# Steam Systems, Retrofit Measure Packages, Hydronic Systems

Russell Ruch
Elevate Energy

Peter Ludwig
Elevate Energy

PARR
The Partnership for Advanced Residential Retrofit

ELEVATE ENERGY
Smarter energy use for all

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

Building AMERICA
U.S. Department of Energy

# 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

# Retrofit Packages Study

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

"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

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

# Retrofit Packages



## 6-Unit Steam Building, built 1927

## 31.8% Site Savings

| Measure | Cost | Annual MMBtu Site Savings | Annual MMBtu Source Savings | Annual $ Savings | Percent Site Savings | Payback Years |
|---|---|---|---|---|---|---|
| Insulate steam pipes | 1,450 | 54.30 | 54.30 | 543 | 4.8% | 2.7 |
| Air seal and insulate roof cavity | 4,612 | 124.06 | 124.06 | 1,240 | 10.9% | 3.7 |
| Install low flow fixtures | 0* | 12.85 | 12.85 | 129 | 1.1% | -- |
| Install boiler controls & indoor sensors | 3,395 | 65.48 | 65.48 | 655 | 5.7% | 5.2 |
| Insulate domestic hot water pipes | 1,200 | 8.13 | 8.13 | 81 | 0.7% | 14.8 |
| Resize risers and replace main line vents | 5,890 | 97.99 | 97.99 | 980 | 8.6% | 6.0 |

# Retrofit Packages



- Significant, cost-effective savings are possible in old steam & hydronic buildings

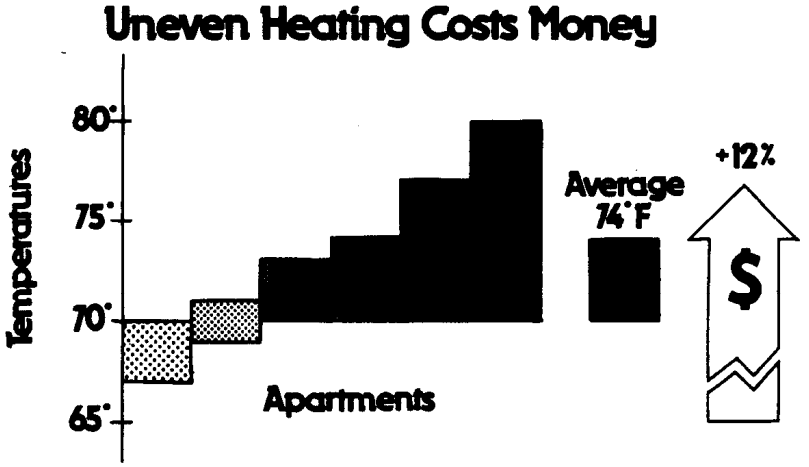
- The most cost-effective packages address
  - Thermal envelope (air sealing & insulating roof cavity, basement)
  - Heating controls (outdoor reset, temperature averaging)
  - Distribution (heating and DHW pipe insulation, system balancing)
  - Lighting fixtures

- 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?

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

## Utility savings

- Katrakis, J. et al (2010): 5-15% savings, 2-5 yr payback
- PARR: average 10% off heating load in steam bldgs

## Tenant comfort

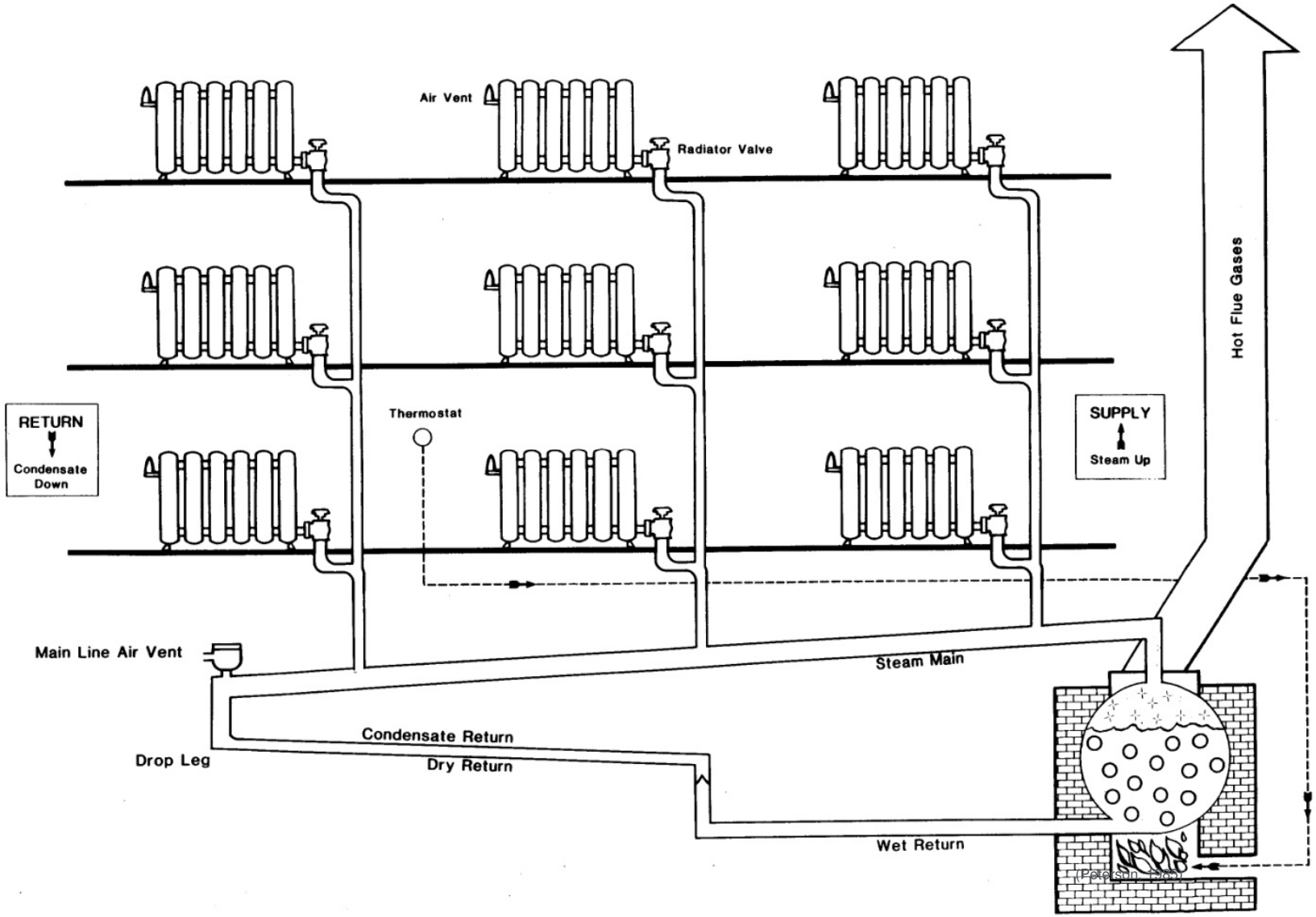
- Fewer open windows in winter
- Less supplemental heating e.g. space heaters, oven ranges
- Reduce humidity & moisture control issues

