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Energy-Efficient Controls for Multifamily Domestic Hot Water

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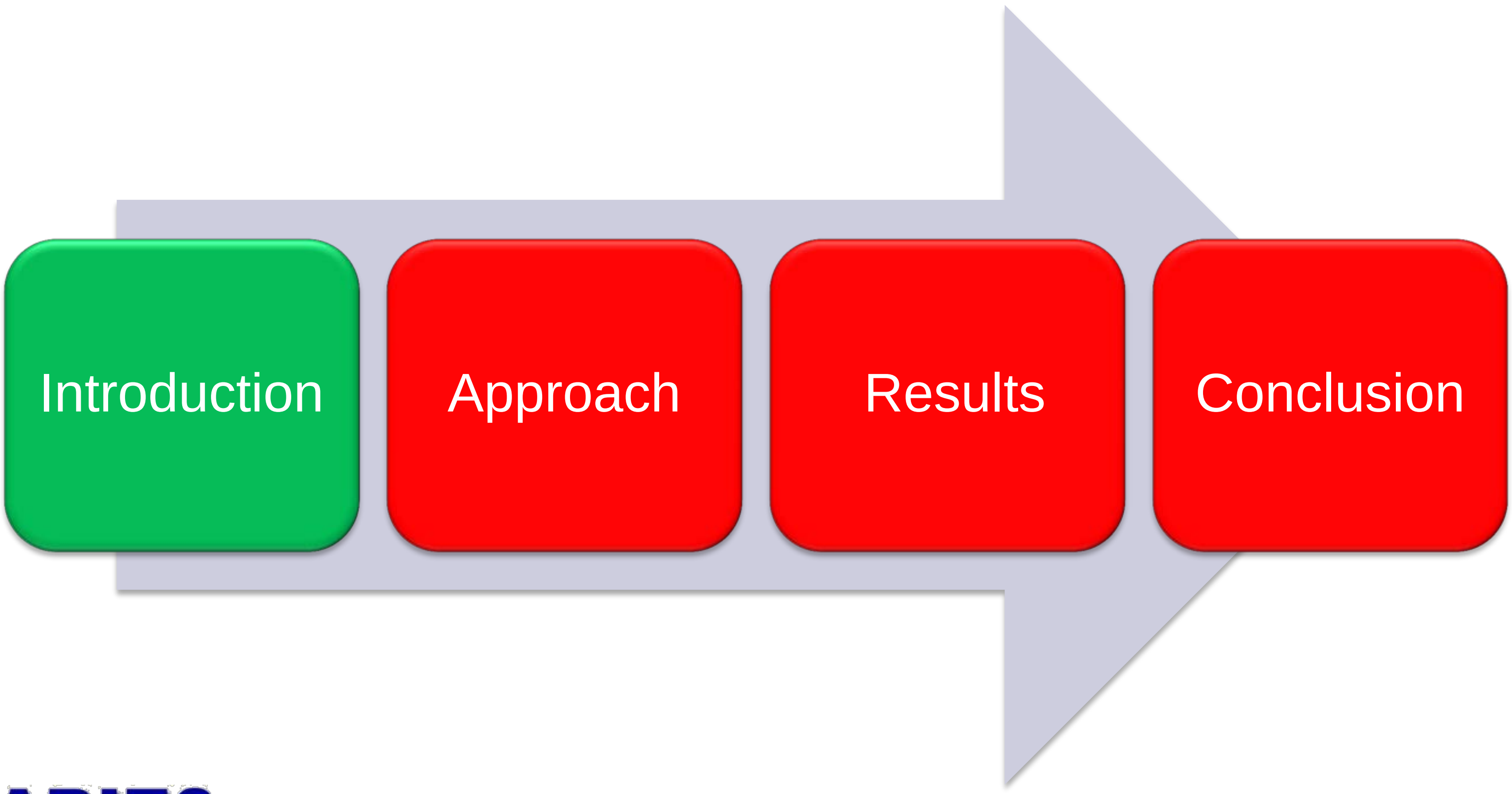
ARIES Collaborative

Advanced Residential Integrated Energy Solutions

Research Sponsors

- The ARIES Collaborative is a Department of Energy, Building America research team led by The Levy Partnership.
- ARIES focuses on reducing energy use in new and existing residential buildings
- Research conducted by: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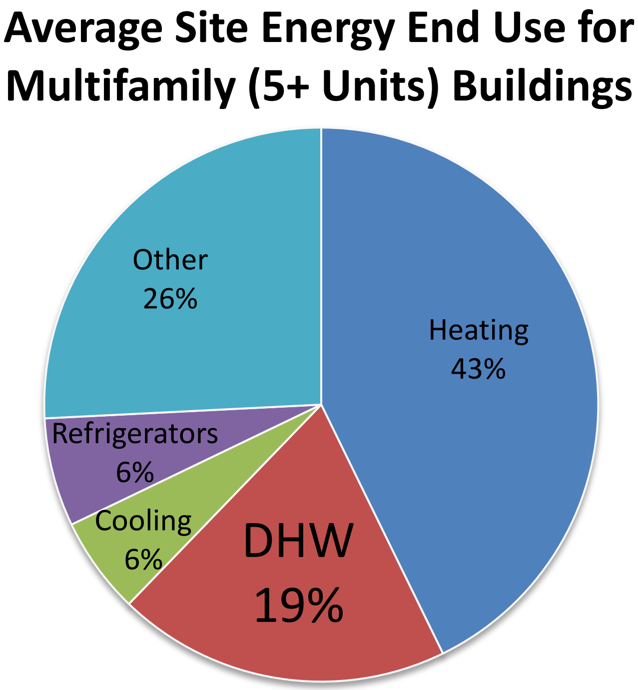
Energy Consumption

Domestic water heating is one of the largest multifamily energy uses



Source: U.S. Energy Information Administration, 2009 Residential Energy Consumption Survey

