Improving Commercial Building Operations thru Building Re-tuning: Meta-Analysis

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Frequently Asked Questions about Re-tuning

- What measures should we look for?
- What are the expected savings, if we re-tuned the building?

State of Controls in Commercial Buildings with BASs

- Over the past 8 years PNNL developed and conducted re-tuning training
- As part of the work, PNNL documented and analyzed trend data for about 70 buildings where the field training sessions were held and additional 30 buildings where we helped implement re-tuning
- Almost all buildings had significant potential to save energy (5% to 30%) by making simple changes to their controls

Re-tuning Meta-Study

Re-tuning Meta-Study

- 2007 – 2010
- Funded by State of Washington
- Developed re-tuning training in 2007
- Service providers
- ~25 buildings

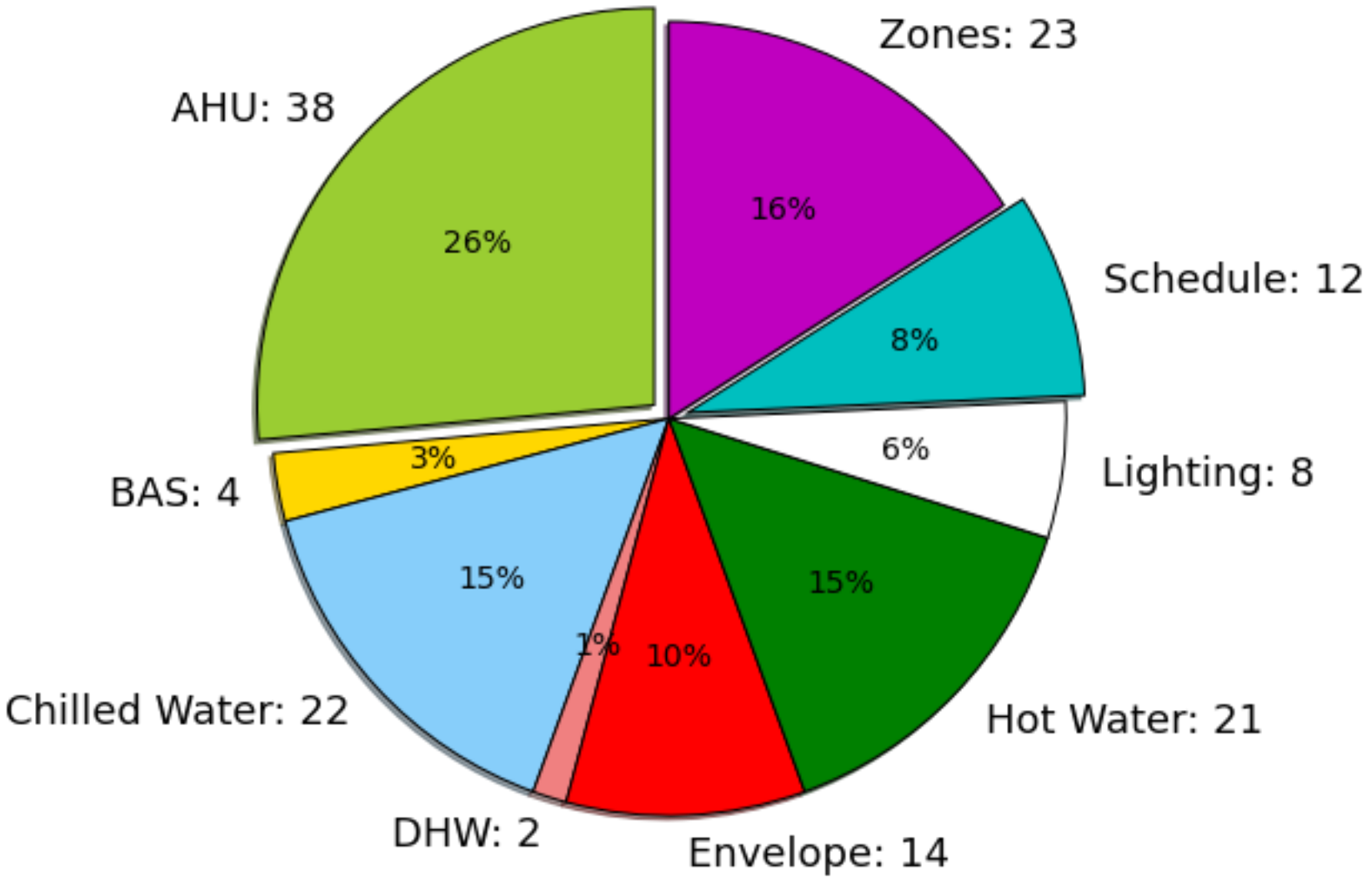
- 2010 – 2013; small programmatic effort in FY14 and FY15
- ARRA funded
- Developed online interactive re-tuning training and training for buildings without BAS
- Large portfolio managers
- ~50 buildings

GENERAL SERVICES ADMINISTRATION

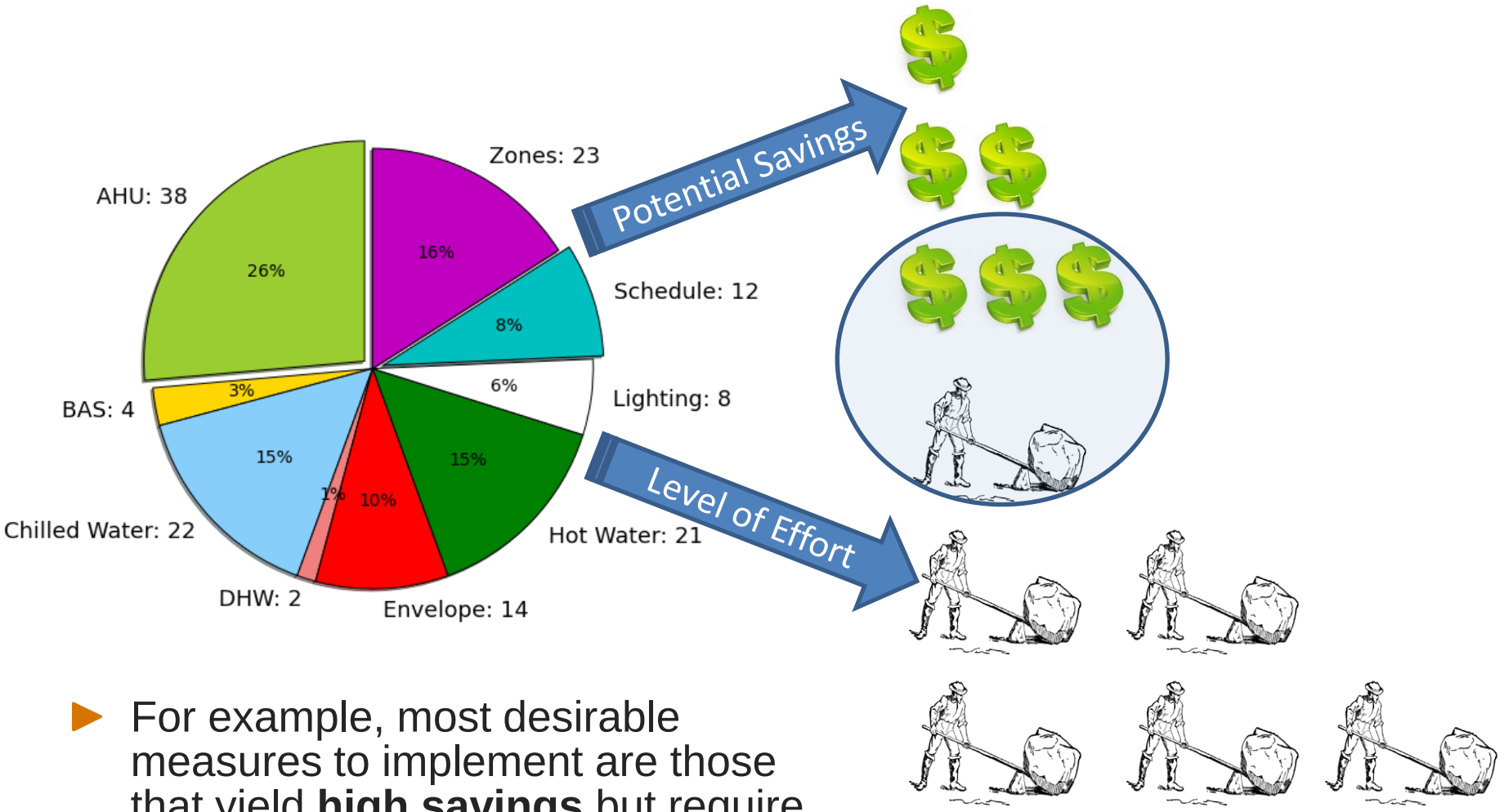
- 2011 –
- Funded by General Services Administration
- Identify and help GSA staff implement re-tuning measures
- ~30 buildings

