

Getting out of hot water: Electrification of VAV reheat

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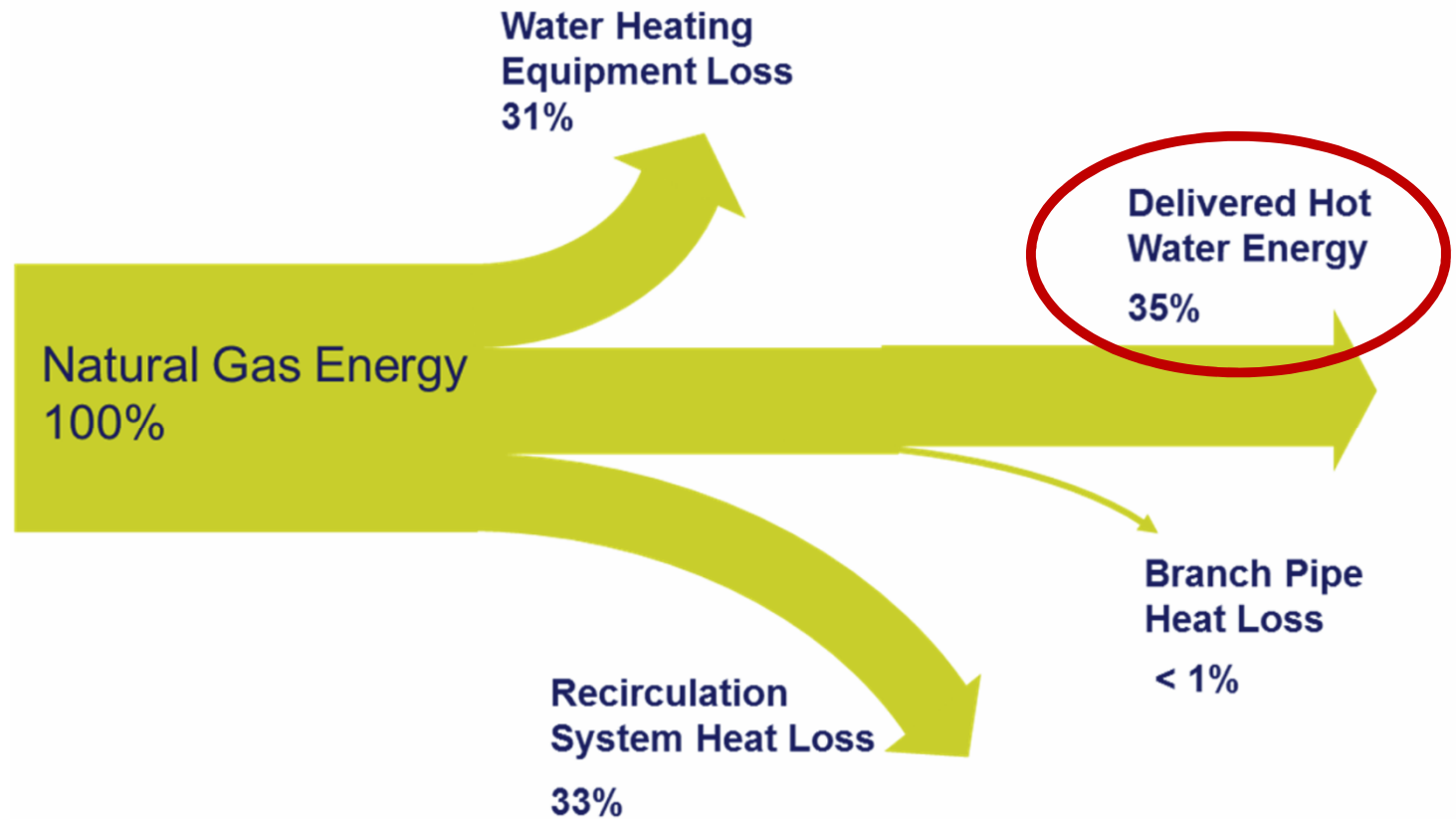
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TRC

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Taylor Engineering



Motivation

Domestic hot
water energy flow
in 28 multi-family
buildings



Zhang et al., Multifamily central domestic hot water distribution systems, CEC-500-2013-011

What about hot water reheat
for HVAC systems?

Is it *actually* more energy efficient and cheaper to
operate than electric reheat?

Overview

Objective

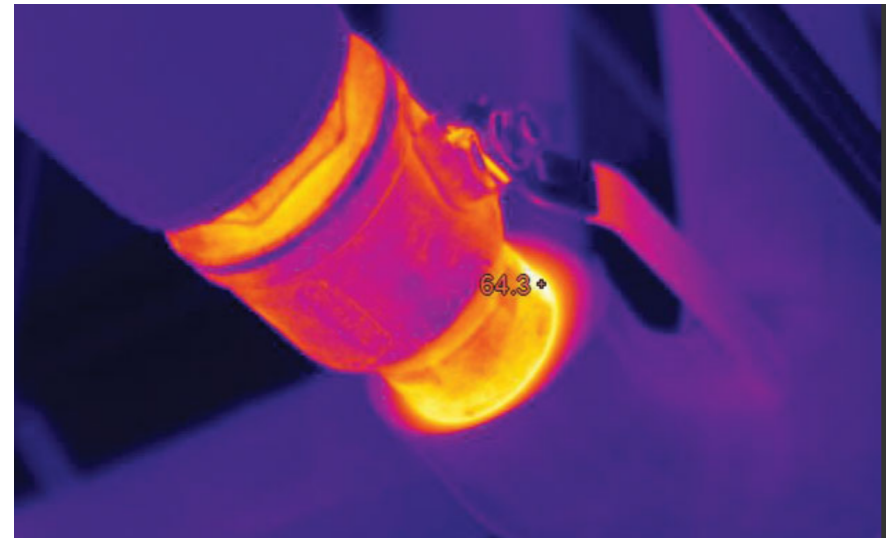
- Investigate VAV hot water reheat use

Approach

- New method for quantifying hot water reheat use and distribution losses
- Evaluate a field study (large office building)
- Compare to electric reheat

Funding

- CBE
- CEC-PIER (Changing The Rules)



Heat loss from hot water piping

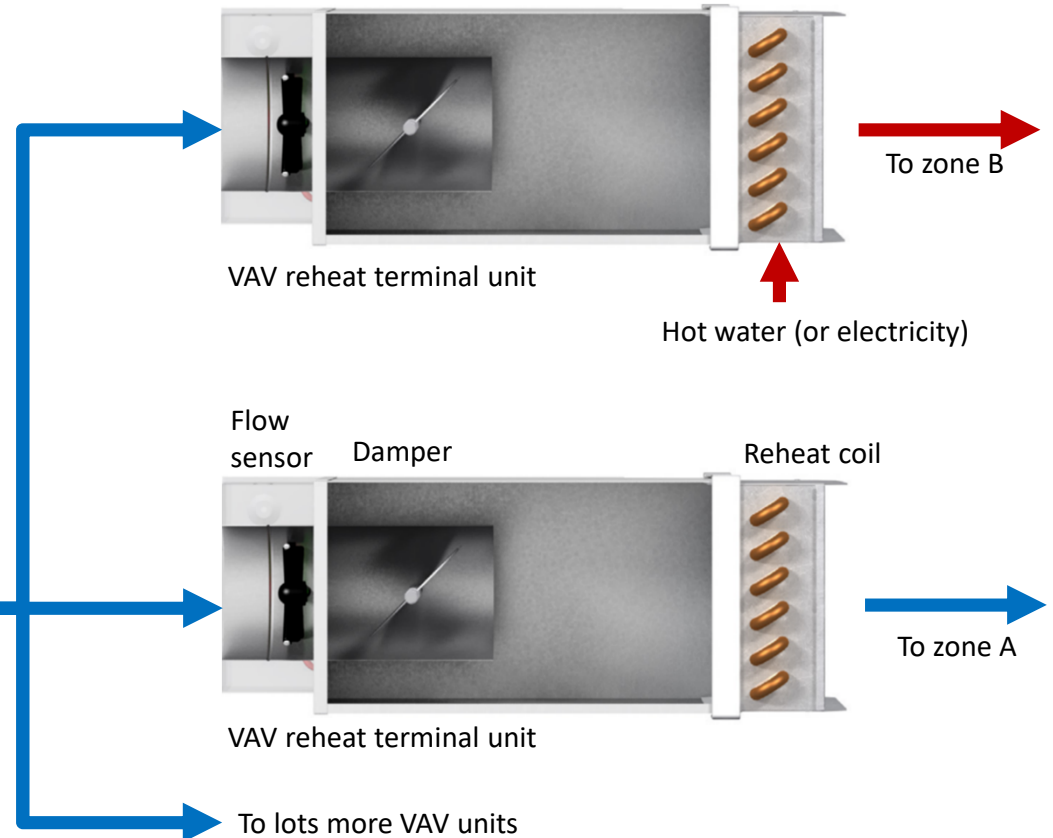
Background: What is reheat?