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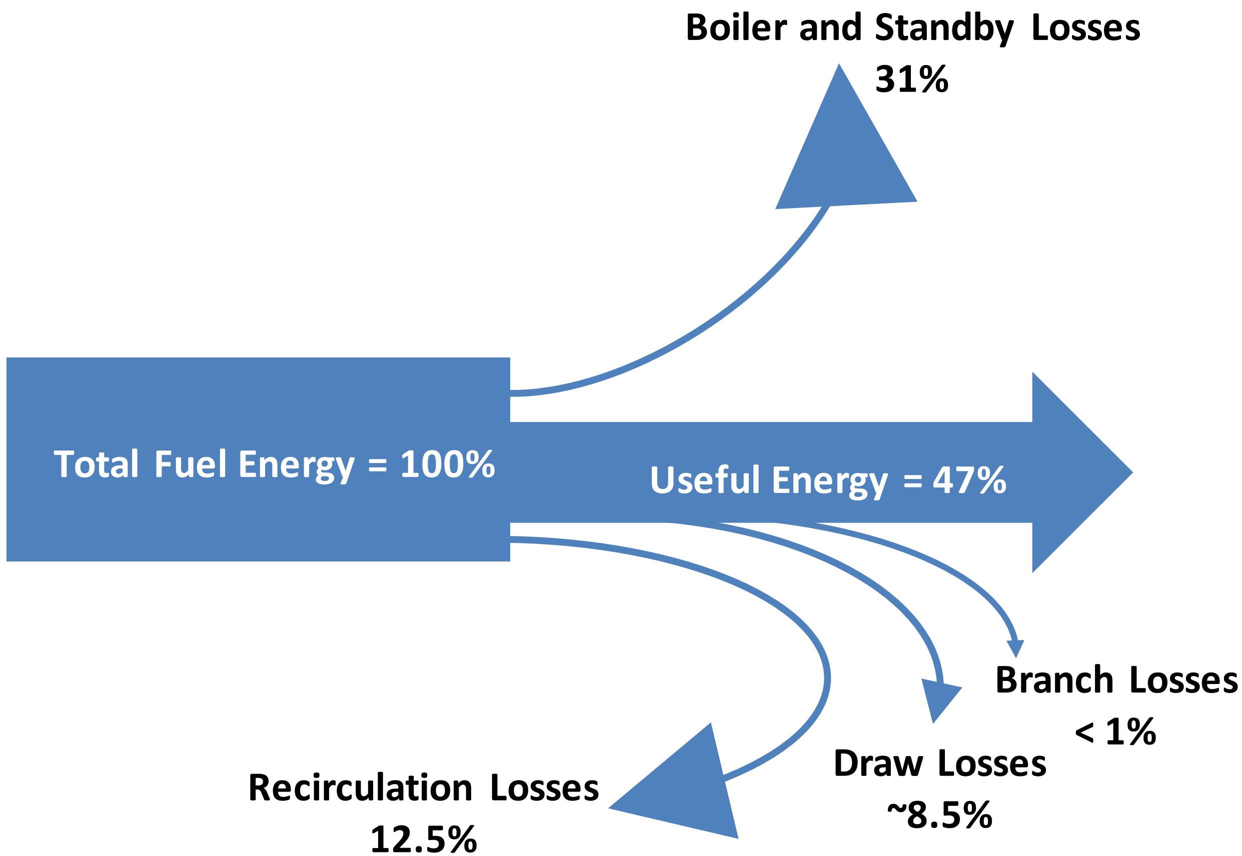
Typical DHW Energy Distribution with Continuous Recirculation



Values based on site A

DHW Recirculation Systems

- Common in commercial and multifamily buildings
- Pump continually moves hot water in piping loop(s) to minimize wait time at the tap
- The pipe loop(s) radiate heat continuously, even during periods when there is no demand for hot water

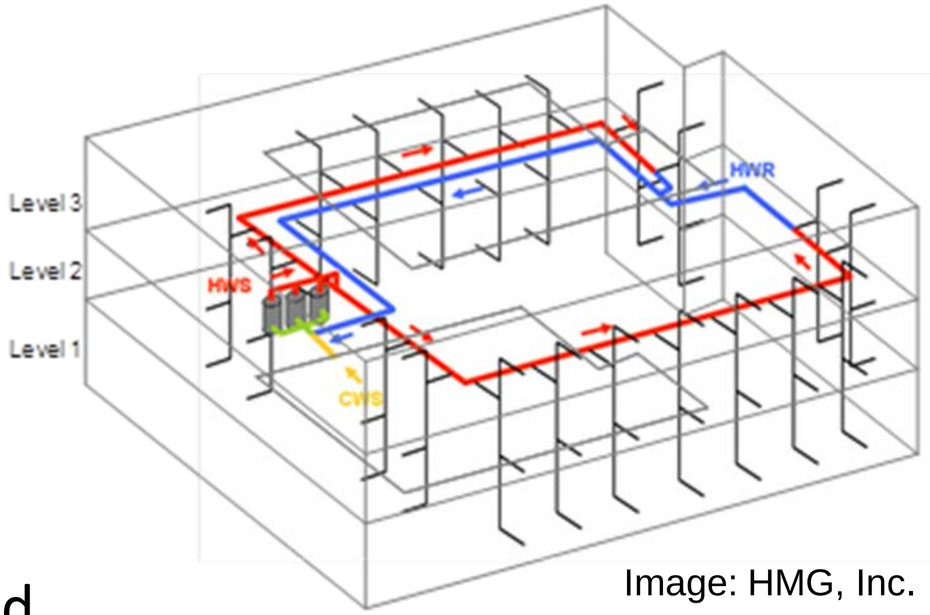


Image: HMG, Inc.

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DHW Control Strategies

- Timer Control
- Temperature Control
- Temperature Modulation (TM) Control
- Demand Recirculation Control
- Combination: Demand + TM Control

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Timer Control

- Turns pump on and off according to a daily schedule
- Off periods should approximate the peak DHW usage periods
- When a user demands hot water during an "off" period, they may waste water if they have to wait for the temperature to increase

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Temperature Control

- Return line aquastat turns pump on and off based on return temperature (usually 120˚F)
- Less pump electricity, but keeps the distribution loop hot to maintain 120˚F even when there is no demand
- Often turned up past the supply temperature by building staff (effectively bypassing the control)

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Temperature Modulation Control

- Modulates DHW supply temperature according to a daily schedule
- Lowers supply water temperature during periods of low demand – late night and mid-day in residential buildings

- Energy savings can be achieved via lower distribution losses, but pump runs continuously

Demand Control

- Uses two pieces of information
  1. Real-time user demand (detects flow)
  2. Return water temperature (pump cuts in below 100˚F)
- The pump only runs if both conditions above are satisfied or the pump has not run for five hours
- Saves DHW fuel and pump electric

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Previous Research

Report	Location	Building Characteristics	Control Type	Annual Savings
Benningfield (2009)	California	35 sites, 1,540 units	Demand	35 therms/unit
Enovative (2008)	Los Angeles, CA	5 story, 50 units	Demand	30%
Enovative (2009)	Los Angeles, CA	5 story, 189 units	Demand	12%
Enovative (2010a)	Escondido, CA	2 story, 8 units	Demand	18%
Enovative (2010b)	Irvine, CA	3 story, 21 units	Demand	16%
Enovative (2011)	Malibu, CA	30 units	Demand	15%
Goldner (1999)	New York City	6 sites, 5-6 stories, 25-103 units	Timer (nighttime off)	6%
			Timer (peak hours off)	6%
			Return temperature	11%
HMG (2008)	Saint Helena, CA	2 story, 8 units	Demand	44%
			Temperature modulation	35%
			Timer (late evening off)	1%
	Oakland, CA	3 story, 121 units	Demand	5%
			Return temperature	-5%
			Timer (late evening off)	-1%

