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Sensors/Controls/Diagnostics Benefits Analysis

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Background

- Many commercial buildings consume more energy than they should and yet cannot maintain adequate comfort
- There are many reasons for the current state of commercial buildings
  - Policy, **technology**, resources, etc.
- Our inability to sense, monitor and control buildings effectively, leads to significant energy waste
- For example, between 80% and 90% of buildings do not have adequate control infrastructure – many of these buildings still rely on time clocks, thermostats and manual switches
- Even those buildings that have sophisticated building automation systems (BASs), don't use the full capabilities of the system, leading to many operational problems that lead to significant energy waste

Commercial Building Energy Efficiency and Cost Savings Opportunities

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- Significant opportunities exist to improve energy efficiency of the existing commercial building stock
  - Between 10% and 30% reductions in energy consumption is possible by **improving** and **ensuring persistence** of building operations
  - Energy retrofits can also lead to significant energy savings, 30% to 50%; updating existing buildings to meet current code will provide significant savings as well
  - Combining deep retrofits with operational improvements can lead to energy savings between 40% and 60% in existing building stock
  - Additional opportunities also exist to reduce energy cost and emissions by implementing transactional energy services (demand response, load shifting, participation in ancillary services market, etc.)

What is the Need?

- Low-cost, open, standard, reliable technology
  - Inexpensive reliable sensors
  - Open, standard and reliable controls infrastructure, especially for the 90% of the buildings
  - Solutions that scale
- Make controls infrastructure a commodity product
- Industry has been slow to respond to these needs
  - Interoperability is still a myth
  - Solutions do not scale
- Research, development and deployment (RD&D) of sensors, monitoring, diagnostics and control on a large scale
- Quantify benefits from use of sensors, controls and diagnostics is essential to justify the RD&D investments

Evaluating Benefits of Sensors and Controls Strategies Today

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- Benefits estimated by a practitioner, by an expert modeler, or by using case studies
  - Custom business specific spreadsheets that estimate reduced runtime or improved efficiency based upon what the practitioner thinks will happen
  - Expert modelers (typically researchers) 'adjust' systems operation to effect a change and let the model sum up the energy savings
  - End user or design engineer uses 'case studies' to estimate potential impact
- Not easy to model to estimate savings
  - Simulation tools are not configured to easily model these problems
    - For example, select a particular control strategy (demand response, load shifting, etc.) and assess its impact on a specific system or component
    - Additionally, most of the components are physics based representations and not calibrated to actual equipment performance or operation
- The existing building reference models vary by the entity that constructed them, so the results will vary based upon the capability of the modeler and their method of adjusting the model
- The 50% and 30% energy savings estimates from DOE's advanced design guides assume all known control strategies work (non-grid related) and are implemented (perfectly commissioned, perfectly optimized)

Proposed Methods for Estimating Savings

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- To improve the energy savings estimates and allow for the evaluation of specific controls strategies (or addition of sensors), both demand side and grid side, a set of standardized **building reference** models needs to be constructed that allow the modeler to select a control measure against a specific system/component in the building to estimate the energy and financial impact. The proposed steps to get this done are as follows:
  - Evaluate any existing building reference models for energy savings forecasting capability (EE, Controls, Grid)
  - Determine whether the systems/components in the existing models are calibrated
  - Select the best models to be used as a starting point
  - Modify the models such that they can 'disaggregate' the effects of EE or control strategies and add grid related strategies (DR, Ancillary Services).
  - Post these new 'Building Reference' models for public comment.
  - Incorporate relevant comments
  - Regularly update the reference building models as new data becomes available
- These steps will create a set of building reference models that DOE can use to evaluate sensors and controls strategies

Beyond Sensors & Controls (S&C) Reference Models

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- Once a set of building reference models is created, expert modelers more effectively evaluate S&C impacts for a variety of projects. However, we still need an easy to use tool for non-modelers to estimate energy efficiency (EE), grid impacts and financial savings
- Reference models can be used to execute a series of parametric simulations to create a table of results that can be 'looked up' using a simple user interface
  - To manage the scope and scale, this process will need to be guided by the most likely scenarios
  - In addition, this would be an opportune time to design and develop a simulation process that generates a statistical result as opposed to a absolute value (which is rarely accurate)
- These are the steps that would be needed to accomplish the task:
  - Determine the main building types to be evaluated
  - Determine the climate zones to be evaluated
  - Determine the measures, both EE and controls, that are relevant to the building type (systems) and climate zone that will be simulated
  - Construct a database that will hold the results
  - Publish the Reference models for comment
  - Run the simulations
  - Update regularly

Beyond S&C Reference Models Step 2

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- The parametric runs will produce a standard set of energy results. However, this is only marginally useful to the building owner as they are interested in financial benefits they can expect from both EE and S&C projects
- The standard output (to be determined) will be published so that third parties can develop software tools that use the energy results (8760 hourly?) as input to their analytical tools for applications such as rate analysis
- This could take the form of a:
  - Lab call,
  - FOA or
  - Challenge

Analysis Results

Objective of Sensors, Controls/Diagnostics Benefits Analysis

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- A narrow, but focused, scoping analysis to develop a framework and apply it to a set of buildings to show how the ultimate objective described previously can be achieved
- Assess the energy (and cost benefits) from use of accurate sensors, proper and advanced controls, automated fault detection and diagnostics (AFDD) and integration of buildings and grid by leveraging knowledge in:
  - Building controls,
  - Buildings simulation,
  - Building re-tuning,
  - AFDD and
  - Building-grid integration

Limitations of the Work

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- The absolute energy consumption values may or may not be useful, but relative consumption (percent reductions) can be useful in assessing alternate scenarios
- The EnergyPlus models, although based on industry input, have a lot of assumptions
- The severity levels for operational improvements are based on our best "guess" at what we have seen in the field
- However, translating them to a national impact requires another set of assumptions – prevalence of the operational problems in the building stock
- Retrofit measures selected are not "deep" but bring the 1990 vintage to the current building code
- Retrofit measures also do not include advanced building systems (chilled beams, variable refrigerant flow, thermal storage, etc.)
- Demand response measures considered are mostly standard measures; they do not include support for ancillary services, which require rapid response and are difficult to model with EnergyPlus

U.S. Commercial Building Stock Characterization: CBECS 2003

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Total Site Energy: 6,523 trillion Btu - Total Area: 71,659,183,126 sf

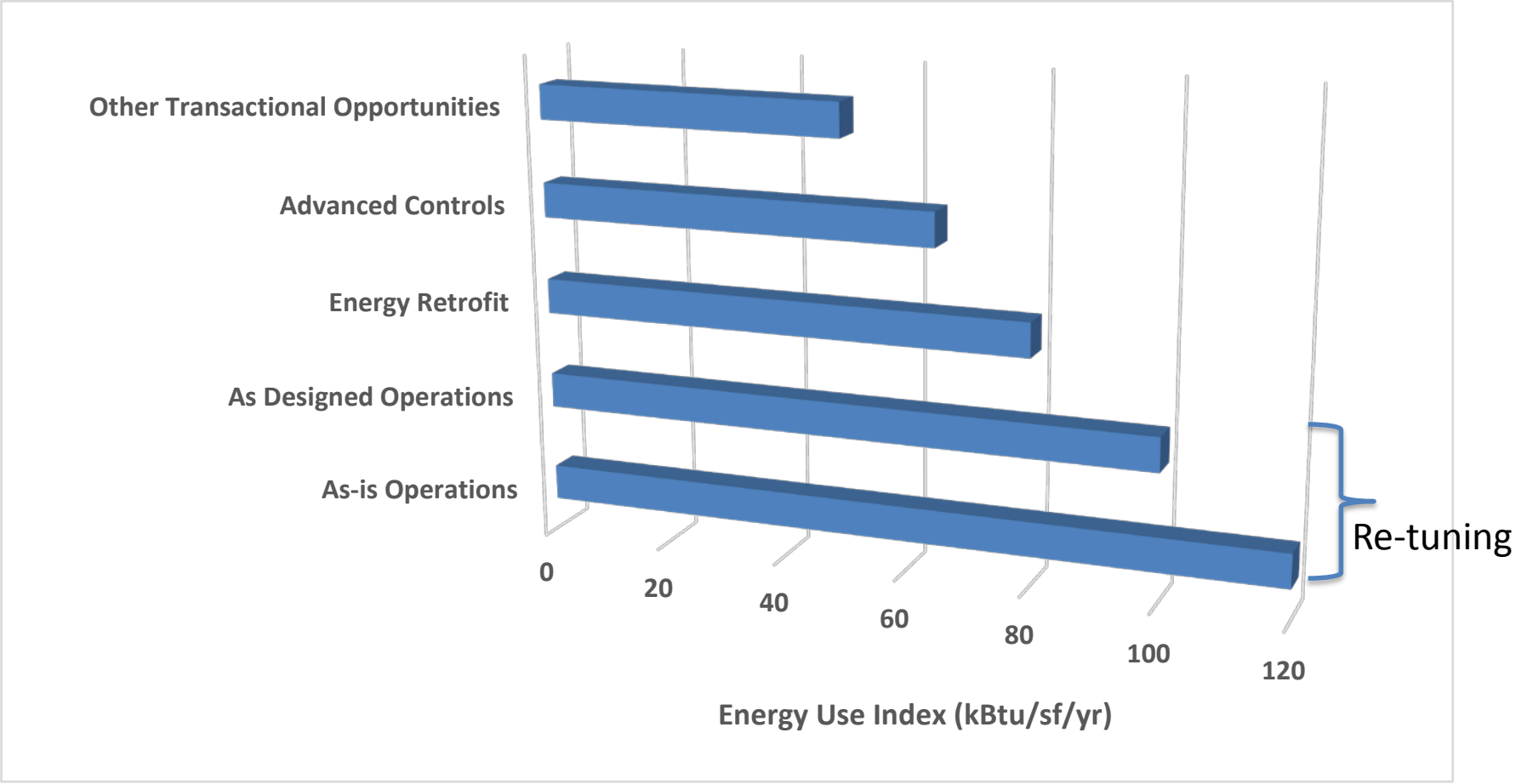
Group A: DOE/PNNL E+ Ref. Models Exist
Fraction of Total: Area - 0.64; Energy - 0.65;

- Large Office
- Medium Office
- Small Office
- Primary School
- Secondary School
- Stand-alone Retail
- Strip Mall
- Supermarket
- Quick Service Restaurant
- Full Service Restaurant
- Small Hotel
- Large Hotel
- Hospital
- Outpatient Healthcare
- Warehouse (non-refrigerated)

Group B: No E+ Ref. Models Exist
Fraction of Total: Area - 0.36; Energy - 0.35

- Enclosed Malls
- Public Assembly
- Public Order & Safety
- Religious Buildings
- Service (e.g. garage, post office, vehicle storage etc.)
- Colleges
- Retail Dealership
- Food Sales - Convenient Stores, Gas Stations and Other food sales
- Lodging - Dormitory
- Other and Nursing Homes
- CBECS Vacant

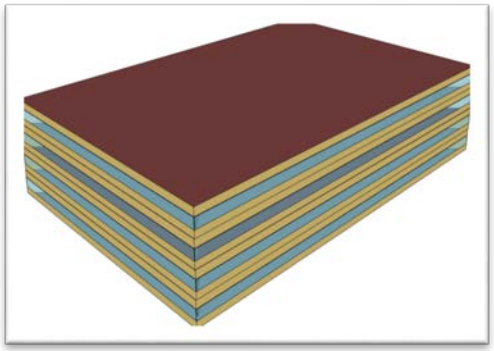
Re-tuning, Retrofits, Advanced Controls and Transactional Services

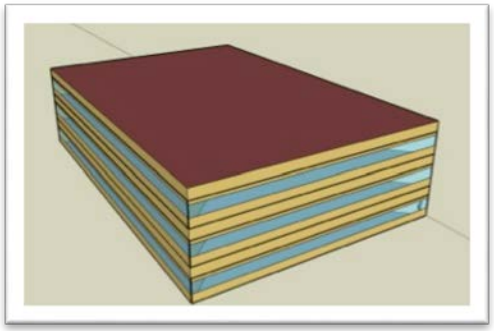


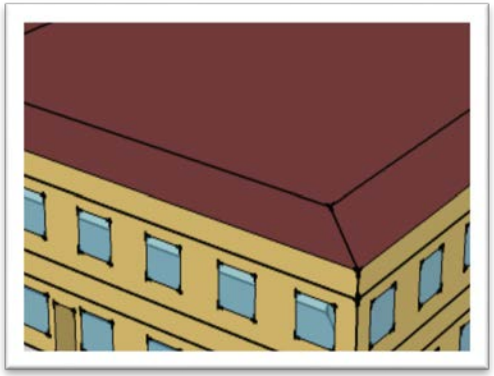
*EUI values are for illustration purpose only

Buildings Analyzed and Climate Zones Considered

- Analyzed Commercial Building Energy Consumption Survey (CBECS 2003) to determine the subset of building types
  - Large office
  - Medium office
  - Small office
- Climate zones for the analysis
  - 16 U.S. climate zones from ASHRAE Standard 90.1
- Building vintage
  - Existing buildings constructed in 1990s







Simulation Analysis Process

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- Developed and documented EnergyPlus reference simulation models (not a formal report, but reference material)
  - Leveraged existing office building models (advanced energy retrofit guide, PNNL models for codes development and other related work)
  - Refined existing models
  - *"Benchmarked" the models to have comparable EUIs with CBECS 2003*[@]
  - "*Documented*"[*] the models (features and EUIs in various climate zones)
- Completed development of reference models

[@]First order comparison of base case results with CBECS 2003 consumption data
[*]Not formal reports, but working notes

Simulation Analysis Process (cont.)