- Zone A needs cooling
- Zone B needs heating
- Heating by coils in the VAV terminal unit is known as 'reheat'
- We want to calculate *intentional* reheat used by all of the reheat coils



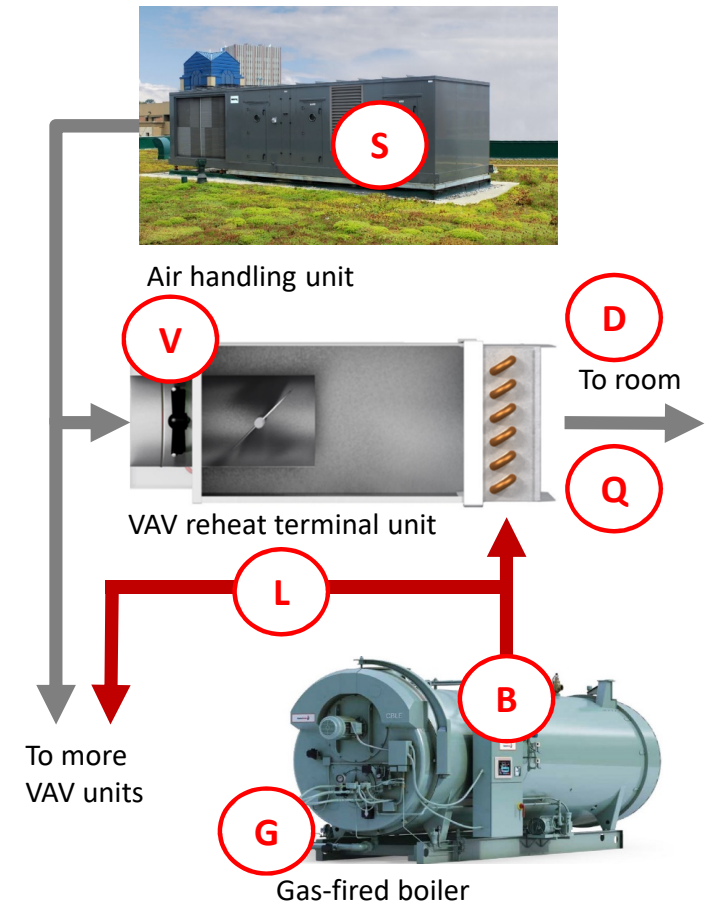
Air handling unit

Supplies
cool air
through
ductwork



New method for calculating intentional reheat use

- Use only sensors typically installed
- When reheat valve is (and has been) closed:
 - $Q = 0$
 - $\Delta T = D - S$ (long term average)
- When reheat valve is (or was recently) open:
 - Modified airside heat balance
 - $Q = (D - S - \Delta T) * V * \text{heat capacity}$
 - Discards duct and passing valves heat gains
- Measure heat supplied by boiler, B
- Hot water distribution losses, $L = B - \Sigma Q$
- Metered gas consumption, G



Field study overview

Building

- 5 floors, 120,000 ft² office
- Redwood City (California Bay Area)

HVAC

- Two DX roof top units
- Two gas boilers - serving only reheat
- 140 VAV boxes - 98 with reheat coils
- Full controls retrofit by Taylor Engineering
 - Best practice control sequences (ASHRAE Guideline 36)
 - Replaced all reheat valves

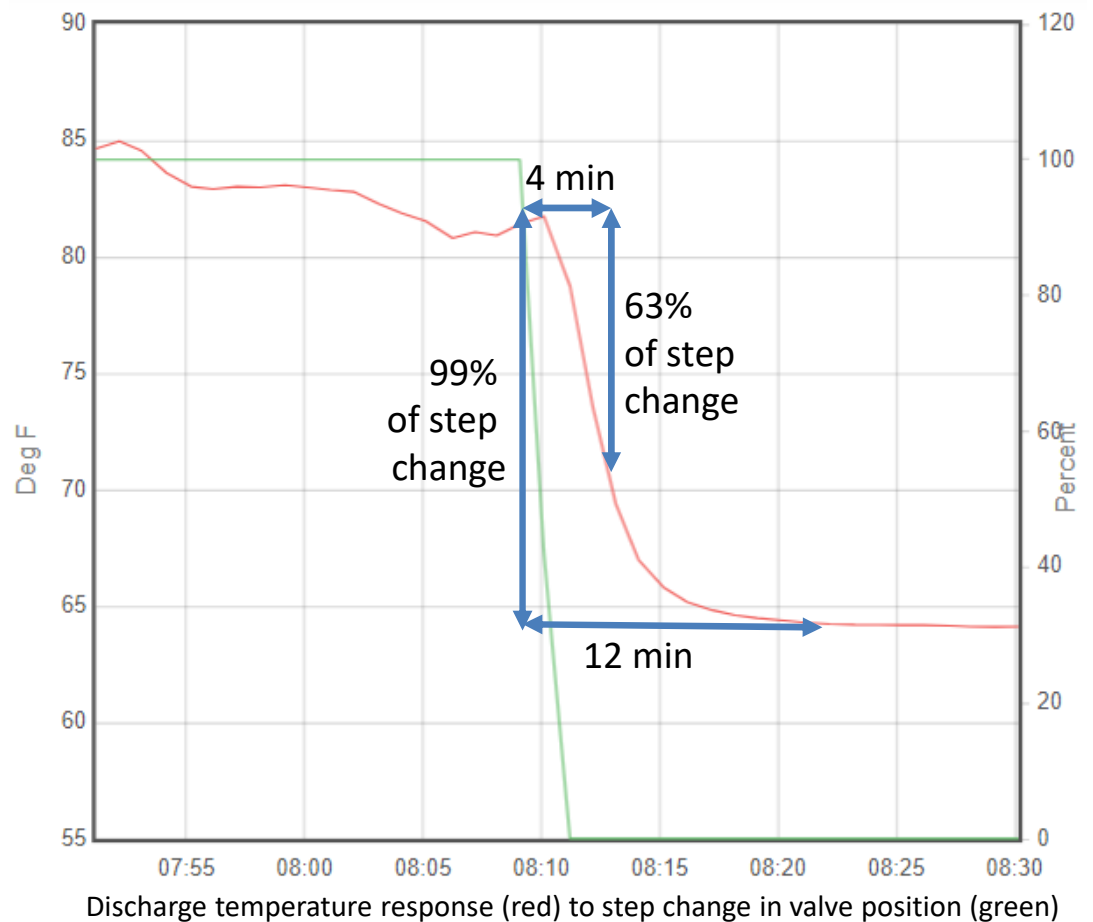
Data

- One year of 1-minute interval zone level data
- Measured gas consumed and hot water supplied by boiler