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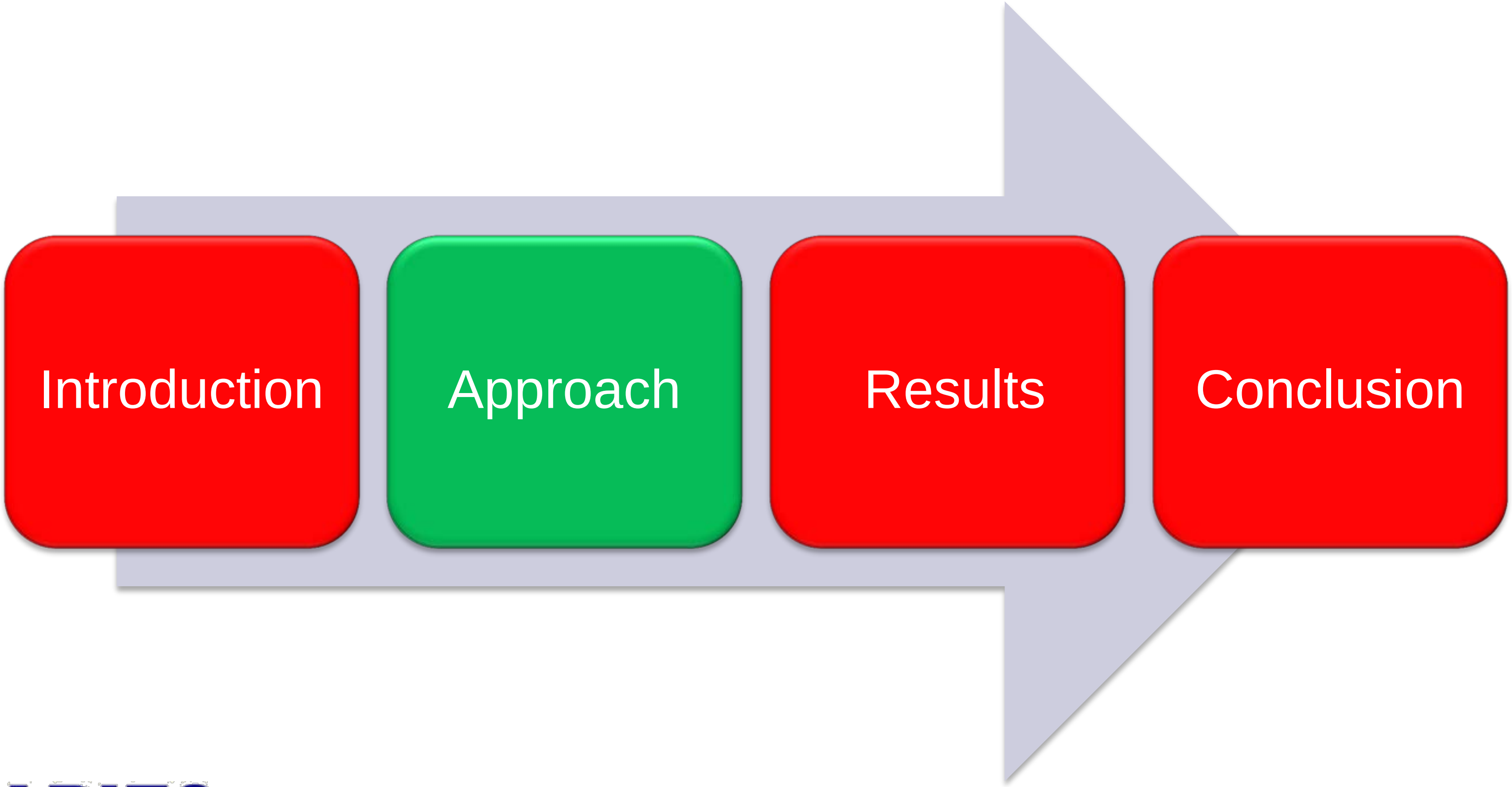
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Key Questions

1. How do control strategies compare to constant pumping and to each other in terms of energy savings?
2. What is the cost effectiveness of a multifamily DHW control system retrofit?
3. How might the interactive effects between DHW energy savings and the heating/cooling loads affect payback?
4. What potential complications might be encountered in getting these controls to work well?

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Building Characteristics

Property	Building A	Building B	Building C	Building D
Collection Period	January 2013 - January 2014	January 2013 - January 2014	August 2013 - April 2014	August 2013 - March 2014
Control Methods Tested	All	All	Demand Only	All
DHW System	Dedicated boiler and storage tank	Winter: tankless coil with mixing valve, Summer: dedicated	Dedicated boiler and storage tank	Dedicated boiler and storage tank
Number of Bedrooms	66	294	81	72
Number of Floors	7	15	3	3
Average Supply Temperature	135°F	119°F	159°F	131°F
Average DHW Gallons/Bedroom/Day	34	38	38	41
Measured Boiler Efficiency	82%	80%	83%	85%

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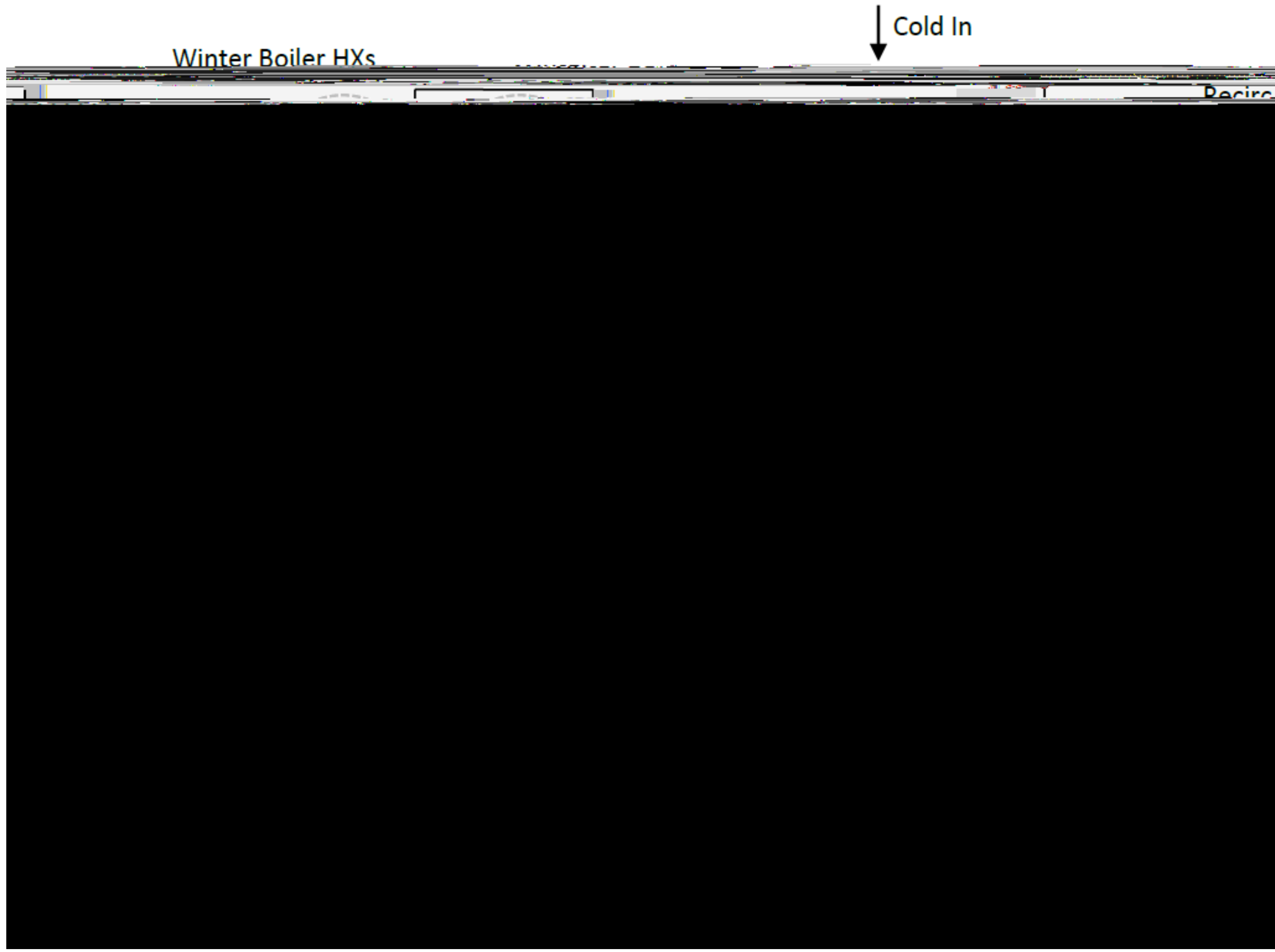
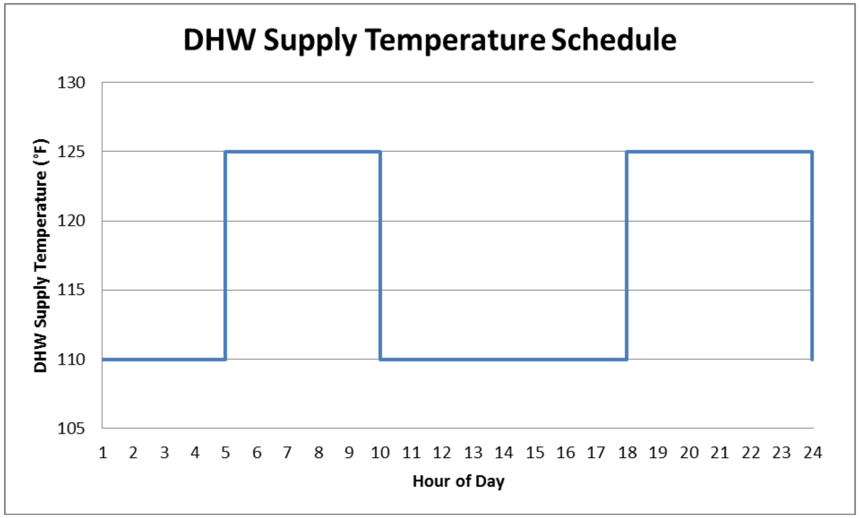
Monitoring Equipment

