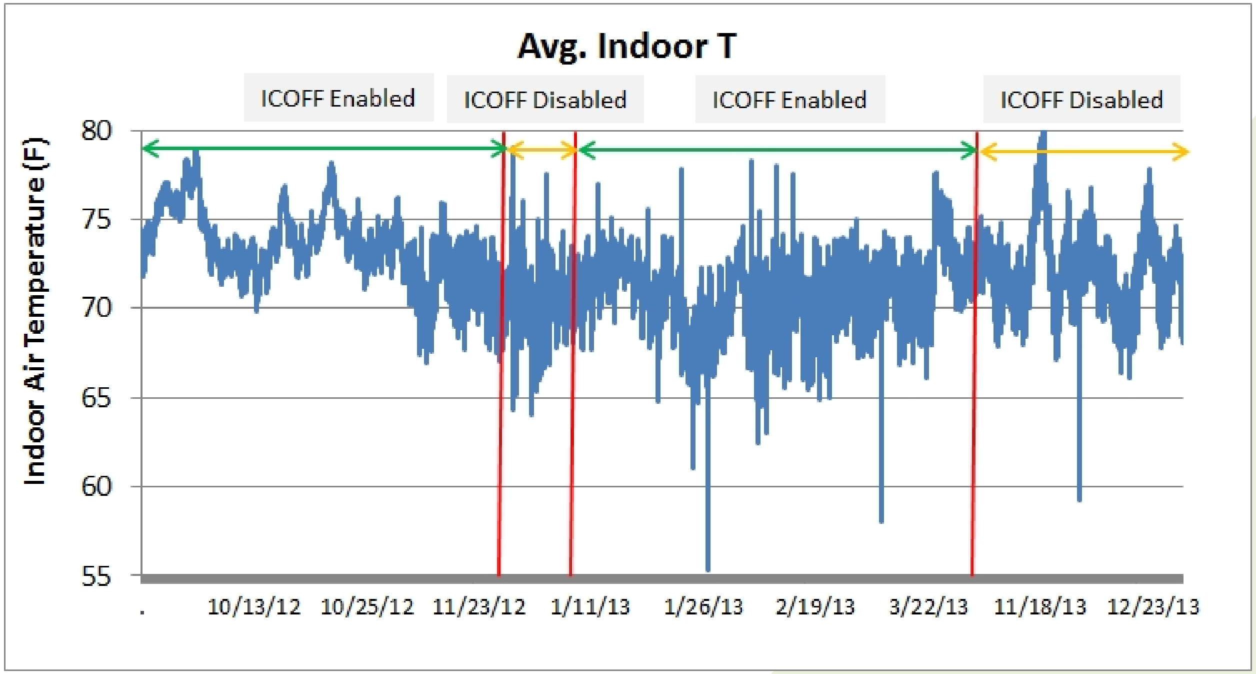
ON / OFF SCHEDULE

- Enabled Oct-Nov 2012 and Jan-Apr 2013
- Disabled Nov 2012-Jan 2013 and Oct 2013-Dec 2013



Indoor Cutoff Status	Day (5am-10pm)	Night (10pm-5am)
ON	71.6°F	71.4°F
OFF	72.1°F	71.9°F

Average indoor temperature

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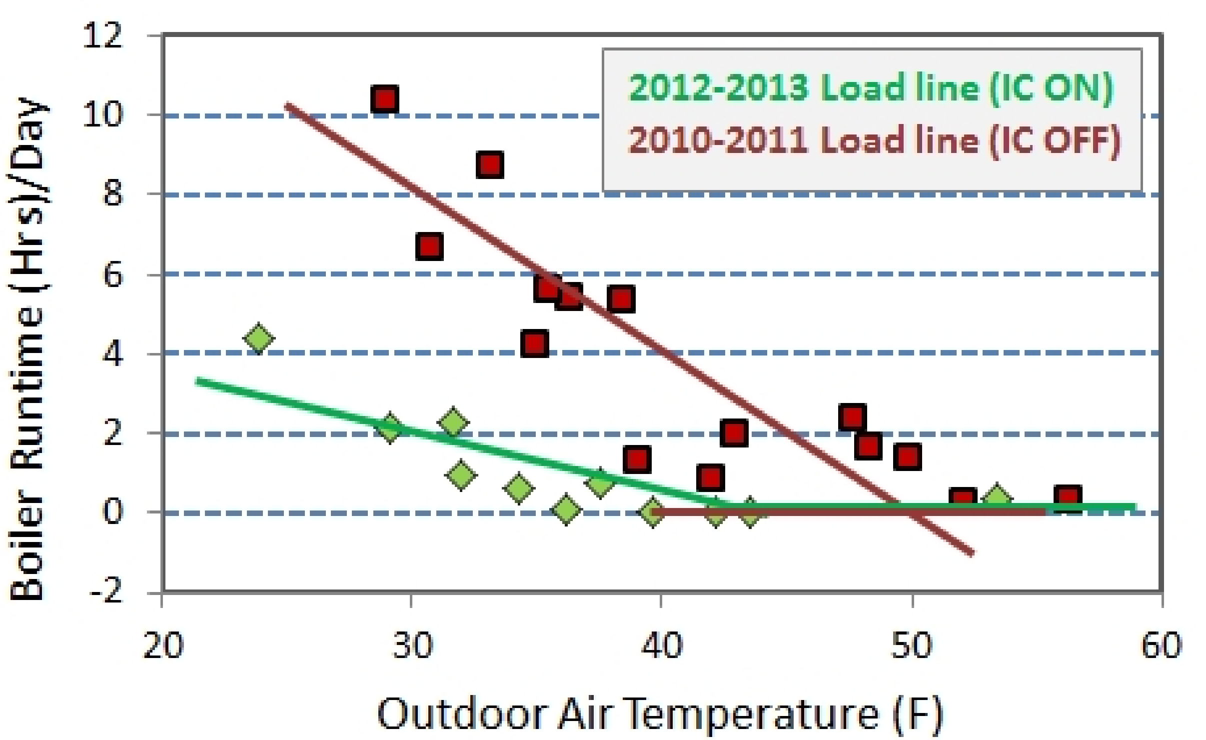
LOAD LINE