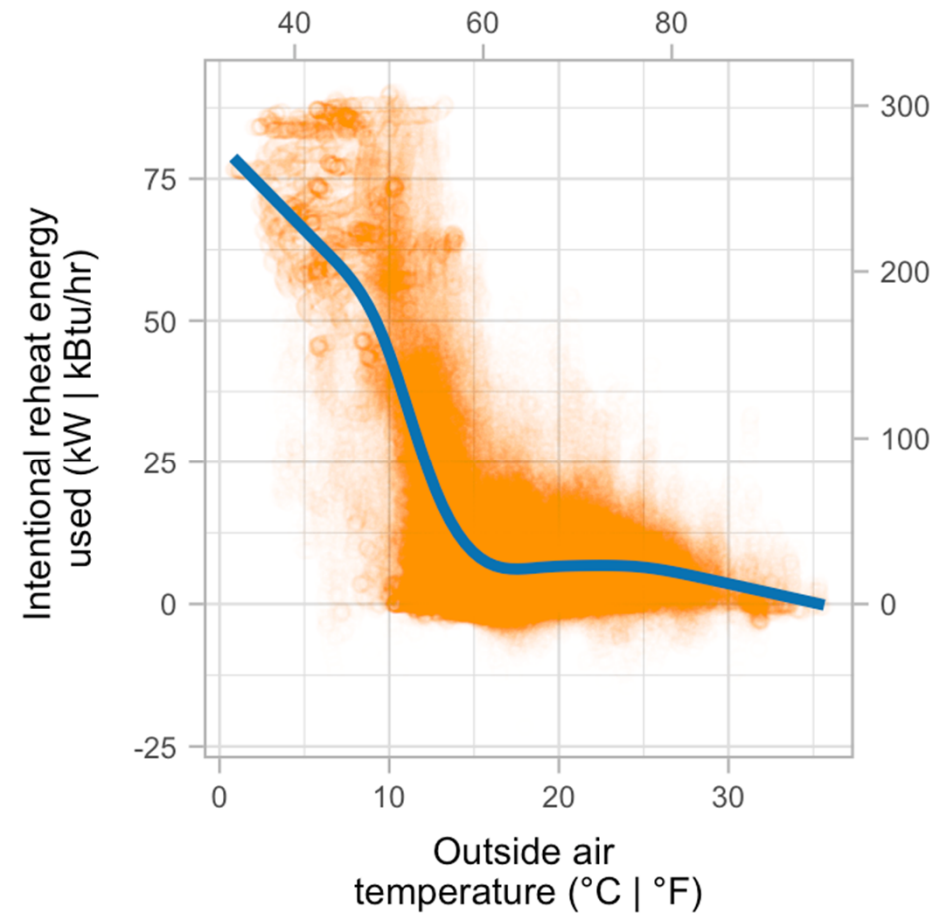
Transient effects

- When has a coil valve been closed long enough to:
 - Safely assume no further heat transfer
 - Begin updating the ΔT estimate
- Determine based on the time constant
 - Roughly 4 minutes in this building
 - After 3 time constants (12 minutes), 99% of the heat is lost from the static water in the coil
- Neglecting this effect reduces intentional reheat estimate by 5.4%

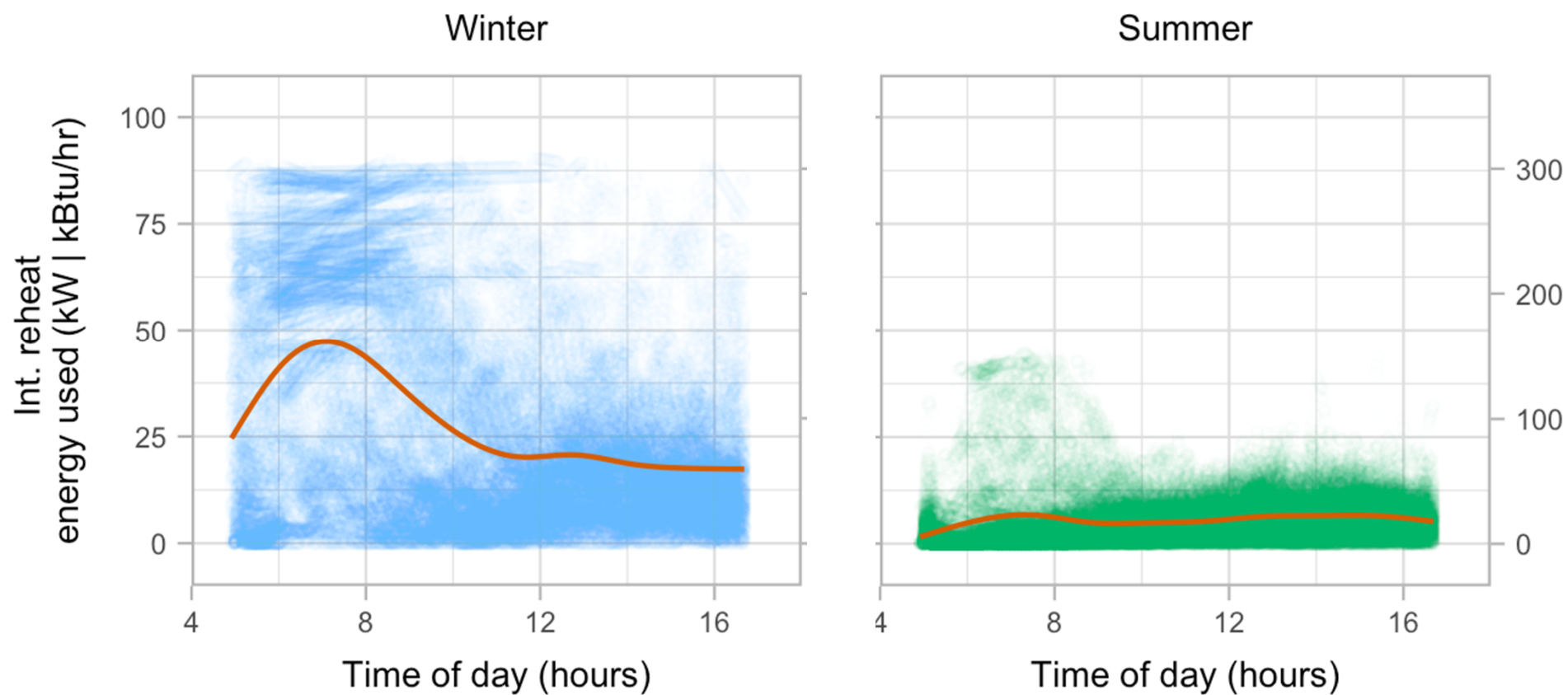


How does this building use reheat?

- Detailed analysis at building and zone level show reasonable, intuitive results
- 'Reheat' increases in colder weather (< 55 °F)

