Steam Systems, Retrofit Measure Packages, Hydronic Systems

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July 16, 2014
Building America Webinar:
Retrofitting Central Space Conditioning Strategies for Multifamily Buildings
Contents

- Retrofit Measure Packages for steam and hydronic MF buildings that save 25-30%

- System Balancing
  - Steam
  - Hydronic
Background

• Over 50% of cold climate MF units are heated by central steam or hydronic systems

• 80% of existing buildings will be in use in 2020

• In Chicago region, 2/3 of residential units were built before 1980; rarely designed for energy efficiency
“Evaluation of CNT Energy Savers Retrofit Packages Implemented in Multifamily Buildings”
Farley, J., Ruch, R.

Research Agenda
• Which cost-effective measure packages are appropriate for steam and hydronic MF buildings?
• Select typical Chicago MF buildings and model savings in TREAT
• Find retrofit packages with 25-30% source energy savings
## Retrofit Packages

### 19-Unit Hydronic Building, built 1920

23.9% Site Savings

<table>
<thead>
<tr>
<th>Measure</th>
<th>Cost</th>
<th>Annual MMBtu Source Savings</th>
<th>Annual MMBtu Site Savings</th>
<th>Annual $ Savings</th>
<th>Percent Site Savings</th>
<th>Payback Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulate heating hot water pipes</td>
<td>4,720</td>
<td>229.38</td>
<td>229.38</td>
<td>2,294</td>
<td>11.9%</td>
<td>2.1</td>
</tr>
<tr>
<td>Air seal and insulate basement windows</td>
<td>390</td>
<td>96.15</td>
<td>96.15</td>
<td>962</td>
<td>5.0%</td>
<td>0.4</td>
</tr>
<tr>
<td>Install Energy Star refrigerators</td>
<td>8,550</td>
<td>46.38</td>
<td>15.46</td>
<td>1,960</td>
<td>0.8%</td>
<td>4.4</td>
</tr>
<tr>
<td>Install boiler controls &amp; indoor sensors</td>
<td>4,735</td>
<td>99.23</td>
<td>99.23</td>
<td>992</td>
<td>5.2%</td>
<td>4.8</td>
</tr>
<tr>
<td>Weather strip exterior doors</td>
<td>1,330</td>
<td>18.10</td>
<td>18.10</td>
<td>181</td>
<td>1.0%</td>
<td>7.3</td>
</tr>
</tbody>
</table>
# Retrofit Packages

## 6-Unit Steam Building, built 1927

31.8% Site Savings

<table>
<thead>
<tr>
<th>Measure</th>
<th>Cost</th>
<th>Annual MMBtu Site Savings</th>
<th>Annual MMBtu Source Savings</th>
<th>Annual $ Savings</th>
<th>Percent Site Savings</th>
<th>Payback Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulate steam pipes</td>
<td>1,450</td>
<td>54.30</td>
<td>54.30</td>
<td>543</td>
<td>4.8%</td>
<td>2.7</td>
</tr>
<tr>
<td>Air seal and insulate roof cavity</td>
<td>4,612</td>
<td>124.06</td>
<td>124.06</td>
<td>1,240</td>
<td>10.9%</td>
<td>3.7</td>
</tr>
<tr>
<td>Install low flow fixtures</td>
<td>0*</td>
<td>12.85</td>
<td>12.85</td>
<td>129</td>
<td>1.1%</td>
<td>--</td>
</tr>
<tr>
<td>Install boiler controls &amp; indoor sensors</td>
<td>3,395</td>
<td>65.48</td>
<td>65.48</td>
<td>655</td>
<td>5.7%</td>
<td>5.2</td>
</tr>
<tr>
<td>Insulate domestic hot water pipes</td>
<td>1,200</td>
<td>8.13</td>
<td>8.13</td>
<td>81</td>
<td>0.7%</td>
<td>14.8</td>
</tr>
<tr>
<td>Resize risers and replace main line vents</td>
<td>5,890</td>
<td>97.99</td>
<td>97.99</td>
<td>980</td>
<td>8.6%</td>
<td>6.0</td>
</tr>
</tbody>
</table>
• Significant, cost-effective savings are possible in old steam & hydronic buildings

• The most cost-effective packages address
  – Thermal envelope (air sealing & insulating roof cavity, basement)
  – Heating controls (outdoor reset, temperature averaging)
  – Distribution (heating and DHW pipe insulation, system balancing)
  – Lighting fixtures

• Optimizing and balancing the heating distribution system can be a source of significant (10-15%) heating fuel savings
Why balancing?