Re-tuning Measures - 144

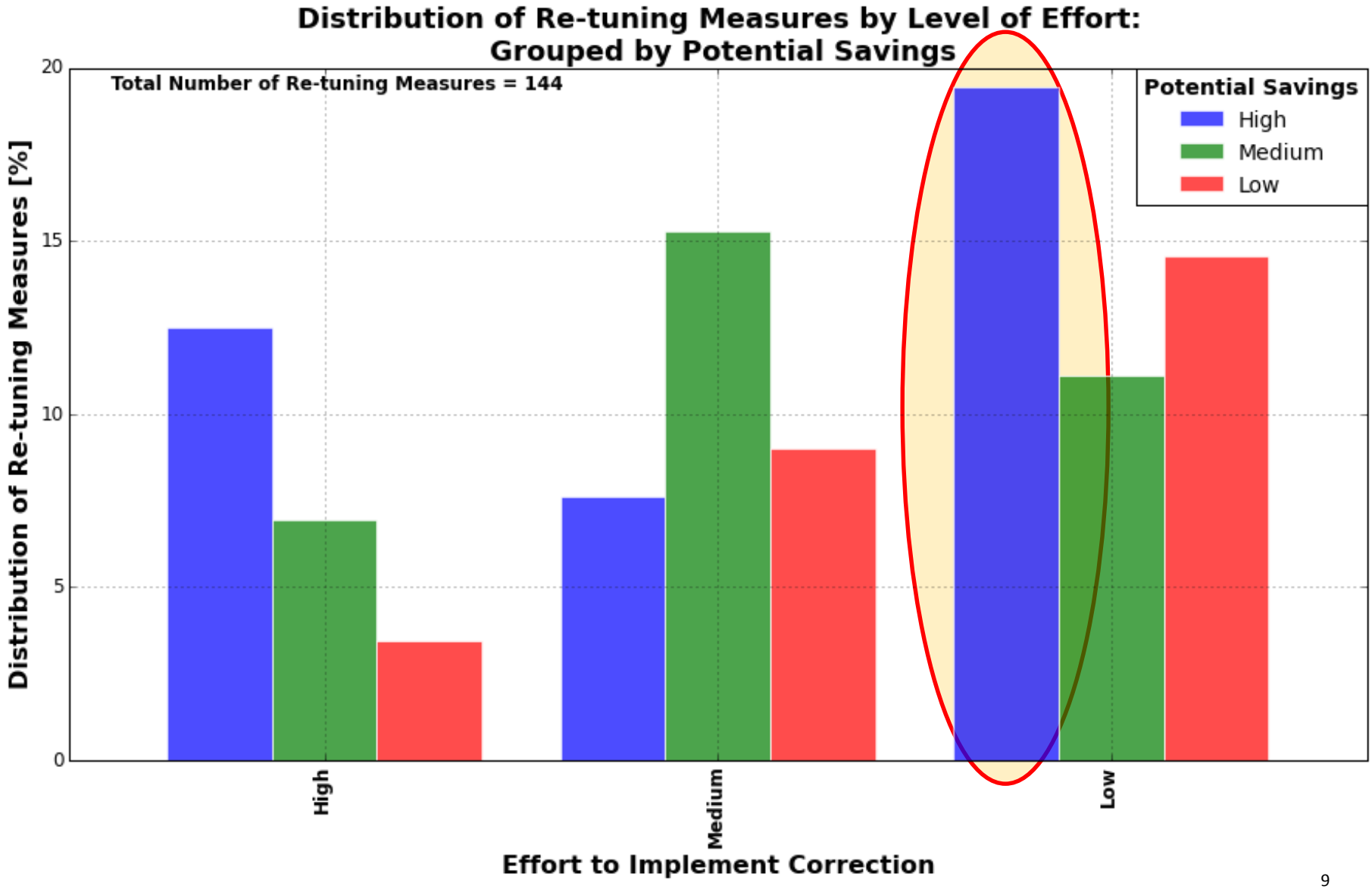
Universe of Re-tuning Measures: 144

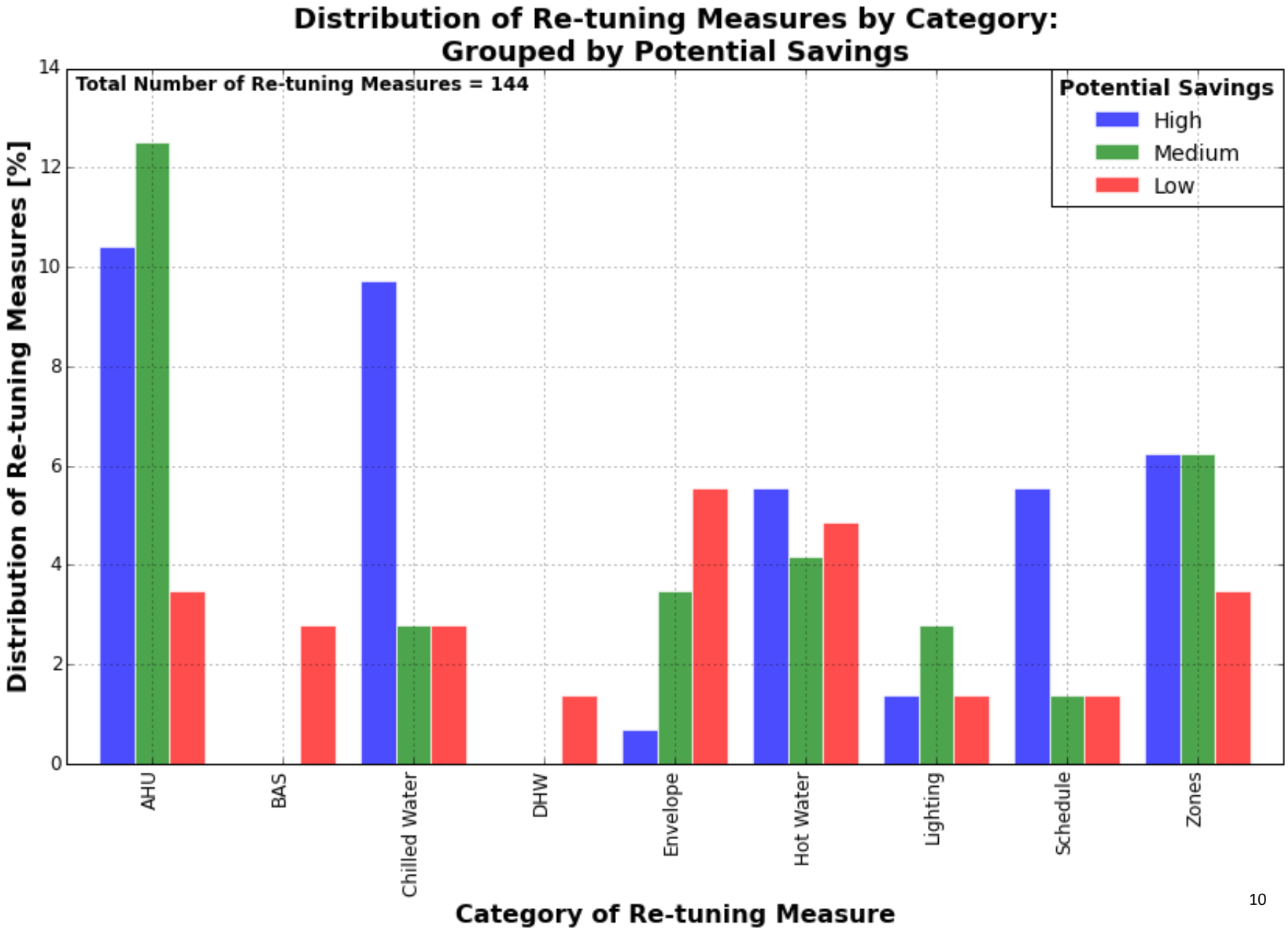


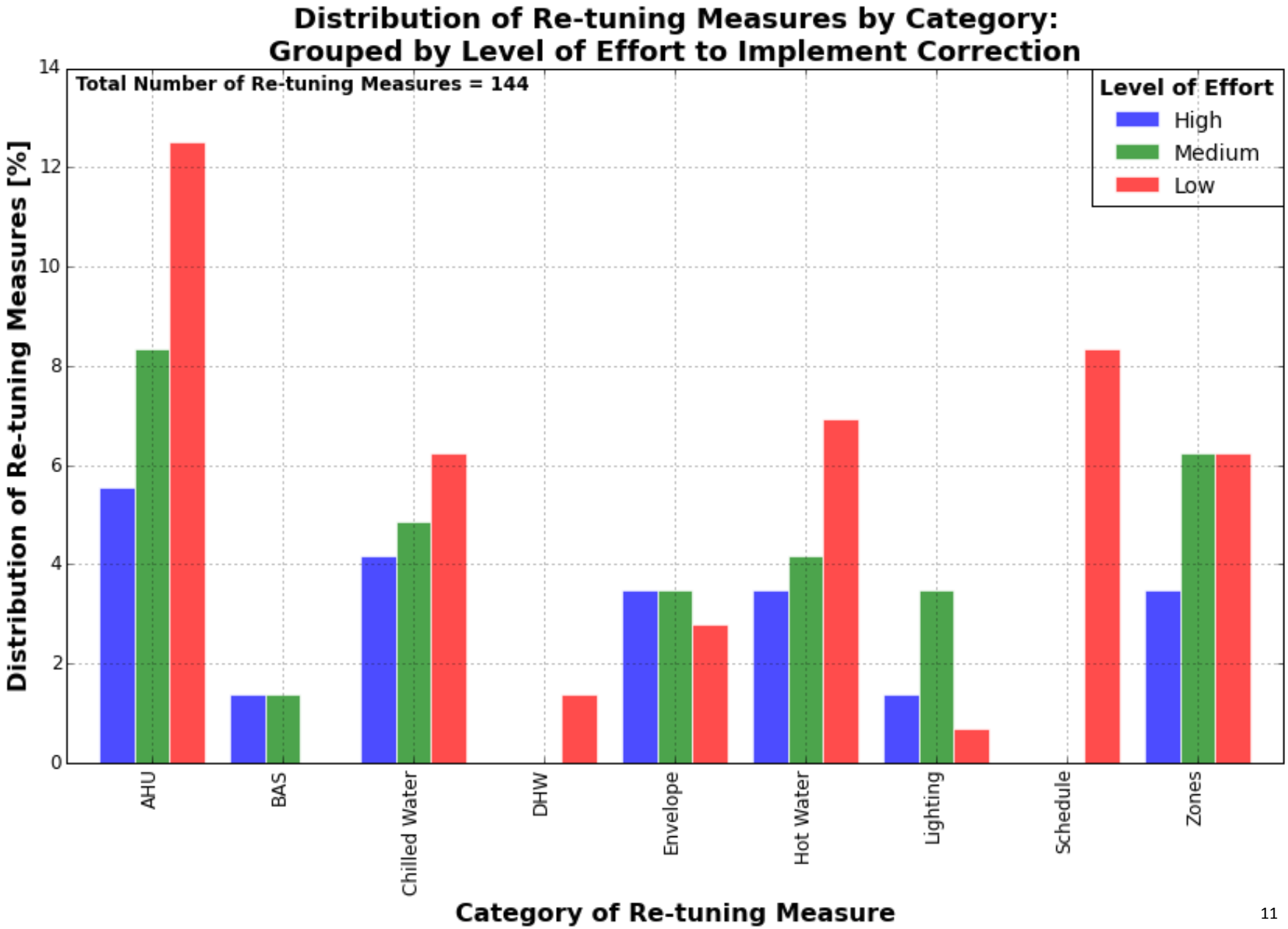
Classification of Re-tuning Measures

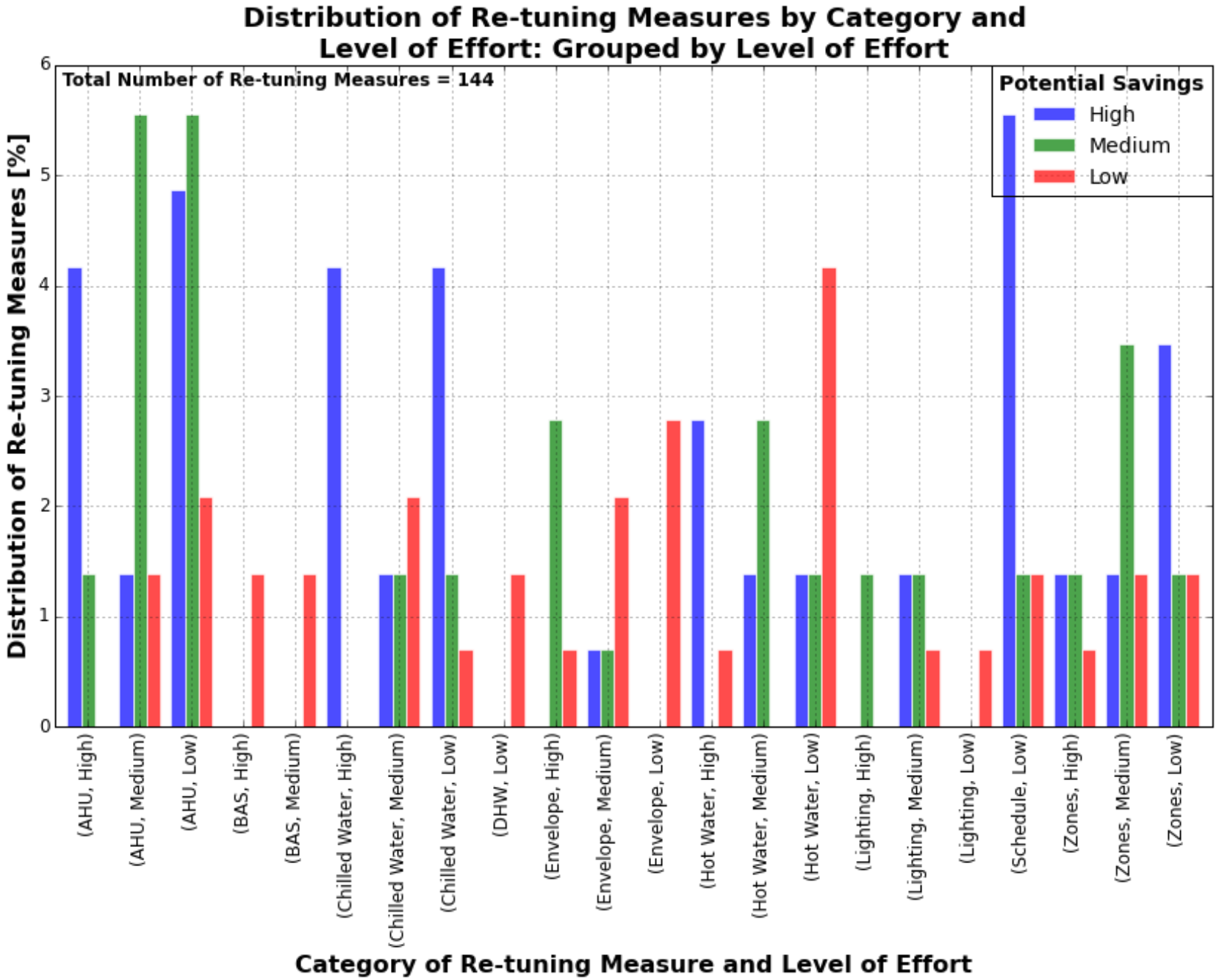


- For example, most desirable measures to implement are those that yield **high savings** but require **low effort**
  - Scheduling measures fall in this category

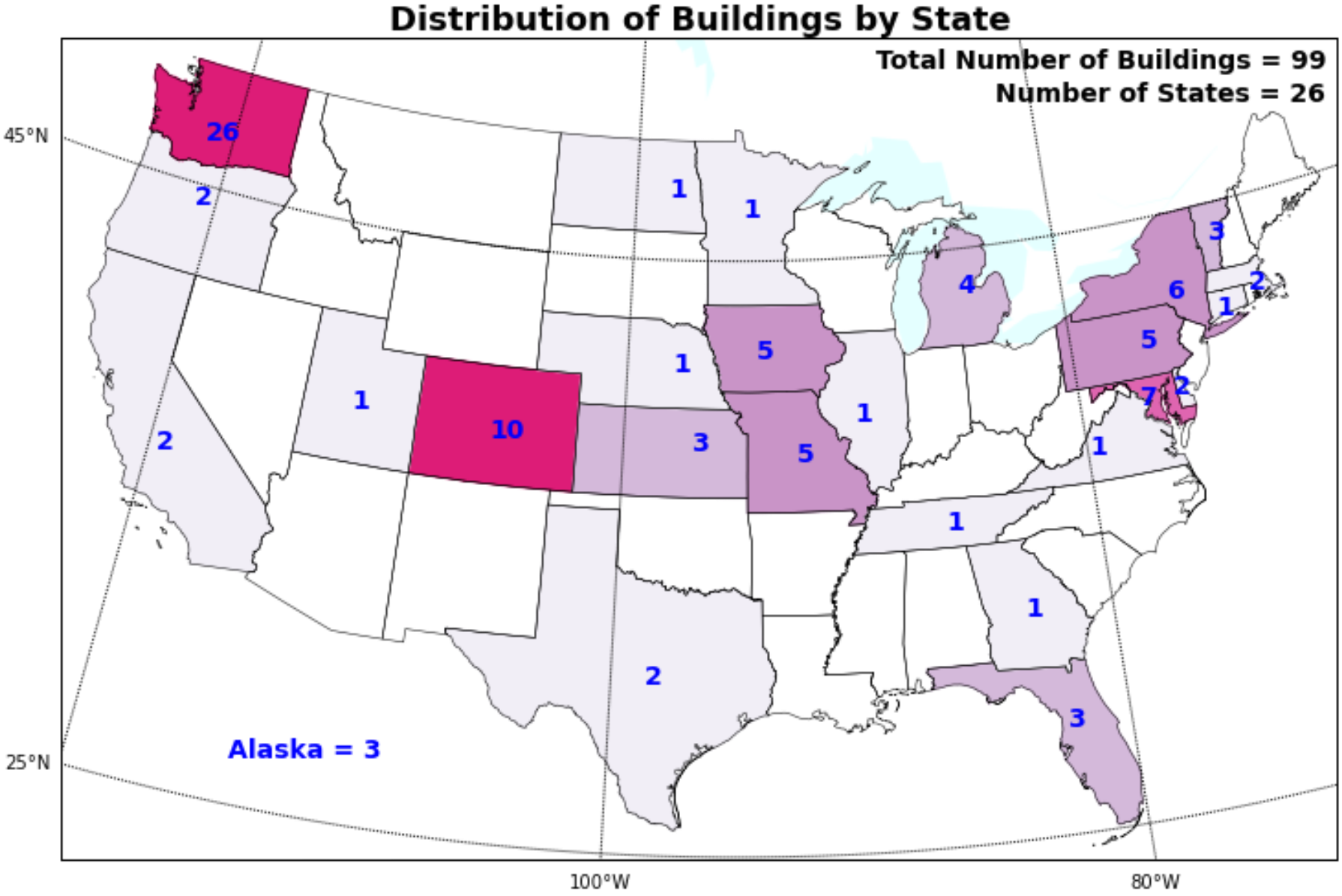

Distribution of Re-tuning Measures by Level of Effort:
Grouped by Potential Savings
Total Number of Re-tuning Measures = 144
Potential Savings
High
Medium
Low
Distribution of Re-tuning Measures [%]
0
5
10
15
20
High
Medium
Low
Effort to Implement Correction

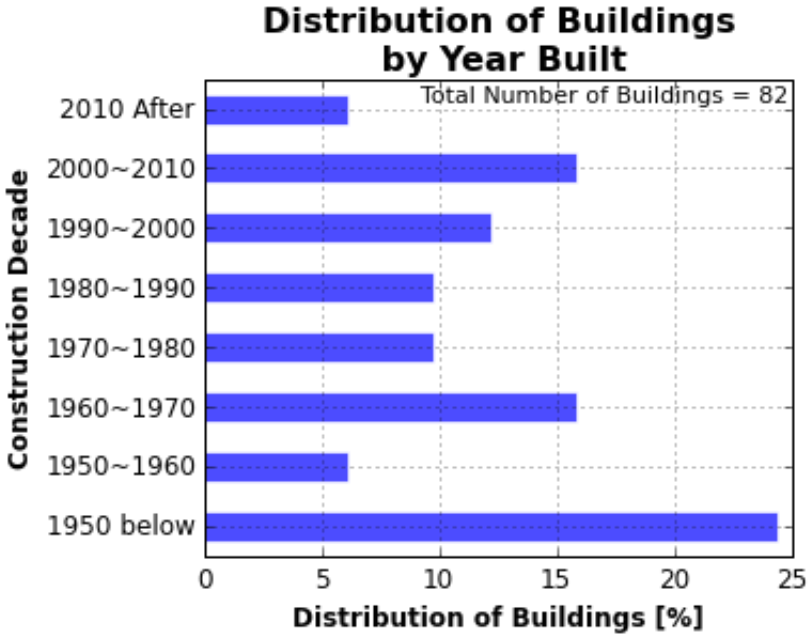

Distribution of Re-tuning Measures by Category:
Grouped by Potential Savings
Total Number of Re-tuning Measures = 144
Potential Savings
High
Medium
Low
Distribution of Re-tuning Measures [%]
0
2
4
6
8
10
12
14
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones
Category of Re-tuning Measure