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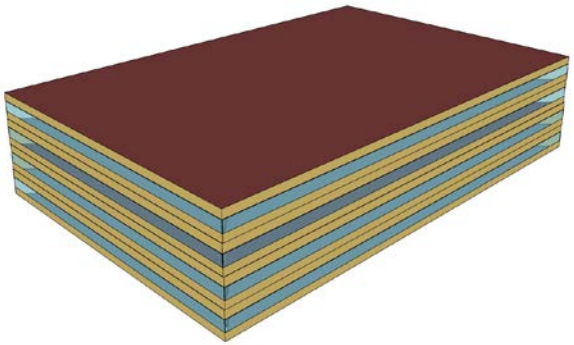
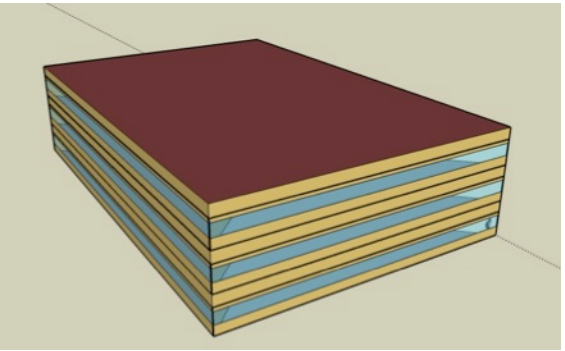
- Created a list of measures that are relevant to each building type (and systems) and in each climate zone that will be simulated
- Developed modeling strategies for the identified measures
- Designed the simulation grid to consider both individual measures and packages of measures
- Completed simulation runs for individual measures
- Completed simulation runs for the package of measures

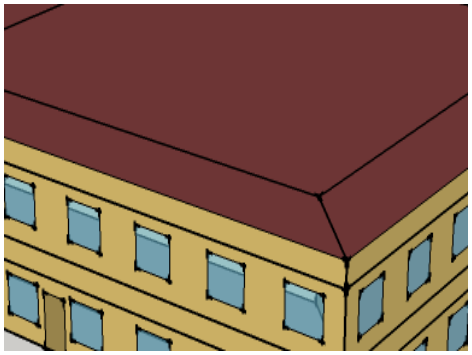
Building Types



Large Office
(~200,000 sf)

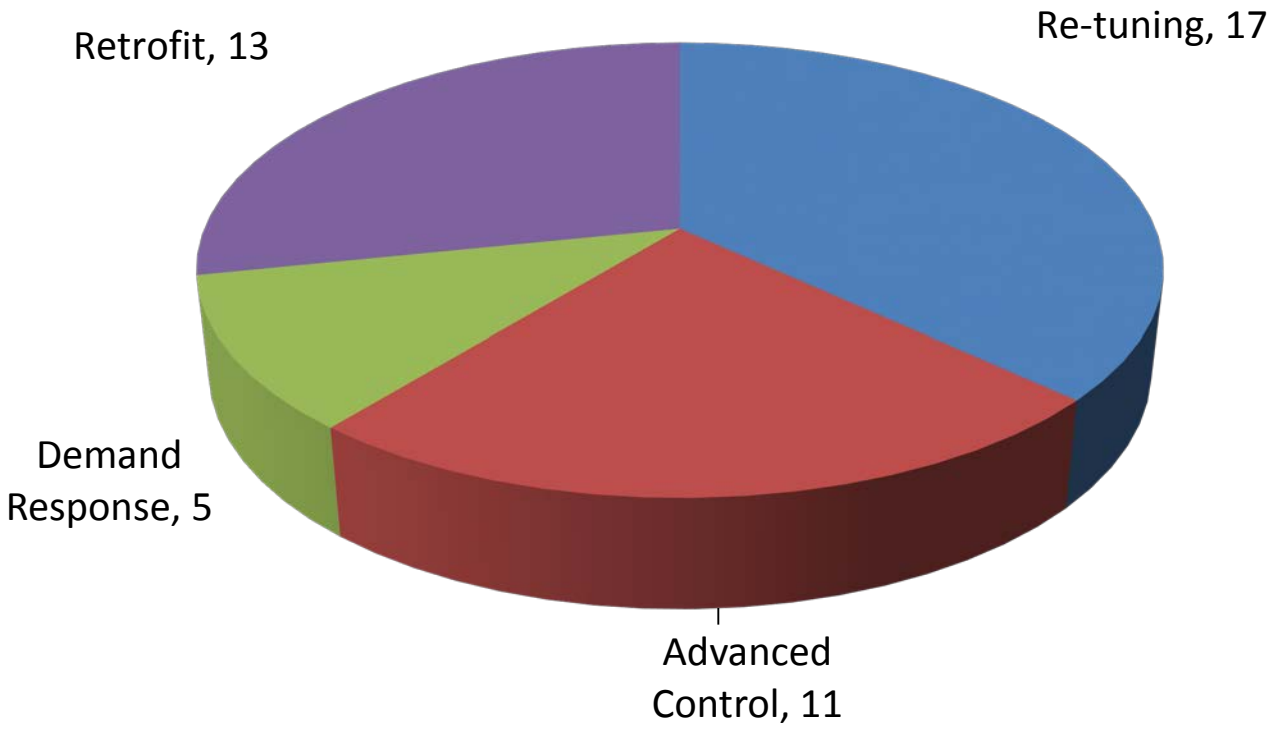


Medium Office
(~50,000 sf)



Small Office
(20,000 sf)

Measures Simulated



Retrofit Measures

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- Interior lighting retrofit to reduce lighting power density (LPD) (LO, MO, SO)
- Exterior lighting fixtures retrofit (LO, MO, SO)
- Replace supply fan motor and variable frequency drive (VFD) (for variable-speed fans) (LO, MO)
- Replace boilers with higher efficiency models (LO)
- Replace chillers with higher efficiency models (LO)
- Replace RTUs with higher efficiency units (MO, SO)
- Replace RTUs with units that use evaporative cooling (MO, SO)
- Replace RTUs with air-to-air heat pumps (SO)
- Increase efficiency of service hot water system (LO, MO, SO)
- Retrofit electric transformers with higher efficiency models (LO, MO)
- Replace windows (LO, MO, SO)
- Add wall insulation (LO, MO, SO)
- Add roof insulation (LO, MO, SO)

LO: Large Office; MO: Medium Office; SO: Small Office
Taking 1990s vintage building to either current ASHRAE 90.1 Standard levels or in some cases to advanced energy guide levels

Re-tuning Measures

- Sensor calibration (sensor faults) (LO, MO, SO)
- Correct refrigerant charge (MO, SO)
- Fix water coil valve leakages (LO)
- Correcting HVAC operation schedules (LO, MO, SO)
- Supply air temperature set point reset (LO, MO)
- Economizer (LO, MO, SO)
- Exhaust fan shut down during unoccupied periods (LO, MO, SO)
- Static pressure reset (LO, MO)
- Close outdoor air damper during unoccupied periods (LO, MO, SO)
- Plant shut down when there is no load (LO)
- Chilled water supply temperature reset (LO)
- Chilled water pump differential pressure reset (LO)
- Condenser water temperature reset (LO)
- Hot water pump differential pressure reset (LO)
- Hot water supply temperature reset (LO)
- Lower minimum air flow rate for VAV terminals (LO, MO)
- Widen thermostat set point dead band (LO, MO, SO)

LO: Large Office; MO: Medium Office; SO: Small Office

Advanced Control Measures

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- Occupancy sensor for lighting control (LO, MO, SO)
- Daylight control (LO, MO, SO)
- Exterior lighting control (LO, MO, SO)
- Demand-controlled ventilation (LO, MO, SO)
- Advanced on/off control for plug loads (LO, MO, SO)
- Night purge ventilation (LO, MO, SO)
- Advanced rooftop unit (RTU) controls (SO)
- Elevator cab lighting and ventilation control (LO, MO)
- Water-side economizer (LO)
- Cooling tower controls (variable-speed fan) (LO)
- Optimal start/stop (LO, MO, SO)

LO: Large Office; MO: Medium Office; SO: Small Office

Grid Demand Response Measures

- Thermostat set points reset (LO, MO, SO)
- Duty cycle (LO, MO, SO)
- Pre-cooling (LO, MO, SO)
- Lighting controls (LO, MO, SO)
- Chilled water temperature control with fan controls (LO)

LO: Large Office; MO: Medium Office; SO: Small Office

Results Presentation Plan

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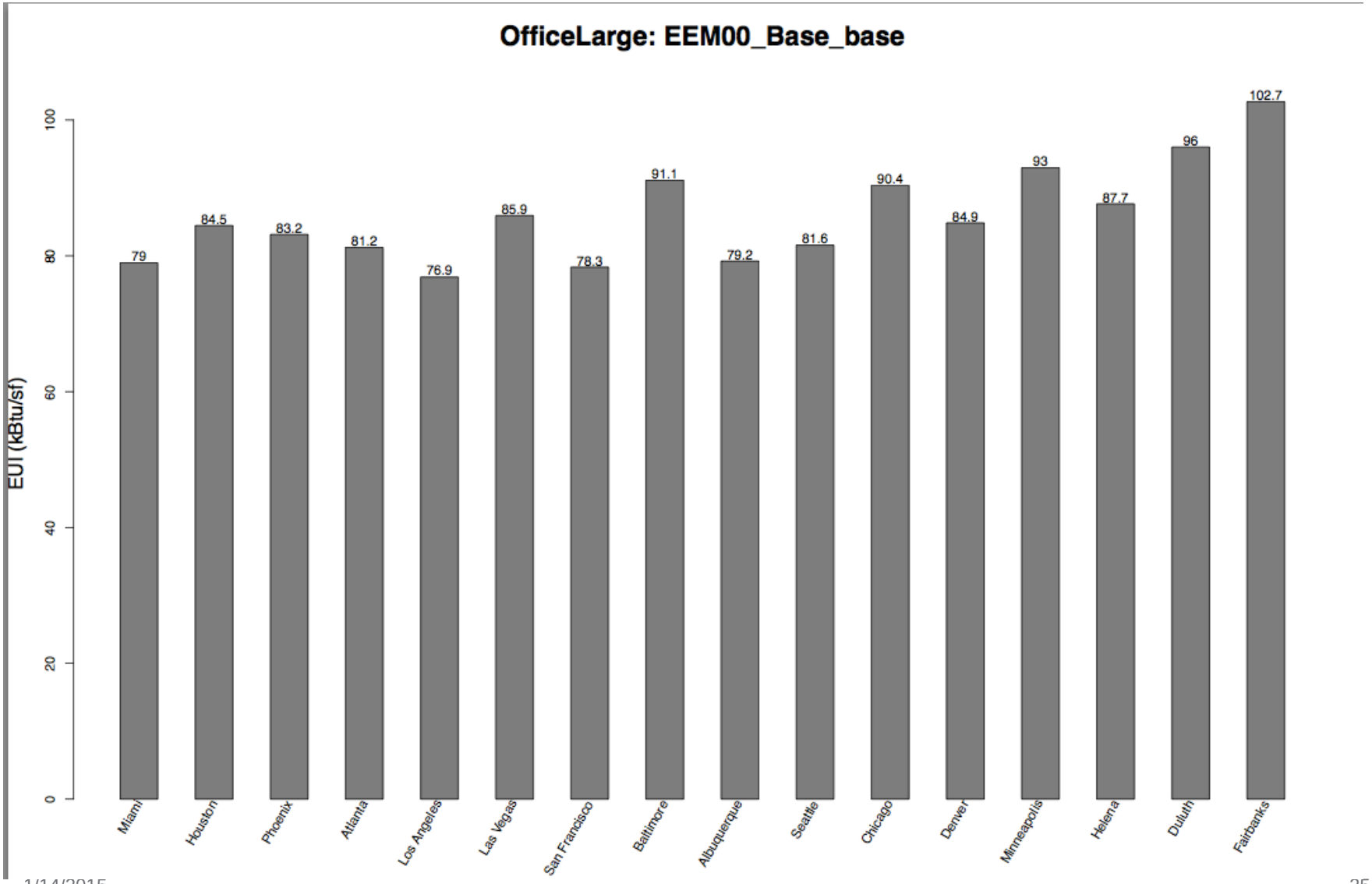
- As-operated building EUIs (Baseline)
- Percentage of building EUI reduction for individual measures
- Percentage of building EUI reduction for each proposed package of measures
- *Fraction of electric demand reduction (in the DR period) for each DR measure*