## Operation savings

- Improving tenant comfort can stabilize occupancy
- Reduce the time spent dealing with low-heat calls

# Steam Heating Basics

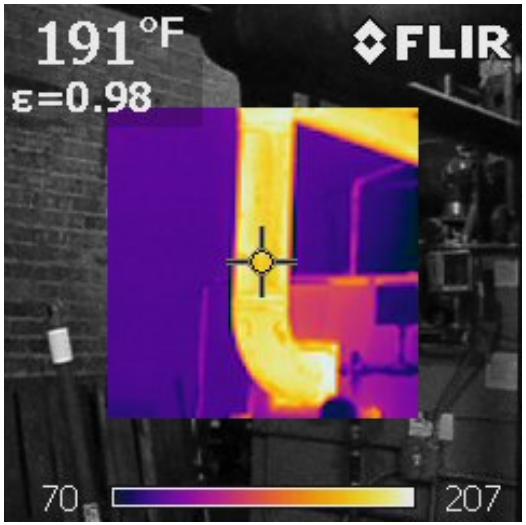


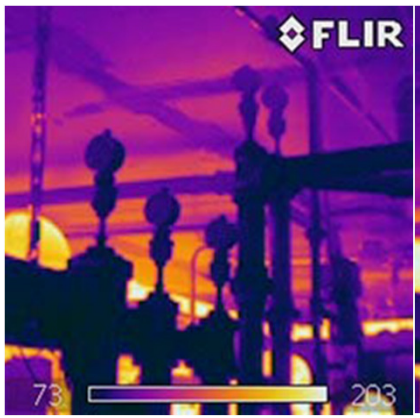


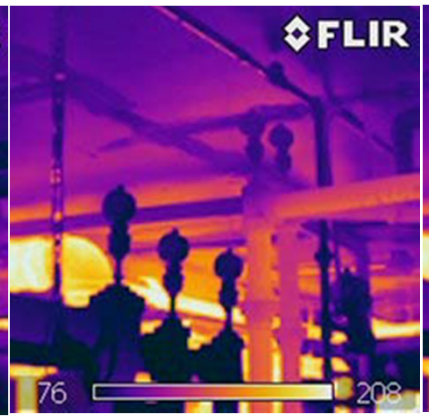
# Steam Heating Basics

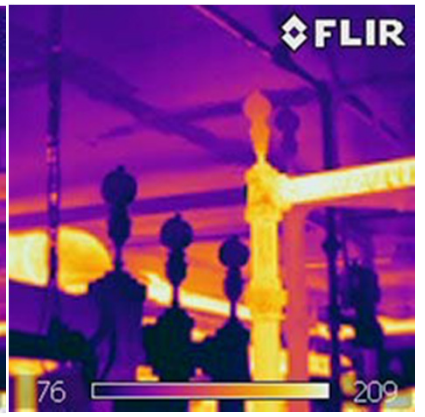


In the boiler room:



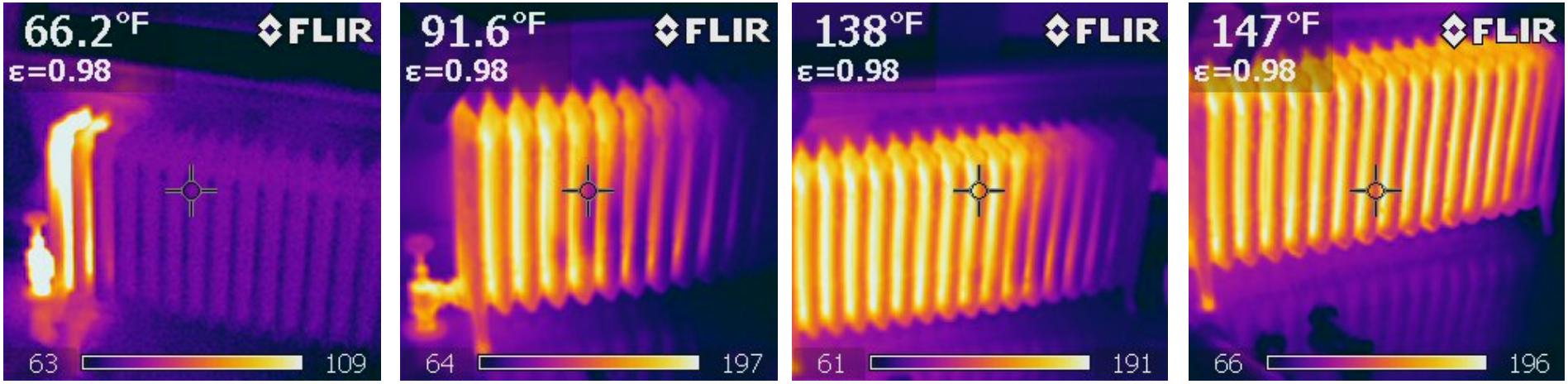




Boiler turns on | 8 min | 30 min

# Steam Heating Basics

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

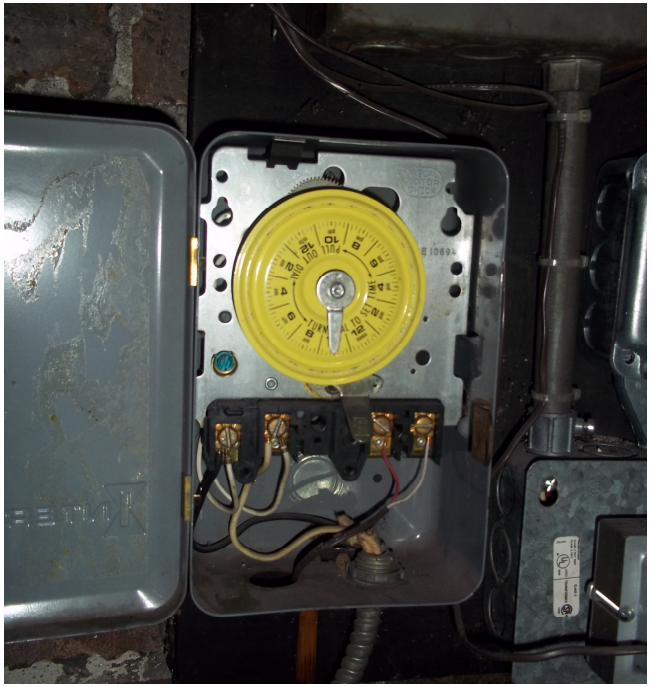
Meanwhile, in a unit:




This is what should happen during a boiler cycle; however, there are often problems…

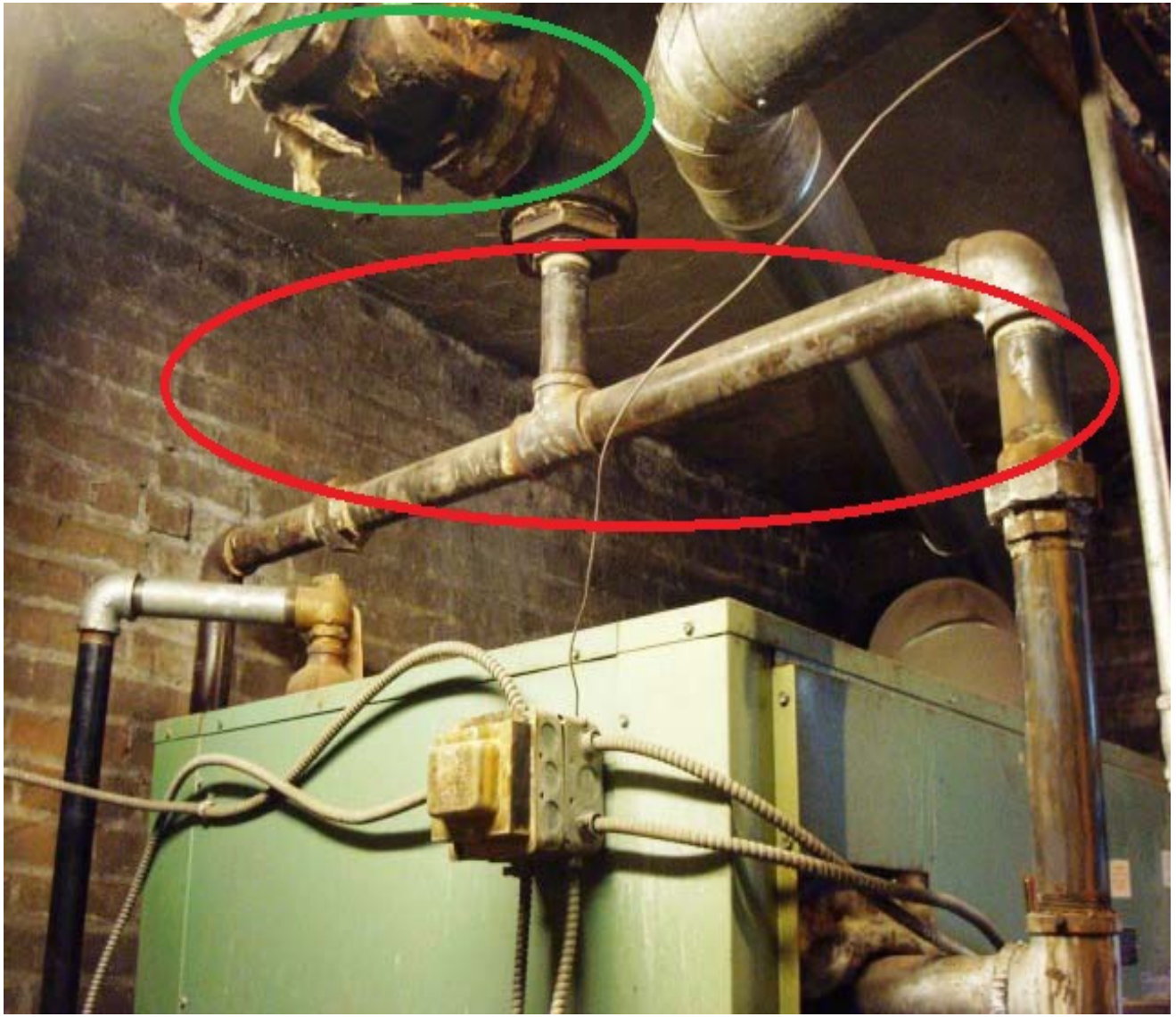
# Steam Heating Basics - Problems

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



# 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

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

"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

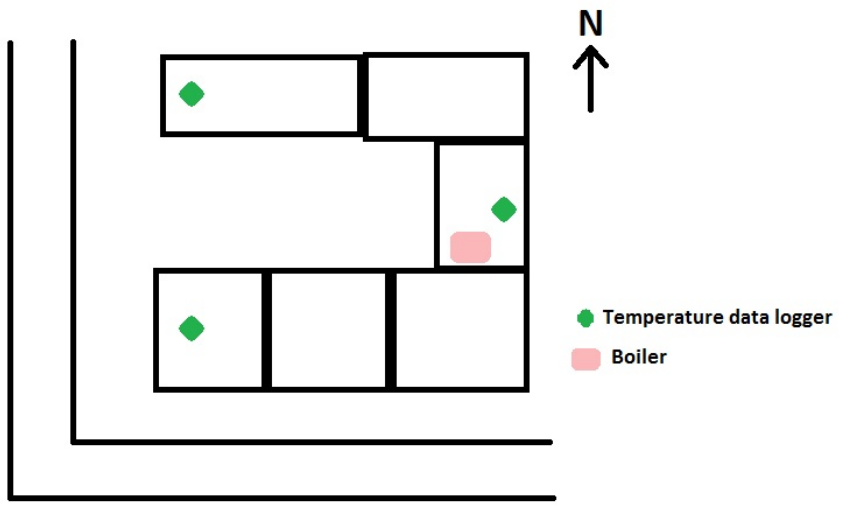


- 10 buildings
- Single-pipe steam
- 15-30 units
- Uneven heating
- Boiler in good condition