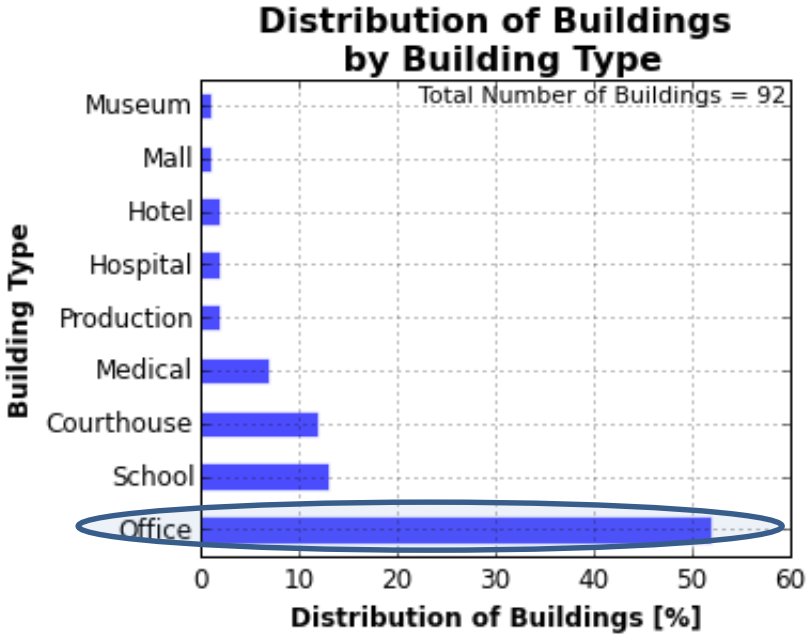

Distribution of Re-tuning Measures by Category:
Grouped by Level of Effort to Implement Correction
Total Number of Re-tuning Measures = 144
Level of Effort
High
Medium
Low
Distribution of Re-tuning Measures [%]
0
2
4
6
8
10
12
14
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones
Category of Re-tuning Measure

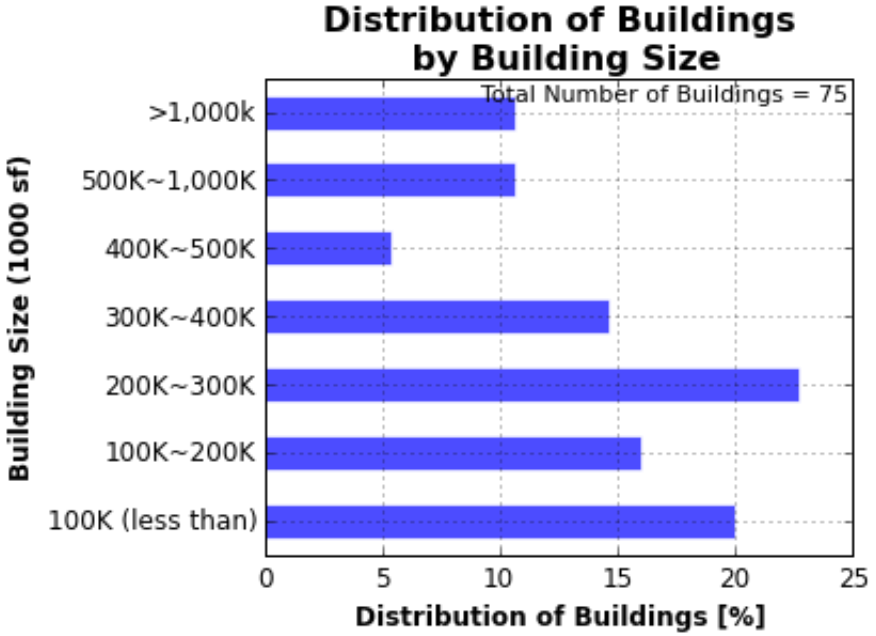

Distribution of Re-tuning Measures by Category and Level of Effort: Grouped by Level of Effort
Total Number of Re-tuning Measures = 144
Potential Savings
High
Medium
Low
Distribution of Re-tuning Measures [%]
0
1
2
3
4
5
6
(AHU, High)
(AHU, Medium)
(AHU, Low)
(BAS, High)
(BAS, Medium)
(Chilled Water, High)
(Chilled Water, Medium)
(Chilled Water, Low)
(DHW, Low)
(Envelope, High)
(Envelope, Medium)
(Envelope, Low)
(Hot Water, High)
(Hot Water, Medium)
(Hot Water, Low)
(Lighting, High)
(Lighting, Medium)
(Lighting, Low)
(Schedule, Low)
(Zones, High)
(Zones, Medium)
(Zones, Low)
Category of Re-tuning Measure and Level of Effort

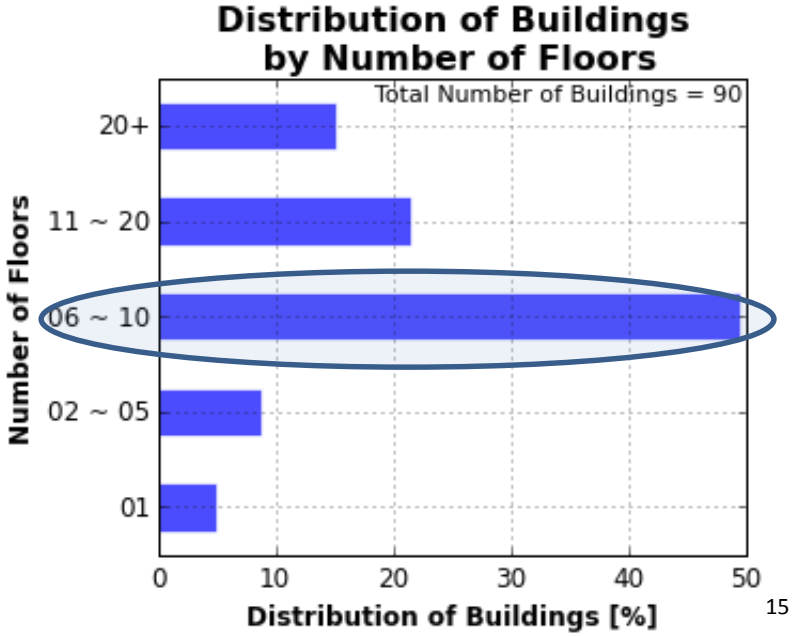
Details of the Sample Buildings - 99

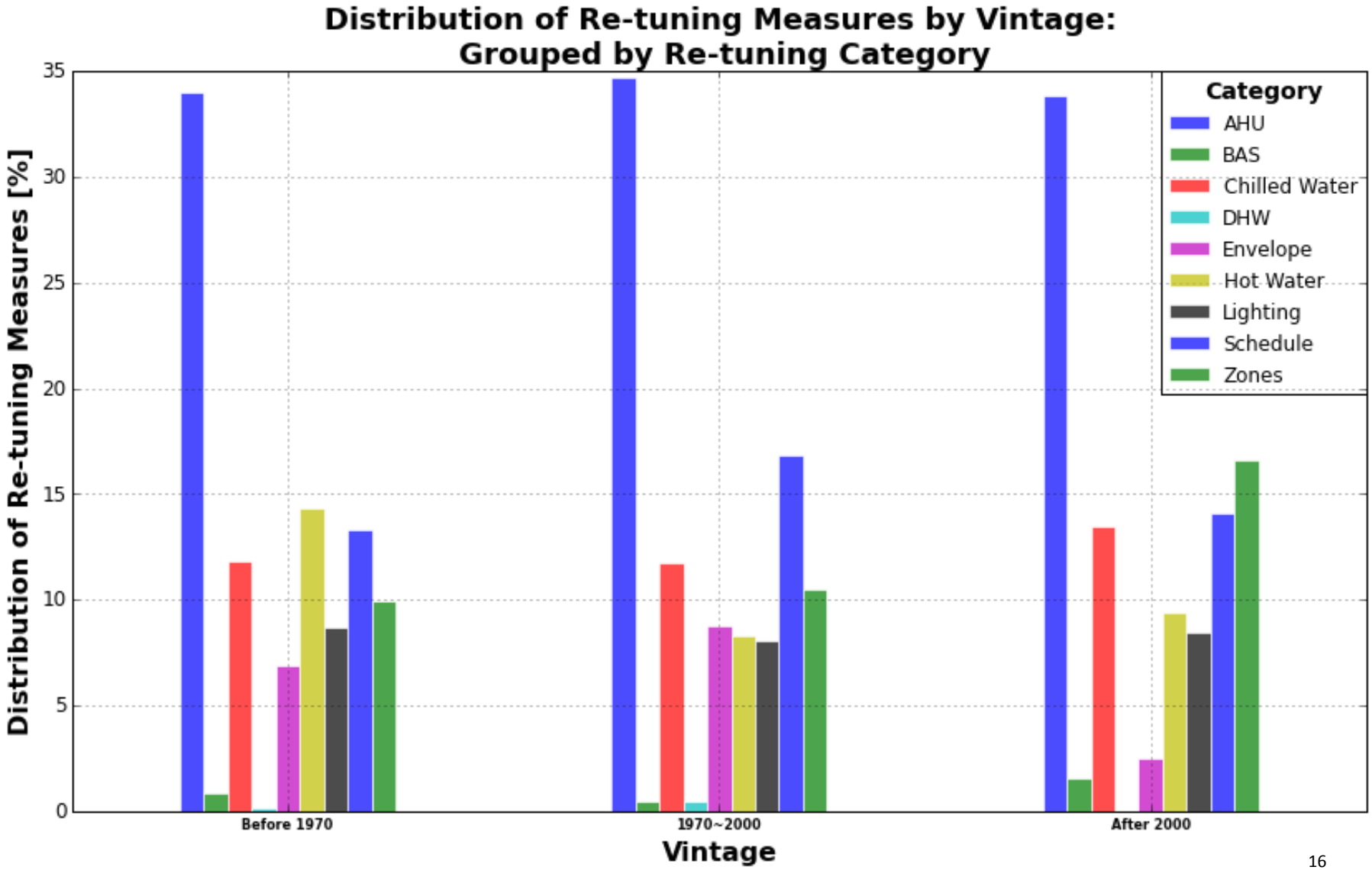

Distribution of Buildings by State
Total Number of Buildings = 99
Number of States = 26
45°N
25°N
100°W
80°W
26
2
1
1
4
3
6
2
1
5
5
1
7
2
1
10
3
5
1
2
1
1
2
3
Alaska = 3

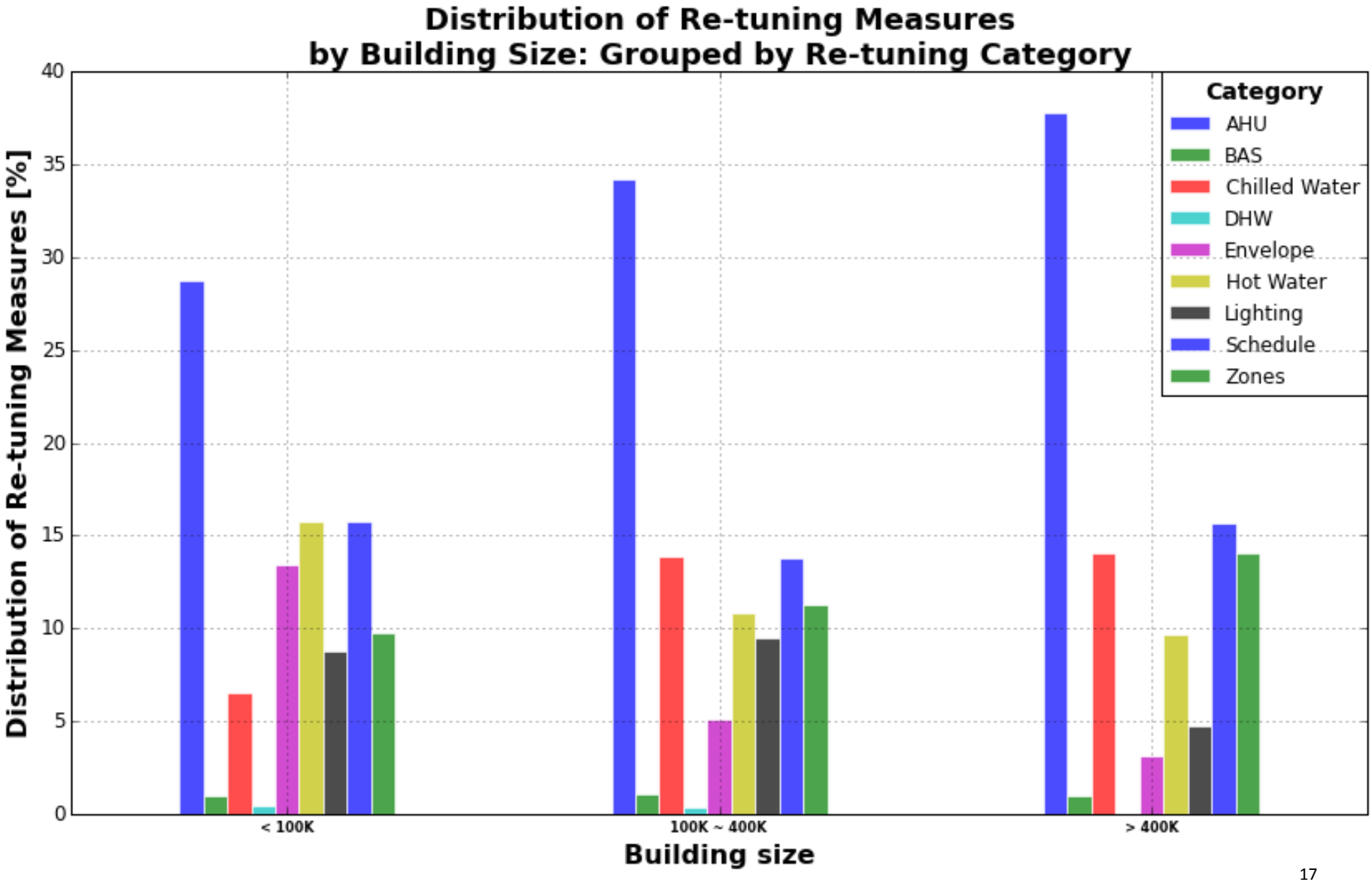

Distribution of Buildings
by Year Built
Total Number of Buildings = 82
Construction Decade
2010 After
2000~2010
1990~2000
1980~1990
1970~1980
1960~1970
1950~1960
1950 below
0
5
10
15
20
25
Distribution of Buildings [%]