Temperatures, flowrates, pump and boiler runtime were monitored



Test Strategy

- Demand recirculation
- Temperature modulation
  - 125°F for 4-5 hour morning and 6-7 hour evening "peaks"
  - 110°F midday and late night
- Demand with temperature modulation control
- Each strategy alternated for 1-3 weeks in succession with baseline mode through all seasons



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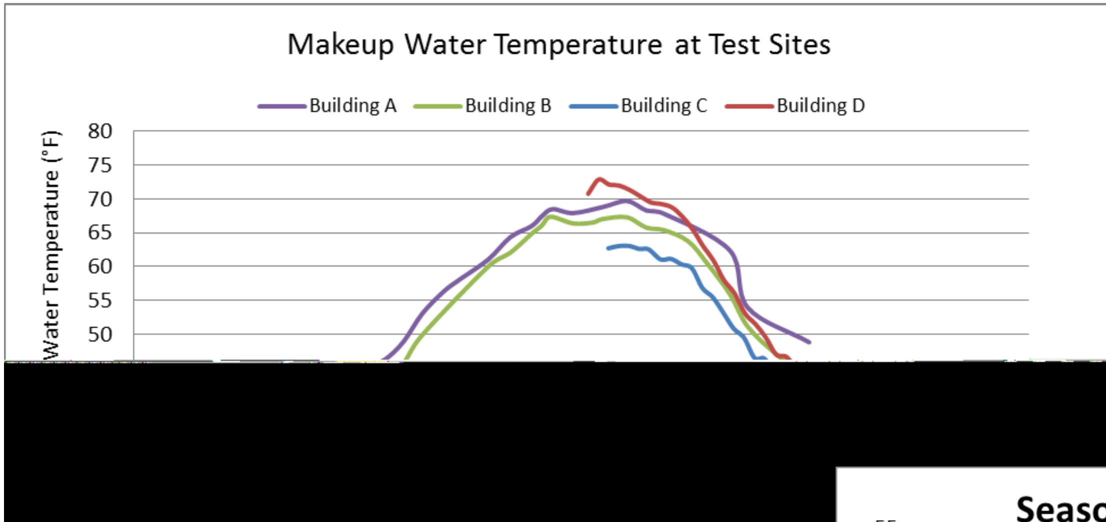
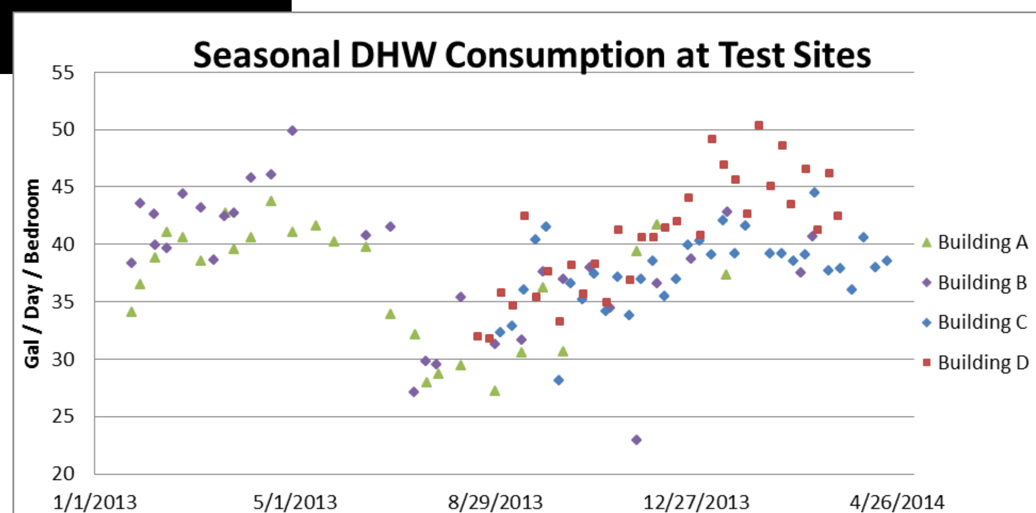
Accounting for Changes in Temperature and DHW Use



[redacted]