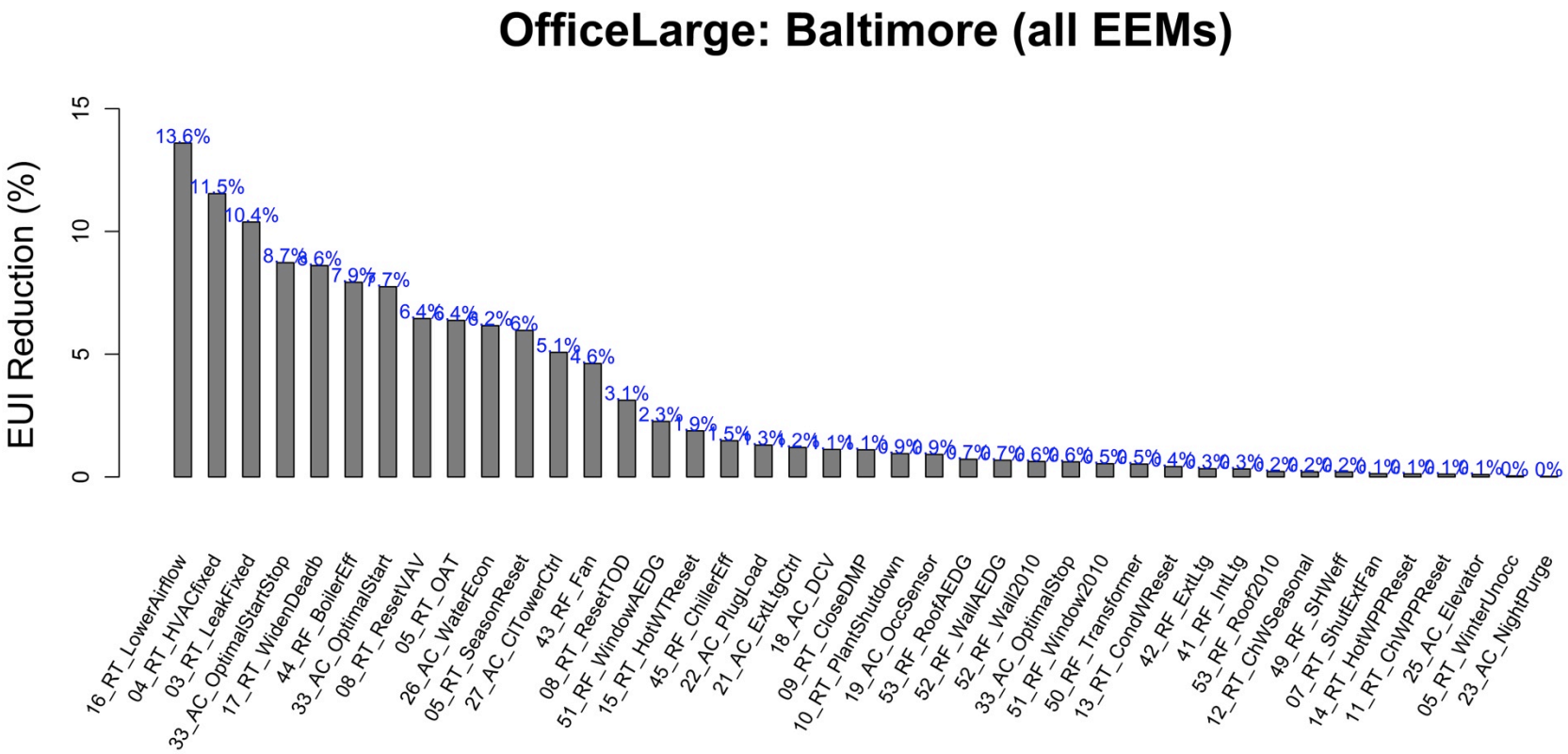
- There is lot of data and information, only a small sample of the information is being presented
  - Results from Baltimore, which represents an “average” climate zone
  - Results averaged across climate zones
    - Hot/Humid, Warm/Mixed, Cold
    - National (average of all 16 climate locations)

Large Office Analysis Results

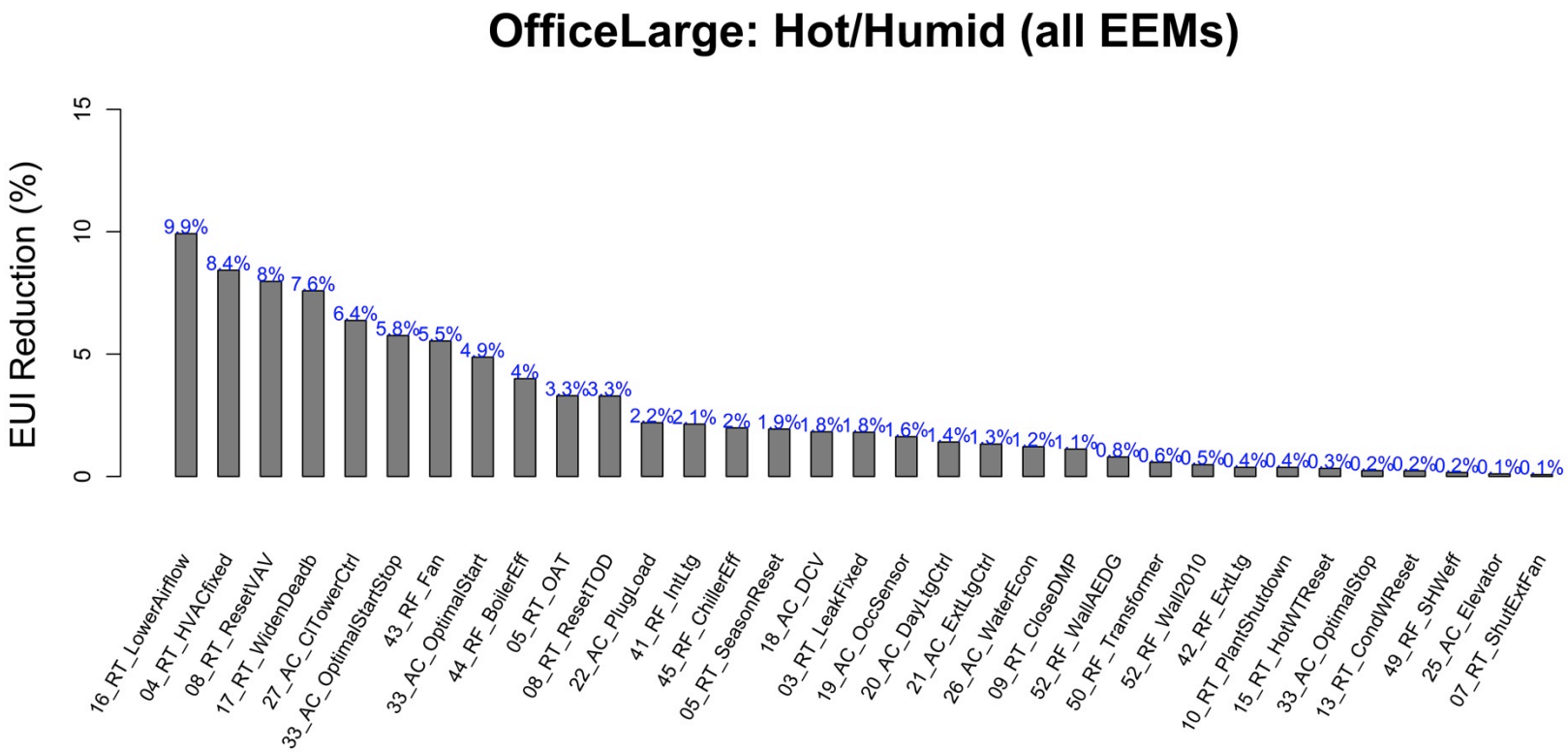
Large Office Baseline EUIs



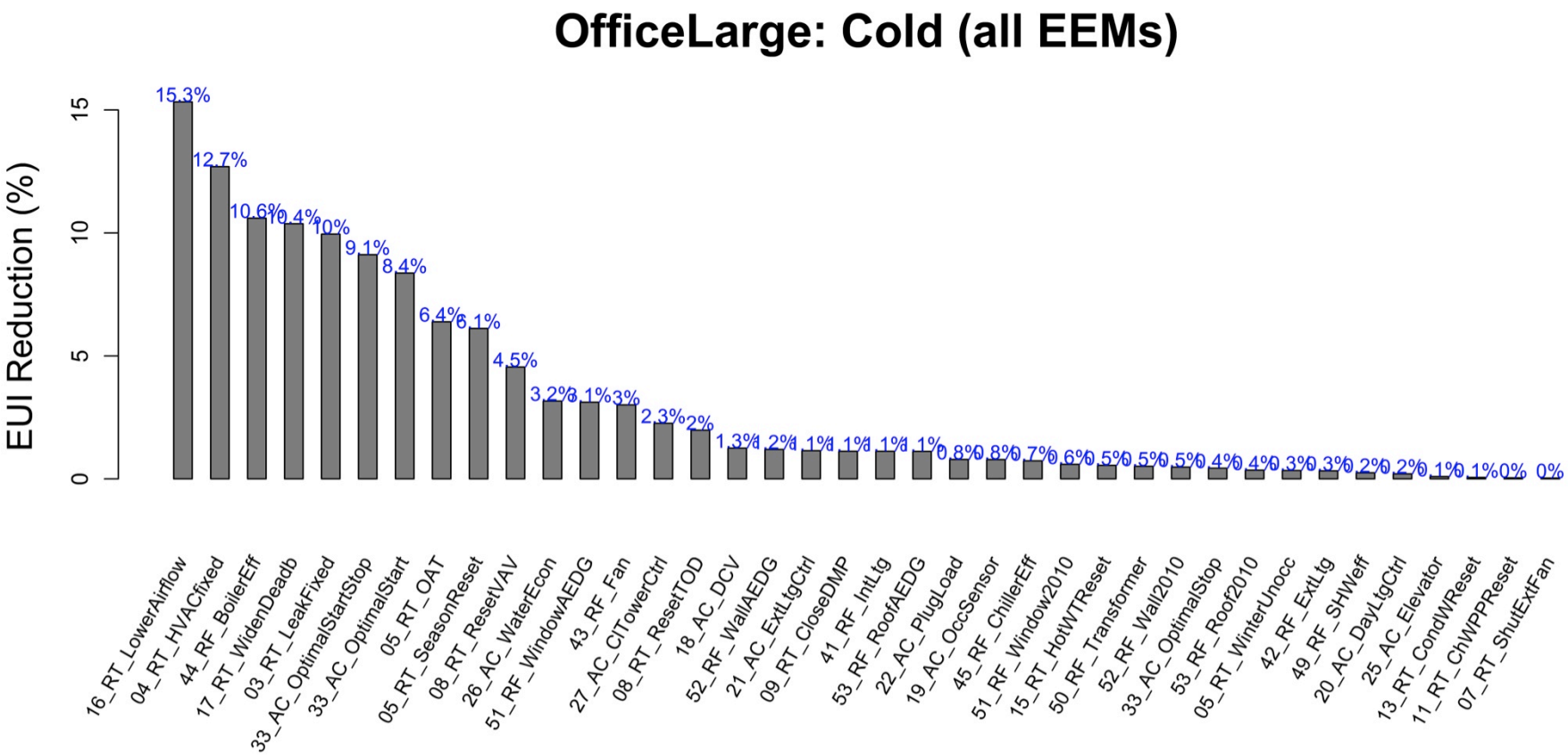
Savings from each Individual Measure: Large Office - Baltimore