# Steam Balancing Study - Timeline



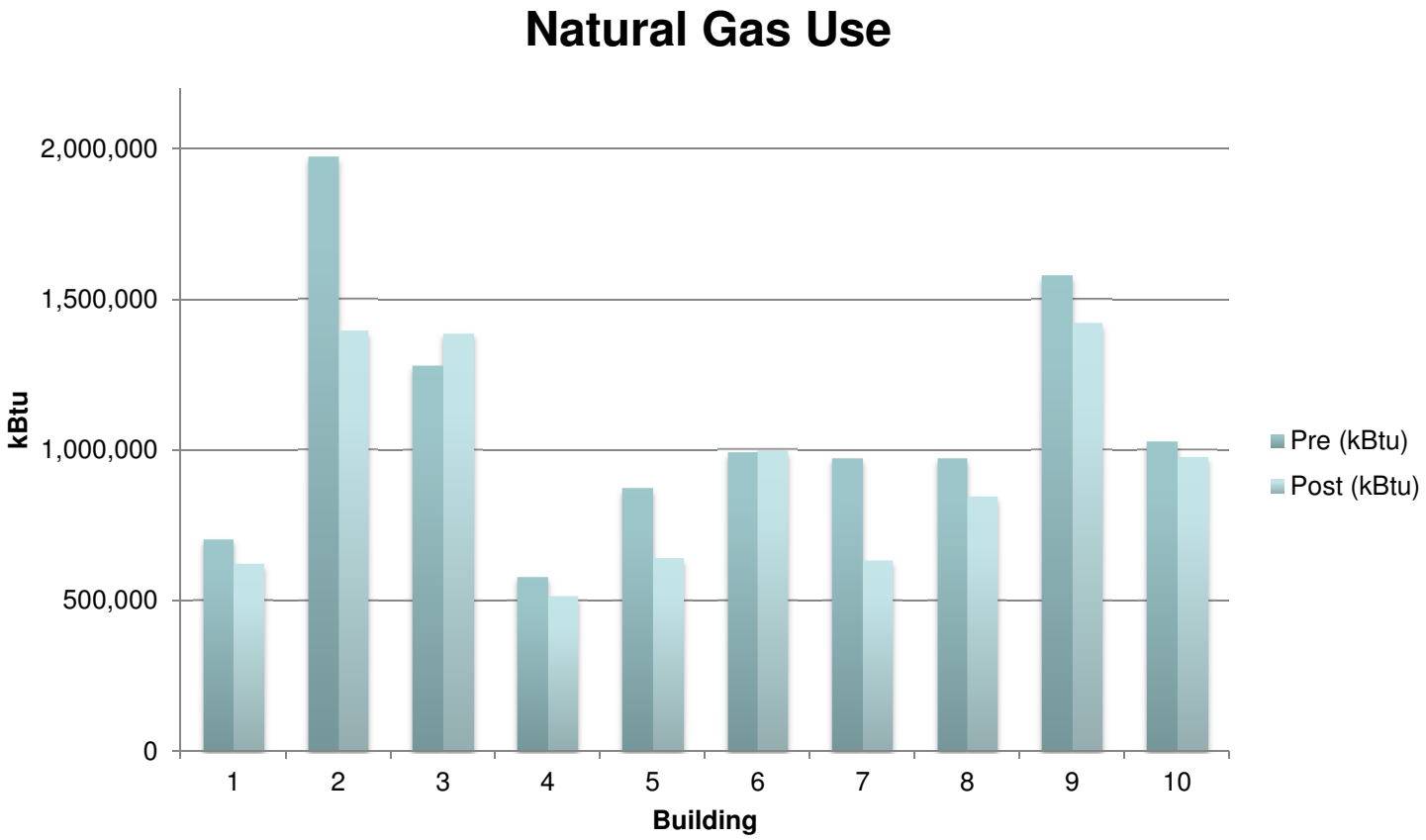
1. Collected pre-retrofit data
   - Building, boiler, piping, condition of vents, existing controls
   - Data logging of unit temperatures, boiler cycles
   - Tenant survey, heat calls
2. Developed detailed scopes for steam balancing work to be done
3. Oversaw general contracting and inspected work
4. Collected post-retrofit temp data
5. Conducted utility bill analysis comparing pre- and post-retrofit energy use



# Steam Balancing Study

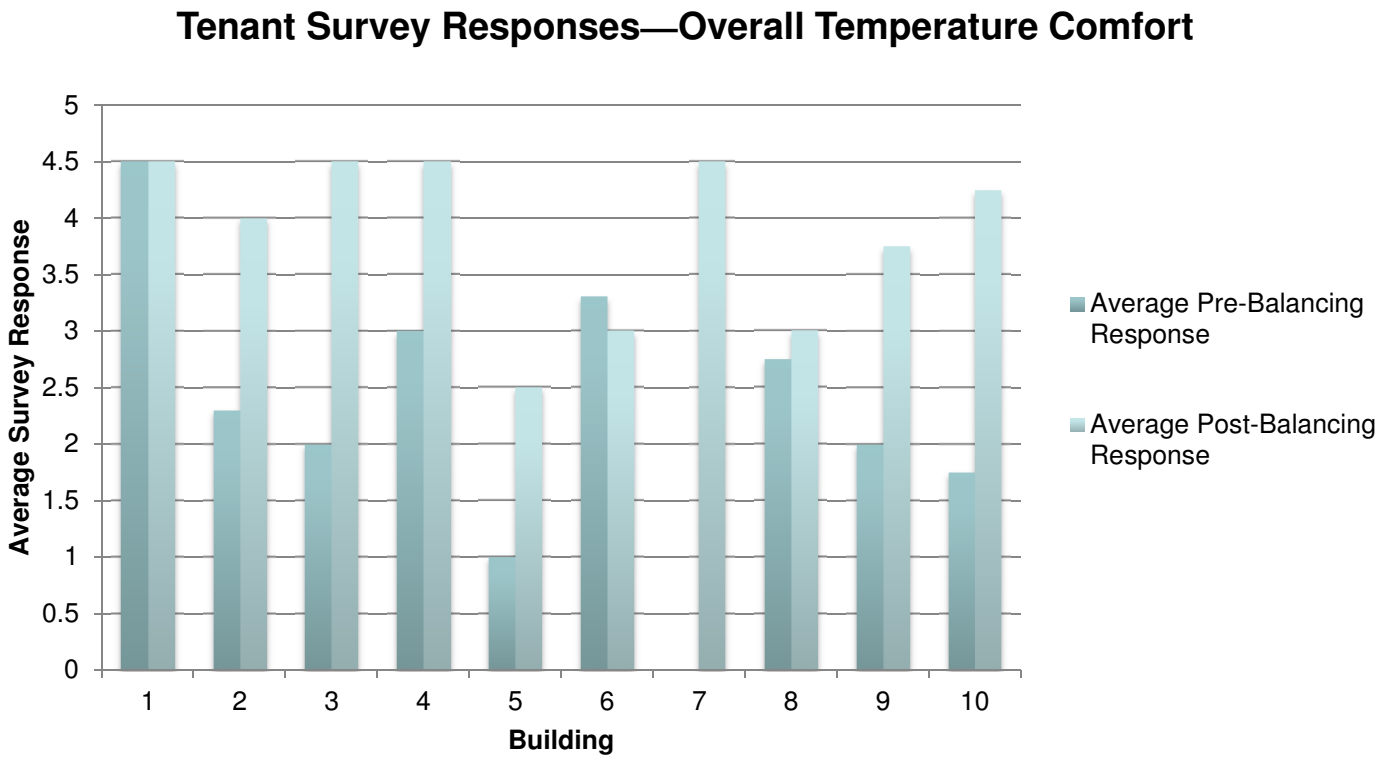


| Measure | Average Cost |
|---|---|
| Adding or upgrading to high-capacity main line air vents (with new risers) | $1,800 |
| Replacing Radiator Vents | $3,680 |
| Upgrading Boiler Control System | $5,060 |