May be due to mixing with colder CW at tap



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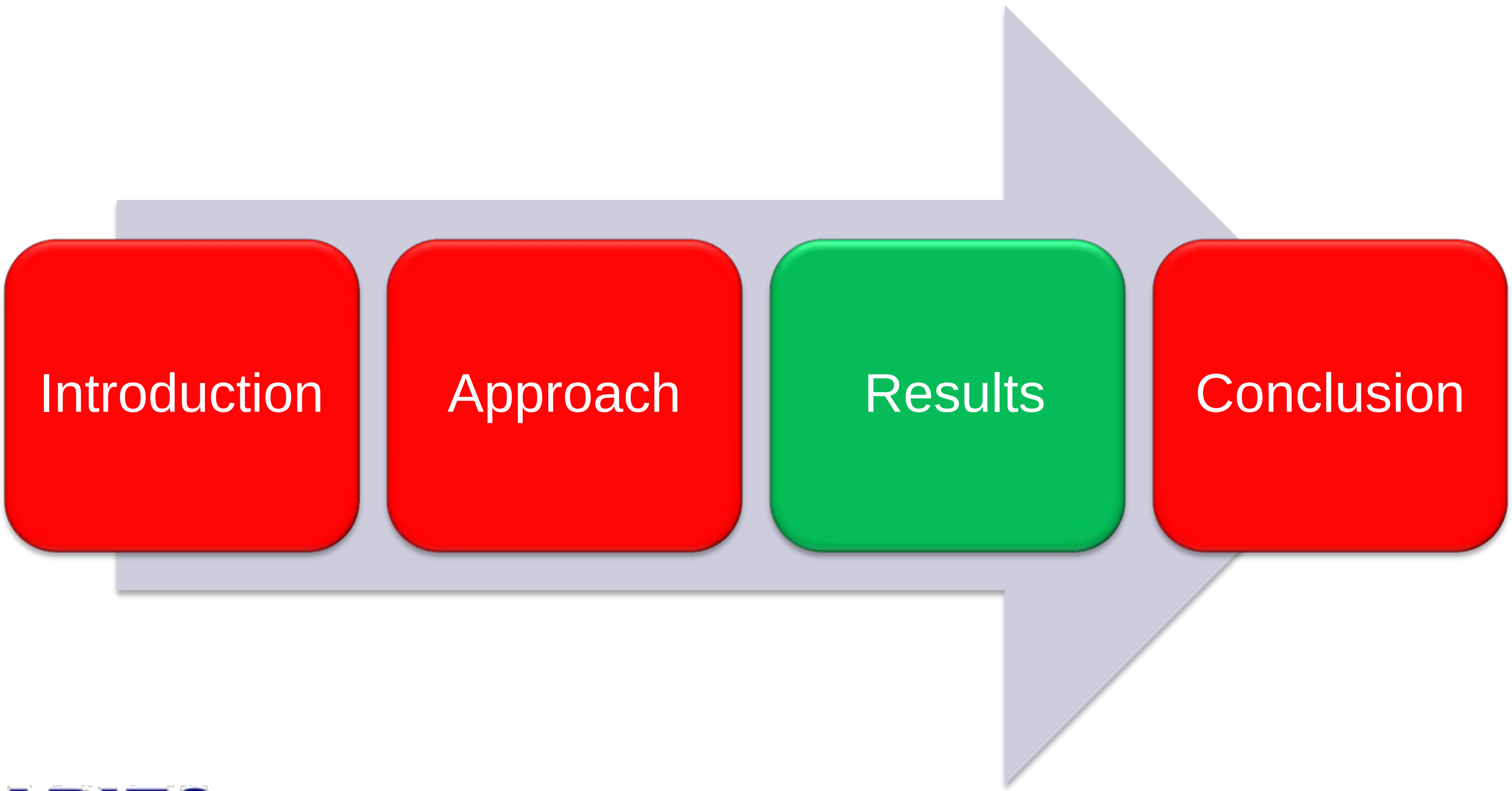
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Installed Costs

- Demand Recirculation Control: $3,000
  - without new pump: $2,500

- Temperature Modulation Control:
  - storage tank control: $2,000
  - new electronic tempering valve: $5,300

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Supply & Return Temperatures

Property	Building A	Building B	Building C	Building D
Baseline	138°F/135°F	125°F/122°F	159°F/153°F	132°F/129°F
Demand Control	139°F/98°F	120°F/83°F	159°F/77°F	131°F/95°F
Temperature Modulation	130°F/128°F	117°F/114°F	-	128°F/125°F
Demand Control & Temperature Modulation	130°F/98°F	114°F/79°F	-	129°F/97°F
Makeup Water	57°F	53°F	48°F	55°F

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Recirculation Pump Runtimes

- Average of 14 minutes/day
- 99% reduction from continuous operation

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Measured DHW Fuel Savings

Property\Mode	Building A	Building B	Building C	Building D
Annual Baseline DHW Consumption	175 therms/br	94 therms/br	184 therms/br	112 therms/br
DHW Fuel Reduction with Demand Control	**12%** (20.4 therms/br)	**9%** (8.0 therms/br)	**6%** (10.3 therms/br)	**7%** (8.3 therms/br)
DHW Fuel Reduction with Temperature Modulation	**2%** (3.4 therms/br)	**8%** (7.8 therms/br)	-	**2%** (1.9 therms/br)
DHW Fuel Reduction with Demand Control & Temperature Modulation	**15%** (25.9 therms/br)	**12%** (11.3 therms/br)	-	**15%** (16.2 therms/br)

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Space Conditioning Interactivity

Parameter	Least Effect	Middle Case	Greatest Effect
Heating Efficiency	85%	75%	65%
Heating Hours	2,686	3,263	4,074
Cooling Efficiency (Btu/Wh)	8	10	12
Cooling Hours	1,080	540	540
Percent Interaction	50%	75%	100%

For central scenario:

- Heat penalty was **37%** of the DHW fuel reduction
- Average cooling bonus was **10%** of total dollar savings
- Reduced pump electricity contributed **25%** to dollar savings

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Simple Payback

Property	Building A	Building B	Building C	Building D
Annual DHW Cost (incl Recirc Pump Electricity)	$15,900	$31,200	$16,400	$9,200
Installed Cost of Demand/Temp Mod. Controls	$3,000/$2,000	$2,500/$5,300	$3,000	$3,000/$2,000
Demand Control Payback	2.1	1.0	3.0	3.7
Temperature Modulation Payback	11.2	3.0	-	18.5
Demand Control & Temperature Modulation Payback	3.0	2.5	-	4.0

Average annual cost savings, including interactive effects:

- 9% w/ demand controls
- 3% w/ temperature modulation controls
- 12% w/ both combined

Worst-case average payback: <4 years for demand control; 21 years for temperature modulation