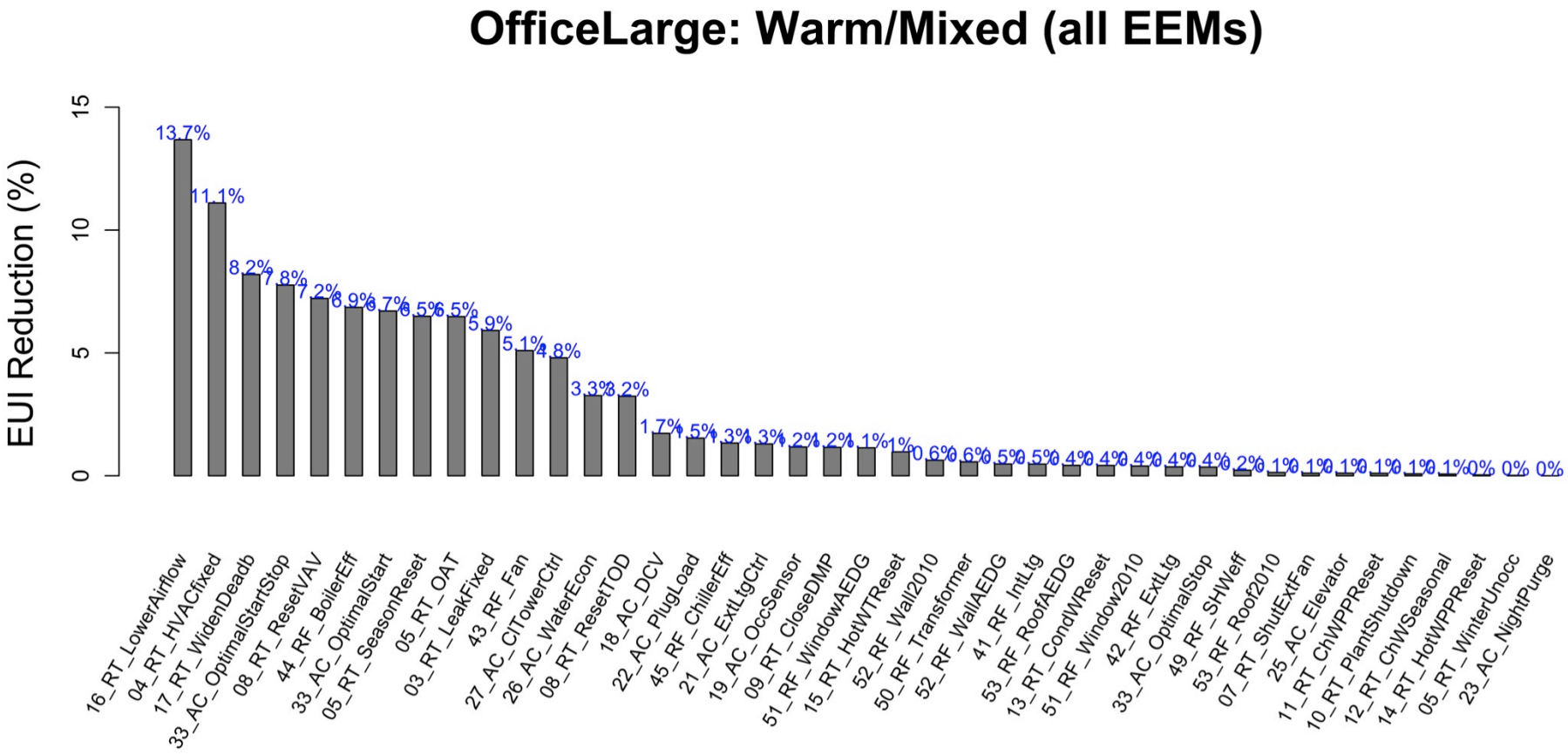
Savings from each Individual Measure: Large Office – Hot/Humid Climate



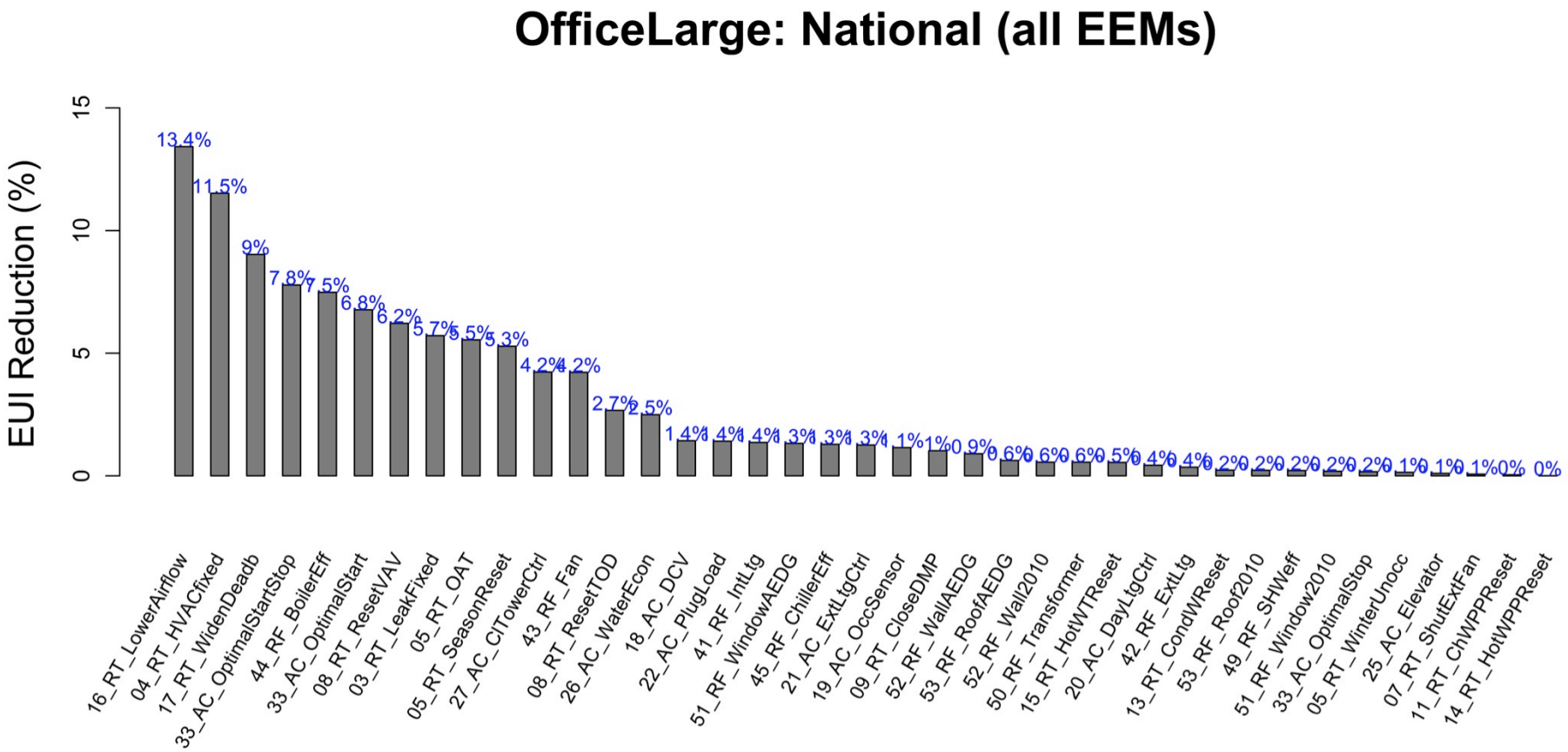
Savings from each Individual Measure: Large Office – Cold Climate



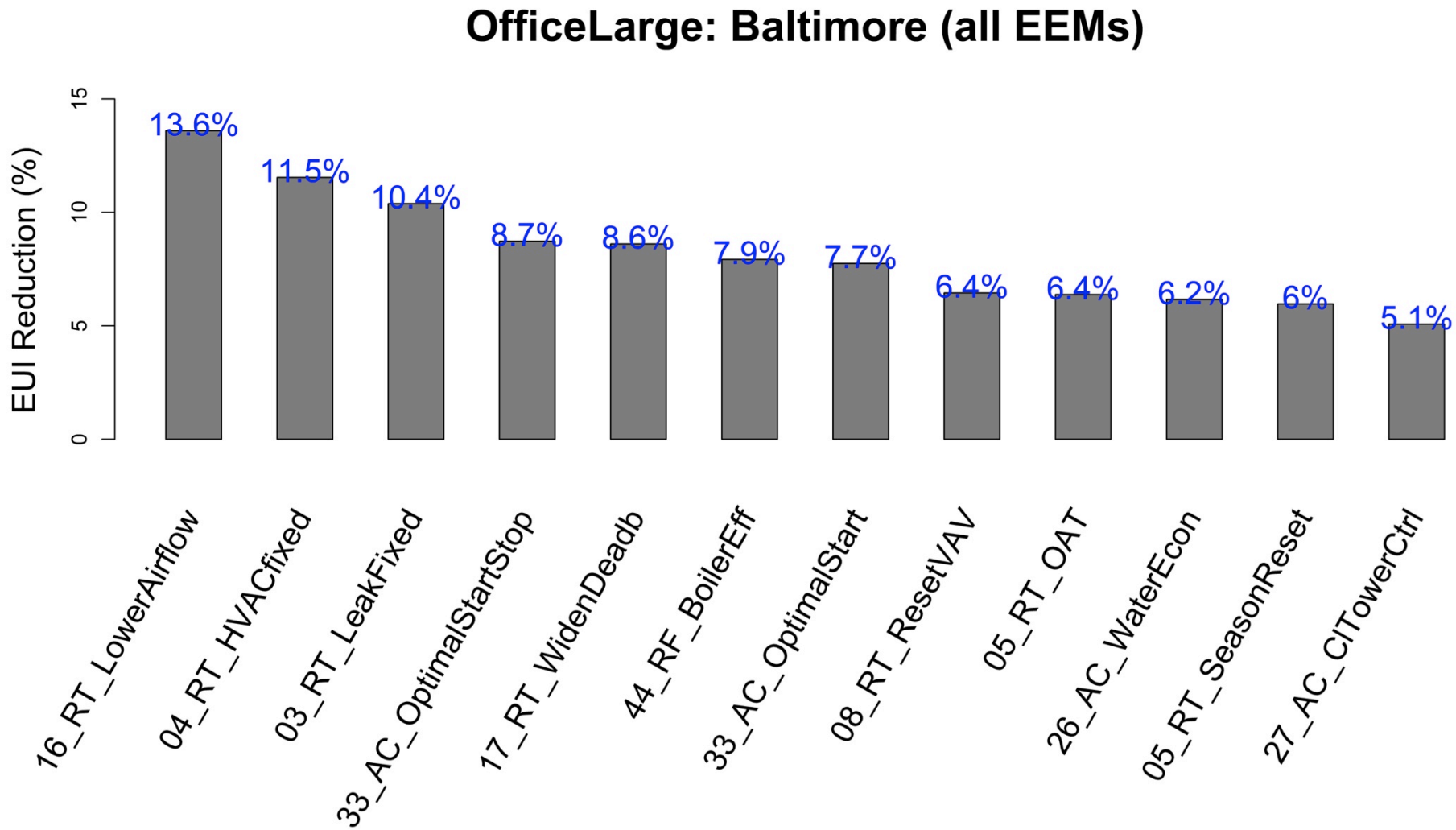
Savings from each Individual Measure: Large Office – Warm/Mixed Climate