Dependence of boiler runtime on outdoor air temperature at night only:

Diamonds and green line = Indoor Cut-off activated
Squares and red line = Indoor Cut-off deactivated
Each point is daily data for approximately 1 week period



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EFFECT OF INDOOR CUT-OFF ON BOILER RUN TIME

Time	% Change in Boiler Runtime Compared to when Indoor Cut-off was Disabled	Hours ICOFF was in Effect as a % of Hours when Indoor Cut-off was Enabled	Indoor Cut-off Temp. Threshold
Day	-1%	7%	73°F
Night	-71%	65%	68°F
Total	-28%	26%	

During the day the outdoor reset schedule was nearly as good as indoor cut-off at preventing overheating.

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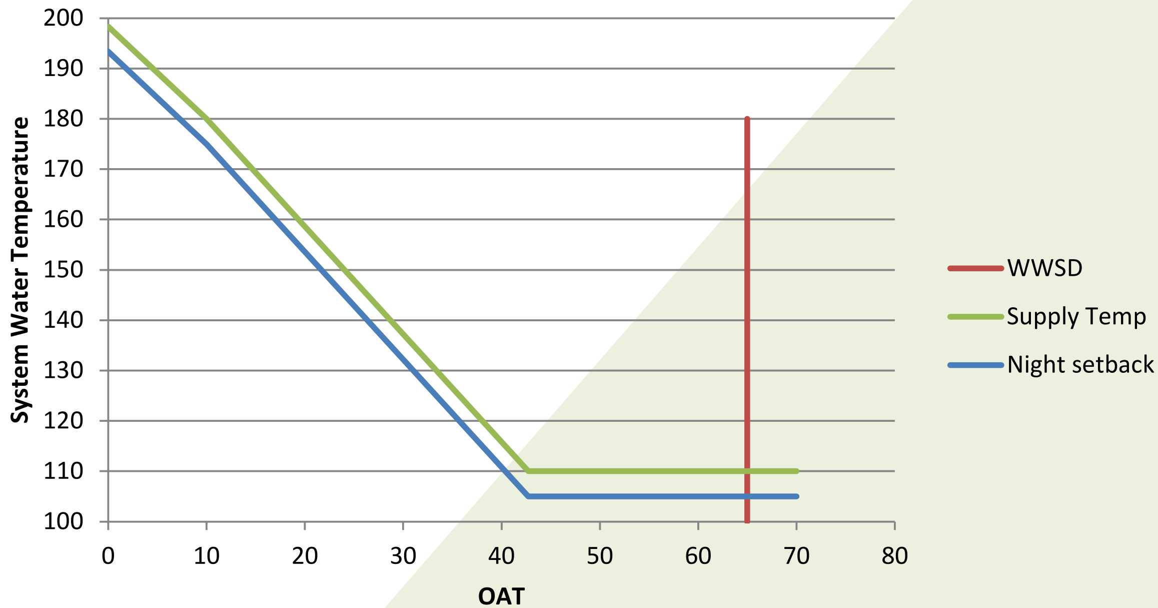
NIGHT-TIME SETBACK: BUILDING 55

Reset schedule

- 180°F at 10°F outdoor temperature, decreasing to 70°F at 70°F outdoors with a minimum boiler supply temperature of 110°F.
- 5°F night-time setback