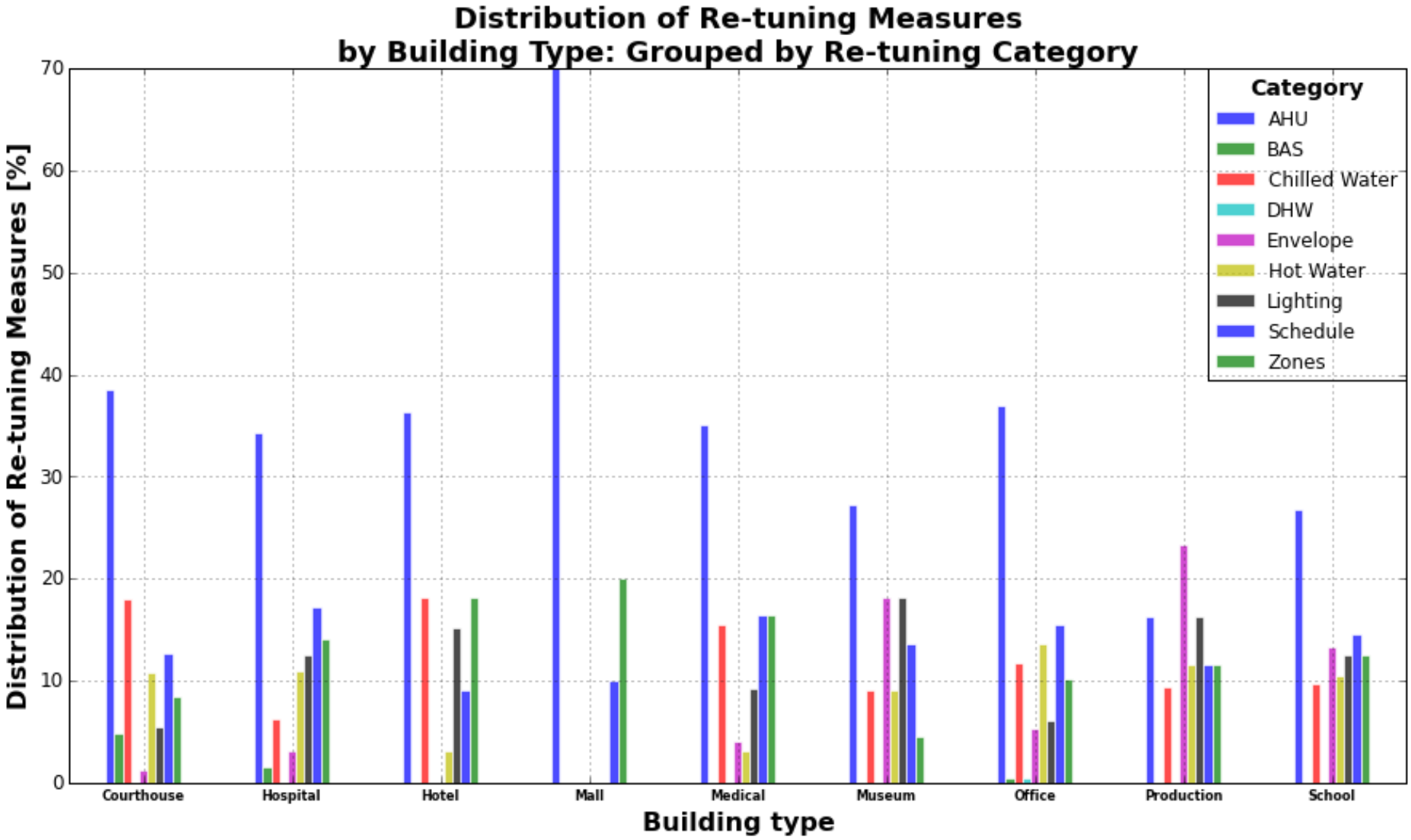

Distribution of Buildings
by Building Type
Total Number of Buildings = 92
Building Type
Museum
Mall
Hotel
Hospital
Production
Medical
Courthouse
School
Office
0
10
20
30
40
50
60
Distribution of Buildings [%]


Distribution of Buildings
by Building Size
Total Number of Buildings = 75
Building Size (1000 sf)
>1,000k
500K~1,000K
400K~500K
300K~400K
200K~300K
100K~200K
100K (less than)
0
5
10
15
20
25
Distribution of Buildings [%]

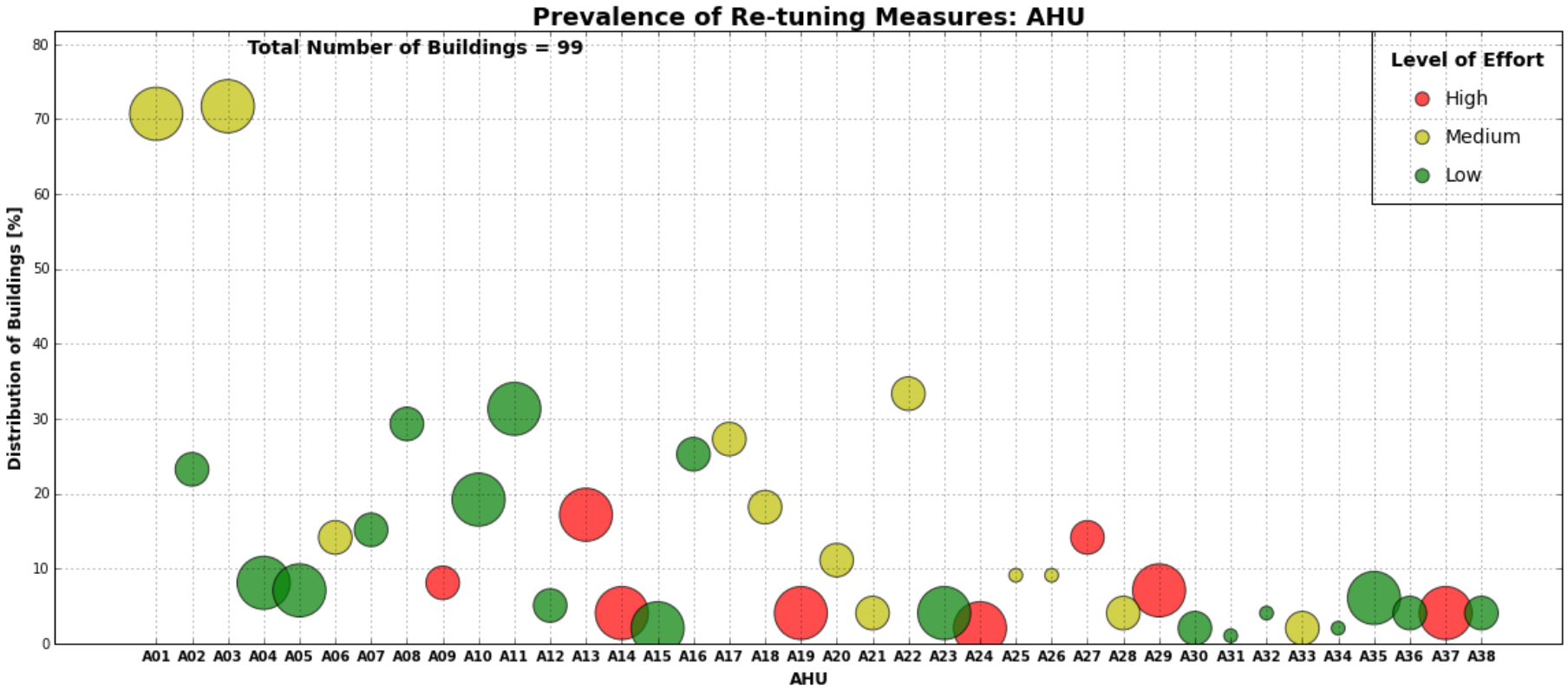

Distribution of Buildings
by Number of Floors
Total Number of Buildings = 90
Number of Floors
20+
11 ~ 20
06 ~ 10
02 ~ 05
01
0
10
20
30
40
50
Distribution of Buildings [%]


Distribution of Re-tuning Measures by Vintage:
Grouped by Re-tuning Category
Distribution of Re-tuning Measures [%]
0
5
10
15
20
25
30
35
Before 1970
1970~2000
After 2000
Vintage
Category
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones


Distribution of Re-tuning Measures
by Building Size: Grouped by Re-tuning Category
Distribution of Re-tuning Measures [%]
0
5
10
15
20
25
30
35
40
< 100K
100K ~ 400K
> 400K
Building size
Category
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones


Distribution of Re-tuning Measures
by Building Type: Grouped by Re-tuning Category
Distribution of Re-tuning Measures [%]
0
10
20
30
40
50
60
70
Courthouse
Hospital
Hotel
Mall
Medical
Museum
Office
Production
School
Building type
Category
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones

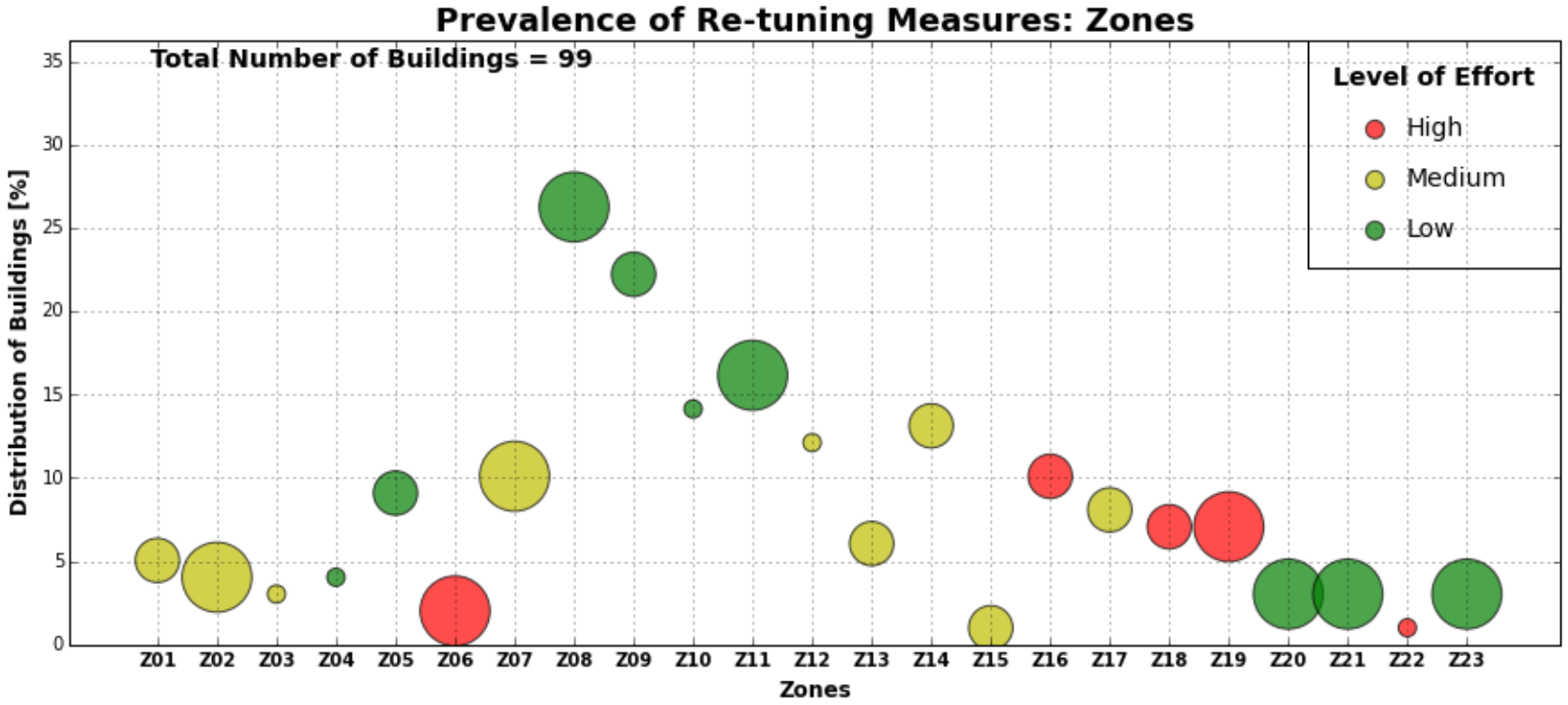
Prevalence of Re-tuning Measures in the Sample



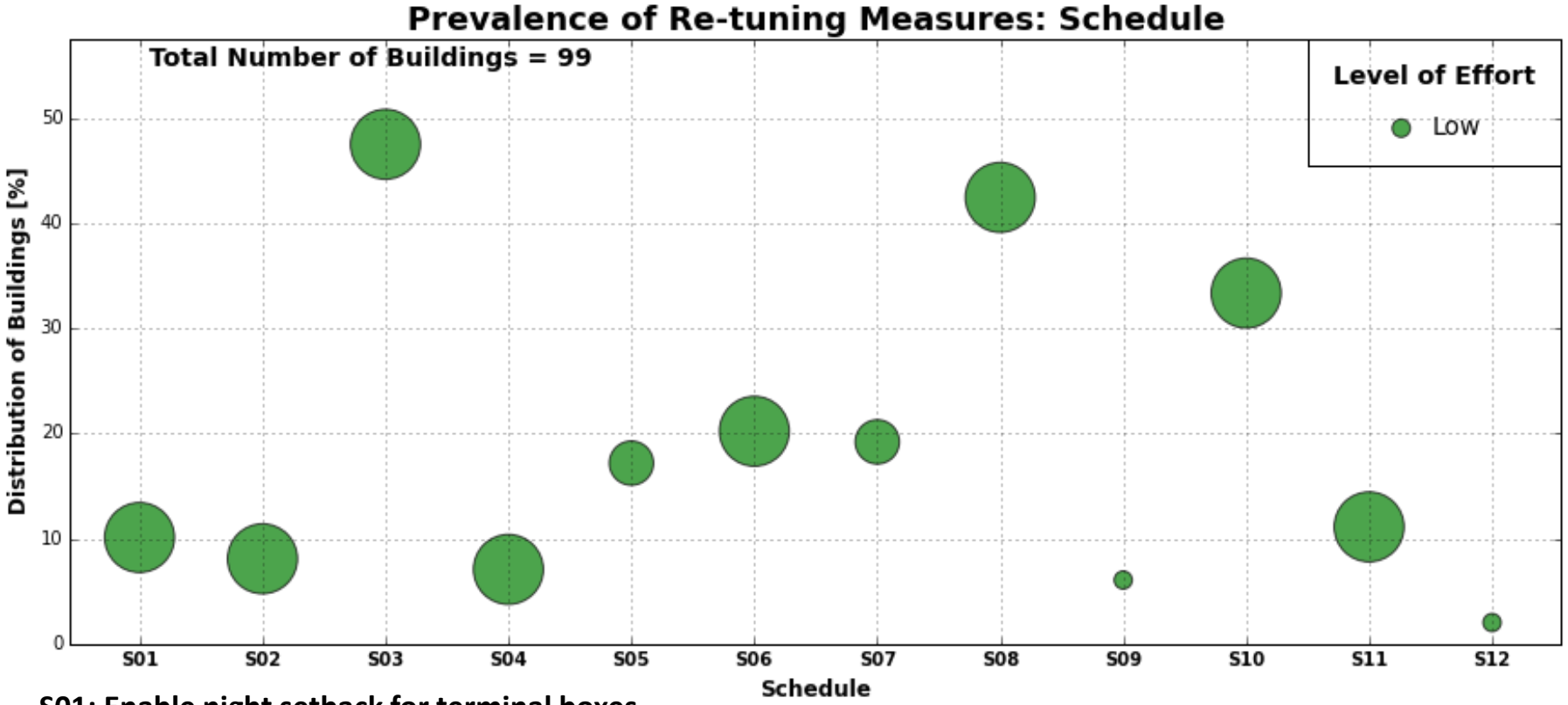
A1: Implement/improve duct static pressure reset
A3: Implement/improve discharge air temperature reset
A4: Reprogram/implement night setback set points
A5: Widen DAT heating/cooling dead band (set point adjustments)
A10: Review economizer set points (high limit, low limit, lockout) and adjust accordingly
A11: Reduce minimum outdoor air to 0% during unoccupied hours and building warmup
A13: Install VFD on supply and return fans (and static pressure sensor if needed)
A14: Install VFD on exhaust fan
A15: Optimize VFD and SAT control for single zone units
A19: Add RTU/AHU systems to building controls (DDC) and put them on an operating schedule
A29: Upgrade pneumatics to DDC
A35: Improve Outdoor Air-handling unit supply temperature control
A36: Improve Outdoor Air-handling unit ERV wheel control
A37: Add or improve carbon monoxide control of garage exhaust/make-up fans