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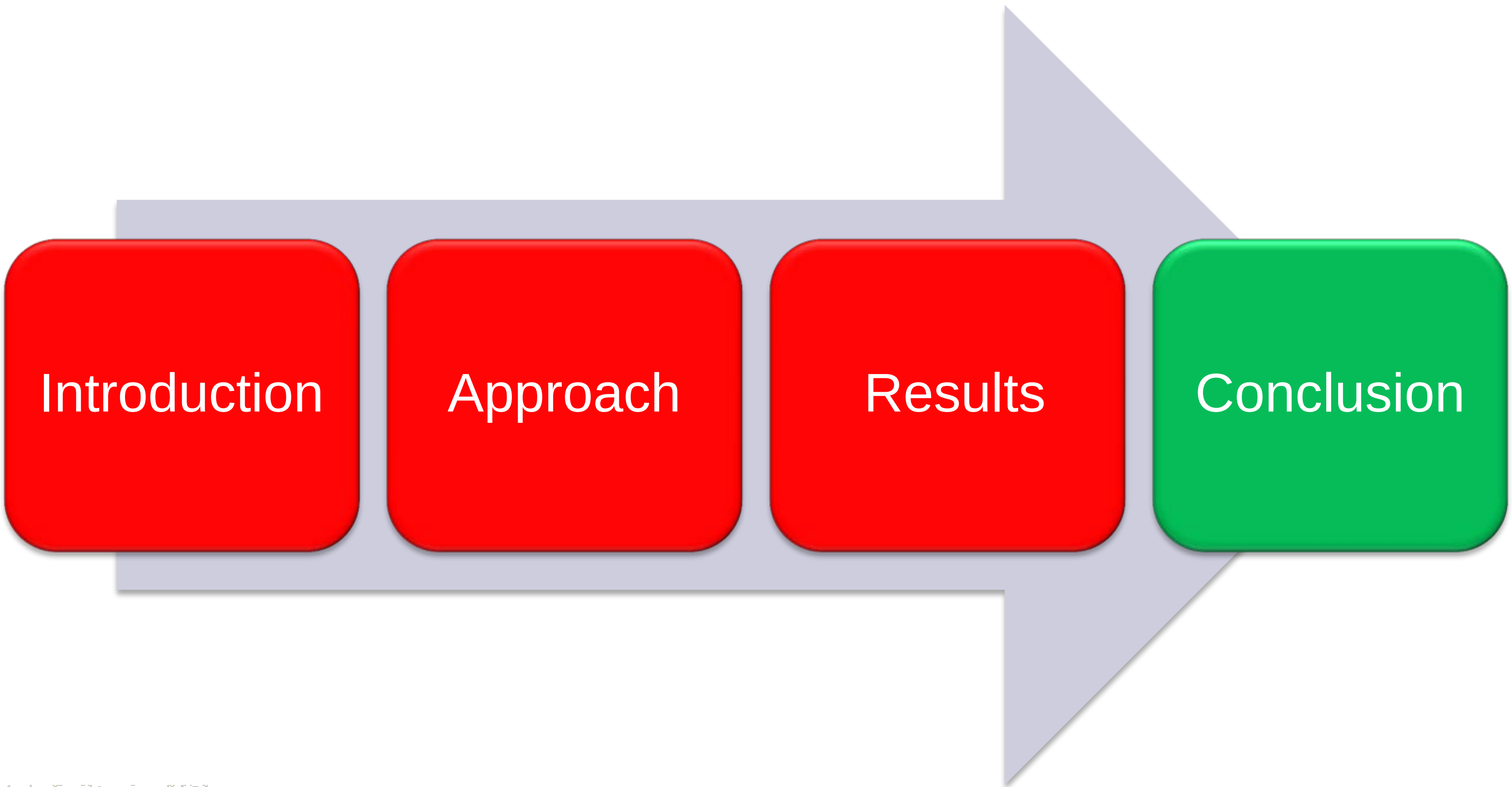

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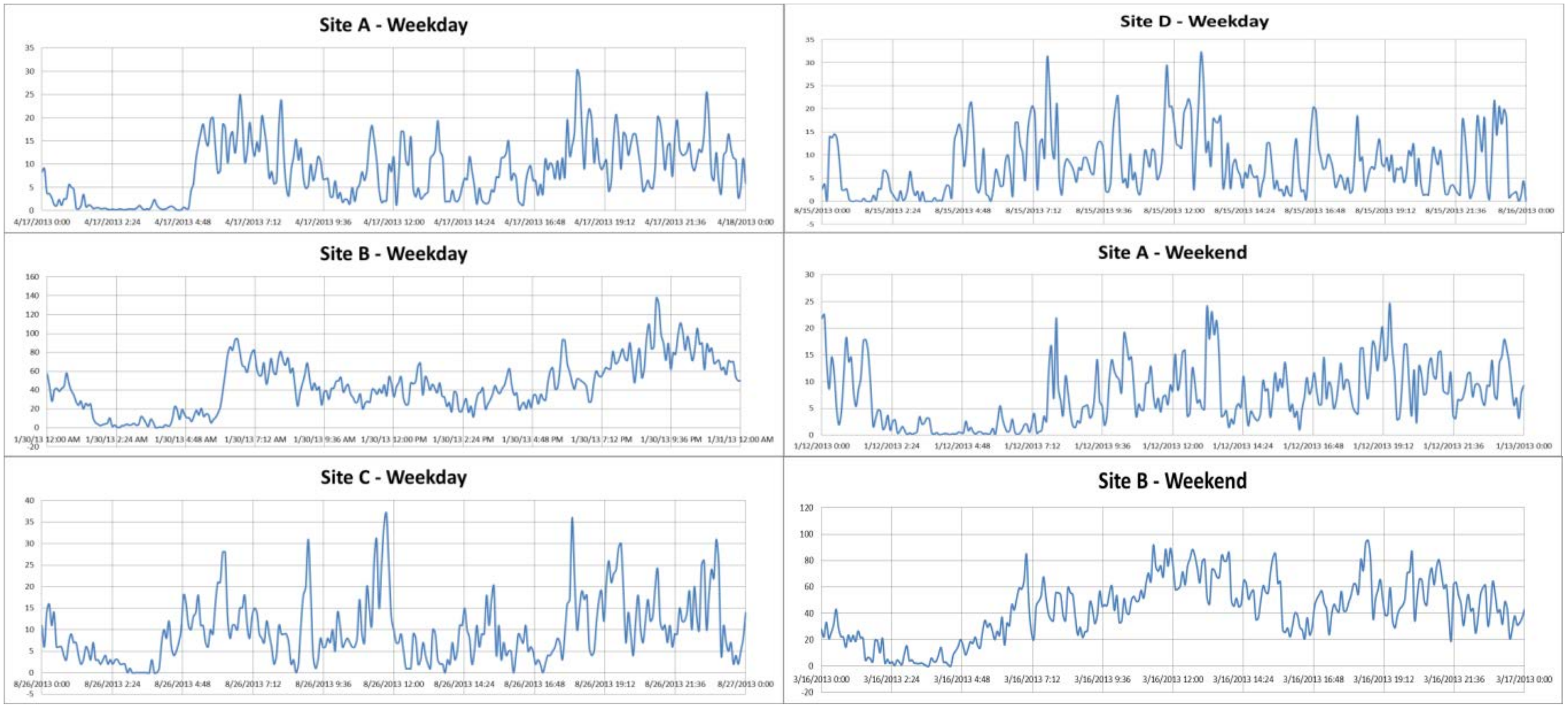
Lesson: Demand Profiles



24-hour demand profiles from test buildings (gallons per 5-minute interval) illustrate that brief spikes in usage can occur at any time of day, including lower temperature “off-peak” TM control periods

