Energy-Efficient Controls for Multifamily Domestic Hot Water

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New York, NY
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:

THE LEVY PARTNERSHIP

ARIES Collaborative
Water Heating is one of the largest multifamily energy uses.
Typical DHW energy distribution with continuous pump operation

- Total Fuel Energy = 100%
- Useful Energy = 47%
- Boiler and standby losses = 31%
- Ricirculation losses = 12.5%
- Branch Losses < 1%
- SL and DHW draw losses ~ 8.5%

Values based on NYSERDA Site #2
Context

• Recirculating domestic hot water (DHW) systems are common in commercial and multifamily buildings
• Recirculation pumps often run 24x7 - increasing energy consumption because the pipes radiate heat continuously, even during periods when there is no demand for hot water.
What is a DHW recirculation system?

Recirculation piping continually moves hot water from the point at which it is heated to the fixtures throughout the building, minimizing wait time.

Figures: HMG, Inc. (left), Danfoss (right)
Why a Recirculation Pump Is Needed

- A recirculation pump keeps the DHW piping loop hot as it gradually loses heat to the surrounding air, reducing wait time at the faucets.

- Without a recirculation pump, one has to wait for the cooled, stagnant water to be removed from the loop.
Types of DHW Control

- Timer Control
- Temperature Control
- Temperature Modulation Control
- Demand Recirculation Control
- Demand + Temperature Modulation Control
Timer Control

• Turns pump on and off according to a time schedule
• Time schedule off periods should approximate the peak DHW usage periods at the building.
• When a user demands hot water during an "off" period, they will waste water as they wait for the temperature to increase.
Temperature Control

• Automatically turns pump on and off based on temperature (usually 120°F) via a sensor on the return line.

• 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).
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
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?
## Previous Research

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Building A</th>
<th>Building B</th>
<th>Building C</th>
<th>Building D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Methods Tested</td>
<td>All</td>
<td>All</td>
<td>Demand Only</td>
<td>All</td>
</tr>
<tr>
<td>DHW System</td>
<td>Dedicated boiler and storage tank</td>
<td>Winter: tankless coil with mixing valve, Summer: dedicated</td>
<td>Dedicated boiler and storage tank</td>
<td>Dedicated boiler and storage tank</td>
</tr>
<tr>
<td>Number of Bedrooms</td>
<td>66</td>
<td>294</td>
<td>81</td>
<td>72</td>
</tr>
<tr>
<td>Number of Floors</td>
<td>7</td>
<td>15</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Average Supply Temperature</td>
<td>135°F</td>
<td>119°F</td>
<td>159°F</td>
<td>131°F</td>
</tr>
<tr>
<td>Average DHW Gallons/Bedroom/Day</td>
<td>34</td>
<td>38</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Measured Boiler Efficiency</td>
<td>82%</td>
<td>80%</td>
<td>83%</td>
<td>85%</td>
</tr>
</tbody>
</table>
Control and Monitoring Equipment
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
Accounting for Changes in Temperature and DHW Use

**Makeup Water Temperature at Test Sites**

- **Building A**
- **Building B**
- **Building C**
- **Building D**

*Graph showing makeup water temperature from Oct-12 to Nov-13.*

**Seasonal DHW Consumption at Test Sites**

- **Building A**
- **Building B**
- **Building C**
- **Building D**

*Graph showing seasonal DHW consumption from 1/1/2013 to 4/26/2014.*
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
# Supply & Return Temperatures