Savings from each Individual Measure: Large Office – National Climate



Savings from Top 12 Measures Across all Categories: Large Office – Baltimore



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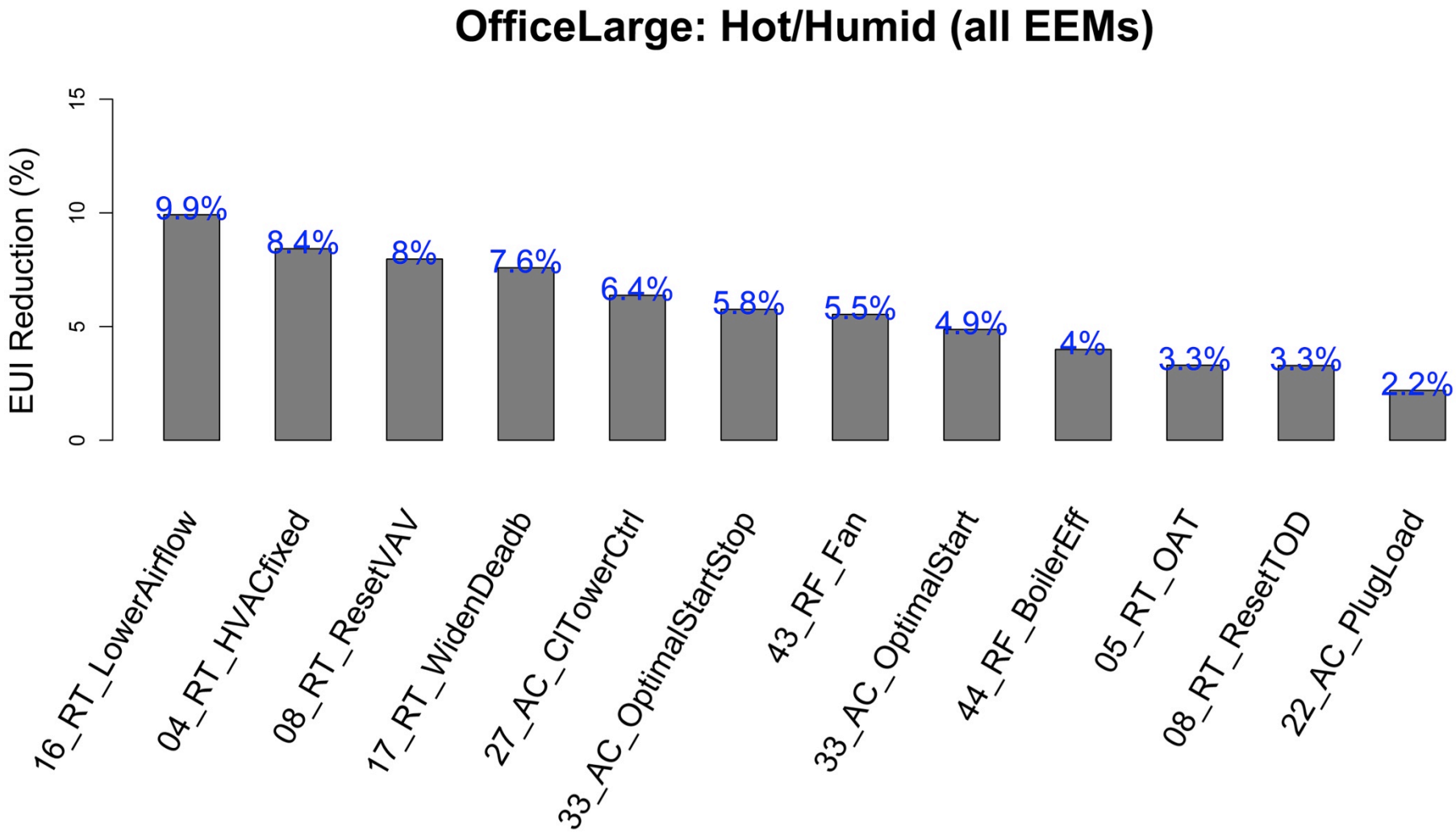
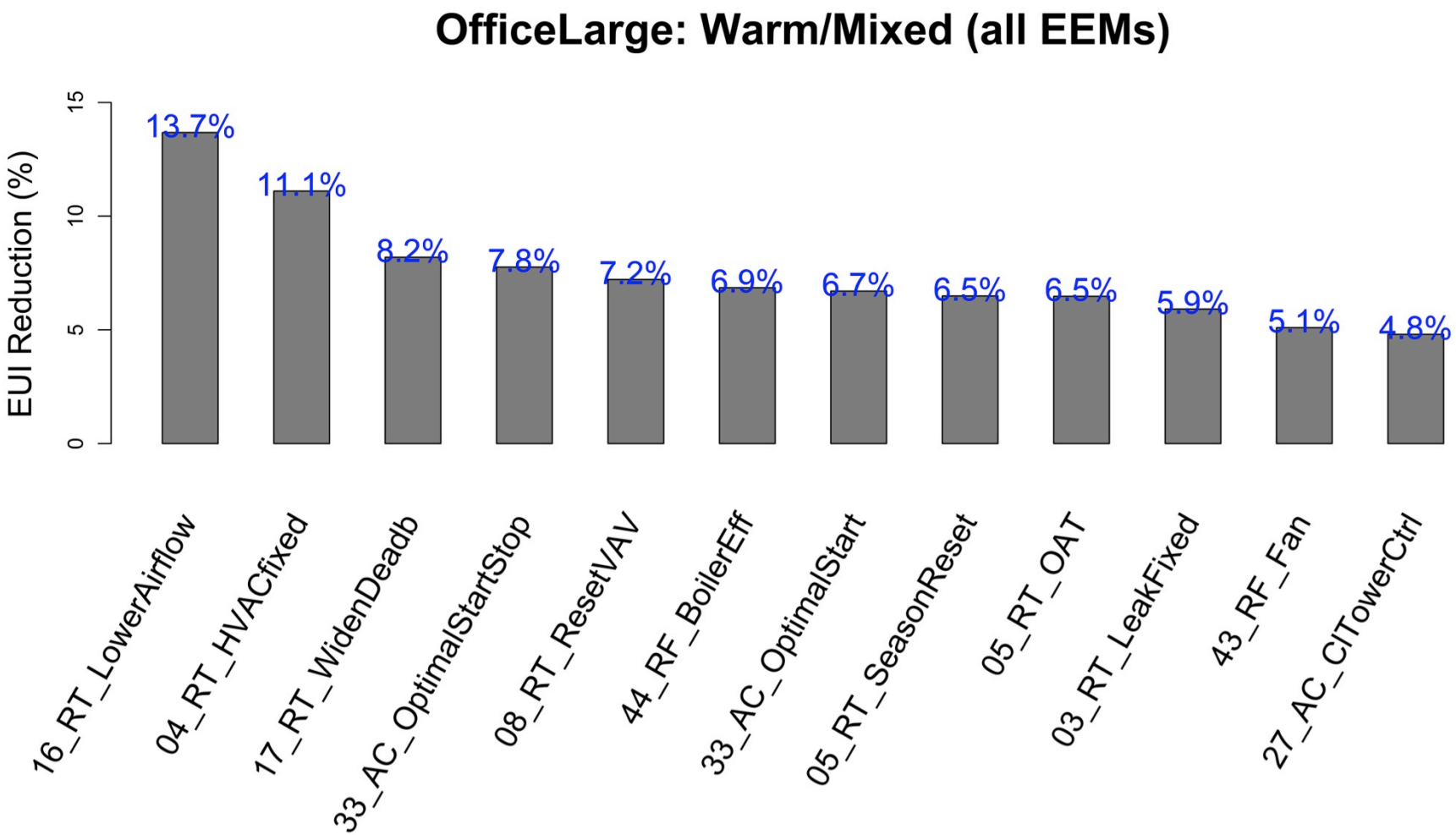
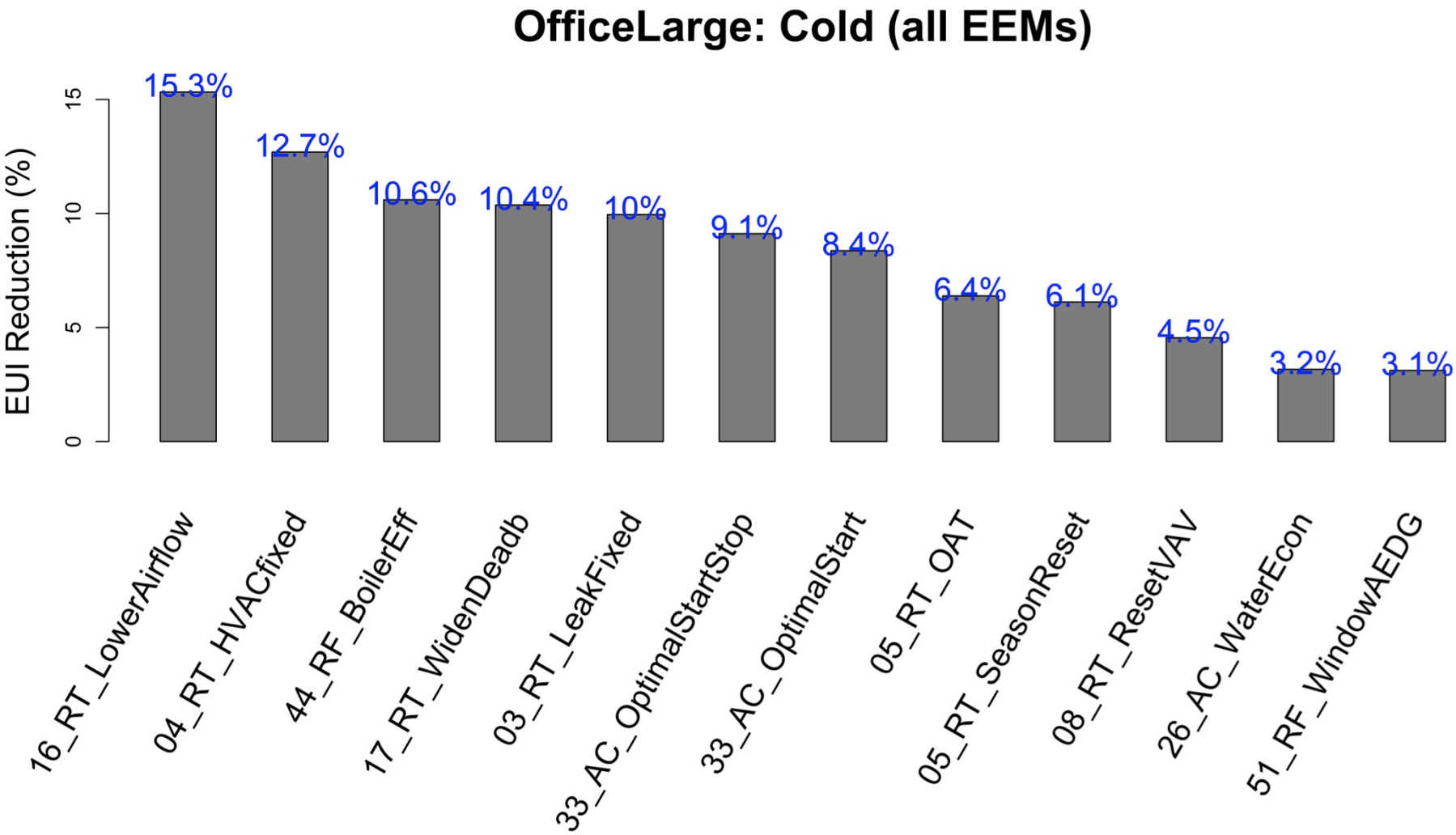
Savings from Top 12 Measures Across all Categories: Large Office – Hot/Humid Climate