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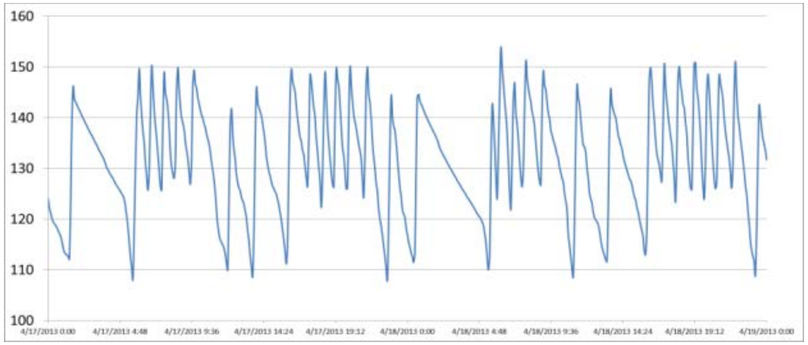
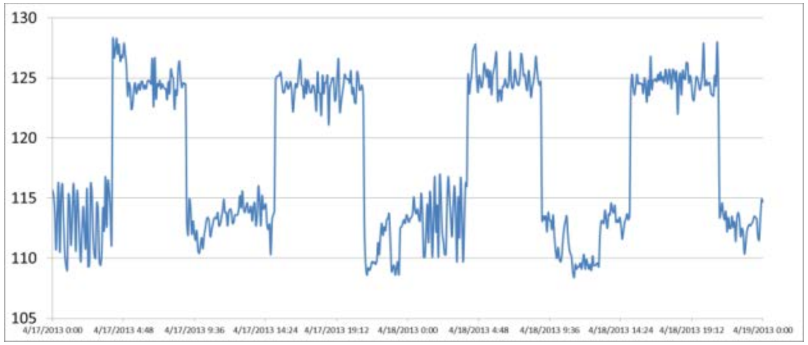
Lesson: Commissioning

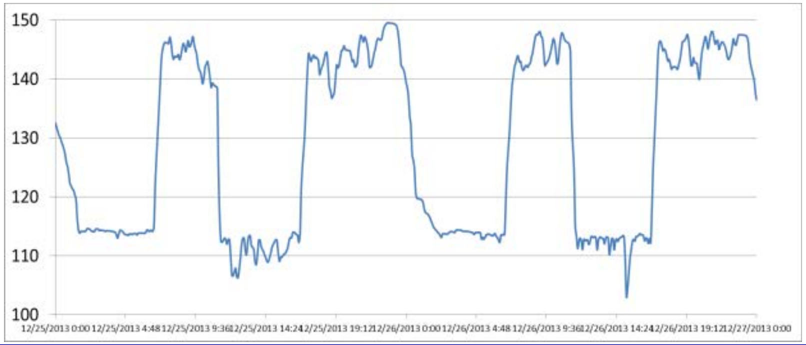
Site A: the lower temperature bounds are as intended, but there is a 20-30°F temperature rise at the start of each boiler cycle (possibly due to mis-wired TM control)





Site B: electronic mixing valve output closely matched the programmed peak and off-peak setpoints

Site D: off-peak temperature correct, peak temperature too high (mis-wiring again)



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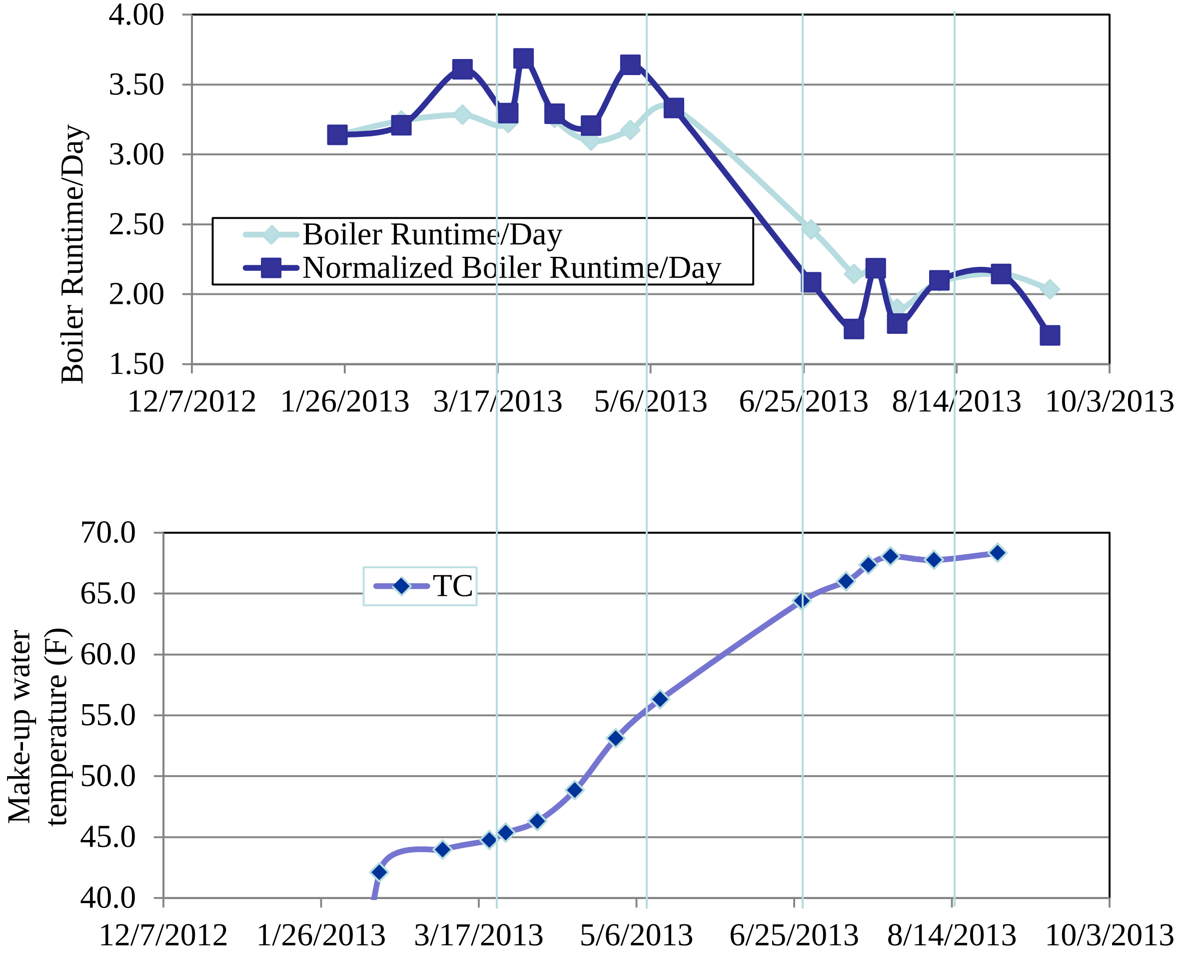
Boiler Runtime vs. DHW Makeup Water Temperature



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Comparison with Prior Studies

- Average 9% and 14% DHW fuel savings from demand and demand + temperature controls, respectively
- Prior studies showed 12-44% DHW fuel savings with demand recirculation
- Prior studies did not account for interactivity

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Mixing Valve Concerns

Concerns:

- Mechanical mixing valves
  - Internal bellows mechanism can fail due to thermal stress
  - Non-continuous flow can void warranty
- Electronic mixing valves
  - Potential to send un-tempered hot water with non-continuous flow
  - Doesn’t void warranty…

Possible Solutions:

- Mechanical mixing valves approved for non-continuous flow
- Dummy recirculation loop

Electronic Mixing Valve Supply Temperatures

Electronic Mixing Valve: Highest Recorded 5-Minute Average Temperatures	
Continuous Flow	145°F
Demand Recirculation	144°F
Temperature Modulation	132°F
Demand + Temp Modulation	147°F