Natural Gas Use
2,000,000
1,500,000
1,000,000
500,000
0
kBtu
1
2
3
4
5
6
7
8
9
10
Building
Pre (kBtu)
Post (kBtu)

# Steam Balancing Study






**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.**

# Steam Balancing Study

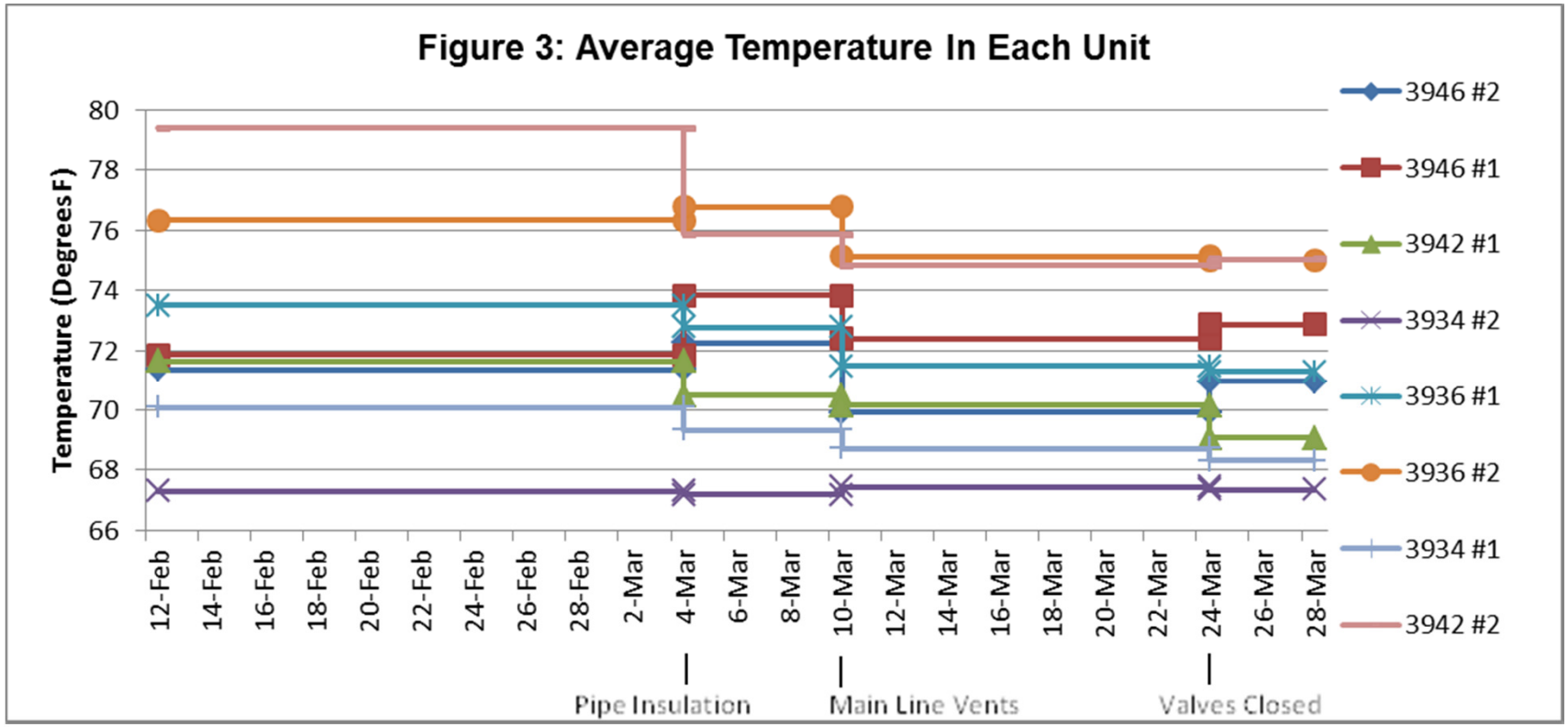


| Building | Natural Gas Use From Energy Use Intensity (kBtu) | | | |
|---|---|---|---|---|
| | Pre-Balancing | Post-Balancing | # of Months in Analysis Periods | % Savings |
| 1 | 703,119 | 621,371 | 8 | 11.63% |
| 2 | 1,971,622 | 1,394,456 | 9 | 29.27% |
| 3 | 1,280,991 | 1,388,438 | 11 | 8.39% |
| 4 | 578,751 | 514,142 | 11 | 11.16% |
| 5 | 873,111 | 640,519 | 9 | 26.64% |
| 6 | 990,039 | 995,768 | 11 | 0.58% |
| 7 | 972,393 | 633,350 | 10 | 34.87% |
| 8 | 972,476 | 844,398 | 8 | 13.17% |
| 9 | 1,578,954 | 1,420,073 | 10 | 10.06% |
| 10 | 1,027,457 | 977,787 | 10 | 4.83% |

**Table 6. Measured Weather-Normalized Natural Gas Use (Heating Only)**

# Steam Balancing Study





# 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)

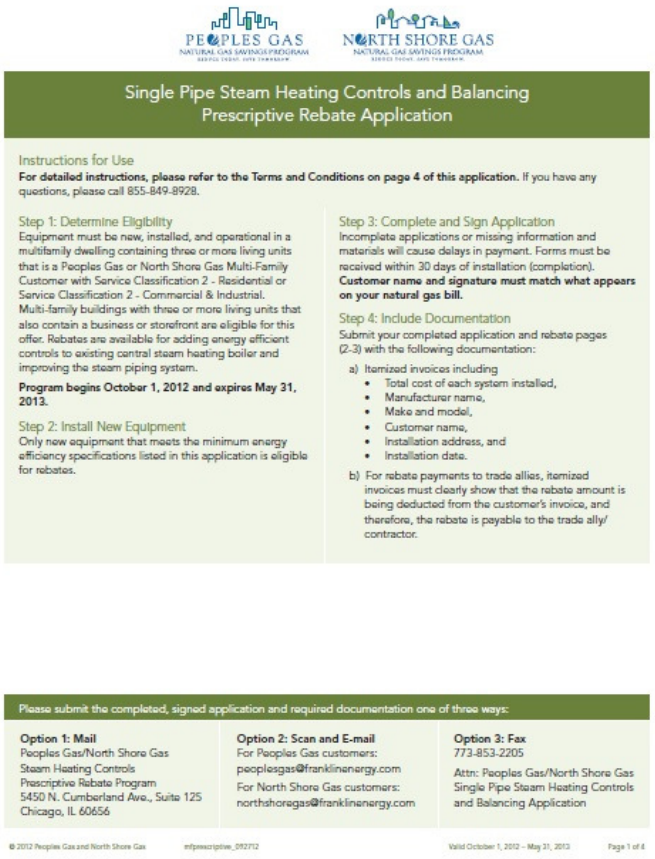
**Procedure**

- 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



PEOPLES GAS NATURAL GAS SAVINGS PROGRAM

NORTH SHORE GAS NATURAL GAS SAVINGS PROGRAM

**Single Pipe Steam Heating Controls and Balancing Prescriptive Rebate Application**

Instructions for Use

**For detailed instructions, please refer to the Terms and Conditions on page 4 of this application.** If you have any questions, please call 855-849-8928.