<table>
<thead>
<tr>
<th>Property</th>
<th>Building A</th>
<th>Building B</th>
<th>Building C</th>
<th>Building D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>138°F/135°F</td>
<td>125°F/122°F</td>
<td>159°F/153°F</td>
<td>132°F/129°F</td>
</tr>
<tr>
<td>Demand Control</td>
<td>139°F/98°F</td>
<td>120°F/83°F</td>
<td>159°F/77°F</td>
<td>131°F/95°F</td>
</tr>
<tr>
<td>Temperature Modulation</td>
<td>130°F/128°F</td>
<td>117°F/114°F</td>
<td>-</td>
<td>128°F/125°F</td>
</tr>
<tr>
<td>Demand Control &amp; Temperature Modulation</td>
<td>130°F/98°F</td>
<td>114°F/79°F</td>
<td>-</td>
<td>129°F/97°F</td>
</tr>
<tr>
<td>Makeup Water</td>
<td>57°F</td>
<td>53°F</td>
<td>48°F</td>
<td>55°F</td>
</tr>
</tbody>
</table>
Recirculation Pump Runtimes

- Average of 14 minutes/day
- 99% reduction from continuous operation
## Measured DHW Fuel Savings

<table>
<thead>
<tr>
<th>Property\Mode</th>
<th>Building A</th>
<th>Building B</th>
<th>Building C</th>
<th>Building D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Baseline DHW Consumption</td>
<td>175 therms/br</td>
<td>94 therms/br</td>
<td>184 therms/br</td>
<td>112 therms/br</td>
</tr>
<tr>
<td>DHW Fuel Reduction with Demand Control</td>
<td>12% (20.4 therms/br)</td>
<td>9% (8.0 therms/br)</td>
<td>6% (10.3 therms/br)</td>
<td>7% (8.3 therms/br)</td>
</tr>
<tr>
<td>DHW Fuel Reduction with Temperature Modulation</td>
<td>2% (3.4 therms/br)</td>
<td>8% (7.8 therms/br)</td>
<td>-</td>
<td>2% (1.9 therms/br)</td>
</tr>
<tr>
<td>DHW Fuel Reduction with Demand Control &amp; Temperature Modulation</td>
<td>15% (25.9 therms/br)</td>
<td>12% (11.3 therms/br)</td>
<td>-</td>
<td>15% (16.2 therms/br)</td>
</tr>
</tbody>
</table>
Space Conditioning Interactivity

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Least Effect</th>
<th>Middle Case</th>
<th>Greatest Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Efficiency</td>
<td>85%</td>
<td>75%</td>
<td>65%</td>
</tr>
<tr>
<td>Heating Hours</td>
<td>2,686</td>
<td>3,263</td>
<td>4,074</td>
</tr>
<tr>
<td>Cooling Efficiency (Btu/Wh)</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Cooling Hours</td>
<td>1,080</td>
<td>540</td>
<td>540</td>
</tr>
<tr>
<td>Percent Interaction</td>
<td>50%</td>
<td>75%</td>
<td>100%</td>
</tr>
</tbody>
</table>
# Simple Payback

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

- Average annual cost savings, including interactive effects:
  - 9% with demand controls
  - 3% with temperature modulation controls
  - 12% with both combined
- Worst-case average payback: <4 years for demand control; 21 years for temperature modulation
Lesson: Demand Profiles

Site A - Weekday

Site D - Weekday

Site B - Weekday

Site A - Weekend

Site C - Weekday

Site B - Weekend
Lesson: Commissioning

Site A

Site B

Site D
Boiler Runtime vs. DHW Makeup Water Temperature
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
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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electronic Mixing Valve:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Highest Recorded 5-Minute Average Temperatures</strong></td>
<td></td>
</tr>
<tr>
<td>Continuous Flow</td>
<td>145°F</td>
</tr>
<tr>
<td>Demand Recirculation</td>
<td>144°F</td>
</tr>
<tr>
<td>Temperature Modulation</td>
<td>132°F</td>
</tr>
<tr>
<td>Demand + Temp Modulation</td>
<td>147°F</td>
</tr>
</tbody>
</table>
Storage Tank Overheating Issue?

Continuous recirculation pumping

Demand-controlled recirculation pumping
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

Conclusion

- All DHW controls implemented without complaints
- DHW demand profiles did not show pronounced peaks and troughs – constant, low supply temperature might be ideal
- 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
Thank You.

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