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EXAMINED BOILER RUNTIME WITH AND WITHOUT NIGHTTIME SETBACK

Time Period	Nighttime Setback	Duration
Sep 27, 2011 - Feb 1, 2012	No	4 months
Feb 2-May 24, 2012	Yes	4 months
May 25 – Oct 18 2012	No heating	
Oct 18, 2012 – May 28, 2013	Yes	7.5 months
May 28 – Oct 1, 2013	No heating	
Oct 1 – Nov 18, 2013	Yes	1.5 months
Nov 19 – Dec 31, 2013	No	1.5 months

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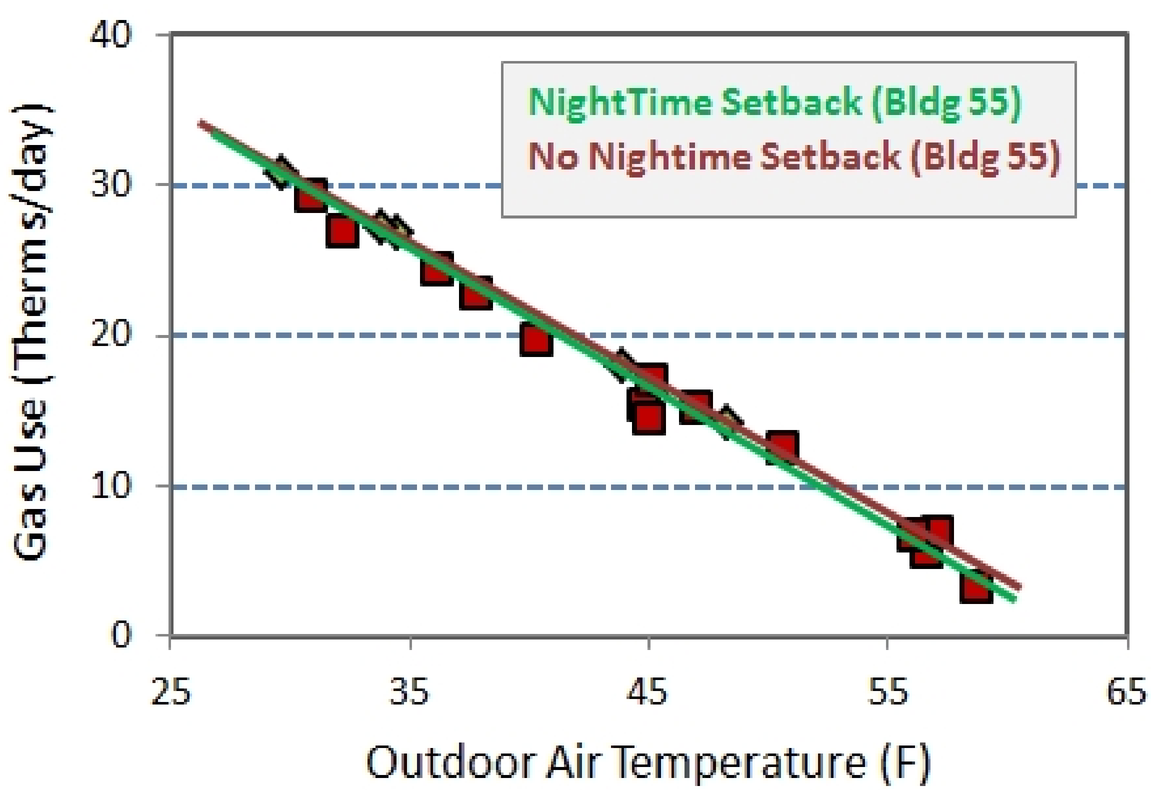
LOAD LINE

Gas use shows no impact of nighttime setback of supply water temperature



Gas use—comparing days with (green) and without (red) setback

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HYDRONIC HEATING RETROFITS FOR LOW-RISE MULTIFAMILY BUILDINGS

Takeaways

- Refining outdoor reset curves yields substantial savings
- Indoor-cutoff can be effective
- Night-time setback ineffective

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Thermostatic Radiator Valve Evaluation

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THIS PRESENTATION WILL…

- Review past research on TRV effectiveness
- Present the results of a field test to evaluate the effectiveness of TRVs on a steam-heated building with convectors
- Present the impact on heating energy use of a multifamily building that underwent a TRV retrofit

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BACKGROUND

- In many multifamily buildings, hydronic or steam boilers provide space heating via radiators
- Imperfect distribution requires overheating of some apartments to maintain adequate heat in others
- TRVs offer one solution by automatically restricting the flow of heat into radiators when room temperature reaches a target
- Independent studies demonstrating the effectiveness of TRVs lacking