Step 1: Determine Eligibility

Equipment must be new, installed, and operational in a multifamily dwelling containing three or more living units that is a Peoples Gas or North Shore Gas Multi-Family Customer with Service Classification 2 - Residential or Service Classification 2 - Commercial & Industrial. Multi-family buildings with three or more living units that also contain a business or storefront are eligible for this offer. Rebates are available for adding energy efficient controls to existing central steam heating boiler and improving the steam piping system.

**Program begins October 1, 2012 and expires May 31, 2013.**

Step 2: Install New Equipment

Only new equipment that meets the minimum energy efficiency specifications listed in this application is eligible for rebates.

Step 3: Complete and Sign Application

Incomplete applications or missing information and materials will cause delays in payment. Forms must be received within 30 days of installation (completion). **Customer name and signature must match what appears on your natural gas bill.**

Step 4: Include Documentation

Submit your completed application and rebate pages (2-3) with the following documentation:

a) Itemized invoices including
- Total cost of each system installed,
- Manufacturer name,
- Make and model,
- Customer name,
- Installation address, and
- Installation date.

b) For rebate payments to trade allies, itemized invoices must clearly show that the rebate amount is being deducted from the customer's invoice, and therefore, the rebate is payable to the trade ally/ contractor.

Please submit the completed, signed application and required documentation one of three ways:

**Option 1: Mail**
Peoples Gas/North Shore Gas
Steam Heating Controls
Prescriptive Rebate Program
5450 N. Cumberland Ave., Suite 125
Chicago, IL 60656

**Option 2: Scan and E-mail**
For Peoples Gas customers:
peoplesgas@franklinenergy.com
For North Shore Gas customers:
northshoregas@franklinenergy.com

**Option 3: Fax**
773-853-2205
Attn: Peoples Gas/North Shore Gas
Single Pipe Steam Heating Controls
and Balancing Application