• Older hydronic & steam systems are almost always imbalanced
  – Systems not zoned by unit will overheat some units in order to adequately heat the coldest ones
  – Can cause tenants to use supplemental heat or open windows during the heating season
  – Fuel waste, tenant discomfort

• Narrowing the temperature spread can bring benefits to tenants and owners alike

(Peterson, G., 1985)
Why balancing?

**Utility savings**
- PARR: average 10% off heating load in steam bldgs

**Tenant comfort**
- Fewer open windows in winter
- Less supplemental heating e.g. space heaters, oven ranges
- Reduce humidity & moisture control issues

**Operation savings**
- Improving tenant comfort can stabilize occupancy
- Reduce the time spent dealing with low-heat calls
Steam Heating Basics

In the boiler room:

Boiler turns on 8 min 30 min
Steam Heating Basics

Meanwhile, in a unit:

This is what should happen during a boiler cycle; however, there are often problems…
Steam Heating Basics - Problems
Steam Balancing Market Barriers

• Lacking knowledge about older steam and hydronic systems in the marketplace

• Balancing not commonly offered as a service or recommended as a measure

• Not tangible – often requires time and dedication rather than basic equipment replacements

• Difficult to convince owners of its value
  – Balancing is a separate issue from boiler replacement
  – Natural gas is cheap, so it is not seen as worth the time or effort
Steam Balancing Study

“Steam System Balancing and Tuning for Multifamily Residential Buildings in Chicagoland”
Choi, J., Ludwig, P., Brand, L.

Research Agenda
• How do steam balancing measures affect unit temperatures, boiler cycles, and gas consumption?

• Install loggers in 10 bldgs and compare performance pre- and post-retrofit

• Found avg 10.2% savings on NG heating loads, avg cost $9,875, simple payback 5.1 years
Steam Balancing – Measures

Replace radiator vents
Add or upgrade main line air venting
Boiler controls (4-6 sensors, indoor averaging)
Steam Balancing – Sample Selection

- 10 buildings
- Single-pipe steam
- 15-30 units
- Uneven heating
- Boiler in good condition
Steam Balancing Study - Timeline

1. Collected pre-retrofit data
   - Building, boiler, piping, condition of vents, existing controls
   - Data logging of unit temperatures, boiler cycles
   - Tenant survey, heat calls

2. Developed detailed scopes for steam balancing work to be done

3. Oversaw general contracting and inspected work

4. Collected post-retrofit temp data

5. Conducted utility bill analysis comparing pre- and post-retrofit energy use
<table>
<thead>
<tr>
<th>Measure</th>
<th>Average Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adding or upgrading to high-capacity main line air vents (with new risers)</td>
<td>$1,800</td>
</tr>
<tr>
<td>Replacing Radiator Vents</td>
<td>$3,680</td>
</tr>
<tr>
<td>Upgrading Boiler Control System</td>
<td>$5,060</td>
</tr>
</tbody>
</table>
Steam Balancing Study

Natural Gas Use

<table>
<thead>
<tr>
<th>Building</th>
<th>Pre (kBtu)</th>
<th>Post (kBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500,000</td>
<td>600,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>3</td>
<td>1,000,000</td>
<td>800,000</td>
</tr>
<tr>
<td>4</td>
<td>700,000</td>
<td>650,000</td>
</tr>
<tr>
<td>5</td>
<td>500,000</td>
<td>450,000</td>
</tr>
<tr>
<td>6</td>
<td>300,000</td>
<td>350,000</td>
</tr>
<tr>
<td>7</td>
<td>200,000</td>
<td>250,000</td>
</tr>
<tr>
<td>8</td>
<td>100,000</td>
<td>150,000</td>
</tr>
<tr>
<td>9</td>
<td>50,000</td>
<td>70,000</td>
</tr>
<tr>
<td>10</td>
<td>30,000</td>
<td>40,000</td>
</tr>
</tbody>
</table>
Tenant survey responses rating overall temperature comfort. The tenants were asked to rate the overall temperature comfort within their unit on a scale from 1 = Uncomfortable to 5 = Comfortable. Note: Building 7 received no survey responses pre-retrofit.
<table>
<thead>
<tr>
<th>Building</th>
<th>Natural Gas Use From Energy Use Intensity (kBtu)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Balancing</td>
<td>Post-Balancing</td>
<td># of Months in Analysis Periods</td>
<td>% Savings</td>
</tr>
<tr>
<td>1</td>
<td>703,119</td>
<td>621,371</td>
<td>8</td>
<td>11.63%</td>
</tr>
<tr>
<td>2</td>
<td>1,971,622</td>
<td>1,394,456</td>
<td>9</td>
<td>29.27%</td>
</tr>
<tr>
<td>3</td>
<td>1,280,991</td>
<td>1,388,438</td>
<td>11</td>
<td>8.39%</td>
</tr>
<tr>
<td>4</td>
<td>578,751</td>
<td>514,142</td>
<td>11</td>
<td>11.16%</td>
</tr>
<tr>
<td>5</td>
<td>873,111</td>
<td>640,519</td>
<td>9</td>
<td>26.64%</td>
</tr>
<tr>
<td>6</td>
<td>990,039</td>
<td>995,768</td>
<td>11</td>
<td>0.58%</td>
</tr>
<tr>
<td>7</td>
<td>972,393</td>
<td>633,350</td>
<td>10</td>
<td>34.87%</td>
</tr>
<tr>
<td>8</td>
<td>972,476</td>
<td>844,398</td>
<td>8</td>
<td>13.17%</td>
</tr>
<tr>
<td>9</td>
<td>1,578,954</td>
<td>1,420,073</td>
<td>10</td>
<td>10.06%</td>
</tr>
<tr>
<td>10</td>
<td>1,027,457</td>
<td>977,787</td>
<td>10</td>
<td>4.83%</td>
</tr>
</tbody>
</table>