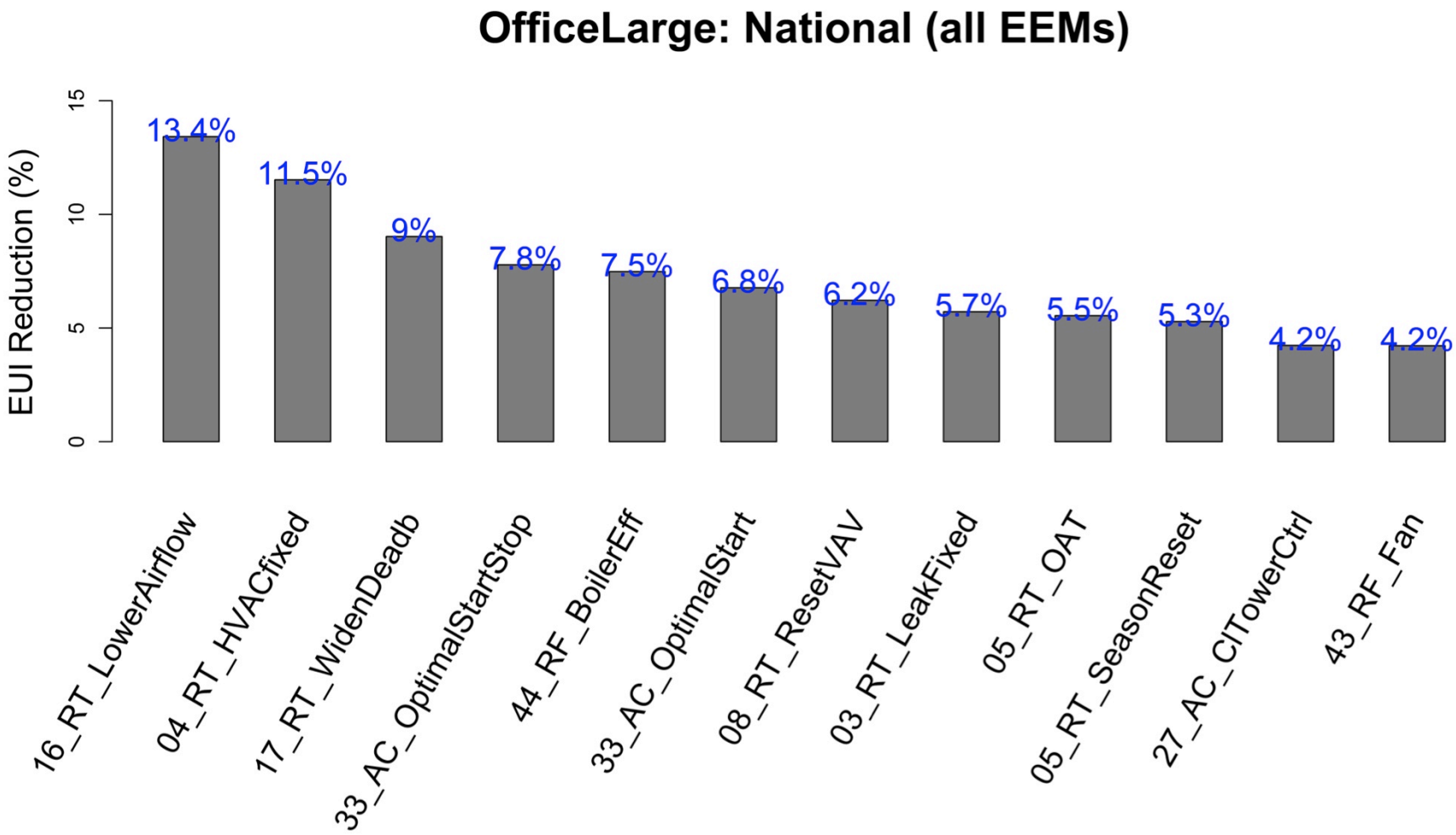
Savings from Top 12 Measures Across all Categories: Large Office – Warm/Mixed Climate



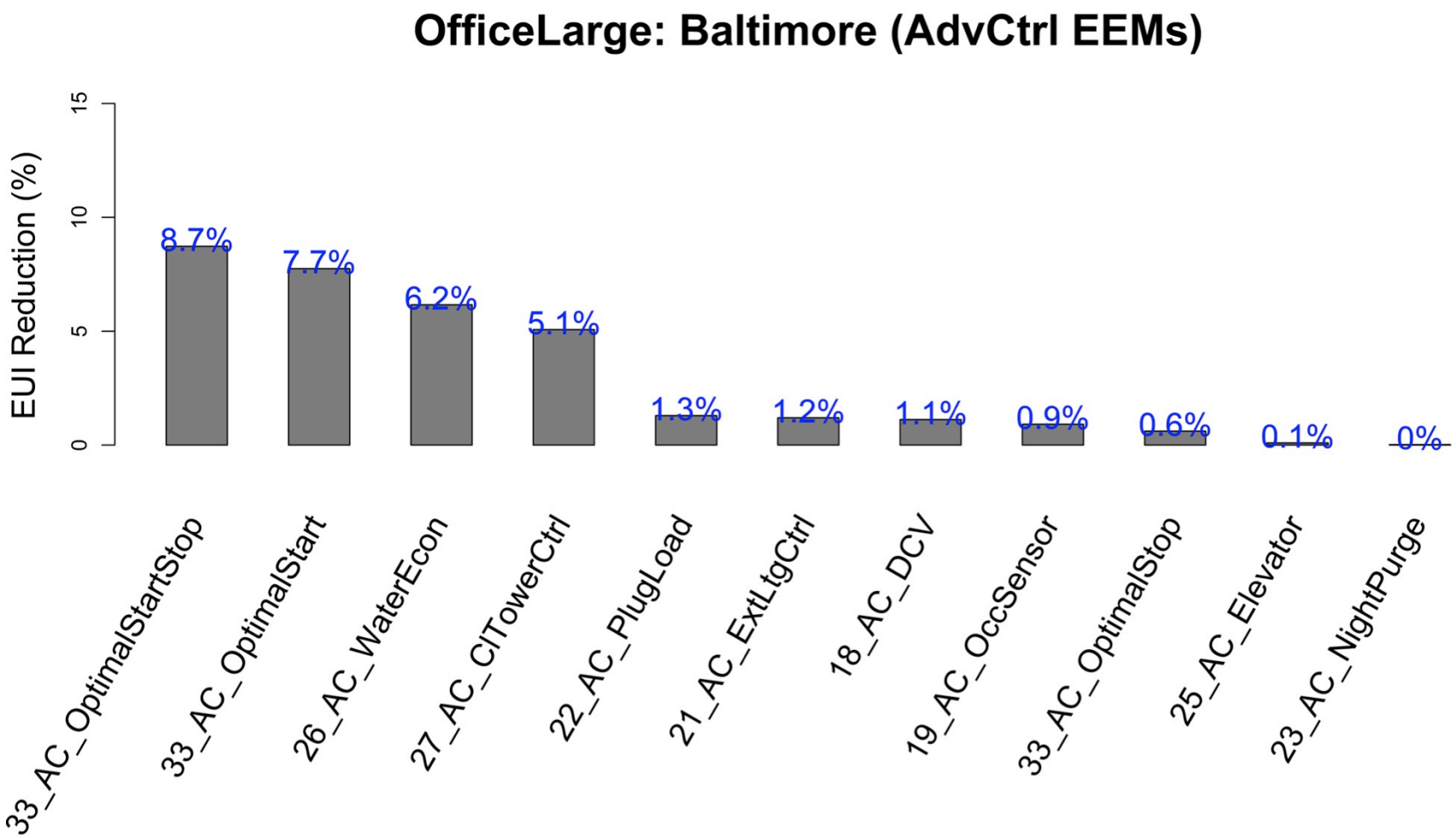
Savings from Top 12 Measures Across all Categories: Large Office – Cold Climate



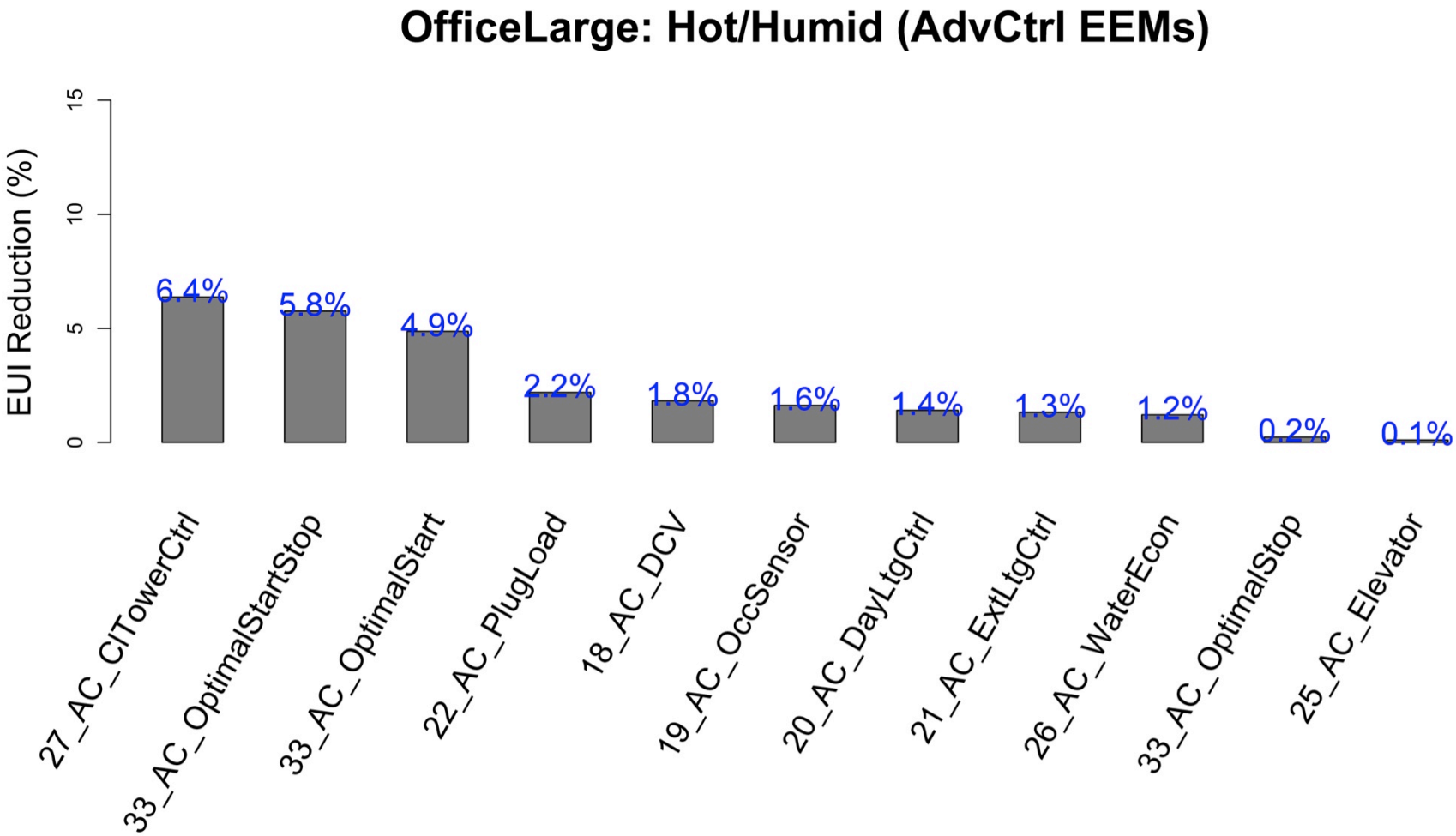
Savings from Top 12 Measures Across all Categories: Large Office – National Climate



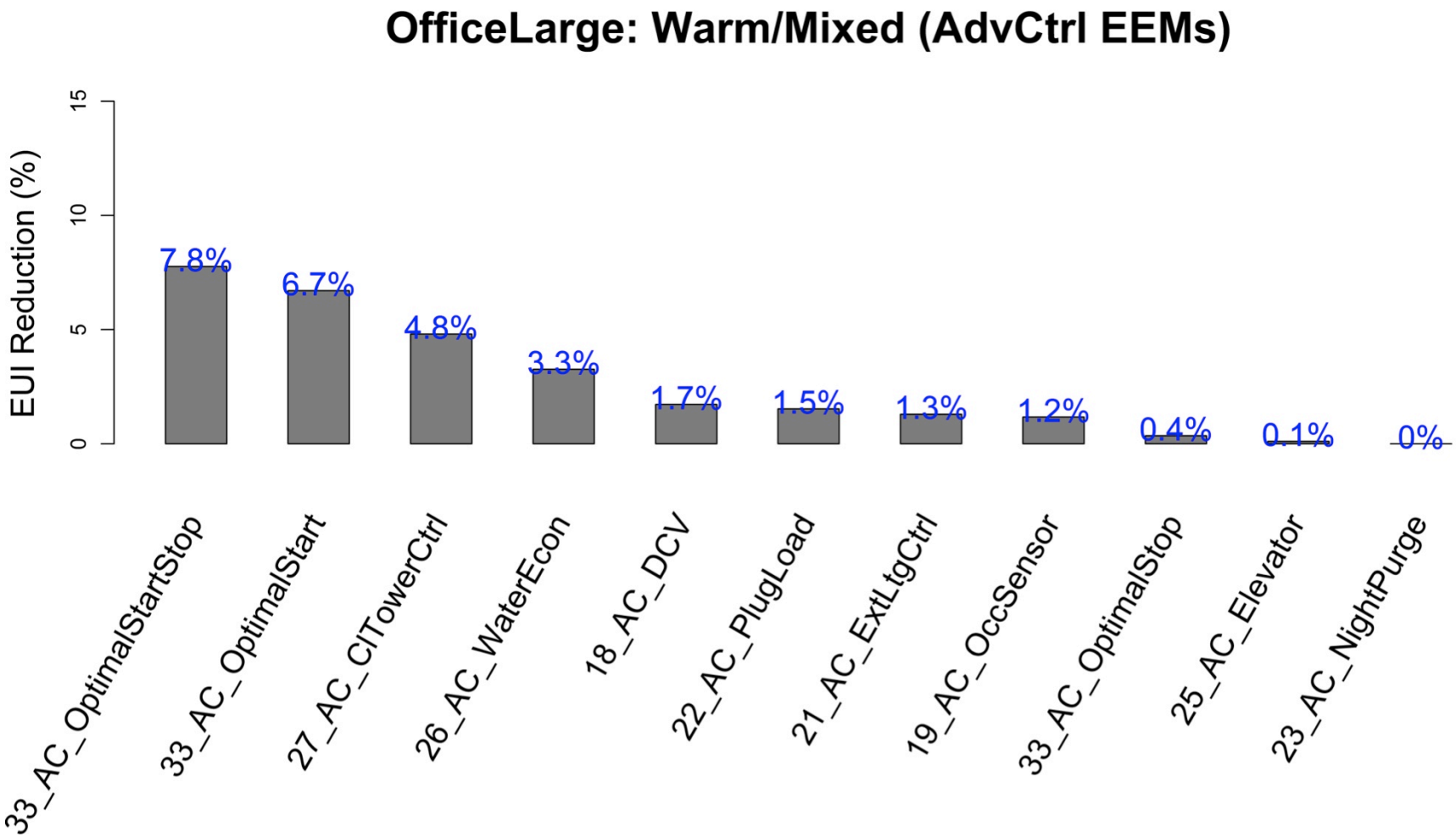
Savings from Top 12 Advanced Controls Measures: Large Office - Baltimore