AHU Re-tuning Measures

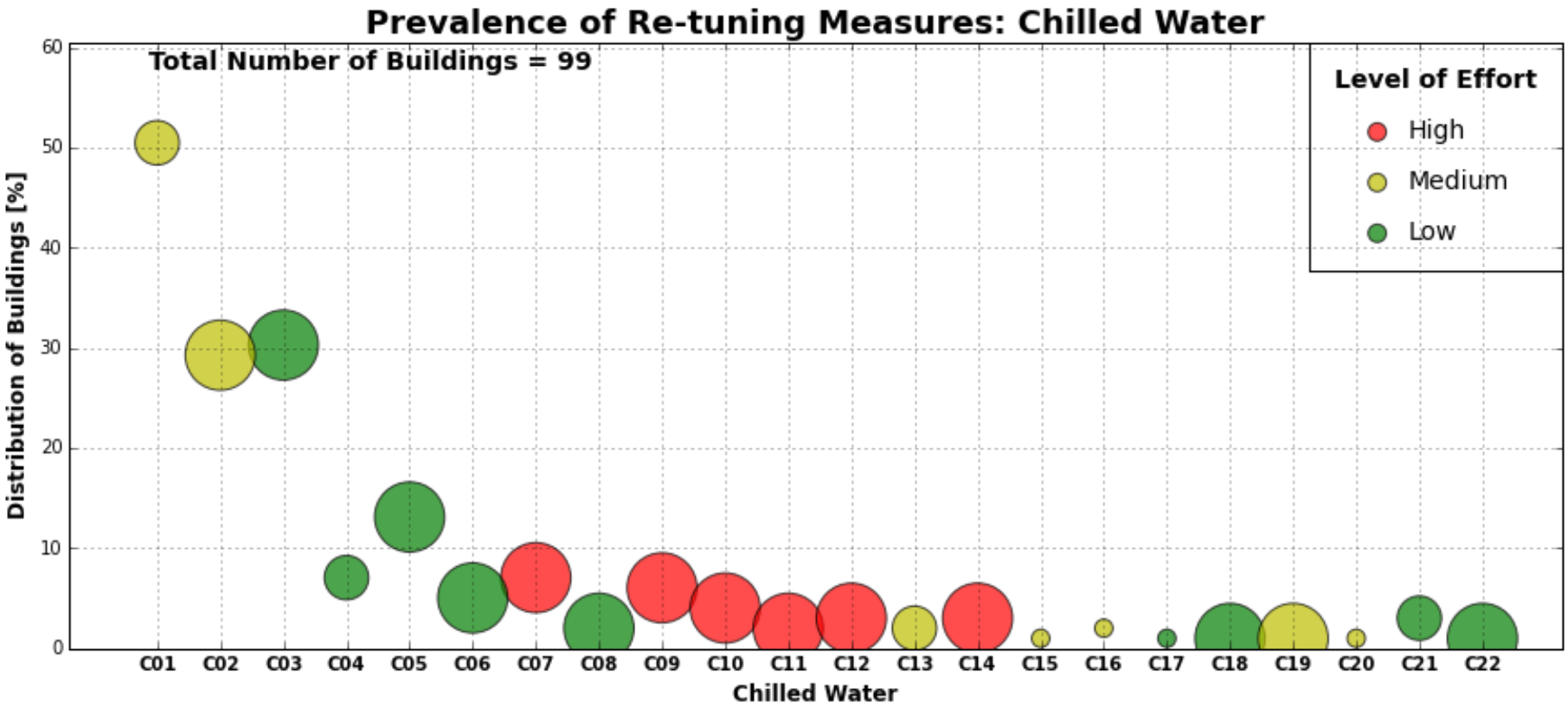
A1: Implement/improve duct static pressure reset
A2: Lockout cooling and heating/preheat coils based on OAT or other means
A3: Implement/improve discharge air temperature reset
A4: Reprogram/implement night setback set points
A5: Widen DAT heating/cooling dead band (set point adjustments)
A6: Fix broken dampers (outdoor, exhaust/relief, and mixed air)
A7: Run relief/exhaust/return fans to maintain positive pressure
A8: Check minimum outdoor air requirements and adjust outdoor air damper accordingly
A9: Investigate and calibrate bad air flow sensors (may require air balancing by contractor)
A10: Review economizer set points (high limit, low limit, lockout) and adjust accordingly
A11: Reduce minimum outdoor air to 0% during unoccupied hours and building warmup
A12: Run fans simultaneously at lower speed to reduce total fan power consumption (VFD for supply, return, exhaust/relief fans)
A13: Install VFD on supply and return fans (and static pressure sensor if needed)
A14: Install VFD on exhaust fan
A15: Optimize VFD and SAT control for single zone units
A16: Review/enable automatic economizer controls (adjust when necessary and ensure integrated economizer control are functioning)
A17: Install/replace or calibrate CO2 sensor and use demand controlled ventilation in designated spaces
A18: Repair and Maintain RTUs/AHUs (replace filters, clean coils, check disconnects, leaky ductwork, etc.)
A19: Add RTU/AHU systems to building controls (DDC) and put them on an operating schedule
A20: Add algorithm to calculate outdoor air fraction
A21: Install mixed-air temperature sensor
A22: Relocate/replace/calibrate faulty temperature and/or pressure sensors
A23: Calibrate air flow stations
A24: Install outdoor-air humidity sensor and control economizer via differential enthalpy
A25: Evaluate and prime condensate drain lines with water. Make sure traps are properly designed and repaired
A26: Add building static pressure sensor to DDC/review set points to ensure slightly positive pressure in building
A27: Fix leaking chilled water and/or hot water/steam valves and clean coil fins
A28: Install return-air temperature sensor and add to differential dry-bulb economizer control strategy
A29: Upgrade pneumatics to DDC
A30: Remove Manual Overrides and Enable Automatic Control
A31: Staggered AHU start-up
A32: Adjust Compressed Air set point for pneumatic devices
A33: Improve PID Loop Tuning of actuators
A34: Implement Night Flush/Purge Cycle
A35: Improve Outdoor Air-handling unit supply temperature control
A36: Improve Outdoor Air-handling unit ERV wheel control
A37: Add or improve carbon monoxide control of garage exhaust/make-up fans
A38: Eliminate fighting HVAC units serving the same space (simultaneous heating/cooling or humidification/dehumidification)



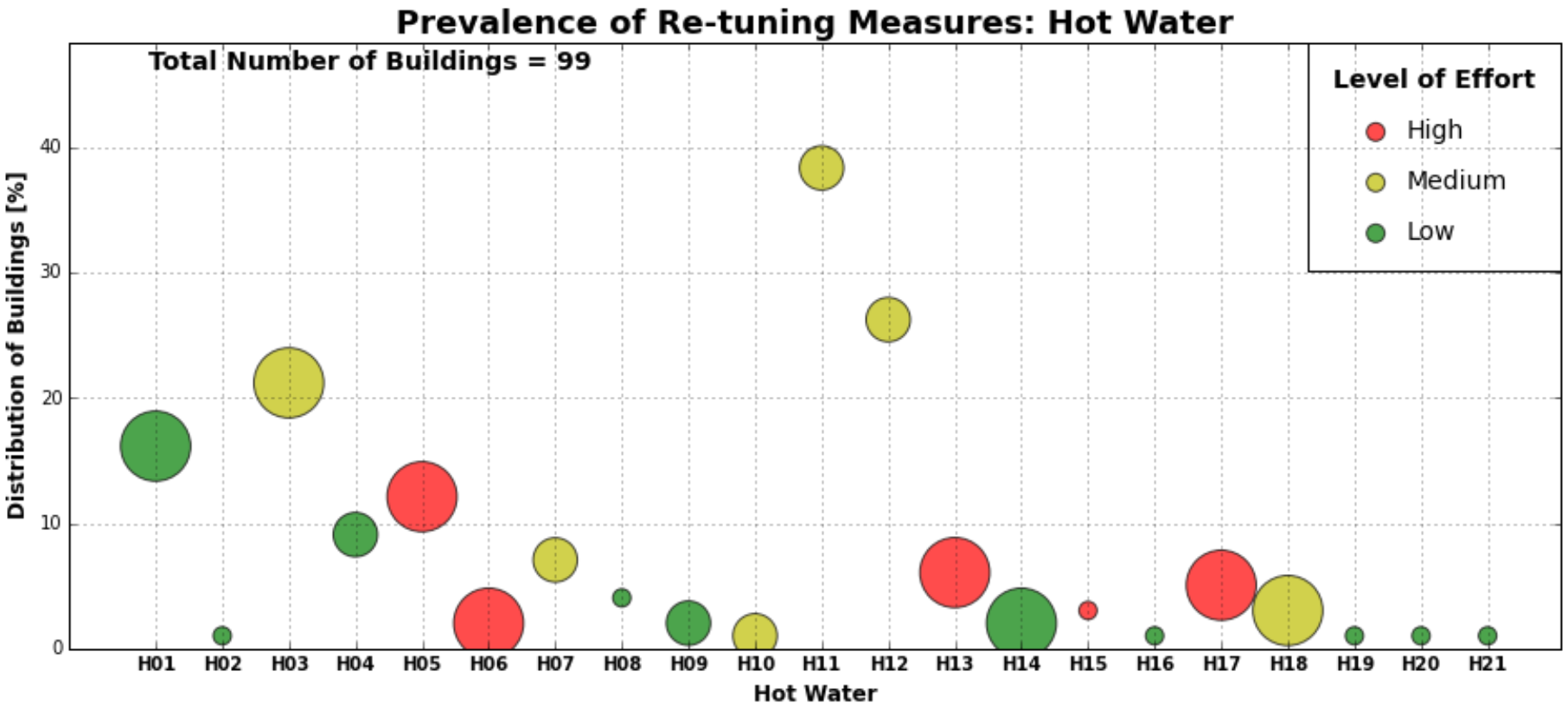
Z01: Disable summer heating in exterior zones (lockout with OAT)
Z02: Allow perimeter heat systems for winter building warmup and delay AHU fans
Z03: Add heating and cooling lockout set points for coil valves on fan coil units
Z04: Increase relative humidity set points in humidity controlled zones
Z05: Reduce VAV minimum air flow rate for certain zones
Z06: Replace constant speed fans with VFD on fan coil or fan powered units
Z07: Allow/add zone standby mode and/or temporary occupancy
Z08: Widen/adjust cooling and heating set points
Z09: Widen dead band for heating and cooling set points
Z10: Review zone temperature and/or humidity/dehumidification set points
Z11: Review and/or implement night setback for all zones
Z12: Replace/relocate bad temperature sensors
Z13: Install outlet strip occupancy sensors on non-critical plug loads
Z14: Investigate and repair/replace stuck zone VAV dampers
Z15: Re-pipe chilled water coils in fan coil units that are backwards to allow for maximum heat transfer
Z16: Investigate and calibrate bad air flow sensors (may require air balancing by contractor)
Z17: Repair/replace leaking hot water valves
Z18: Update pneumatic or manual thermostat/baseboard heating controls to DDC or put in programmable thermostats
Z19: Replace controllers that are not communicating correctly
Z20: Interlock the terminal fan with the proper AHU
Z21: Switch terminal box to unoccupied mode based on occupancy sensors (ensure OS work)
Z22: Install discharge-air temperature sensor on fan-powered boxes
Z23: Improve VAV box control by switching modes (VAV box heating mode, cooling only mode, etc.)



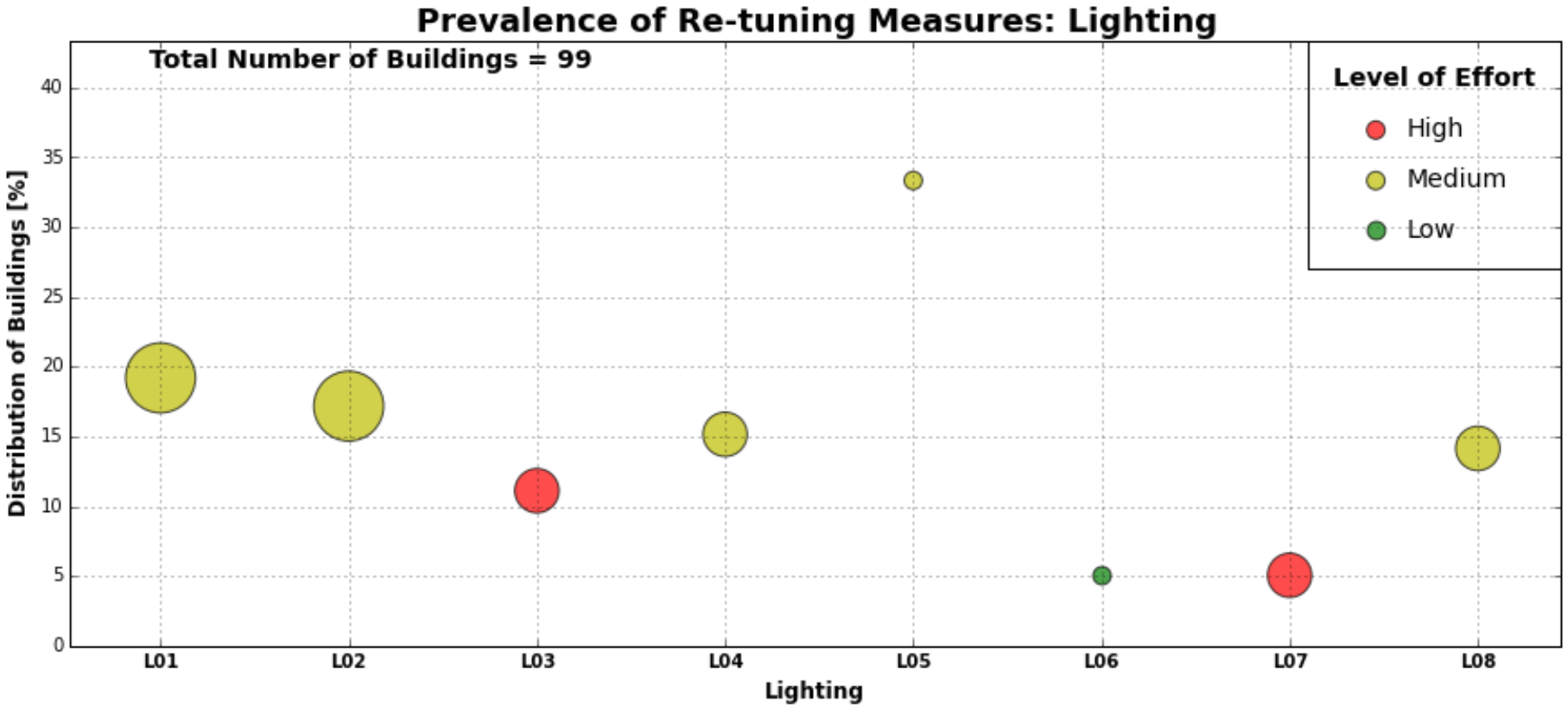
S01: Enable night setback for terminal boxes
S02: Tighten/add schedules on RTUs (weekday, weekend, and holidays)
S03: Tighten/add schedules on AHUs (weekday, weekend, and holidays)
S04: Tighten schedules for programmable thermostats (occupied and set back)
S05: Add/tighten schedule for domestic hot water heater/boiler and pump systems
S06: Tighten schedules on lighting
S07: Tighten/add schedules on variable air volume boxes (sync with AHUs/RTUs)
S08: Add/tighten schedule for exhaust/relief fans and ensure they are off during unoccupied/warmup hours
S09: Interlock make-up air schedules with exhaust fan schedules
S10: Utilize/implement optimal start capabilities
S11: Optimize boiler and chiller schedules
S12: Lockout heating and cooling in boiler room based on outdoor-air temperature