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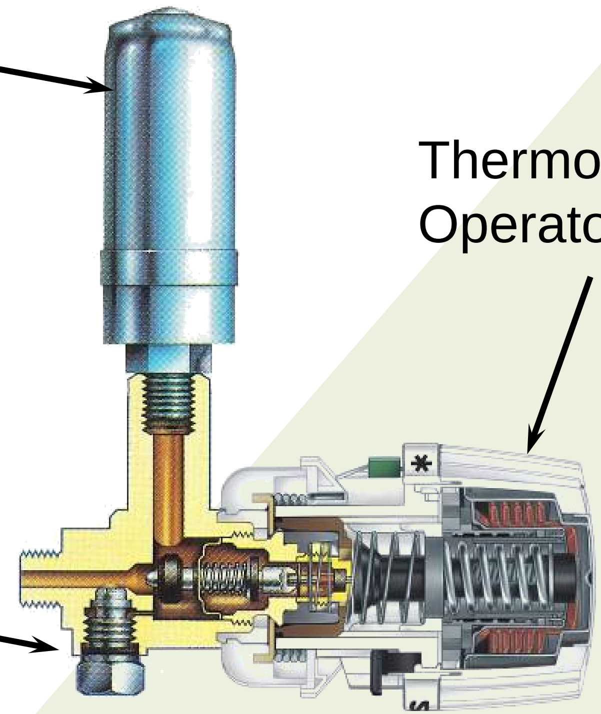
WHAT IS A TRV?

Typical 1-Pipe Steam Thermostatic Radiator Valve Assembly



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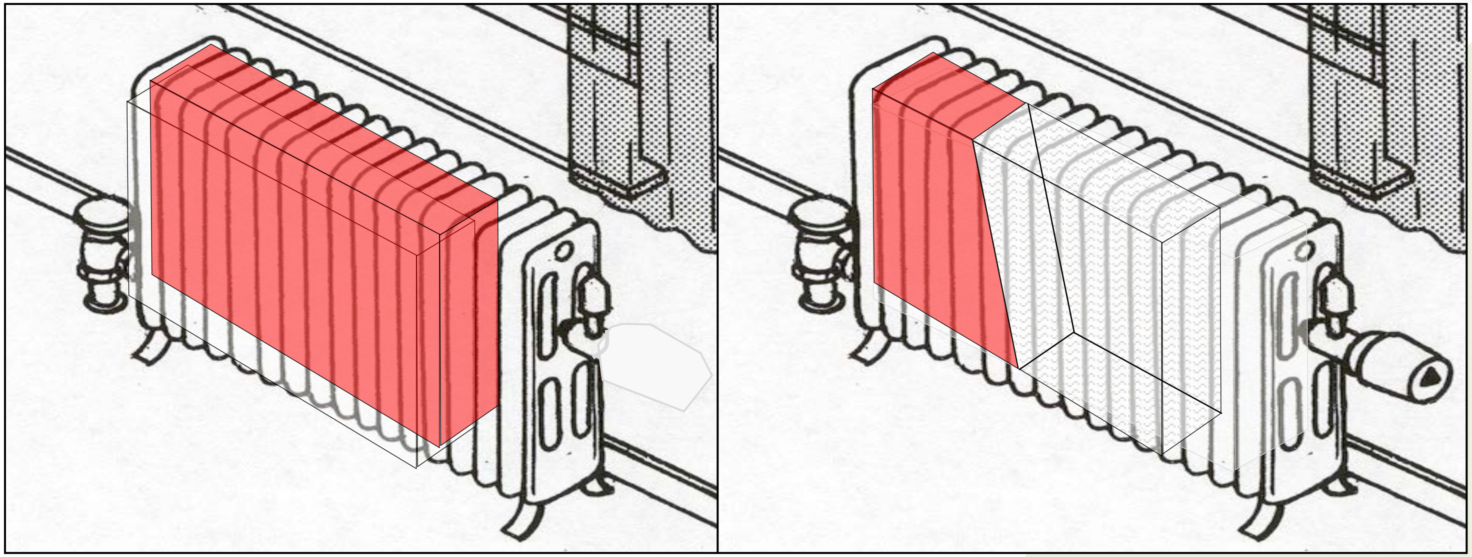
HOW DO TRVS WORK?