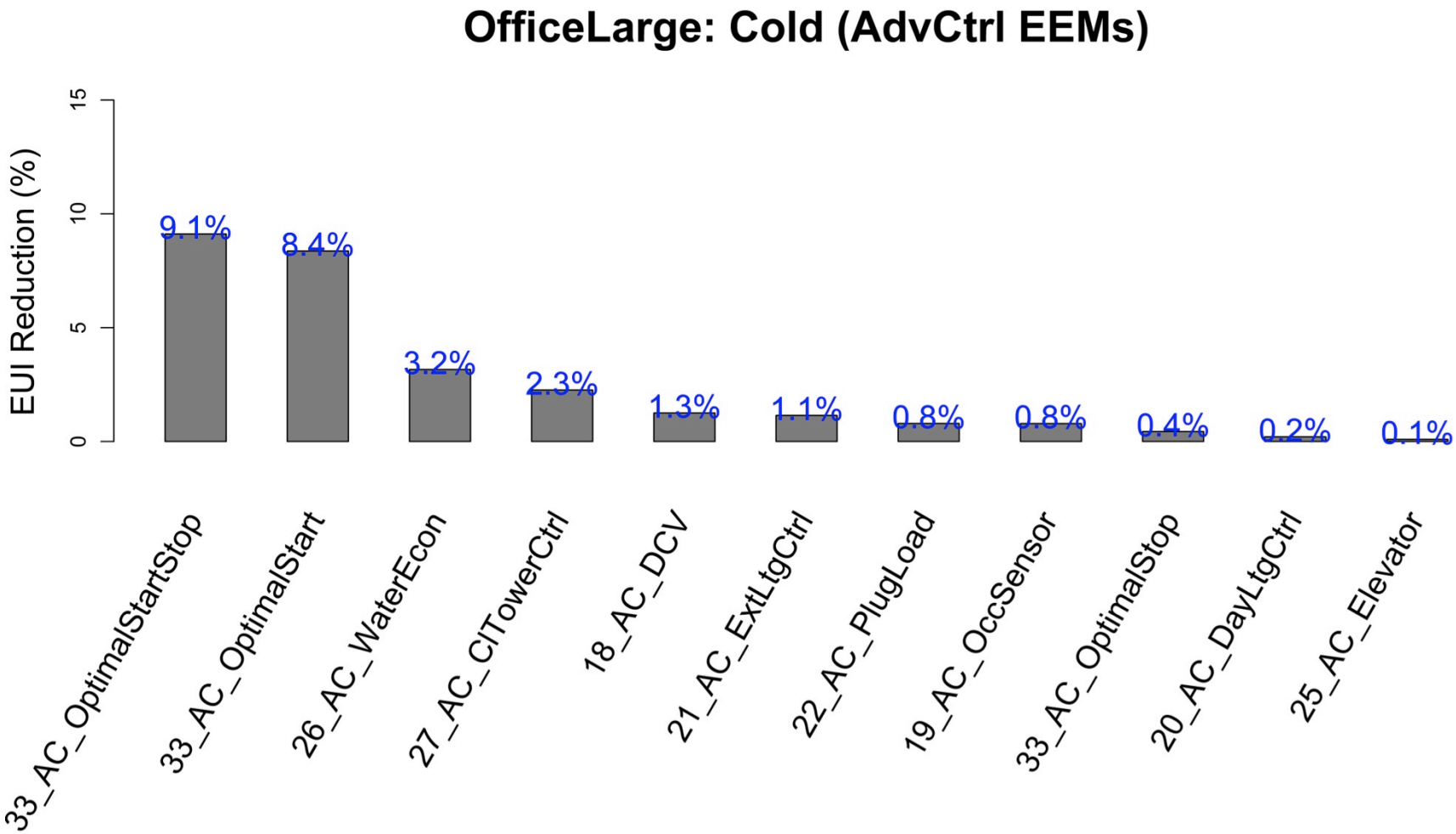
Savings from Top 12 Advanced Controls Measures: Large Office – Hot/Humid Climate



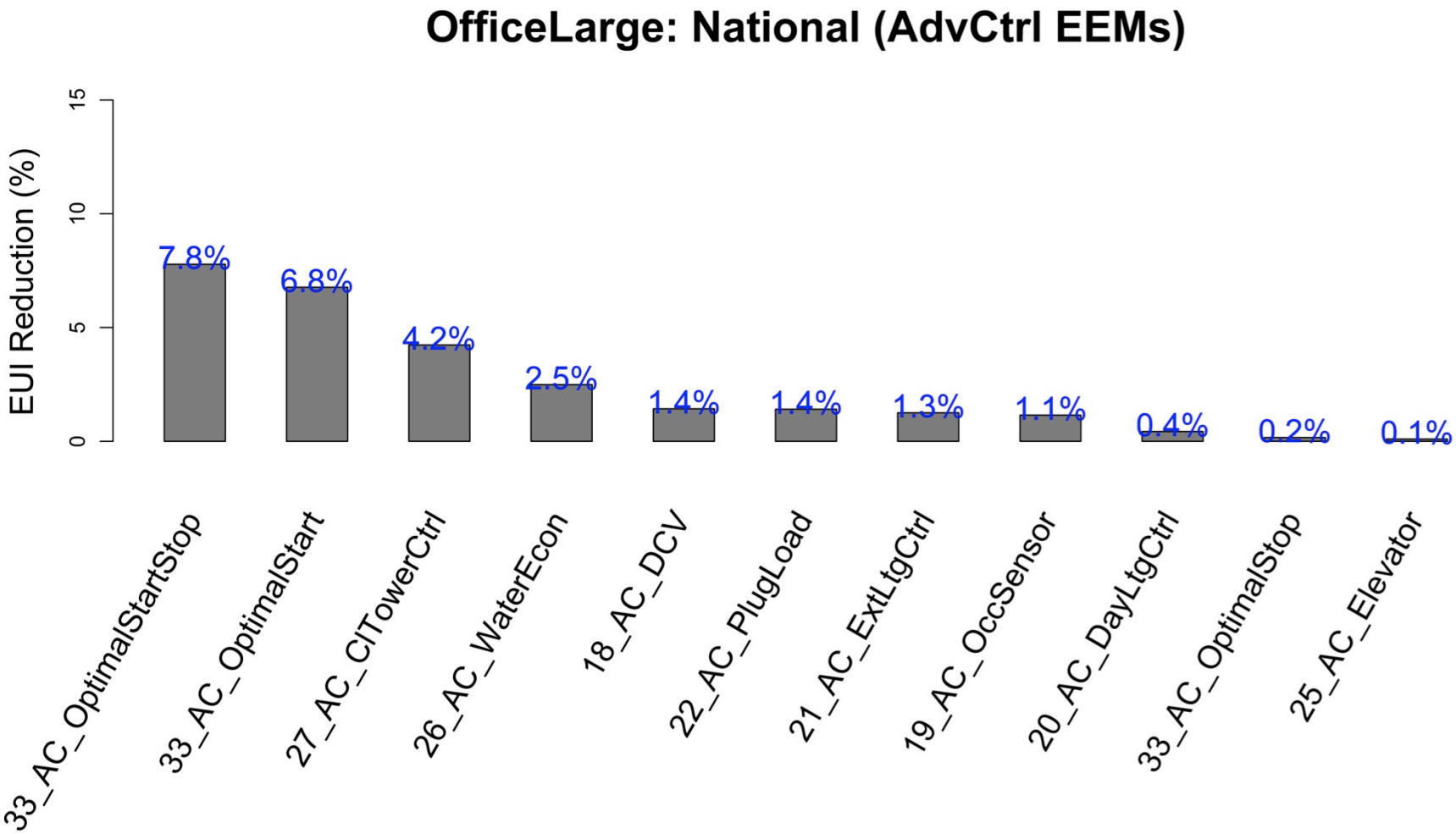
Savings from Top 12 Advanced Controls Measures: Large Office – Warm/Mixed Climate



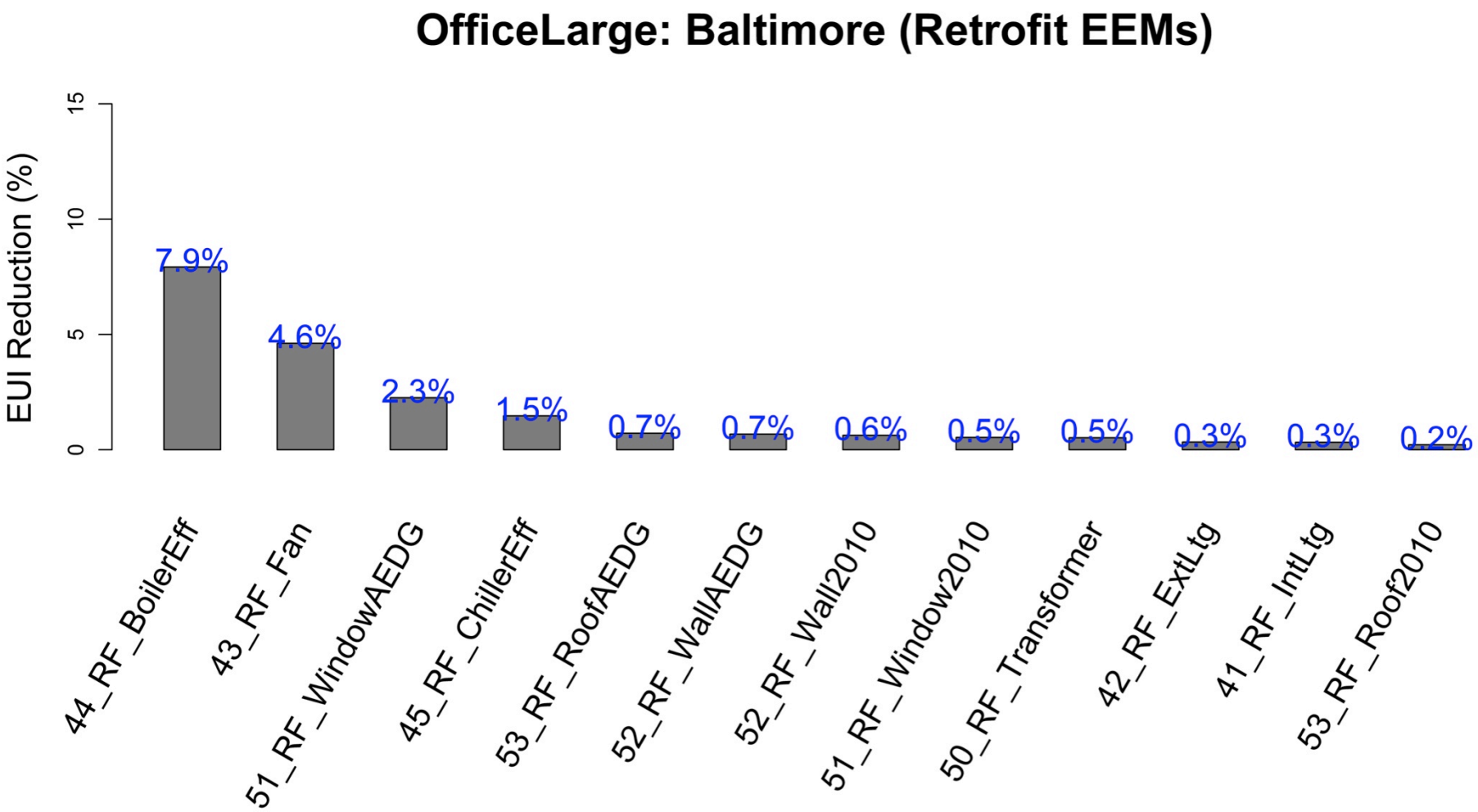
Savings from Top 12 Advanced Controls Measures: Large Office – Cold Climate