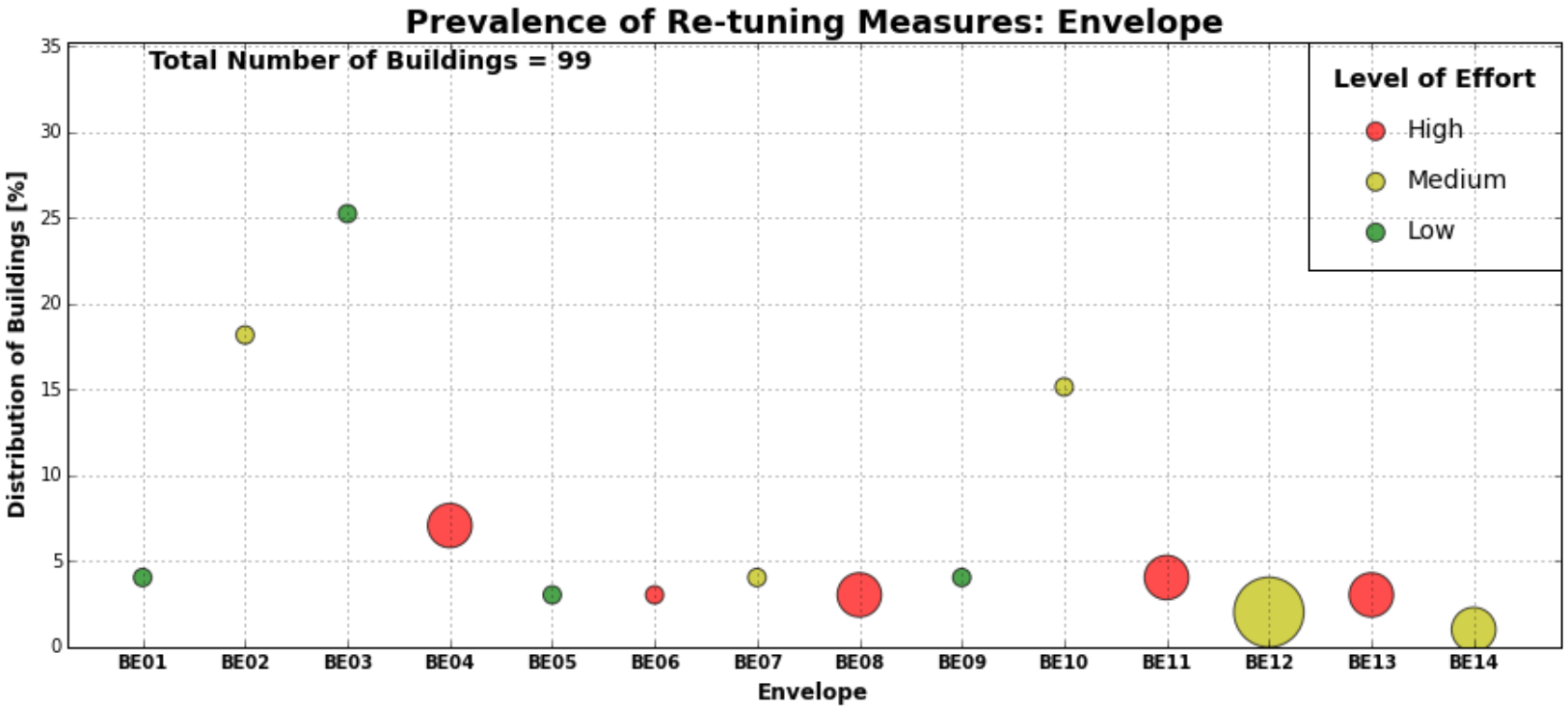
C01: Implement chilled water supply temperature reset
C02: Implement condenser water temperature reset
C03: Implement loop differential pressure reset/reduction and convert 3-way valves to 2-way valves if required
C04: Run parallel VFD chilled water pumps together instead of staging them (both ChW and Cond Water)
C05: Lockout chiller based on demand or OAT
C06: Control chilled water pumps by chilled water valve position or loop deltaT and open up manual isolation valves
C07: Install VFD on chilled water pump
C08: Clean and repair cooling tower
C09: Install VFD on cooling tower fans
C10: Install VFD on condenser water pumps
C11: Code and test water-side economizer implementation
C12: Evaluate using rejected heat to interior spaces during winter months
C13: Enable chiller isolation valve controls so chiller isolation valve is closed when respective chiller is off
C14: Insulate all exposed chiller piping and fittings
C15: Replace failed check valves on chilled water pumps
C16: Investigate staging issues with chillers (e.g. short-cycling)
C17: Improve control of cooling tower basin heaters
C18: Use electric chillers in lieu of steam turbine chillers whenever possible
C19: Fix or Replace chilled water coil valves
C20: Chiller Soft Start
C21: Disable chilled water pumps when chillers are not running
C22: Run One parallel condenser water pump instead of 2 (second not needed)



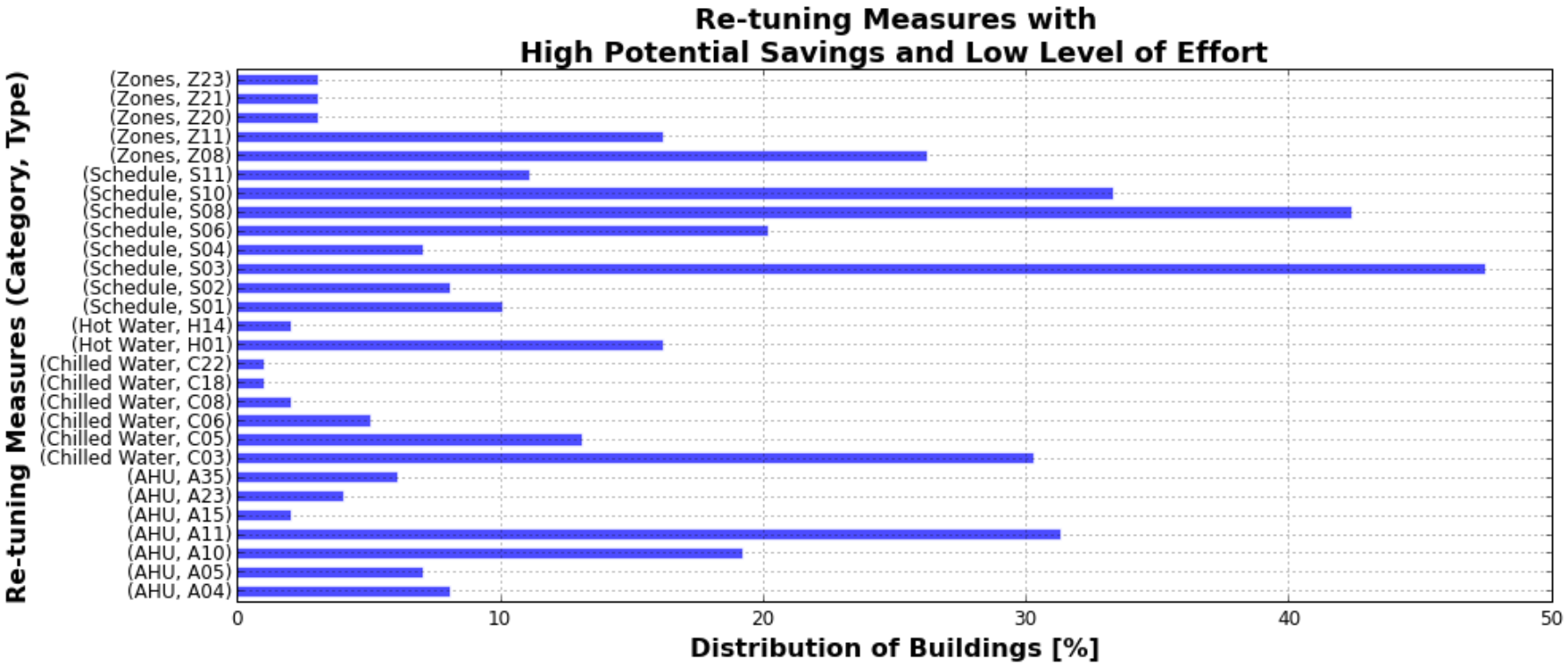
H01: Lockout boiler and pumps or steam heat exchangers based on OAT (and/or Occupancy status)
H02: Allow boiler to come on during setback operations when AHU comes on and calls for heat
H03: Reset loop differential pressure (add sensor if not already installed)
H04: Interlock boiler and hot water pumps
H05: Install VFDs on hot water pumps and run parallel pumps together instead of staging them
H06: Install VFDs on domestic hot water pumps
H07: Fix or Replace hot water valves
H08: Reduce domestic hot water pump pressure set point
H09: Reduce steam pressure based on load requirements
H10: Verify steam traps are working properly and maintained
H11: Implement/improve hot water supply temperature reset
H12: Insulate all exposed hot water/steam piping, fittings, and tanks
H13: Add controls to hot water equipment that has no control/upgrade systems to BAS
H14: Adjust OA reset schedule for lower temperatures
H15: Add or utilize automatic isolation valves so non-running boilers do not have water flowing through them
H16: Valve off hot water lines in baseboard fin-tube radiators in unoccupied spaces
H17: Consider upgrading boilers to high efficiency hot water condensing boilers
H18: Restore or improve Snow Melt Controls
H19: Close Heating Valves in Unoccupied Mode
H20: Improve Control of boiler make-up air units
H21: Soft Start/Gradual Ramp-up for boilers



L01: Install/relocate and/or validate photocell sensors to control outdoor lighting
L02: De-lamp in areas with intensive lighting levels
L03: Upgrade older lighting technology to fluorescents or LED
L04: Install and/or integrate automatic control for lighting to BAS
L05: Install/verify occupancy based control sensors for rooms where it makes sense
L06: Add signage to turn off lights or dim for areas with manual lighting control
L07: Allow for better perimeter zone dimming
L08: Take advantage of daylighting where possible (lobbies, vestibules, hallways)



BE01: Clean OA intake
BE02: Remove old equipment and seal penetrations/cap legacy exhaust
BE03: Adjust/repair/replace door and/or window seals and/or sweeps to mitigate infiltration
BE04: Replace single-pane windows with double-pane windows
BE05: Manage operable windows
BE06: Evaluate window treatments to reduce solar loading during the cooling season
BE07: Fix standing water issues on roof (clean roof drains if needed)
BE08: Paint dark roof white
BE09: Make sure heat trace is off during the cooling season
BE10: Replace missing insulation issues where needed
BE11: Replace exterior doors with more energy efficient doors and repair broken rollup doors
BE12: Adequately insulate soffits and make sure heating is disabled during cooling season if available
BE13: Separate OA intake from exhaust to ensure fresh air is entering the building
BE14: Seal rooftop penetrations (i.e. legacy exhaust fan hoods)



A04: Reprogram/implement night setback set points
A05: Widen DAT heating/cooling dead band (set point adjustments)
A10: Review economizer set points (high/low limit, lockout) and adjust accordingly
A11: Reduce minimum OA to 0% during unoccupied hours and warmup
A15: Optimize VFD and SAT control for single zone units
A23: Calibrate air flow stations
A35: Improve Outdoor Air-handling unit supply temperature control

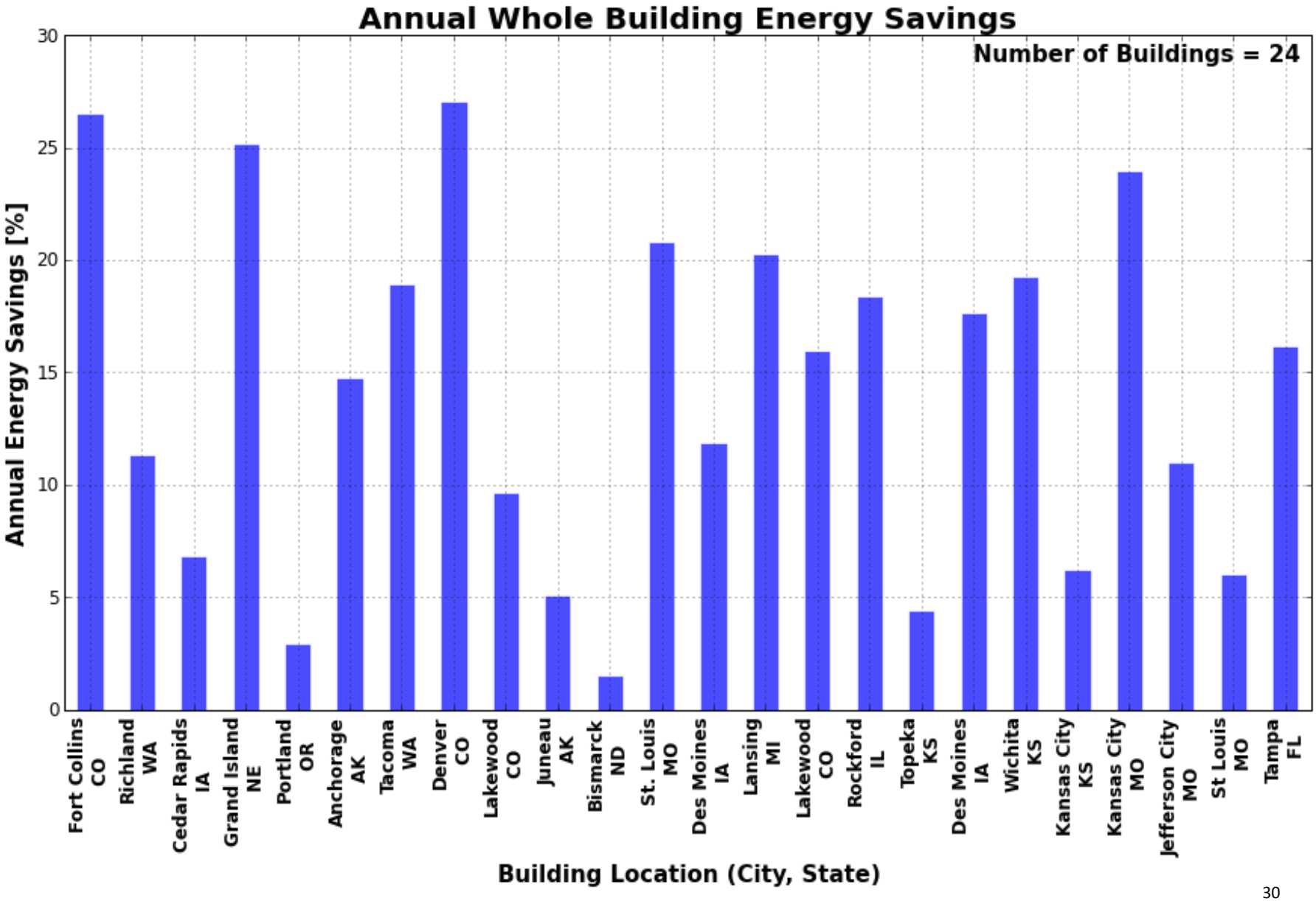
C03: Implement loop differential pressure reset/reduction
C05: Lockout chiller based on demand or OAT
C06: Control chilled water pumps by chilled water valve position/open up isolation valves
C08: Clean and repair cooling tower
C18: Use electric chillers in lieu of steam turbine chillers whenever possible
C22: Run One parallel condenser water pump instead of 2