 mfpresctiptive_092712 Valid October 1, 2012 – May 31, 2013 Page 1 of 4

- 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

# Hydronic Balancing Study

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

"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

# Hydronic Balancing Study



- 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

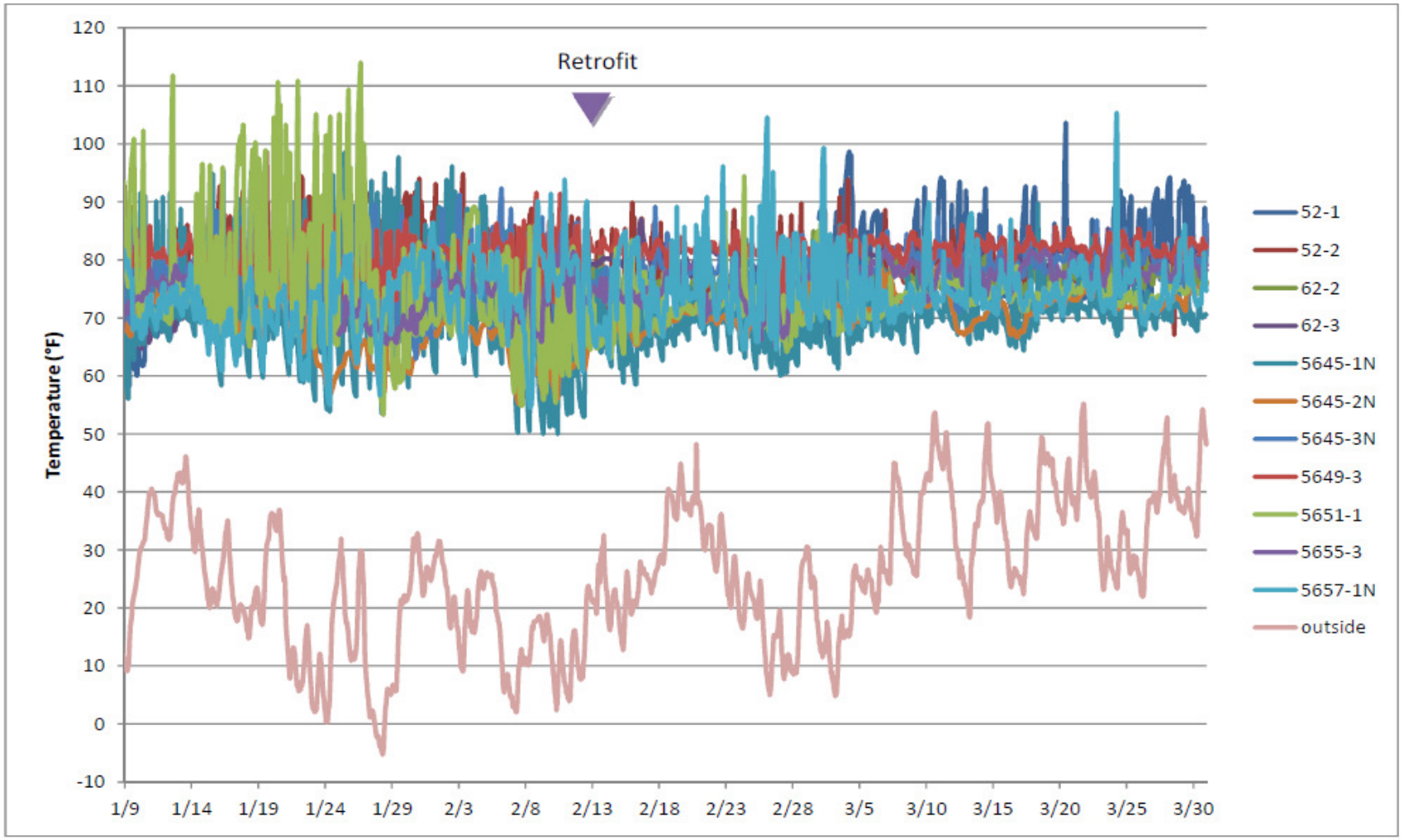
# Hydronic Balancing Study



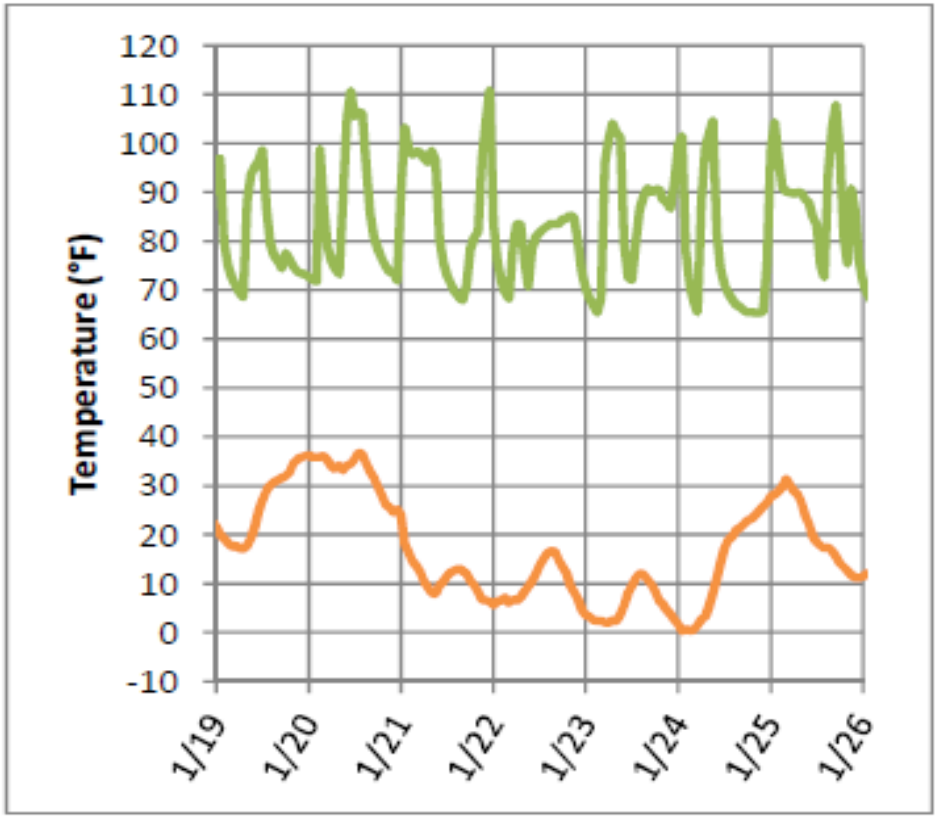

## Building A

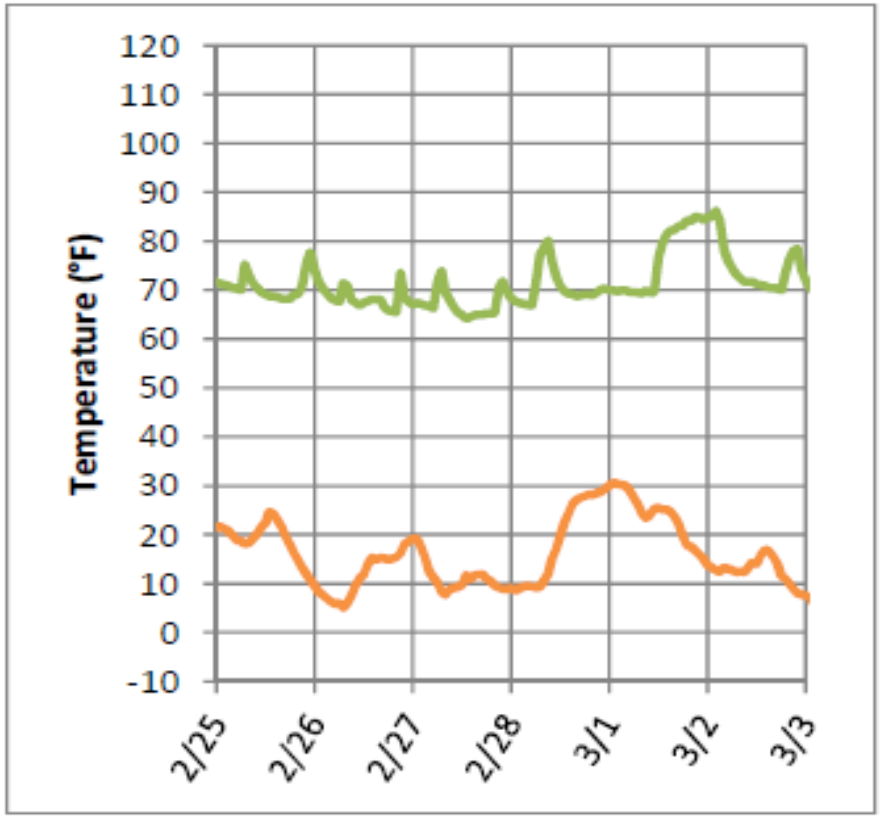
- 33 units, 3 stories
- Built 1920, 39,500 ft$^2$
- Baseboard radiators
- "S"-shaped, 2 zones
  - West: 5657, 5655, 5653
  - East: 5651, 5649, 5647, 5645, 62, 52
- Piping undersized, west loop chronically underheated