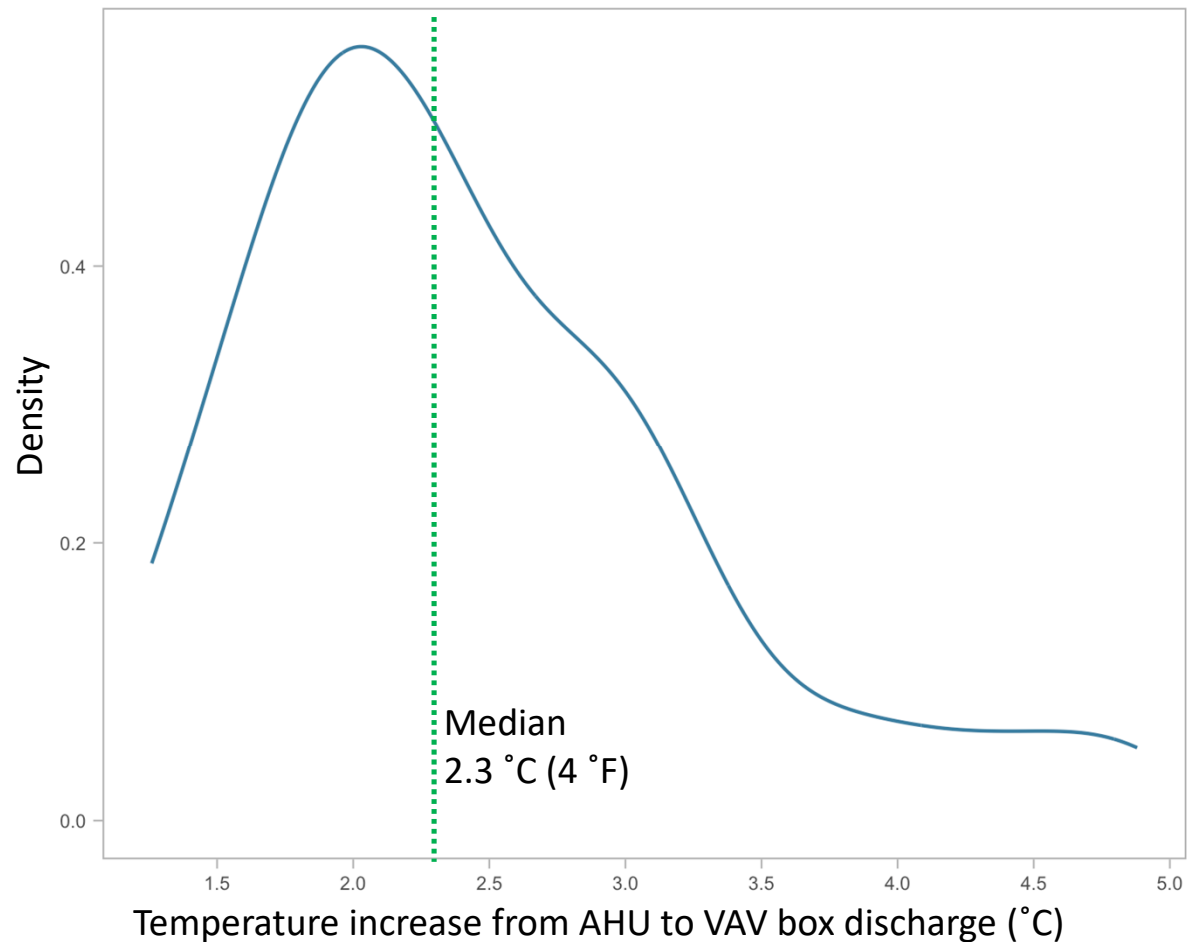


How does this building use reheat?



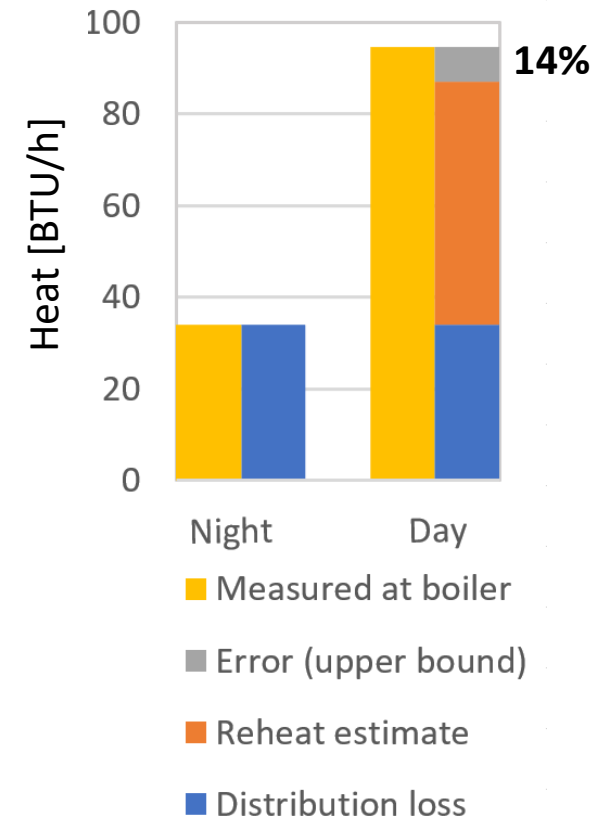
Duct heat gain

- Median duct heat gain from AHU to VAV box is 2.3 °C (4 °F) for all 98 zones in the building
- More than typically estimated at design condition (~ 2 °F) because duct velocity is much lower
- Annual median supply fan speed is 33%

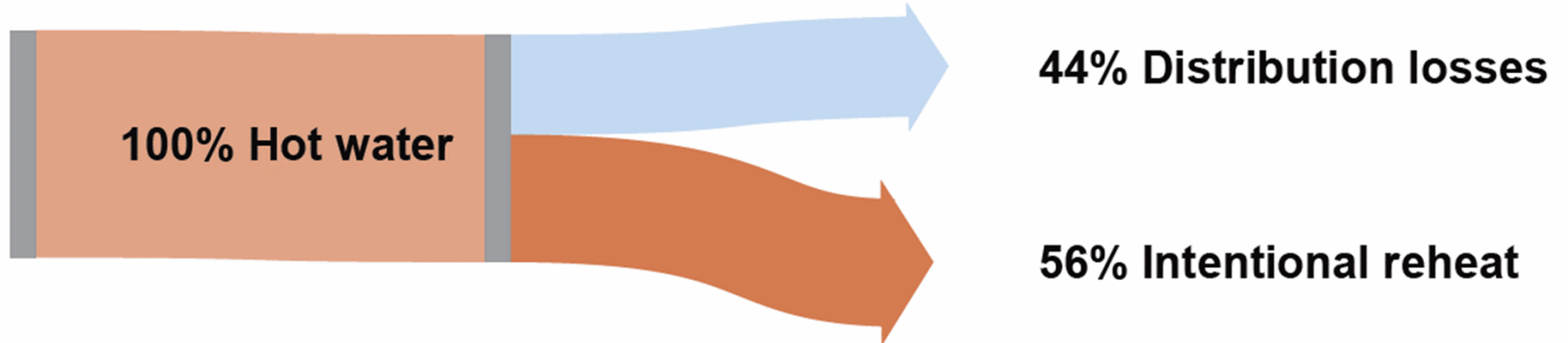


How accurate is the method?

- At night:
 - Boiler and pumps run due to leakage concerns
 - AHUs are off and reheat valves are closed
- Night time heat supplied by boiler is 'ground truth' lower bound for distribution loss during the day
- Method underestimates intentional reheat by at most 14%
- The rest of the presentation only shows data from operating hours, ignoring night time energy use.