Air Vent Only

1. Steam enters the radiator and forces air out through the vent
2. Steam reaches air vent; vent closes
3. Radiator, filled with steam, radiates heat into room
4. Overheating can occur

With TRV

1. Steam enters the radiator and forces air out through the vent
2. When room reaches target temperature, TRV closes, preventing air from escaping and more steam from entering

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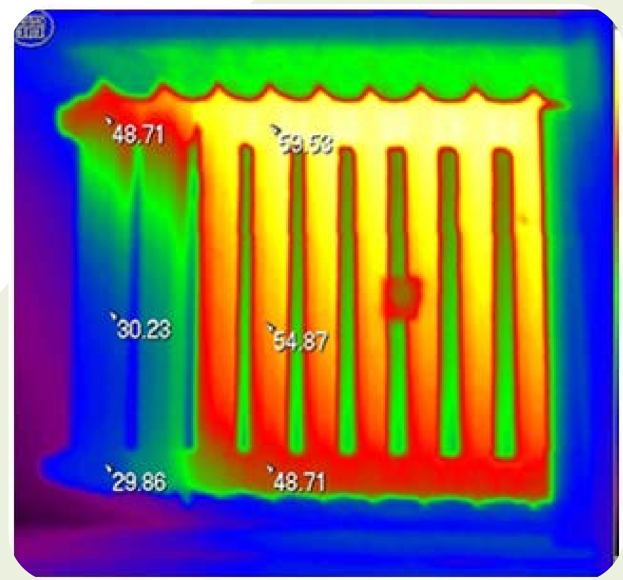
TRV LITERATURE

- No study found to confirm or dispute age degradation
- Four published field evaluations of TRVs:
    - Two on 1-pipe steam radiators
    - Two modeling and lab/field evaluations without comprehensive field test results



TRV LITERATURE

Study	Type	Application	Type of system	Finding
McNamara, 1995	Experimental	Eliminating overheating in multifamily buildings	1-pipe steam	TRVs saved ~15% heating energy. Payback less than five years.
Xu, Fu, & Di, 2008	Modeling	Heating energy savings	Hydronic heating	If the set value of the TRVs were kept on 2-3, about 12.4% reduction of heat consumption could be expected. Additionally, when an apartment stopped using the heating system during a heating season, the heat consumption of its neighboring apartments would increase by about 6-14%.
Weker & Mineur, 1980	Theoretical and experimental	Optimize the design of a TRV	Hydronic heating	Presented performance index for TRVs.
Tahersima et. al (2011) and Tahersima et al. (2010)	Modeling	Stabilize oscillatory behavior of TRVs under low heat demands.	Hydronic heating	A controller of TRVs is presented which keeps it stable over the range of operating conditions.
Peterson, 1985	Experimental	Reducing overheating	1-pipe steam	Rebalancing a steam system can save as much as 15 to 25% heating fuel. It was also shown that TRVs can be used to reduce overheating in a zone.
Trüschel, 2002	Modeling and field work	Reducing overheating	Hydronic heating	TRVs are most effective in low-flow systems due to the radiators' sensitivity to flow changes.

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THE MARKET

- Range of opinions:
  - Steam cycles cause TRV seals to fail early
  - Apartment-level control provides increased comfort mainly due to psychological factors; there isn't much change in space temperature
  - Range-limited TRVs may be effective

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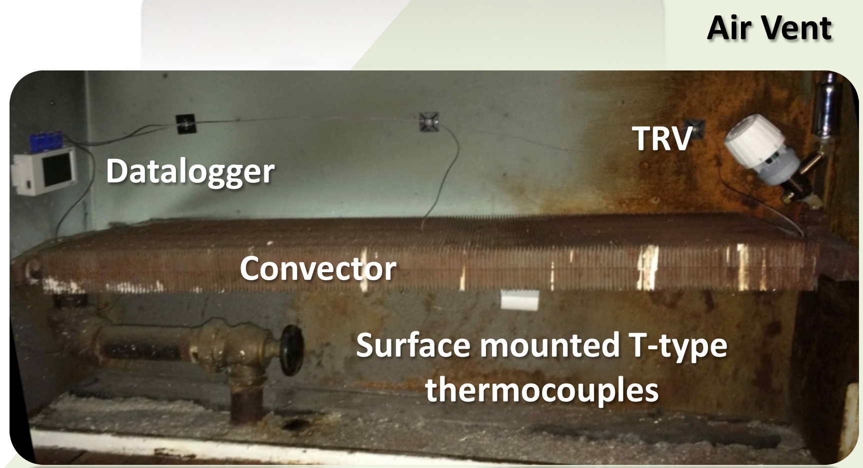
THE EXPERIMENT

- ARIES installed TRVs in two apartments
- One with new TRVs and one with old TRVs
- Sensors measured space and radiator temperature in all rooms before and after TRVs installed



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THE EXPERIMENT

- Similar apartment layouts (2-bedroom, north exposure, first floor same building)
    - 1A: elderly couple – new TRVs
    - 1F: 4-person family – old TRVs
- One-pipe steam convectors, outdoor reset boiler control
- TRVs were installed building-wide before the start of the heating season
- Apt 1F & 1A sensors installed 10-8-2014
- Test TRVs installed on 1-13-2014