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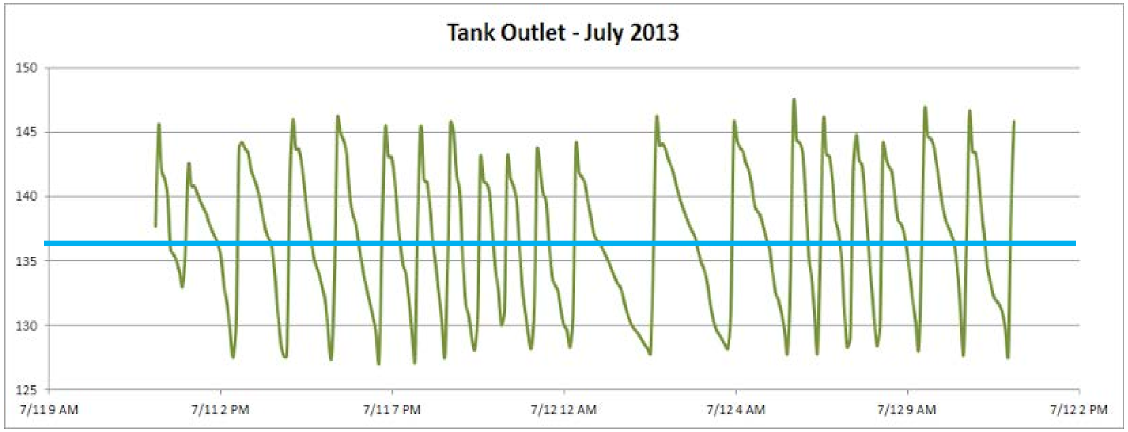
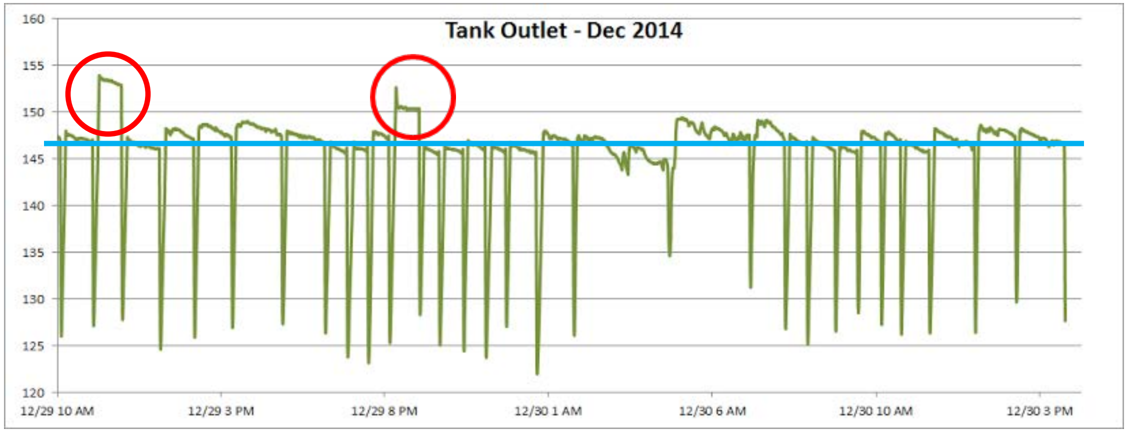
Implications of Storage Tank Stratification vs. Mixing

Continuous recirculation pumping



Demand-controlled recirculation pumping



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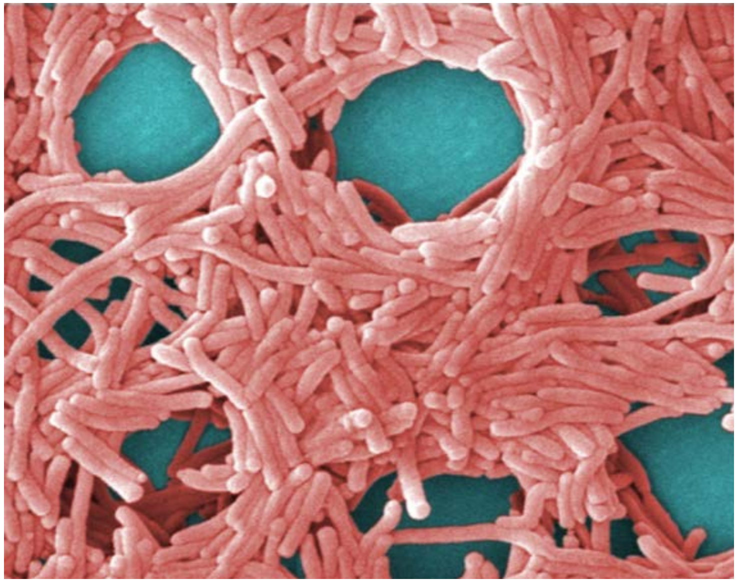
Legionella?

- Temperatures of 77 to 108°F can provide favorable conditions for legionella growth
- OSHA discourages demand control; ENERGY STAR recommends it; California building code requires it for new construction
- Research needed to determine the relative risk of bacterial establishment in DHW recirculation loops with frequent exchange of water



Source: Wikipedia

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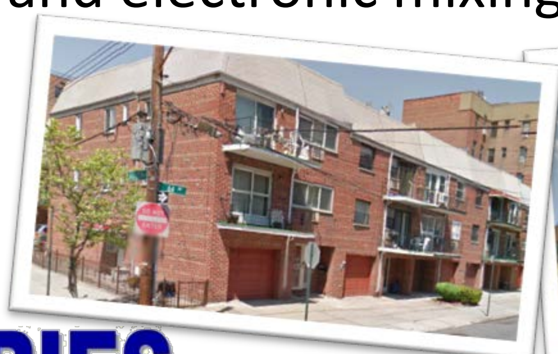
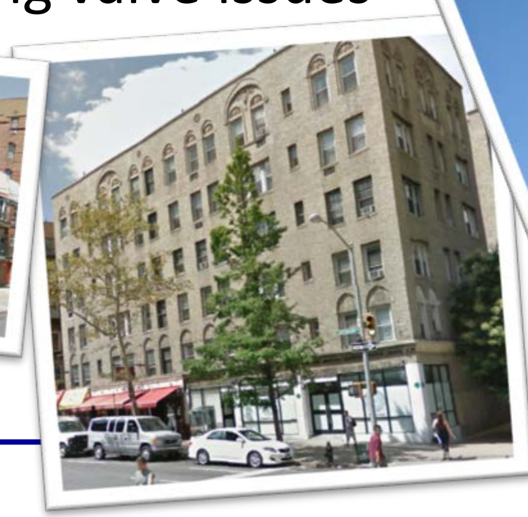
Conclusion

- All DHW controls implemented without complaints
- Variability in off-peak demand undermines argument for temperature modulation as a strategy
- Costs depend on existing DHW configuration
- Demand control paybacks of 1-4 years, also depends on building size

Next Step: 40-Building Rollout

- We're installing demand controls in 40 multifamily buildings and monitoring performance with NYSERDA.
- Buildings in New York welcome to participate
- Exploring optimized supply temperature and electronic mixing valve issues





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Thank You.

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