Results



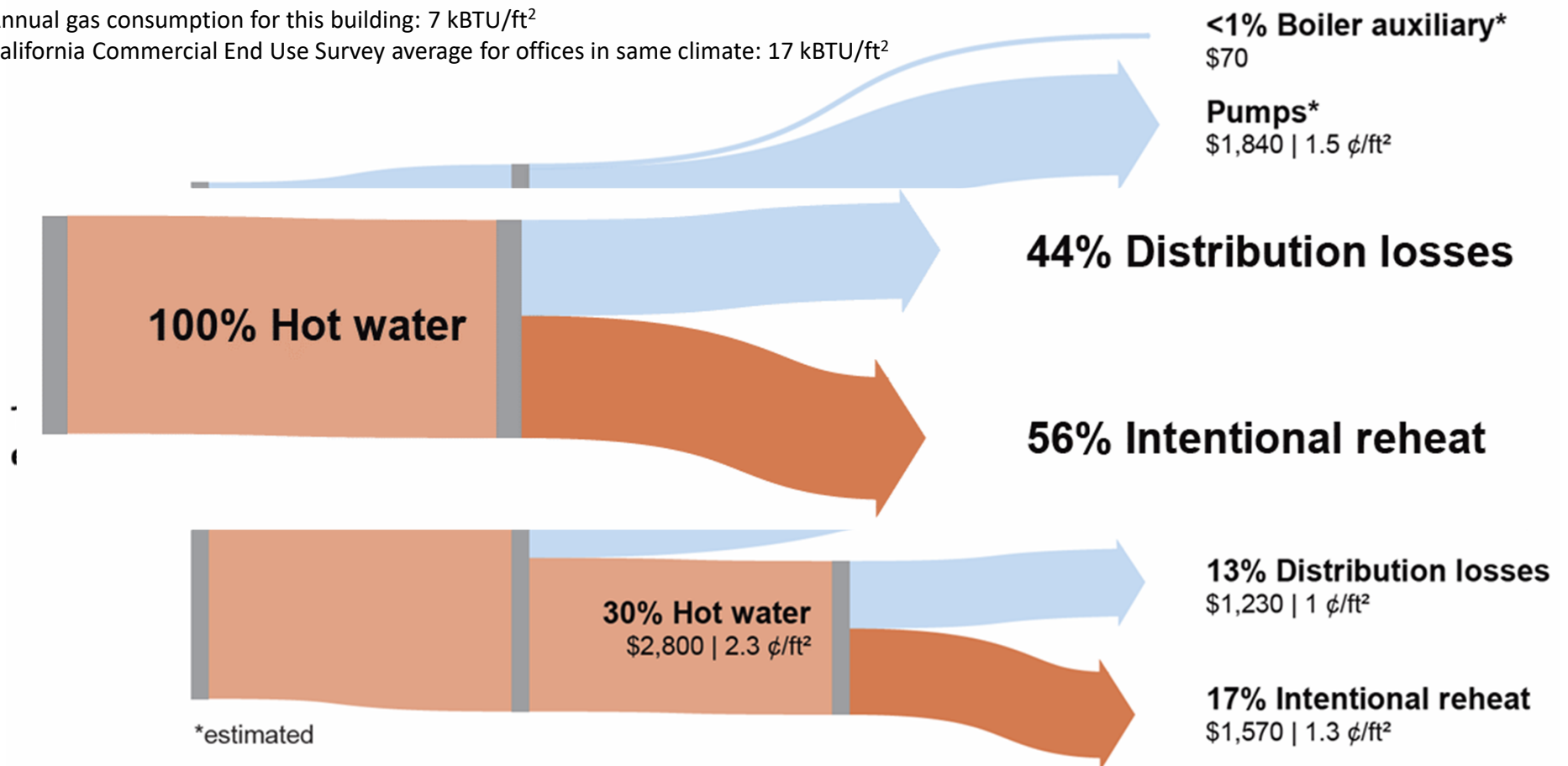
Finding 1

Hot water distribution losses are significant

Results

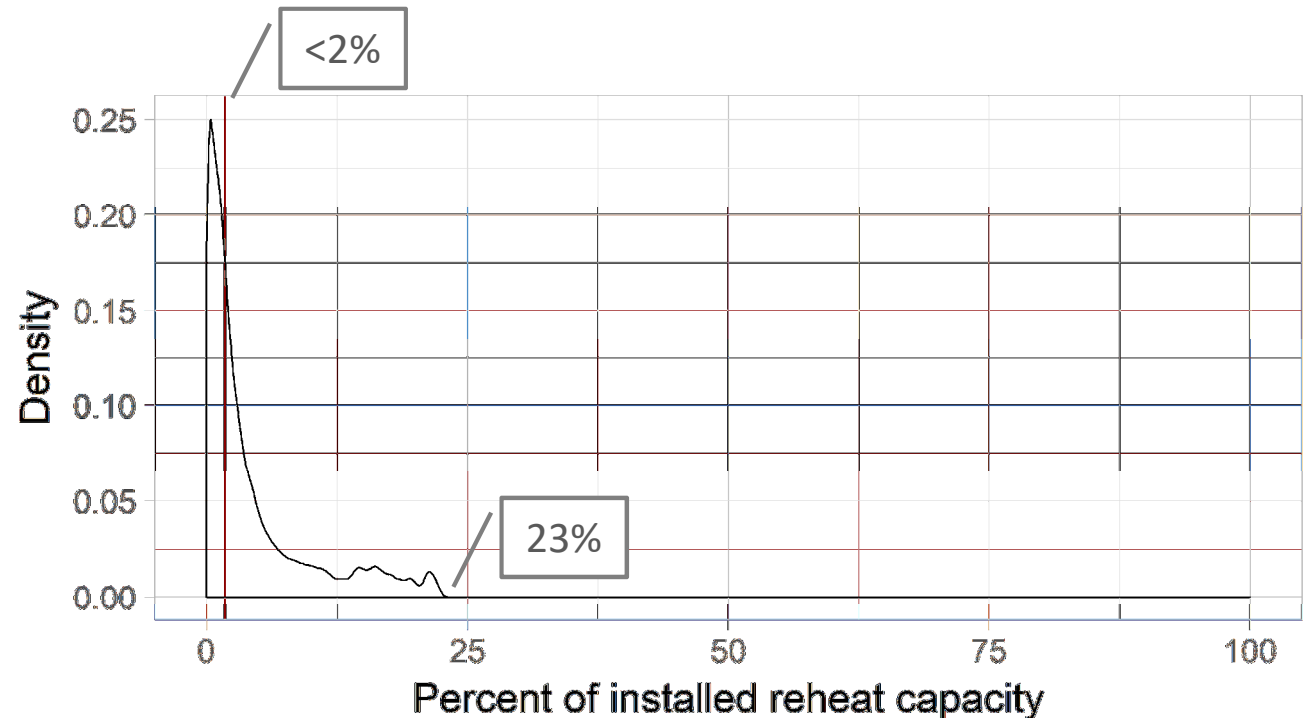
Annual gas consumption for this building: 7 kBTU/ft²

California Commercial End Use Survey average for offices in same climate: 17 kBTU/ft²



Why is the overall efficiency so low?

- Reheat loads are **very low**
 - Median reheat use is < 2% of total installed reheat capacity
 - Maximum reheat use is 23% of total installed capacity
- Distribution losses are relatively fixed
 - 0.3 BTU/h.ft²
 - 44% of total heat supplied by the boiler

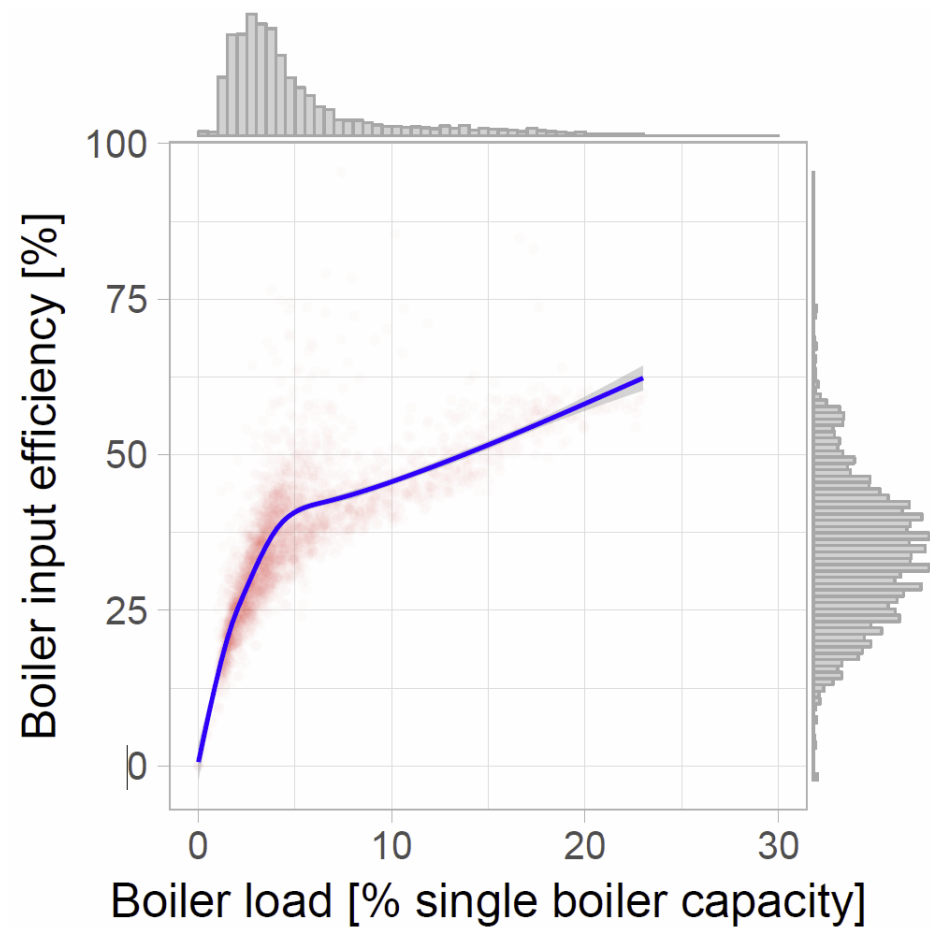


Finding 2

Reheat energy use is surprisingly low (with modern controls)