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ONE-PIPE TRV CONSIDERATIONS

Radiator fill time

- Internal volume (cast iron vs. convector)
- Air vent sizes
- Steam Pressure

TRV reaction

- Sensor fill (gas responds in less than a second; wax or liquid take 2-4x longer)
- Room size/convection current establishment
- Placement
- Setpoint

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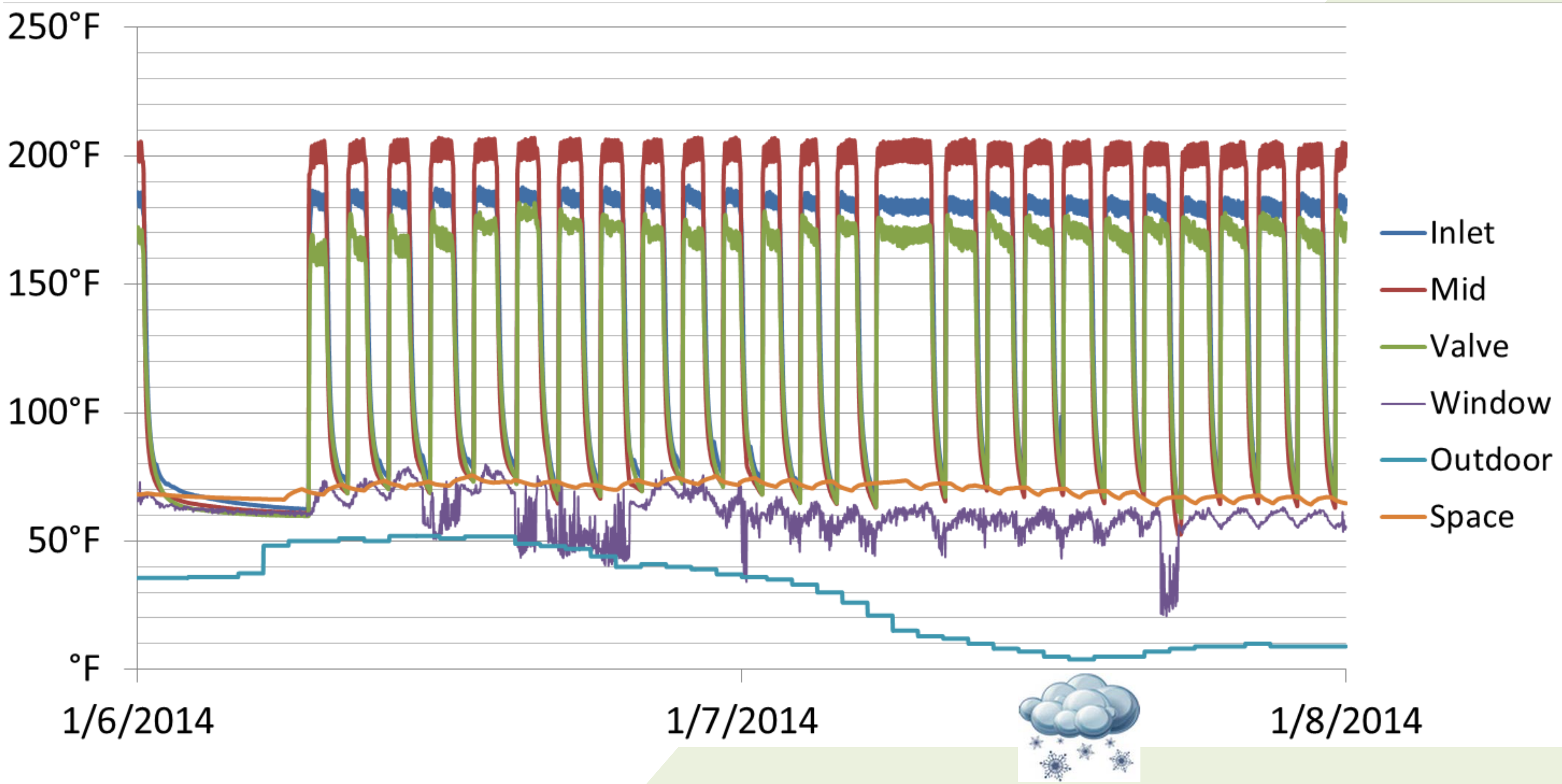
DATA COLLECTED

Master Bedroom, Apartment 1F: January 6th – 8th



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RESULTS

Pre- and Post-Installation Average Space Temperatures

Apartment 1A New TRVs		
Room	**Pre**	**Post**
Kitchen	79	77
Small Bedroom	73	70
Living Room	76	76
Master Bedroom	77	74
Average	**76**	**74**