## Building A temperatures, pre- and post-retrofit



## Temperatures, pre- and post-retrofit, in Unit 5651-1



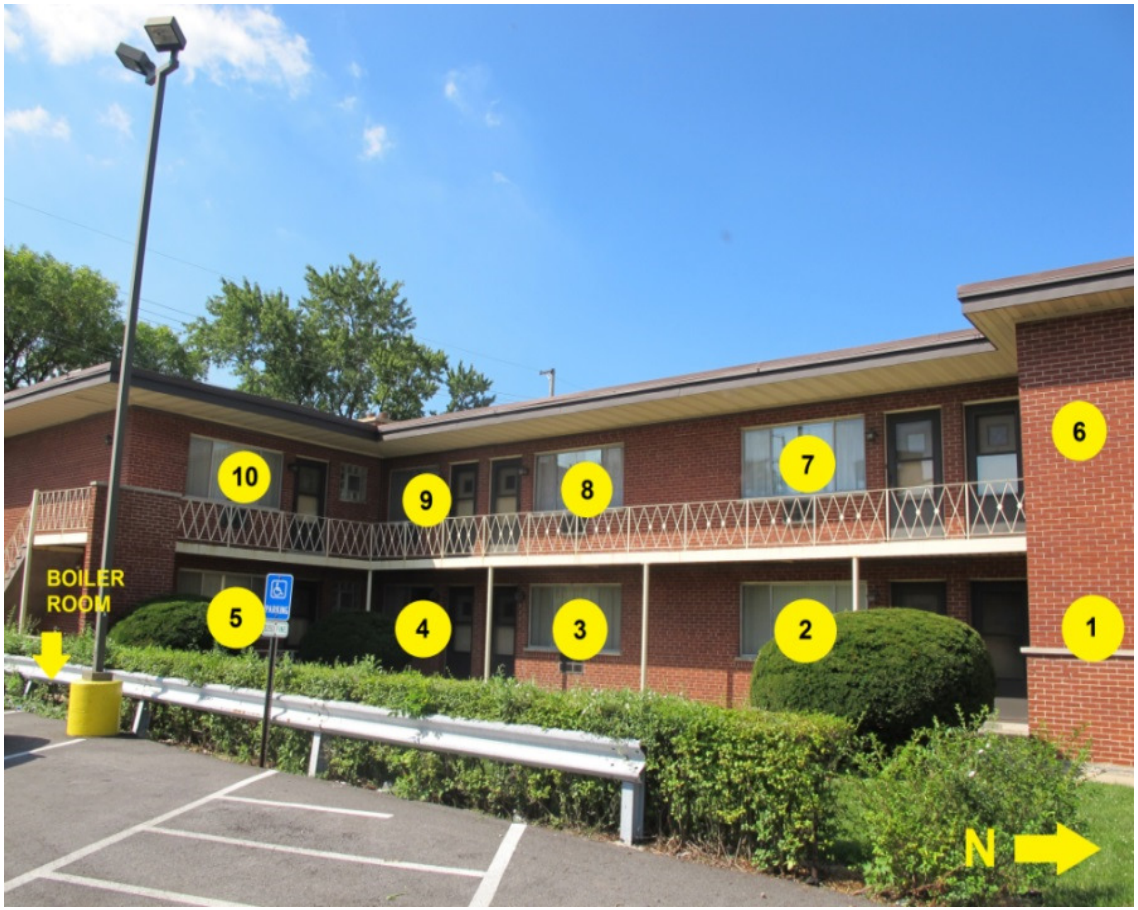



## Temperature imbalance in Building A

| | Pre retrofit | Post retrofit |
|---|---|---|
| **Proportion of half hour intervals in which building spread >30°F** | 17.3% | 1.3% |
| **Proportion of half hour intervals in which building spread <15°F** | 25.4% | 52.4% |

# Hydronic Balancing Study






## Building B

- 10 units, 2 stories
- Built 1961, 6,750 $ft^2$
- Underfloor radiant
- Zoned by unit (thermostats)
- First floor chronically overheated

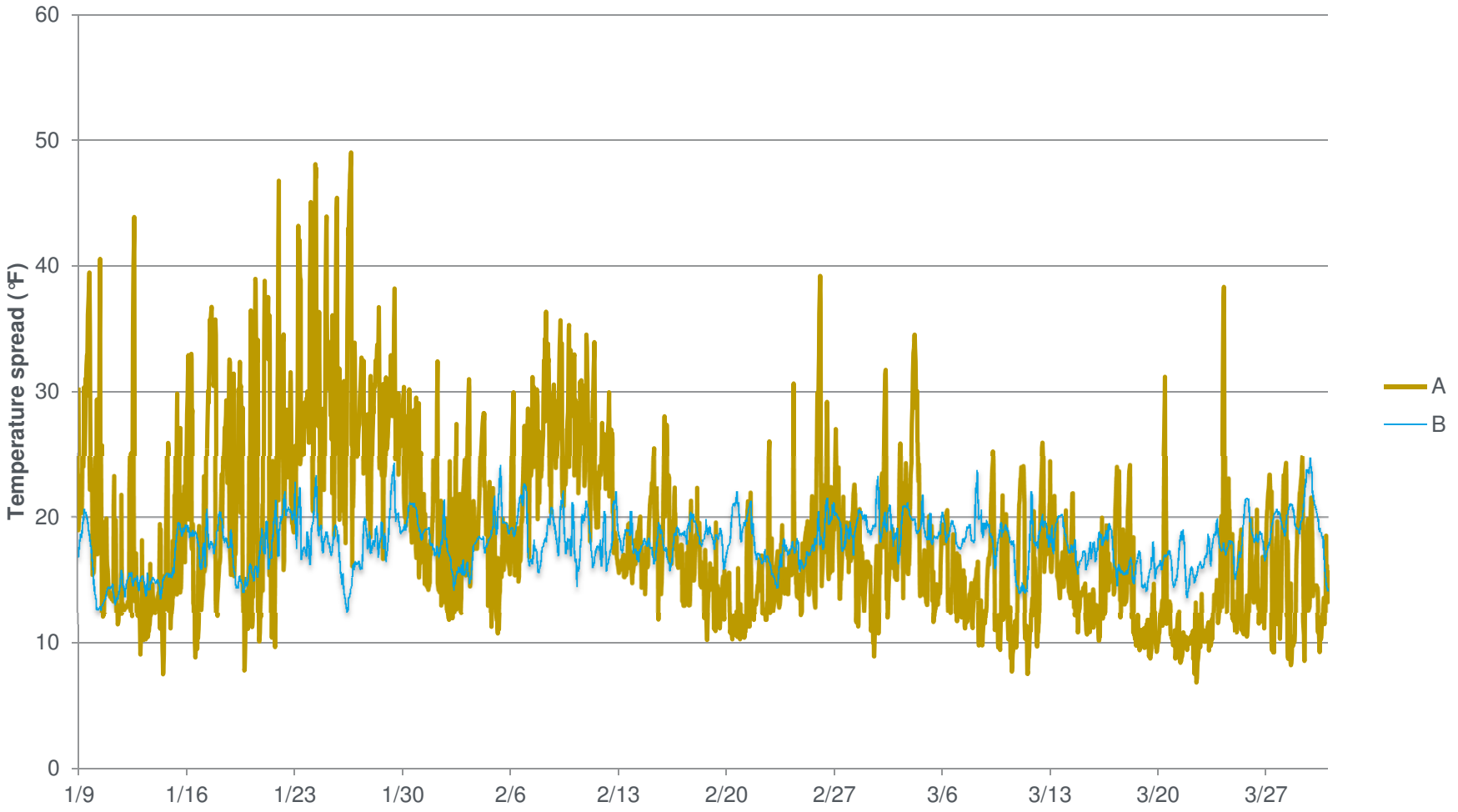
## Building B summary statistics

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

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

| Unit | Setpoint (12/19) | Actual (12/19) | Deviation Max (11/13 3/31) | Deviation Median (11/13 3/31) |
|---|---|---|---|---|
| 1 | 75 | 78.4 | 13.1 | 4.7 |
| 2 | 70 | 79.3 | 13.6 | 9.2 |
| 3 | 75 | 79.5 | 7.3 | 4.5 |
| 4 | 60 | 83.2 | 26.6 | 21.6 |
| 5 | 74 | 79.0 | 11.7 | 6.7 |
| 6 | 74 | 78.2 | 10.1 | 0.6 |
| 7 | 73 | 74.6 | 4.4 | 0.9 |
| 8 | 60 | 64.3 | 12.0 | 4.7 |
| 9 | 73 | 80.0 | 10.8 | 5.3 |
| 10 | 75 | 78.4 | 8.6 | 3.1 |

## 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

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

**Peter Ludwig**
Director, Building Retrofits
Elevate Energy
peter.ludwig@elevateenergy.org

**Russell Ruch**
Senior Energy Analyst
Elevate Energy
russell.ruch@elevateenergy.org