Why is the overall efficiency so low? (continued)

- Boilers are operating at **37% efficiency**:
 - Atmospheric type – no stack damper
 - Oversized
 - Poor part load efficiency – short cycling
 - Staging issues
- But.... most boiler plants would operate inefficiently with these low loads



Finding 3

Boiler part load efficiency losses are significant

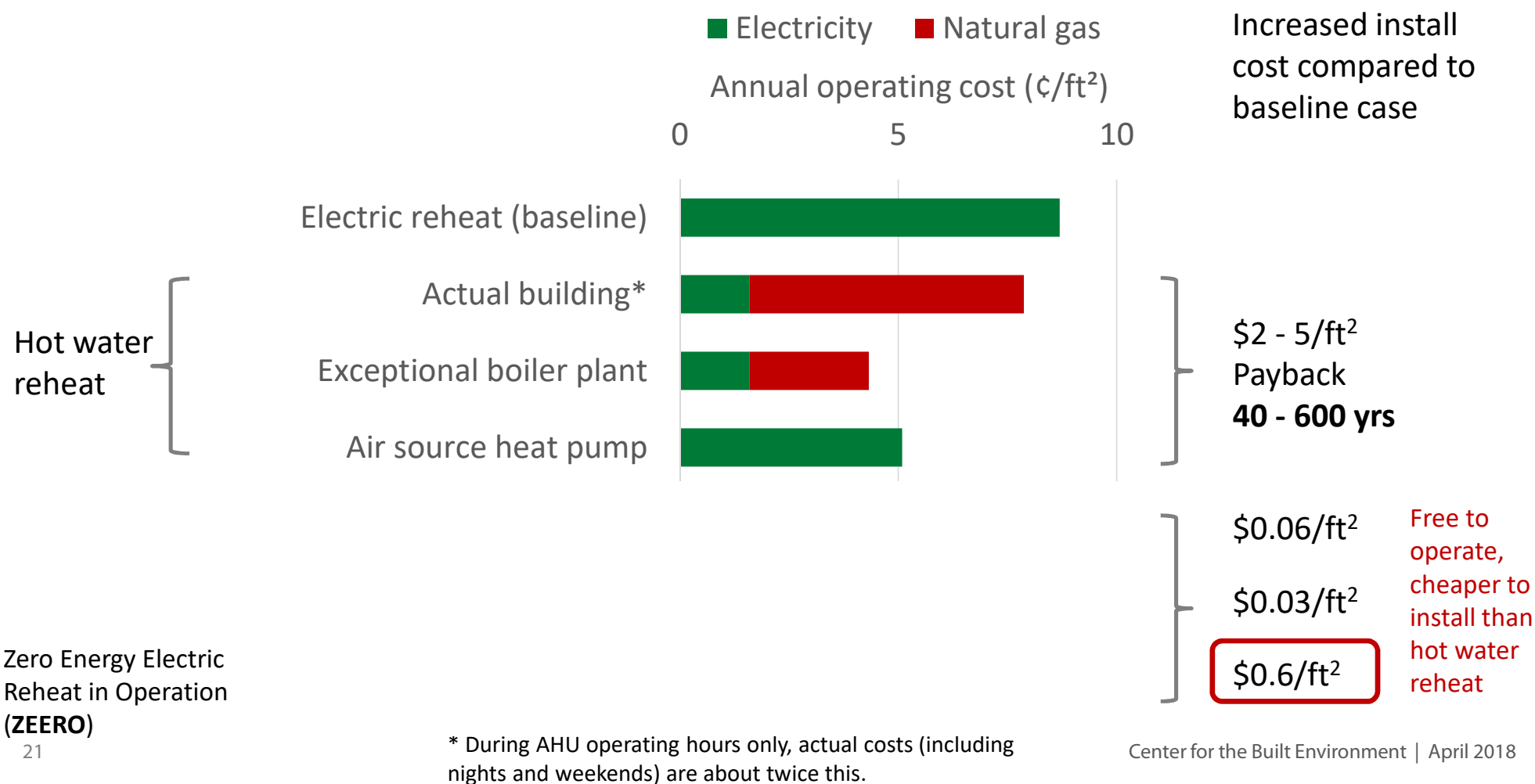
Comparison to electric reheat baseline

- Hot water reheat costs \$2 - 5/ft² more to install than electric reheat
- First cost premium justified based on estimated operating cost savings:
 - Assuming higher reheat energy use
 - Assuming boiler nominal efficiency
 - Ignoring distribution losses

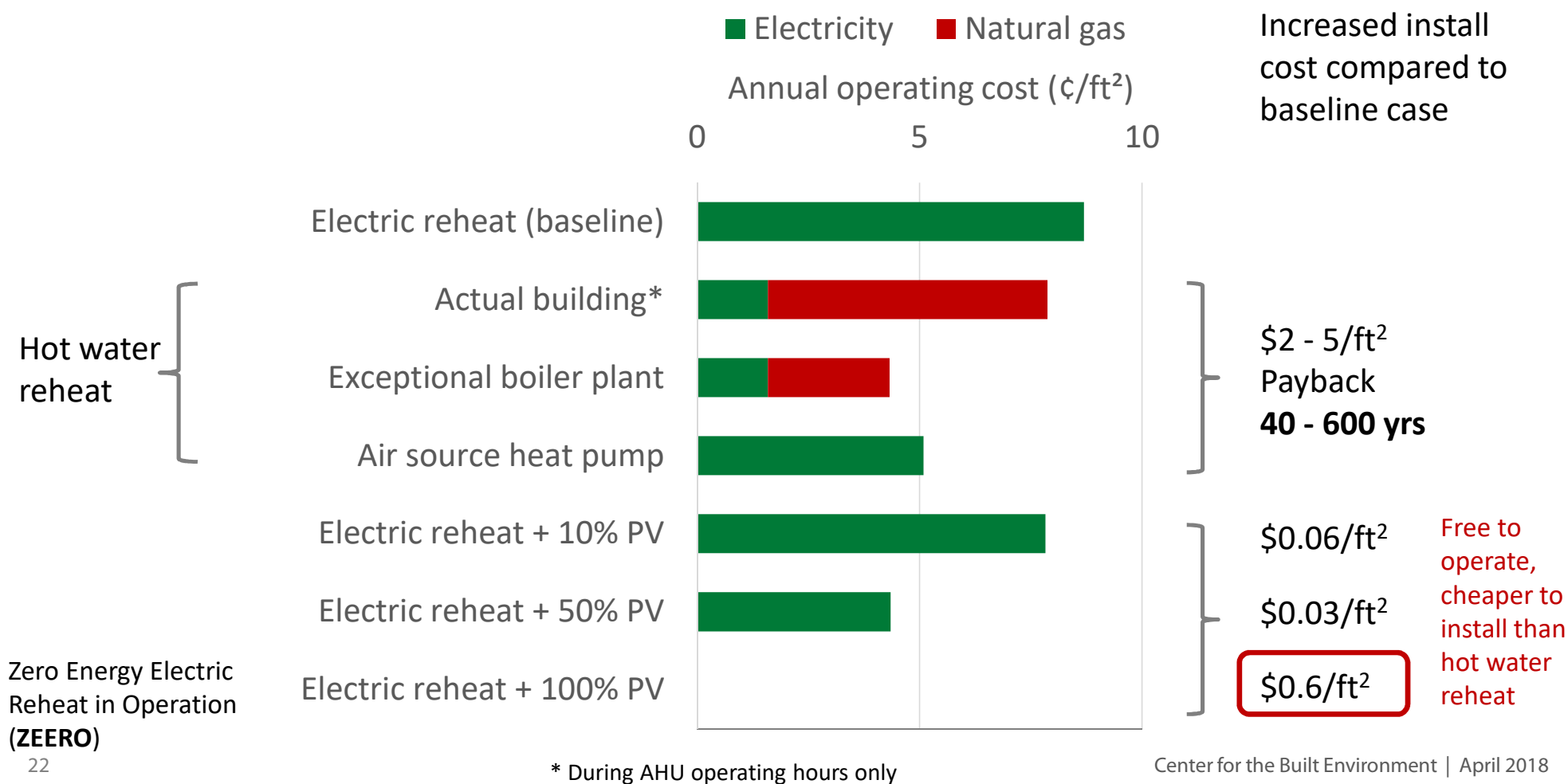
Comparison cases

- High quality electric reheat case (baseline)
 - Modulating Silicon Controlled Rectifier (SCR)
 - Electronic sensor allows control to low airflow
- Actual boiler case (37% efficient)
 - Oversized, inefficient boiler
 - Staging issues
- Exceptional boiler plant (86% efficient)
 - High efficiency condensing gas boiler with 20:1 turndown
 - Boiler plant size = installed reheat capacity
 - Ideally operated and maintained 2-stage boiler plant
- Air source heat pump
 - Average COP of 4