Table 6. Measured Weather-Normalized Natural Gas Use (Heating Only)
Figure 3: Average Temperature In Each Unit
Steam Balancing Study Conclusions

- **Balancing is a multistage process**
  - All information mentioned here should be collected before trying to balance
  - Effectiveness of the initial package of retrofits should be evaluated based on conversations with building manager, tenants, and on temperature data
  - Building may need to be rebalanced, reassessed, and further adjusted

- **Unit locations and building layout are important**
  - Consider them when assessing and balancing a building
  - Each building will have different hot and cold spots, requiring different venting configurations and placement of control sensors

- **Tenants and building managers need to be informed**
  - The success of the balancing process depends on their time & cooperation
  - Tenants should be informed that the work will require occasional access to their units and asked not to tamper with monitoring equipment
  - It is also important to explain to tenants how using space heaters drives up the temperature that indoor averaging systems use to control the boiler
  - Building managers should be properly instructed on how to use the controls
Steam Loop Timing Procedure

Equipment

- Infrared cameras
- Cameras
- Stopwatches
- Sketchpad for diagramming
- Cell phones for communicating among auditor(s)

Procedure

- Have management shut off boiler about ½ hour before arrival
- Walk through: diagram and photograph loops & vents
- Focus infrared cameras on vents, take “before” photos
- Have maintenance fire boiler and take IR photos of the vents until the temperature reaches 200 F
- Record steam arrival time for each vent
Steam Balancing Rebate

Single Pipe Steam Heating Controls and Balancing Prescriptive Rebate

- Through Peoples/North Shore Natural Gas Savings Program
- 3+ living units, Service Class 2 (Residential or C&I)
- $150/unit for central steam boiler controls, $50/unit for improved venting
“Balancing Hydronic Systems in Multifamily Buildings”
Ruch, R., Ludwig, P. Maurer, T.

Research Agenda

- How much can temps vary within and across a hydronic building? What are cost-effective balancing strategies?
- Surveyed literature and evaluated temps in 2 bldgs; added pump capacity in 1 bldg
- Found a 48F spread (!) and reduced avg spread by 6.5F
• Previous research by ARIES (Dentz et al. 2013)
  – Among other conclusions, found very high temperature spreads in hydronic buildings with Energy Management Systems (EMS)
  – Ranged from 14.5 F – 37.9 F when on, 24.5 F – 34.0 F when off
  – Suggested overheating is a significant and common problem in imbalanced hydronic buildings
  – EMS has a limited ability to control temperature and distribution problems
Hydronic Balancing Study - Timeline

1. Collected pre-retrofit data
   • Building, boiler, piping, baseboard, circulators, existing controls
   • Data logging of unit temperatures

2. Developed detailed scope for balancing work to be done

3. Oversaw general contracting and inspected work

4. Collected post-retrofit temp data

5. Conducted temperature data analysis comparing pre- and post-retrofit temperature spreads
Hydronic Balancing Study

Building A

- 33 units, 3 stories
- Built 1920, 39,500 ft²
- Baseboard radiators
- “S”-shaped, 2 zones
  - West: 5657, 5655, 5653
  - East: 5651, 5649, 5647, 5645, 62, 52
- Piping undersized, west loop chronically underheated
Hydronic Balancing Study

Building A temperatures, pre- and post-retrofit
Temperatures, pre- and post-retrofit, in Unit 5651-1
Temperature imbalance in Building A