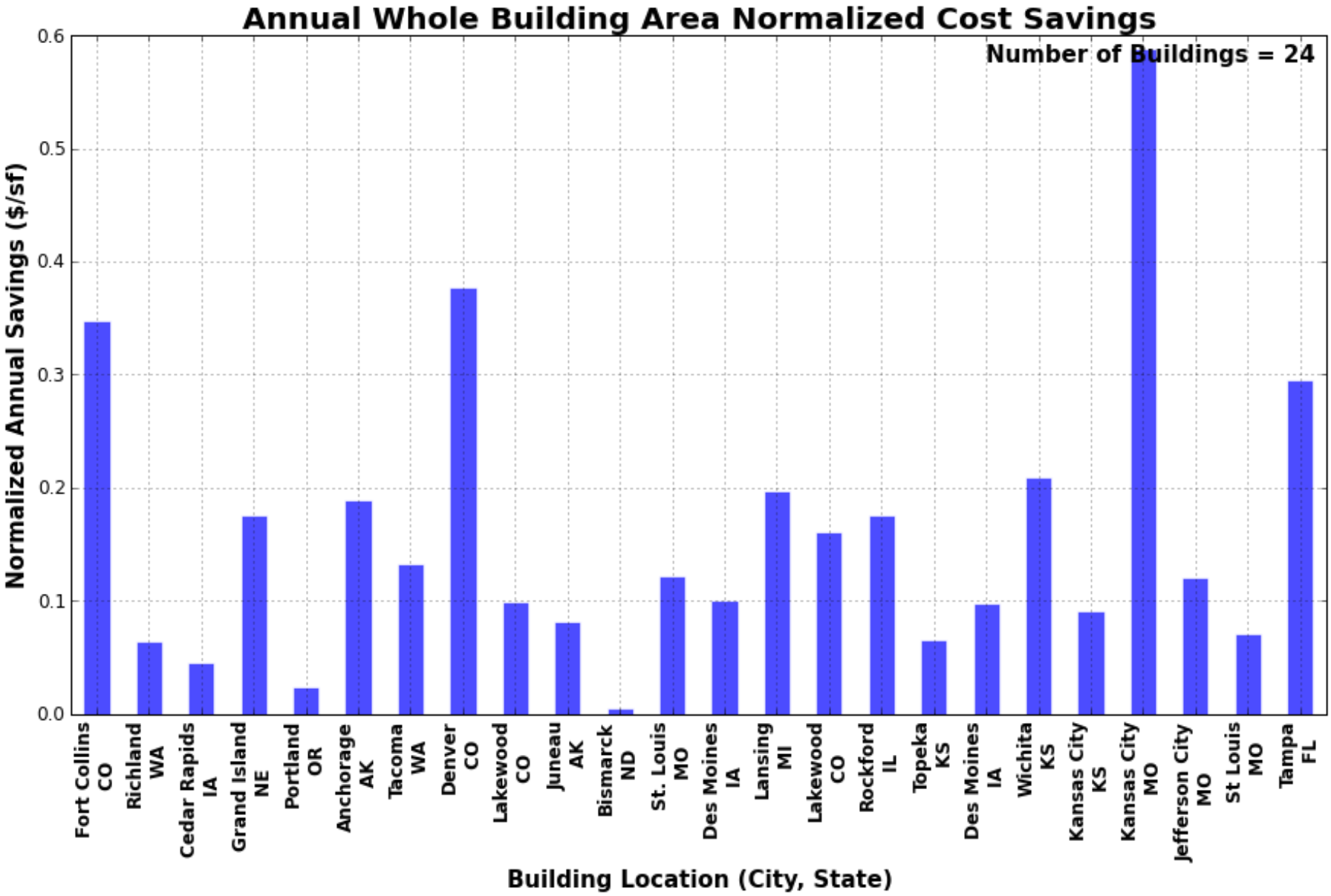
H1: Lockout boiler and pumps during hot weather (OAT lockout)
H14: Adjust outdoor air reset schedule for lower temperatures

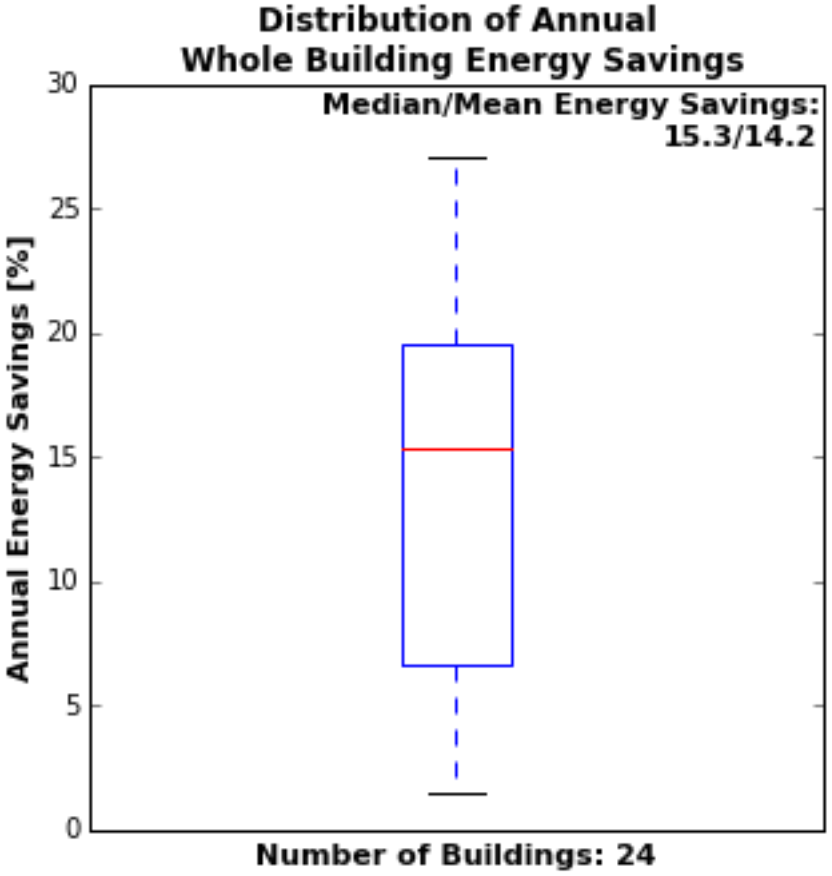
S01: Enable night setback for terminal boxes
S02: Tighten/add schedules on RTUs (weekday, weekend, and holidays)
S03: Tighten/add schedules on AHUs (weekday, weekend, and holidays)
S04: Tighten schedules for programmable thermostats (occupied and set back)
S06: Tighten schedules on lighting
S08: Add/tighten schedule for exhaust/relief fans and ensure they are off during unoccupied hours and during warmup
S10: Utilize/implement optimal start capabilities
S11: Optimize boiler and chiller schedules

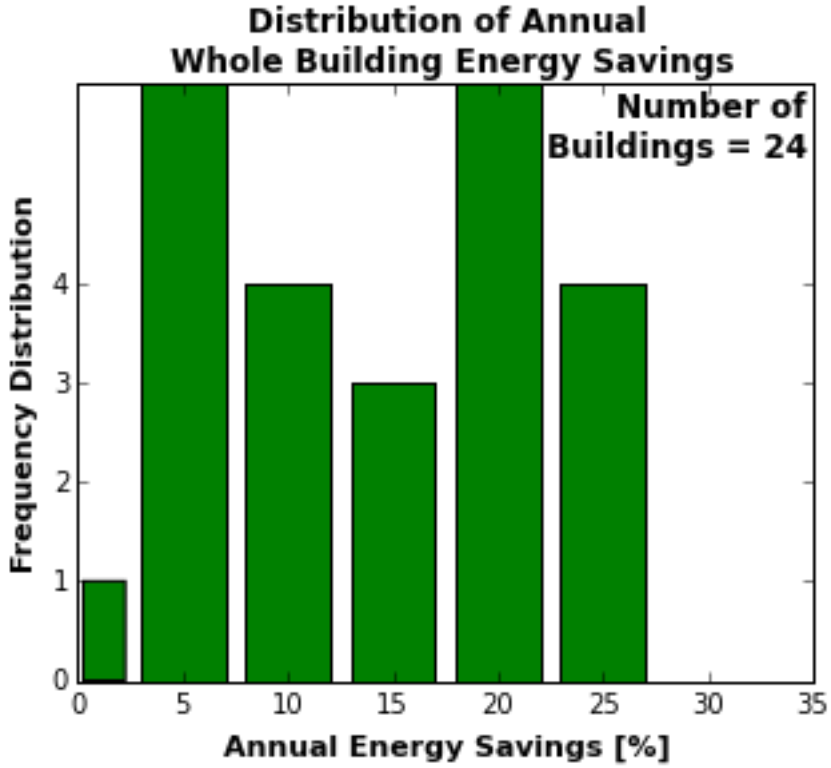
Z08: Widen/adjust cooling and heating set points
Z11: Review and/or implement night setback for all zones
Z20: Interlock the terminal fan with the proper AHU
Z21: Switch terminal box to unoccupied mode based on occupancy sensors
Z23: Improve VAV box control by switching modes (VAV box heating mode, cooling only mode, etc.)

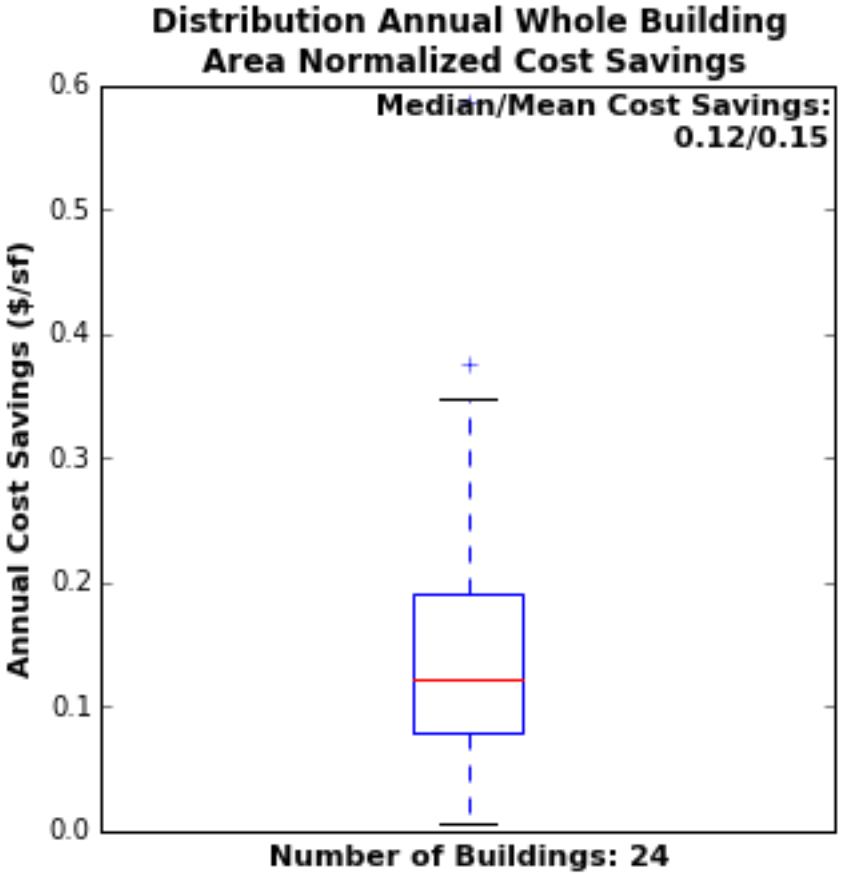
Energy and Cost Savings from Implementing Re-tuning Measures

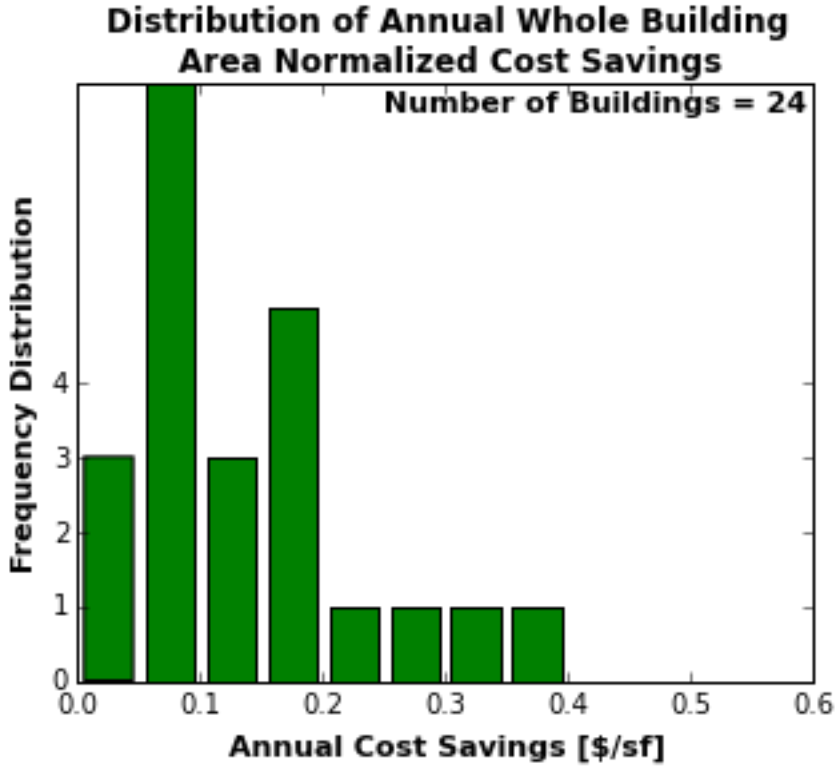

Annual Whole Building Energy Savings
Number of Buildings = 24
Annual Energy Savings [%]
0
5
10
15
20
25
30
Fort Collins CO
Richland WA
Cedar Rapids IA
Grand Island NE
Portland OR
Anchorage AK
Tacoma WA
Denver CO
Lakewood CO
Juneau AK
Bismarck ND
St. Louis MO
Des Moines IA
Lansing MI
Lakewood CO
Rockford IL
Topeka KS
Des Moines IA
Wichita KS
Kansas City KS
Kansas City MO
Jefferson City MO
St Louis MO
Tampa FL
Building Location (City, State)