Apartment 1F Old TRVs		
Room	**Pre**	**Post**
Kitchen	75	77
Small Bedroom	71	71
Living Room	75	75
Master Bedroom	71	71
Average	**73**	**74**

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RESULTS

Apartment 1A				
Room	Mild Weather Space Temperature	Mild Standard Deviation	Severe Weather Space Temperature	Severe Standard Deviation
Kitchen	76	2.9	76	2.9
Small Bedroom	71	2.9	67	2.7
Living Room	76	2.2	73	2.3
Master Bedroom	75	2.3	73	2.4
Average	**75**	**2.6**	**72**	**2.6**

Apartment 1F				
Room	Mild Weather Space Temperature	Mild Standard Deviation	Severe Weather Space Temperature	Severe Standard Deviation
Kitchen	76	4.6	73	4.7
Small Bedroom	71	3.2	68	3.5
Living Room	75	2.5	72	2.6
Master Bedroom	72	3.8	70	3.7
Average	**74**	**3.5**	**71**	**3.6**

- Both apartments experience a several-degree drop in space temperature on cold days
- Greater variability in space temperature not between mild and severe outdoor cold, but between apartments

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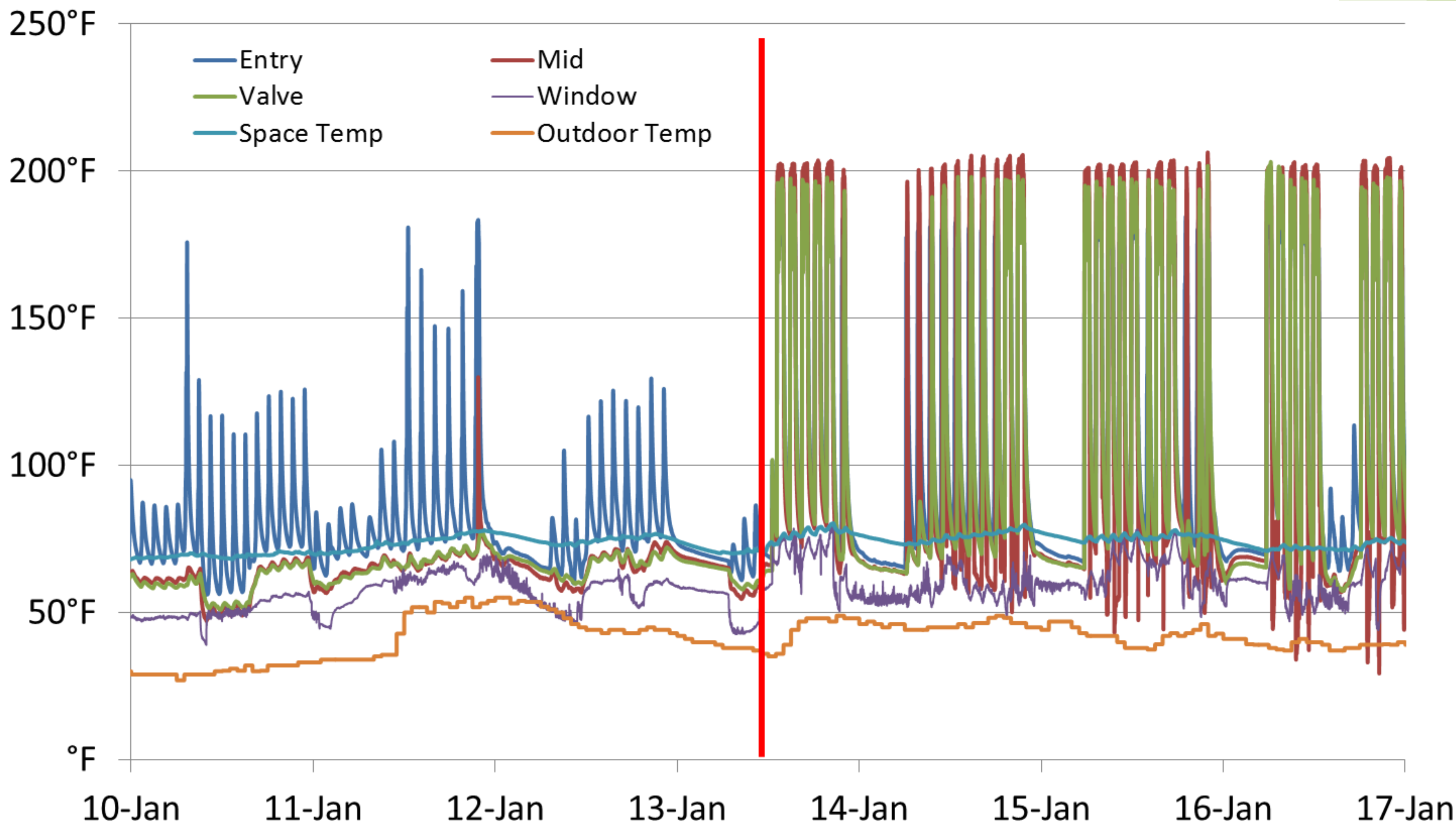
RESULTS