Cost comparison using reheat loads measured in the field study



Cost comparison using reheat loads measured in the field study



Finding 4

Electric reheat & PV would save on
installation and operation costs while
reducing energy use.

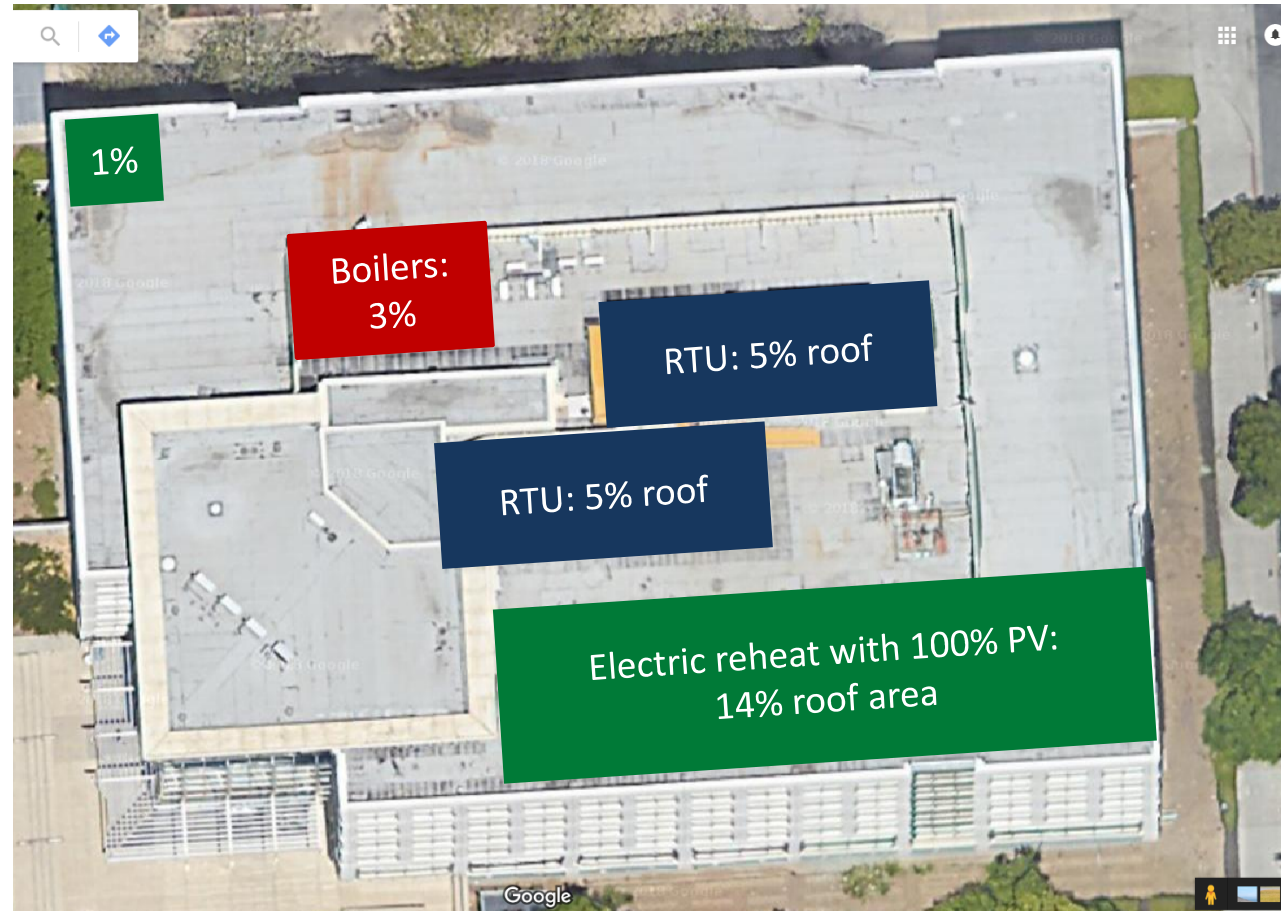
Roof area

Electric reheat with 10% PV

- Lower operating cost than actual building
- Covers 1.4% roof area
- Boiler plant covers 3% of roof area

Electric reheat with 100% PV

- 100% PV: 14% roof area
- ~ equal to boiler area and shading the RTUs with PV



Roof of 555 County Center

How typical is this building compared to others in the same climate?

- The building has new controls, correct ventilation airflow setpoints, and new valves
- Average intentional reheat consumption (0.44 BTU/h.ft²) is similar to Sutardja Dai Hall (0.35 BTU/h.ft²), an office in the same climate zone.
- Gas consumption (7 kBTU/ft²) is lower, but not excessively so, when compared to other buildings:
 - Mean gas consumption for office buildings in the same climate from the California Commercial End Use Survey is 17 kBTU/ft²
 - 5 other buildings where we know reheat is the only gas consumer:
8.6, 16, 17, and 22 kBTU /ft²



Sutardja Dai Hall

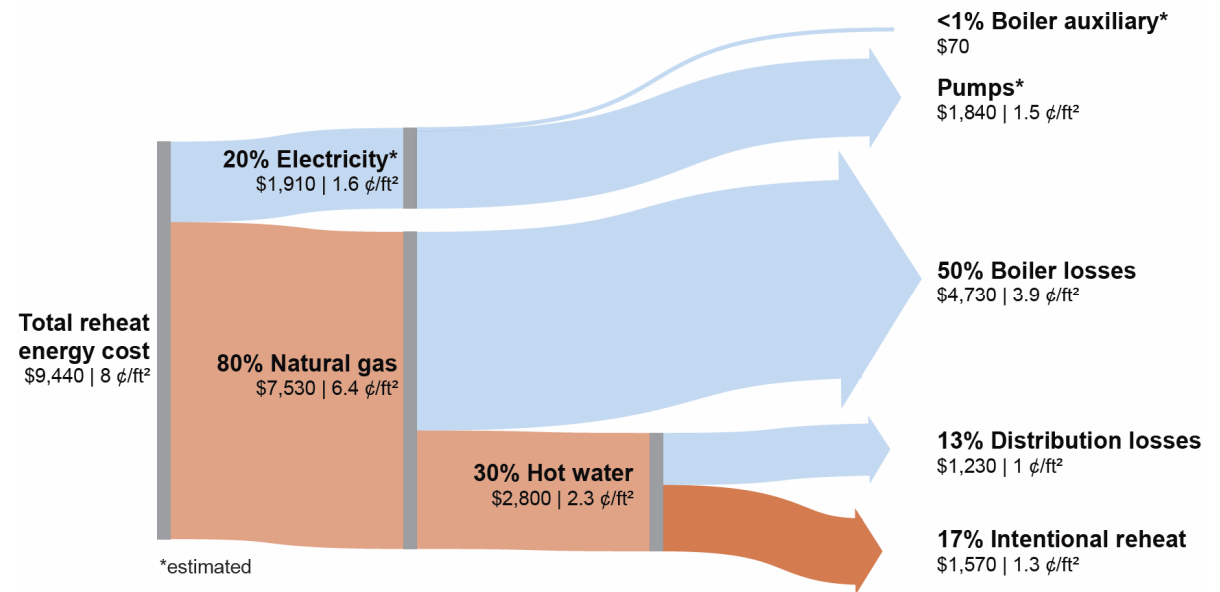
In closing

Practical implications

- Size reheat-only boiler plants smaller than current practice and use 20:1 turndown boilers
- Consider electric reheat and PV instead of hot water reheat