<table>
<thead>
<tr>
<th>Proportion of half hour intervals in which building spread &gt;30 °F</th>
<th>Pre retrofit</th>
<th>Post retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17.3%</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proportion of half hour intervals in which building spread &lt;15 °F</th>
<th>Pre retrofit</th>
<th>Post retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.4%</td>
<td>52.4%</td>
</tr>
</tbody>
</table>
Building B

- 10 units, 2 stories
- Built 1961, 6,750 ft²
- Underfloor radiant
- Zoned by unit (thermostats)
- First floor chronically overheated
## Building B summary statistics

<table>
<thead>
<tr>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72.0</td>
<td>88.1</td>
<td>80.0</td>
<td>79.7</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>75.5</td>
<td>83.6</td>
<td>79.2</td>
<td>79.2</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>75.0</td>
<td>82.3</td>
<td>79.3</td>
<td>79.5</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>69.6</td>
<td>86.6</td>
<td>81.3</td>
<td>81.6</td>
<td>2.6</td>
</tr>
<tr>
<td>5</td>
<td>73.4</td>
<td>85.7</td>
<td>80.4</td>
<td>80.7</td>
<td>2.1</td>
</tr>
<tr>
<td>6</td>
<td>66.2</td>
<td>84.1</td>
<td>75.1</td>
<td>74.6</td>
<td>3.3</td>
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<tr>
<td>7</td>
<td>70.8</td>
<td>77.4</td>
<td>73.8</td>
<td>73.9</td>
<td>1.2</td>
</tr>
<tr>
<td>8</td>
<td>60.4</td>
<td>72.0</td>
<td>64.8</td>
<td>64.7</td>
<td>1.8</td>
</tr>
<tr>
<td>9</td>
<td>70.8</td>
<td>83.8</td>
<td>78.5</td>
<td>78.3</td>
<td>2.3</td>
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<tr>
<td>10</td>
<td>71.0</td>
<td>83.6</td>
<td>77.9</td>
<td>78.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Averaged</td>
<td>70.5</td>
<td>82.7</td>
<td>77.0</td>
<td>77.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>
## Hydronic Balancing Study

### Recorded vs. setpoint temps (°F) in Building B

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>78.4</td>
<td>13.1</td>
<td>4.7</td>
</tr>
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<td>2</td>
<td>70</td>
<td>79.3</td>
<td>13.6</td>
<td>9.2</td>
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<td>3</td>
<td>75</td>
<td>79.5</td>
<td>7.3</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>83.2</td>
<td>26.6</td>
<td>21.6</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
<td>79.0</td>
<td>11.7</td>
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<tr>
<td>6</td>
<td>74</td>
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<td>0.6</td>
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<tr>
<td>7</td>
<td>73</td>
<td>74.6</td>
<td>4.4</td>
<td>0.9</td>
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<tr>
<td>8</td>
<td>60</td>
<td>64.3</td>
<td>12.0</td>
<td>4.7</td>
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<td>9</td>
<td>73</td>
<td>80.0</td>
<td>10.8</td>
<td>5.3</td>
</tr>
<tr>
<td>10</td>
<td>75</td>
<td>78.4</td>
<td>8.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Unit temperature spreads at Buildings A and B
Hydronic Study Conclusions

- **Hydronic buildings can be extremely imbalanced**
  - Unit temps in can range by as much as 48 F (56 F to 104 F)
  - Open windows, intermittent supplemental heating sources likely the culprit
  - As with steam, when zones serve multiple units, there is bound to be significant variation in temperatures across the building
  - Even in buildings where there is ostensibly zone control for each unit (as with Building B), variation from the setpoint can be considerable (21.6 F in Unit #4)

- **The causes of imbalance in hydronic systems are diverse**
  - Include undersized piping, undersized circulators, malfunctioning zone valves, damaged heat emitters, poor air elimination, misconfigured balancing valves
  - Increasing flow to an underheated zone was effective in reducing temp spread

- **Many of the same lessons from steam balancing apply**
  - Balancing is an iterative process; consider loop configurations carefully
  - Work with tenants and building owners to address the impact of supplemental heating on temperature sensors (both for research and controls); the success of the balancing process depends on their time & cooperation
Conclusions

- There exists a need to develop balancing as a viable energy efficiency measure and increase market penetration
- Steam balancing is relatively straightforward
  - Improve/increase mainline and radiator venting
  - Replace timers with temperature averaging controls
- Hydronic balancing depends on multiple factors
  - Piping configuration (series, direct return, reverse return), flow rates and water temperatures, heat emitter type, pipe sizing
- Coordinating with building owners and educating maintenance staff on distribution system and boiler controls is a crucial factor in keeping heating costs down
Contact Information

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