Apartment 1F Living Room

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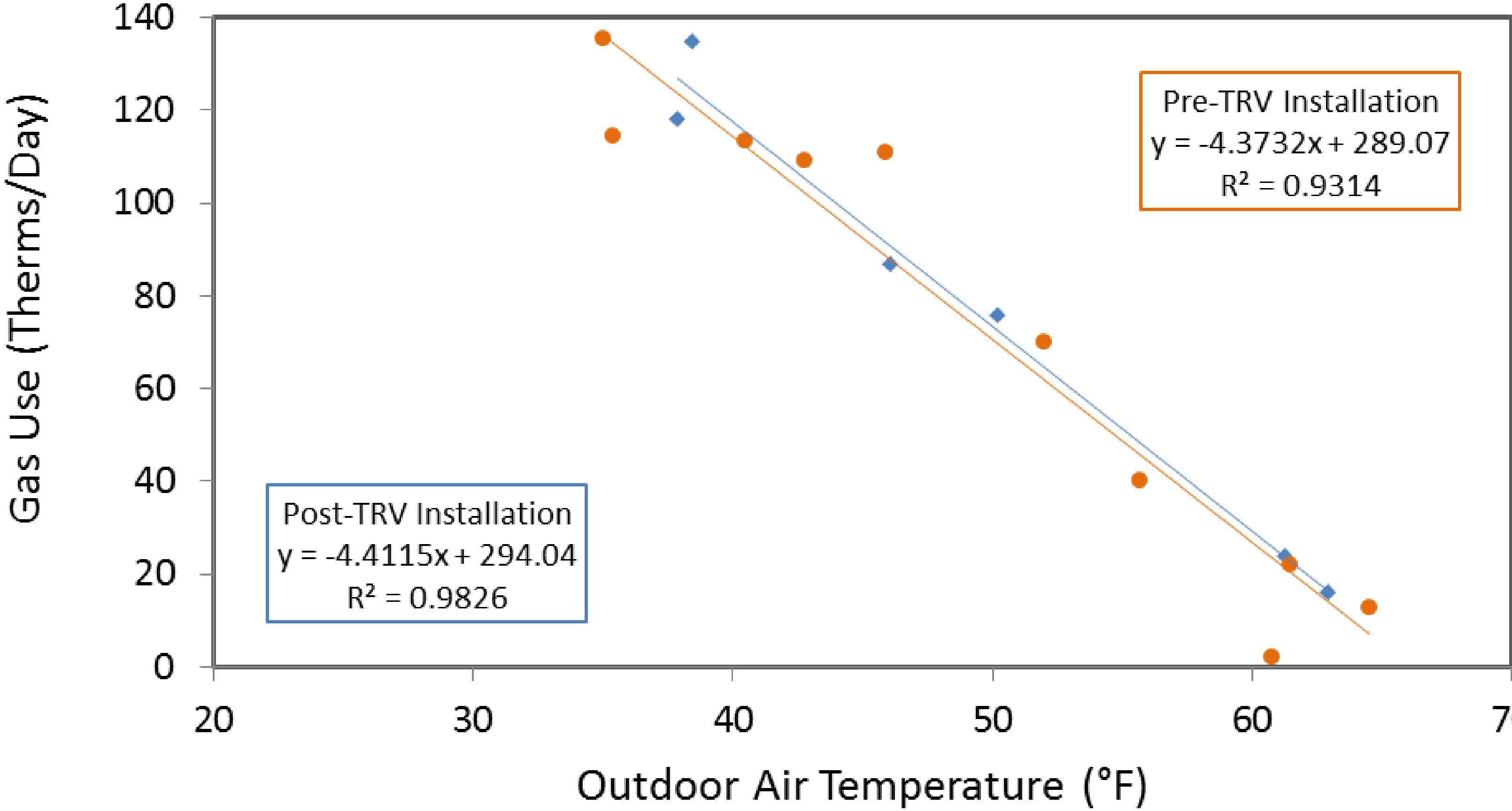
UTILITY BILL ANALYSIS



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TRV EXPERIMENT CONCLUSIONS

- Building-wide data does not indicate fuel savings
- Apartment space temperature data is ambiguous
- Possible reasons for this include:
  - Distribution venting may need balancing – underheating may be as much of an issue as overheating for this property
  - Boiler outdoor reset curve was not adjusted
  - Tenants still open windows often

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Building America Expert Meeting Fall 2014

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