Next steps

- Repeat analysis in other buildings and climates
- Improve electric vs hot water reheat first cost comparison



Flow of operating energy costs in a hot water reheat system

Annual gas consumption for this building: 7 kBTU/ft²

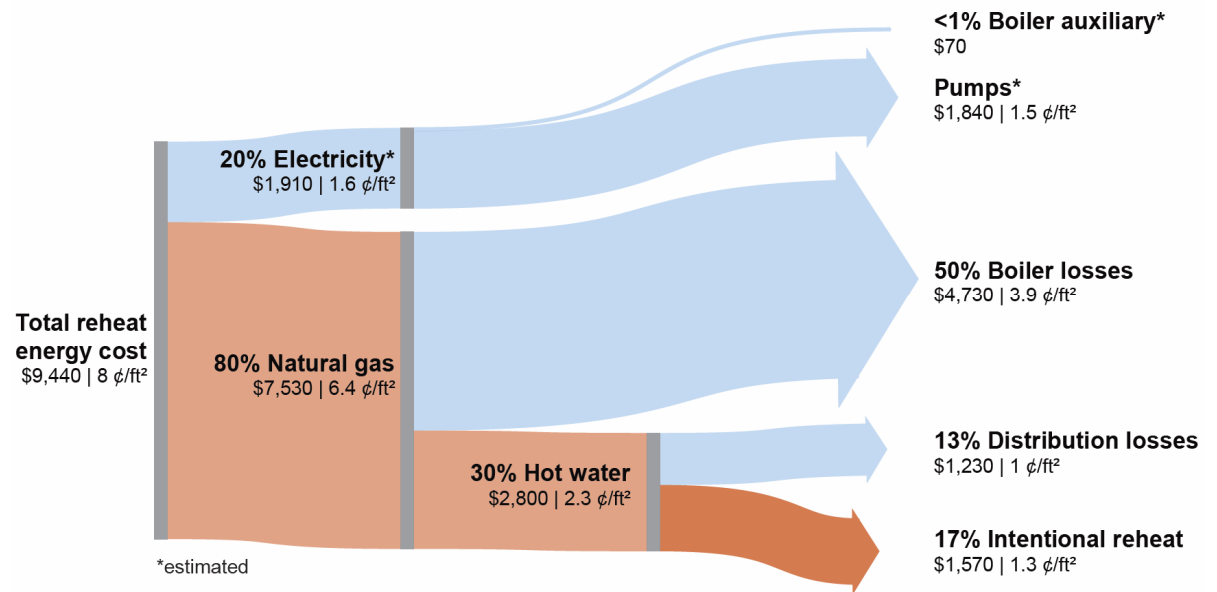
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Q&A

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More detail in
journal article:
bit.ly/reheat-loss

Take a look at distribution
losses in your own building:
Run the hot water system at
night with all reheat valves
closed and measure the gas
consumed



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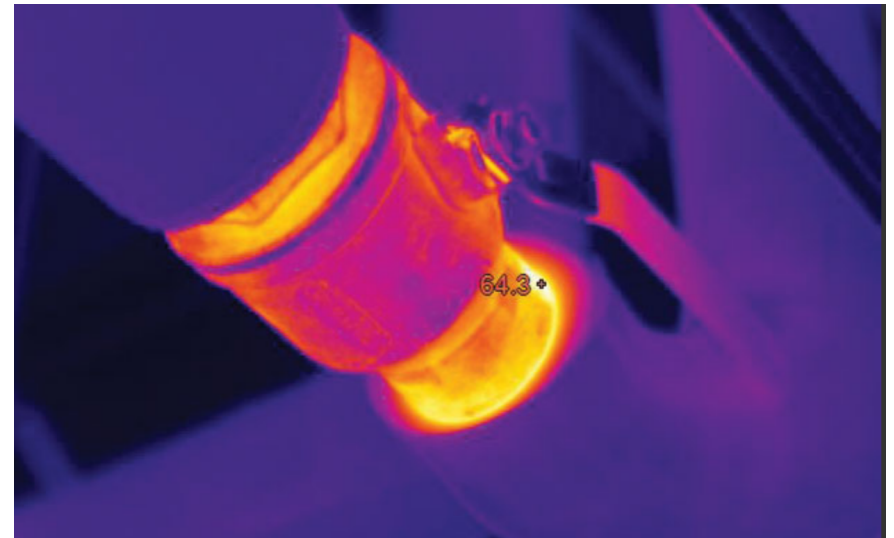
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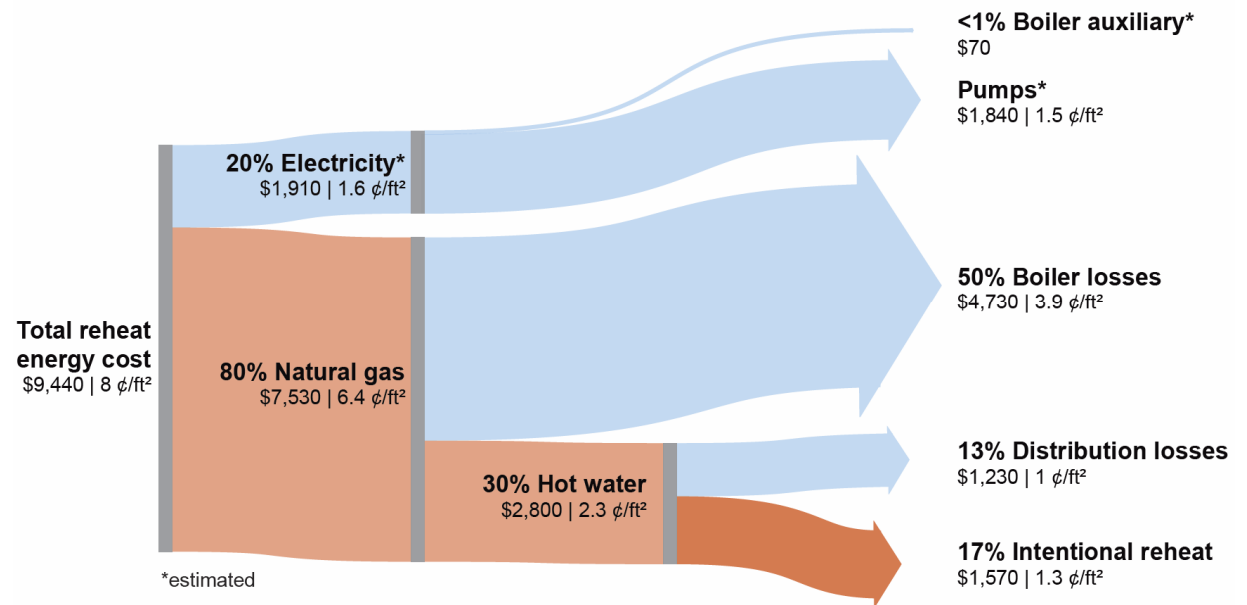
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Heat loss from hot water piping

Conclusions

- VAV reheat systems typically operate at ultra-low part load. Especially true with:
 - Modern controls (dual-maximum logic)
 - Low minimum airflow rates
 - Mild winter climates
- Hot water distribution losses are significant in practice; 44% in this building
- Boiler operation, sizing, and efficiency at part load critical to overall efficiency; 37% in this building
- Electric reheat with PV may save on installation and operation costs while reducing (site and source) energy use.



Flow of operating energy costs in a hot water reheat system.

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