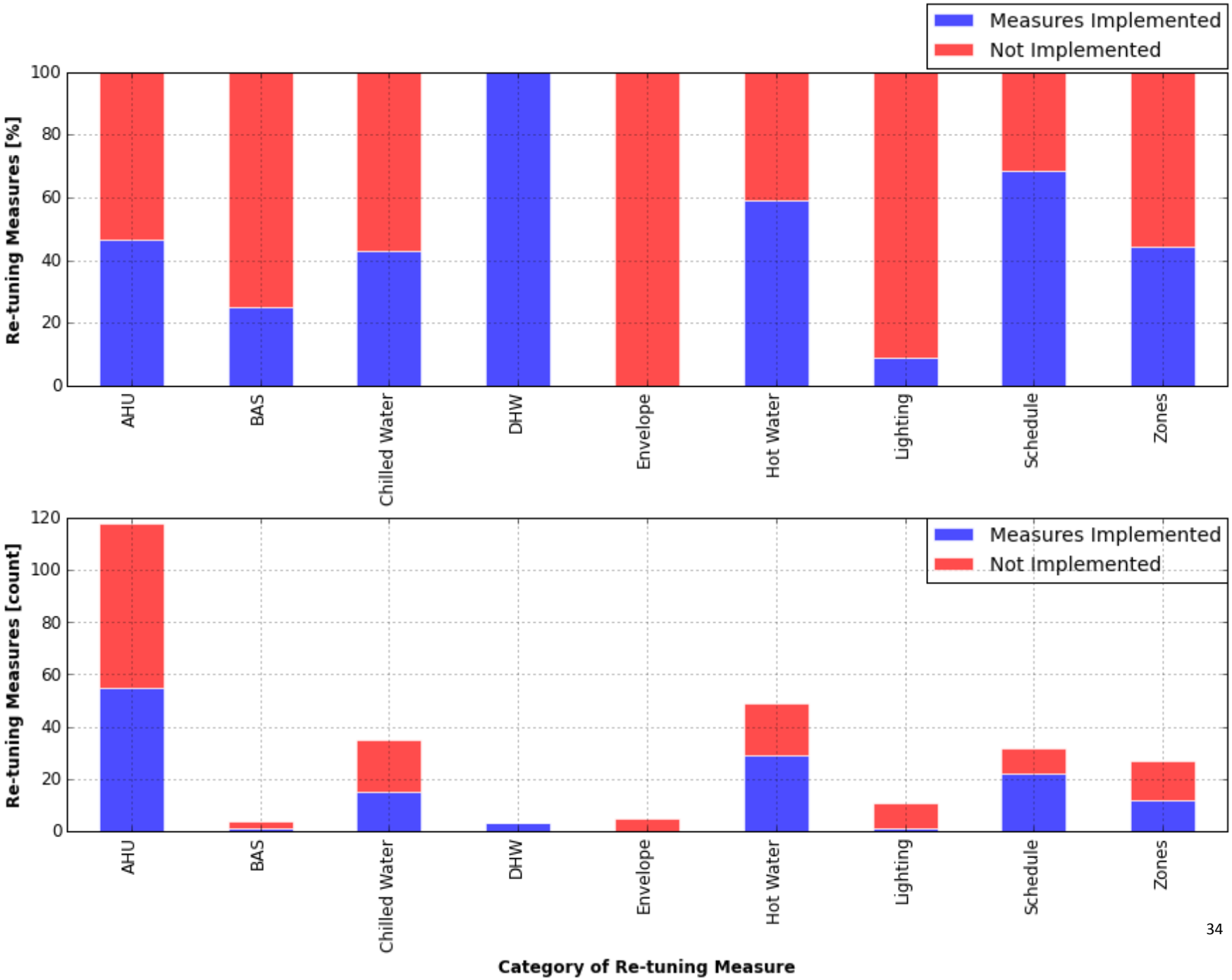

Annual Whole Building Area Normalized Cost Savings
Number of Buildings = 24
Normalized Annual Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Fort Collins CO
Richland WA
Cedar Rapids IA
Grand Island NE
Portland OR
Anchorage AK
Tacoma WA
Denver CO
Lakewood CO
Juneau AK
Bismarck ND
St. Louis MO
Des Moines IA
Lansing MI
Lakewood CO
Rockford IL
Topeka KS
Des Moines IA
Wichita KS
Kansas City KS
Kansas City MO
Jefferson City MO
St Louis MO
Tampa FL
Building Location (City, State)


Distribution of Annual
Whole Building Energy Savings
Median/Mean Energy Savings:
15.3/14.2
Annual Energy Savings [%]
Number of Buildings: 24
0
5
10
15
20
25
30


Distribution of Annual
Whole Building Energy Savings
Number of
Buildings = 24
Frequency Distribution
Annual Energy Savings [%]
0
1
2
3
4
0
5
10
15
20
25
30
35


Distribution Annual Whole Building
Area Normalized Cost Savings
Median/Mean Cost Savings:
0.12/0.15
Annual Cost Savings ($/sf)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Number of Buildings: 24


Distribution of Annual Whole Building
Area Normalized Cost Savings
Number of Buildings = 24
Frequency Distribution
0
1
2
3
4
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Annual Cost Savings [$/sf]


Measures Implemented
Not Implemented
Re-tuning Measures [%]
0
20
40
60
80
100
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones
Measures Implemented
Not Implemented
Re-tuning Measures [count]
0
20
40
60
80
100
120
AHU
BAS
Chilled Water
DHW
Envelope
Hot Water
Lighting
Schedule
Zones
Category of Re-tuning Measure

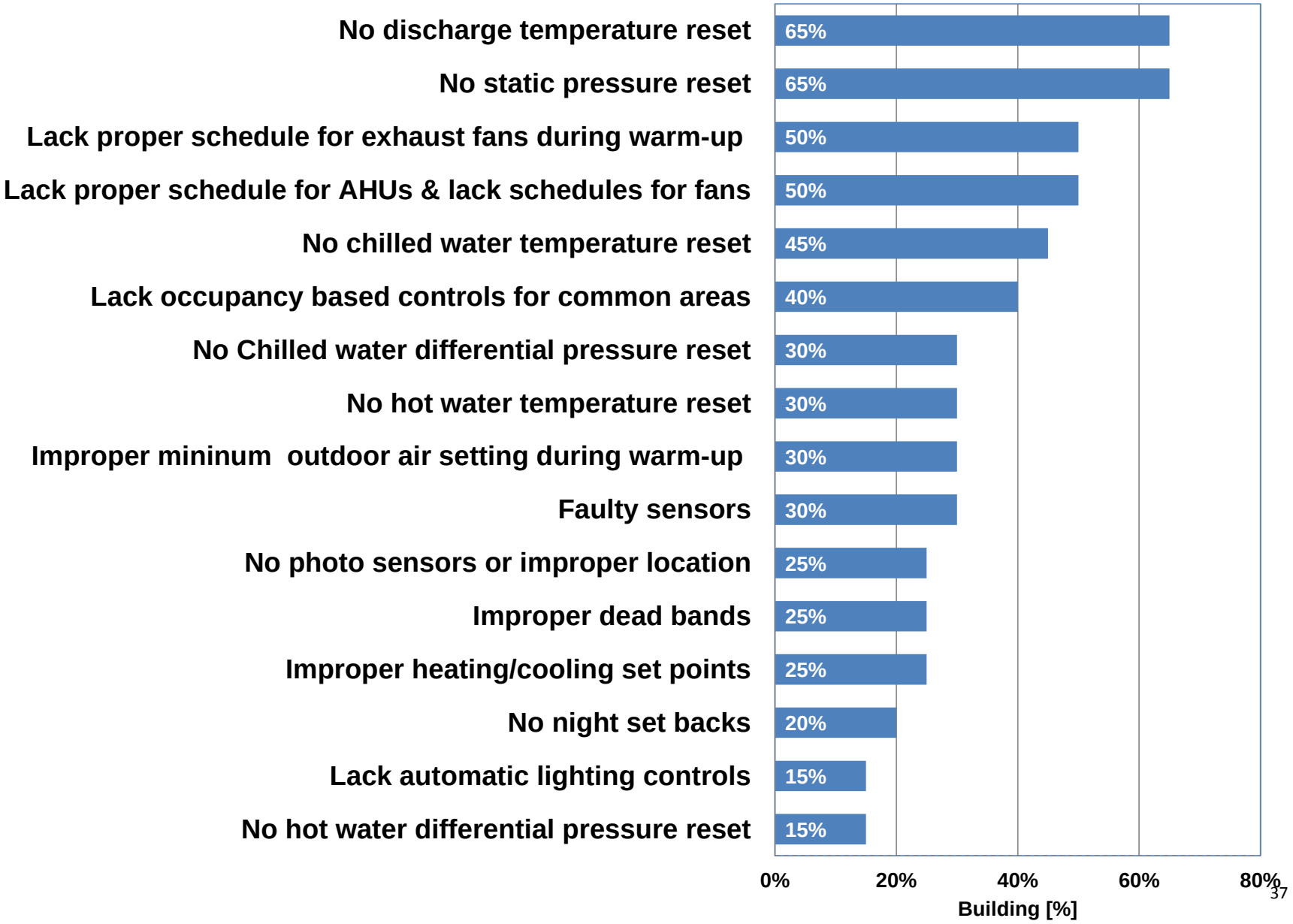
Conclusions from Meta-Analysis

Meta-Analysis: Common Measures

- Almost every building had some re-tuning measures to consider

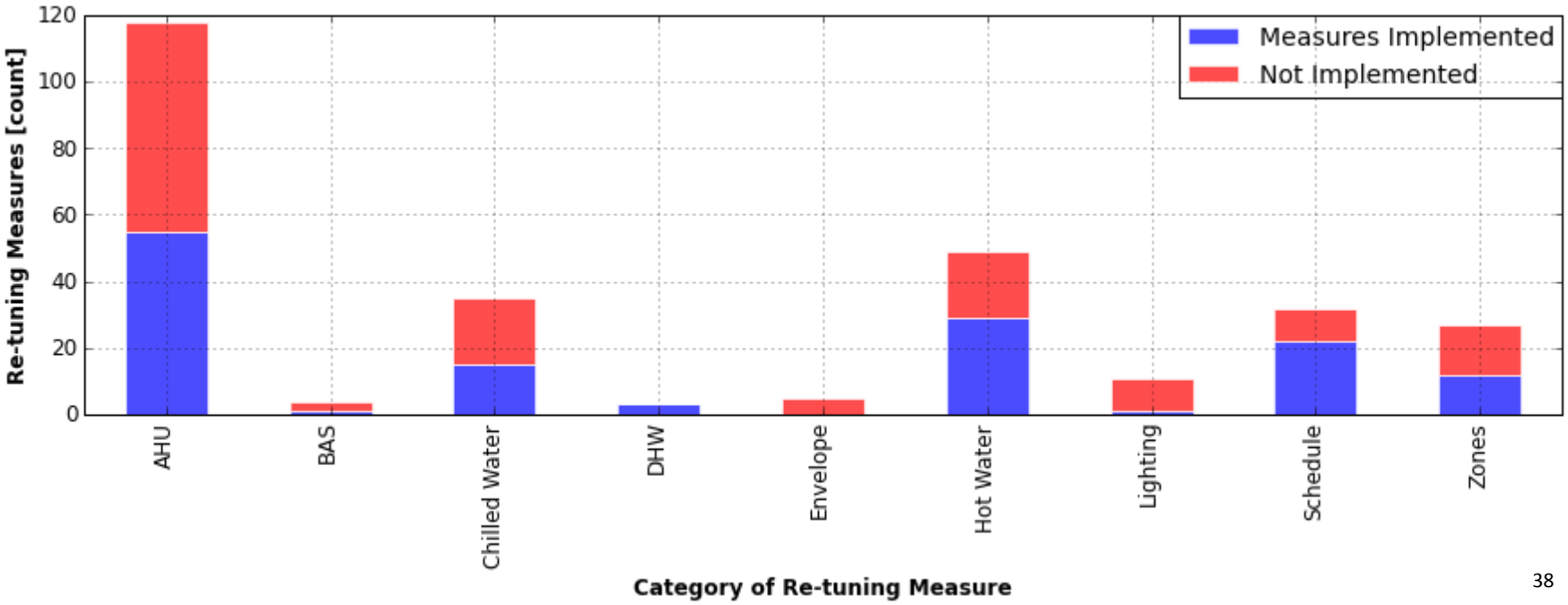
- Lack of proper schedules for HVAC and lighting systems
- Lack of schedules for exhaust fans or fans running during warm-up mode
- Lack of night set backs
- Lack of occupancy-based controls for common areas (conference rooms, kitchen, etc.)
- Lack of photo sensors or sensors in the wrong locations for exterior lighting controls
- Lack of automatic lighting controls
- One or more faulty sensors
- Improper air flow sensors or stuck zone dampers
- Improper minimum outdoor-air setting during morning warm-up
- Lack of static pressure or discharge temperature reset on AHUs
- Lack of chilled/hot water temperature reset
- Lack of differential pressure reset on chilled/hot water distribution loop
- Improper heating/cooling set points or dead bands

Meta-Analysis: Summary



Meta-Analysis: Summary (cont.)

- Annual energy savings ranged between 2% to 26%, with a median savings of 15%
- Annual normalized cost savings ranged between 0.0$/sf to 0.6$/sf, with a median savings of 0.12$/sf
- If all re-tuning measures identified were implemented, the savings could have been even larger



Lessons Learned

Building Re-tuning Trainings

- Over 60 building re-tuning training sessions provided
- Composition of the classes
  - Building operators, energy service providers and retro-commissioning agents
  - Most field training sites were office buildings, but a few institutional, school, retail and healthcare buildings as well
- Every training included field training in a building – to put concepts learned in the classroom to practice
- A number of opportunities were identified in the training buildings

Highlights of Re-Tuning

- Every set point adjustment made will have an impact of some sort on the utility meter
- Can save energy and keep occupants comfortable
- It takes time to tune a building
- There are no magic set points that work all the time
- Always monitor the utility meters (gas & electric) to see what affect you have had
- Look at the big picture when making adjustments
- Watch the meter profiles weekly
- Learn and know the building's personality

Issues for Successful Application of Re-tuning

- Important to make adjustments during the re-tuning process. Deferring implementation until later, does not work
- Building operations staff need to know that they have the authority to implement minor operational changes without risk of reprisal
- Building operation staff need to have confidence in the process. To develop comfort, operators can make small incremental changes over time and observe the responses of occupants

… Key Lessons Learned…

- Many commercial buildings have array of operational problems
- Trained building operations staff can re-tune buildings, if empowered
- Building re-tuning can yield energy savings between 5% and 20% through implementation of no-cost and low-cost measures
- But, the human factor is a real issue in realizing re-tuning benefits in practice
- **In the long run, automation is key to persistence of "optimal" building operation**

Questions?

Srinivas.Katipamula@pnnl.gov

http://retuning.org

http://retuningtraining.labworks.org