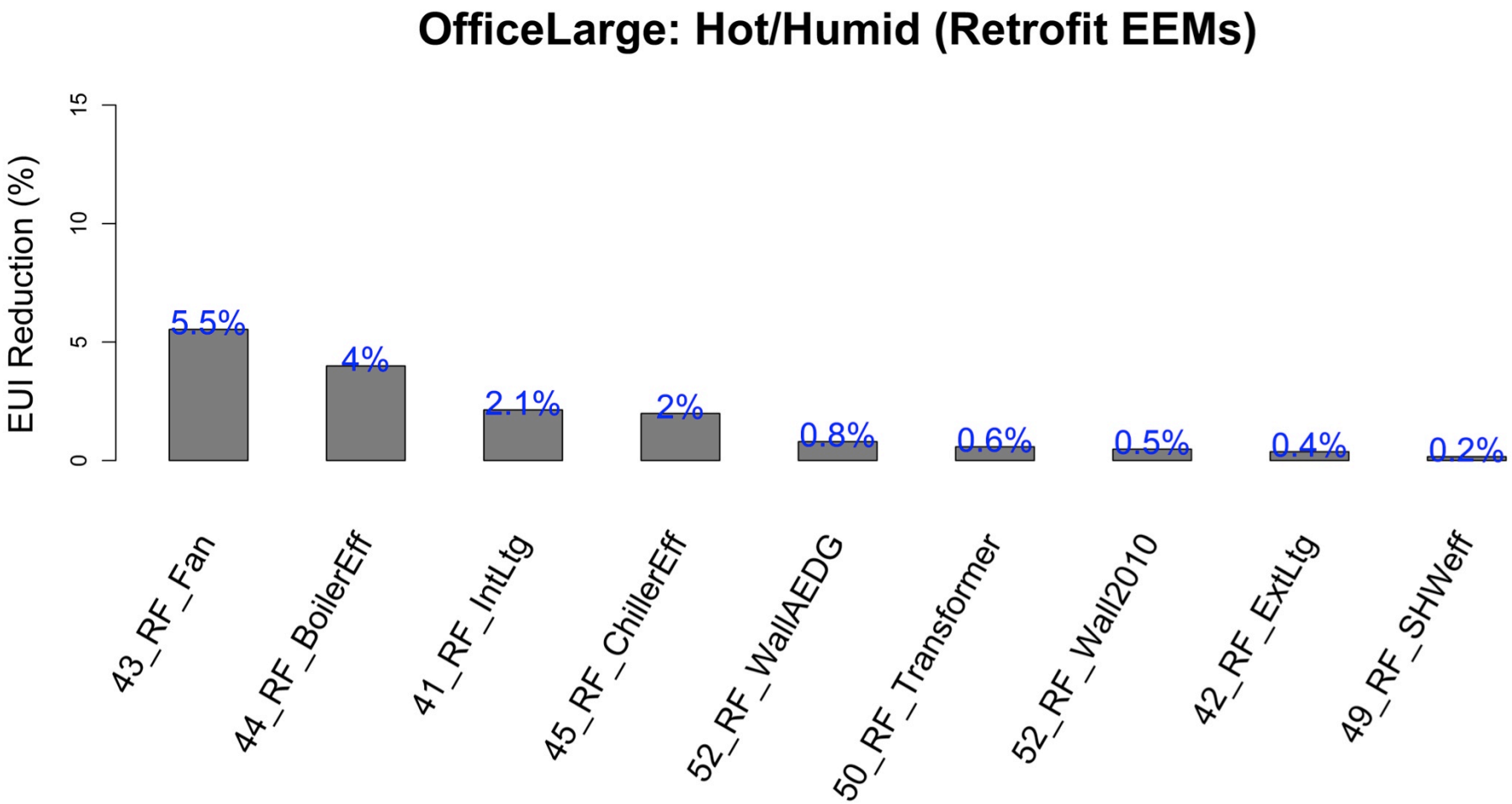
Savings from Top 12 Advanced Controls Measures: Large Office – National Climate



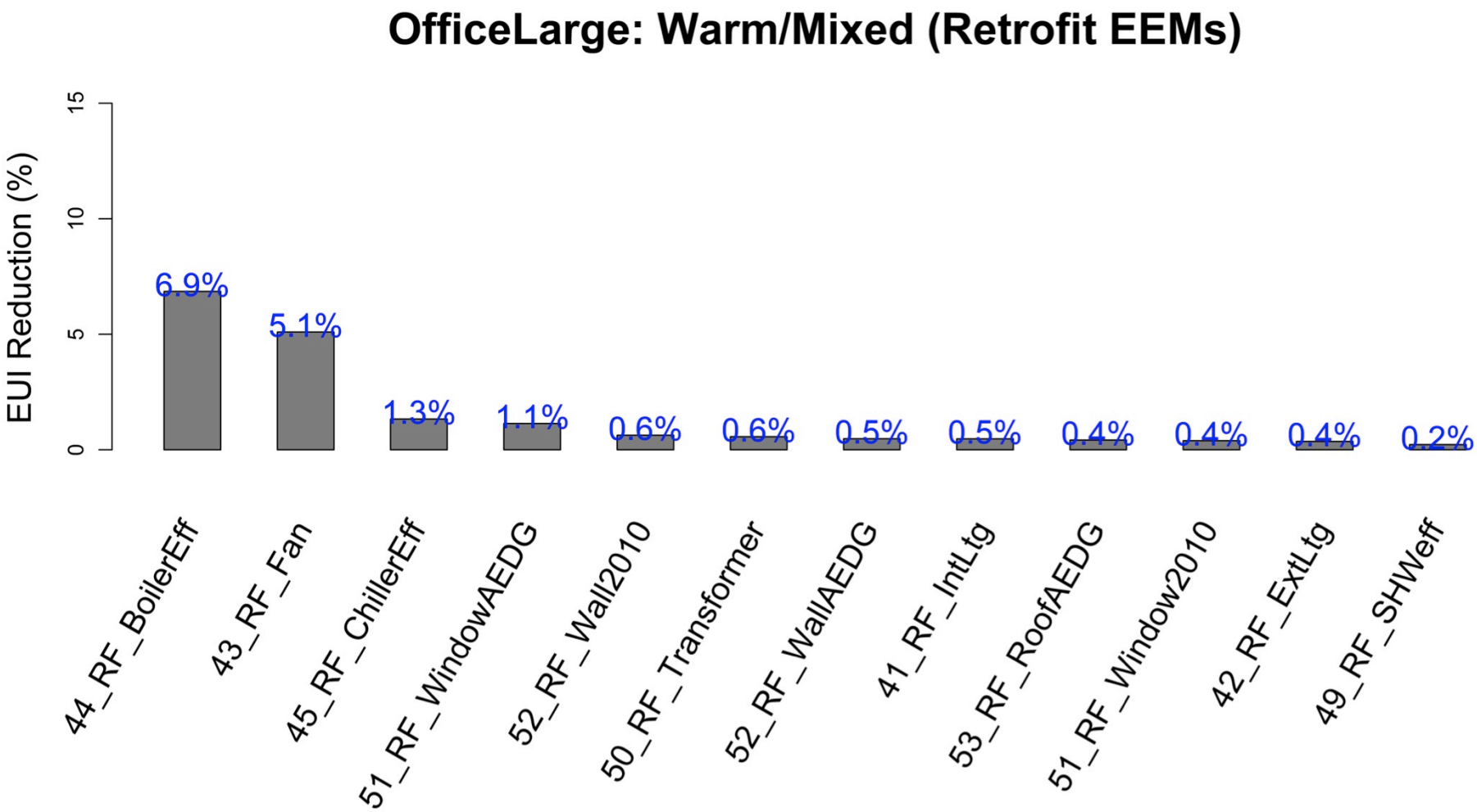
Savings from Top 12 Retrofit Measures: Large Office – Baltimore



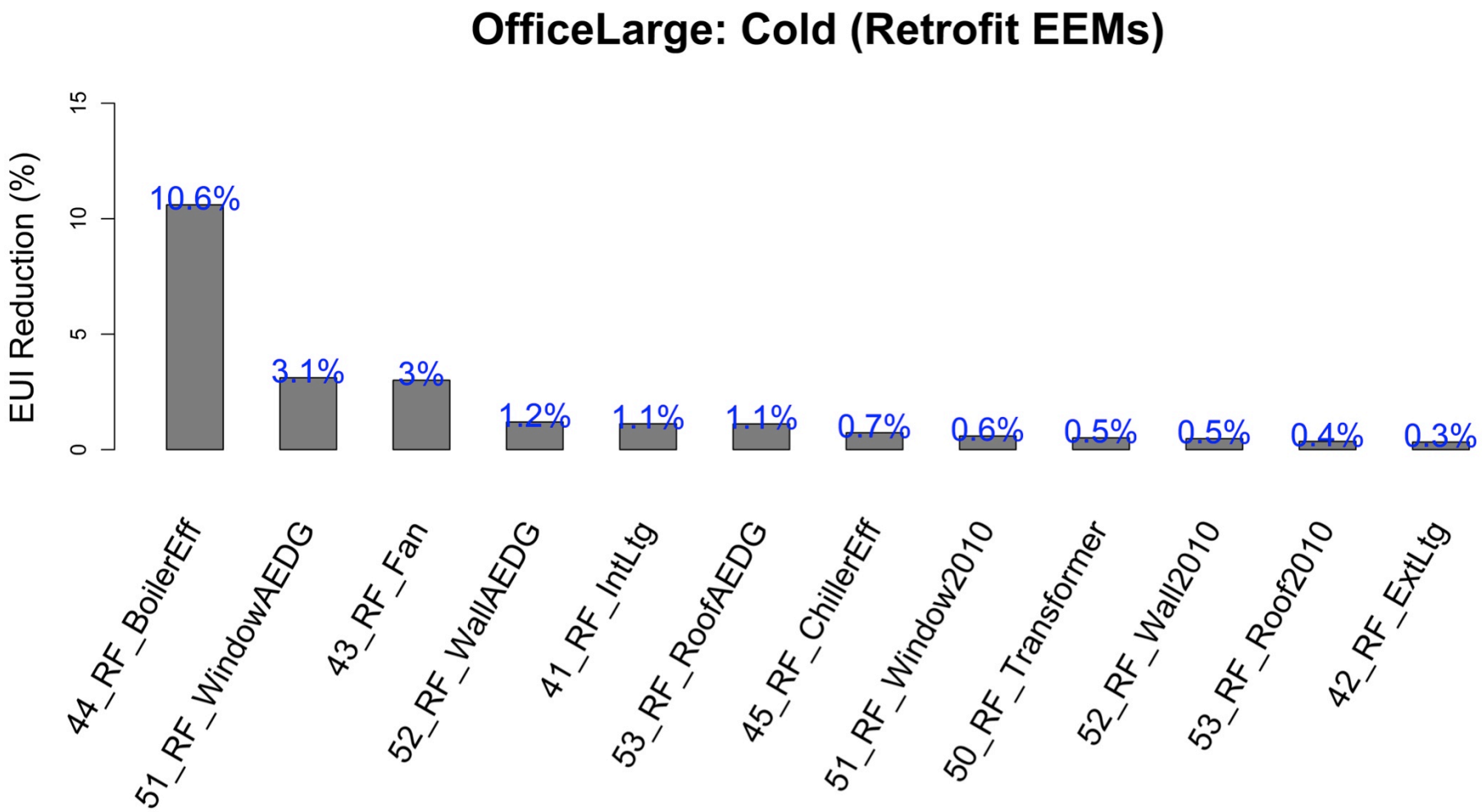
Savings from Top 12 Retrofit Measures: Large Office – Hot/Humid Climate



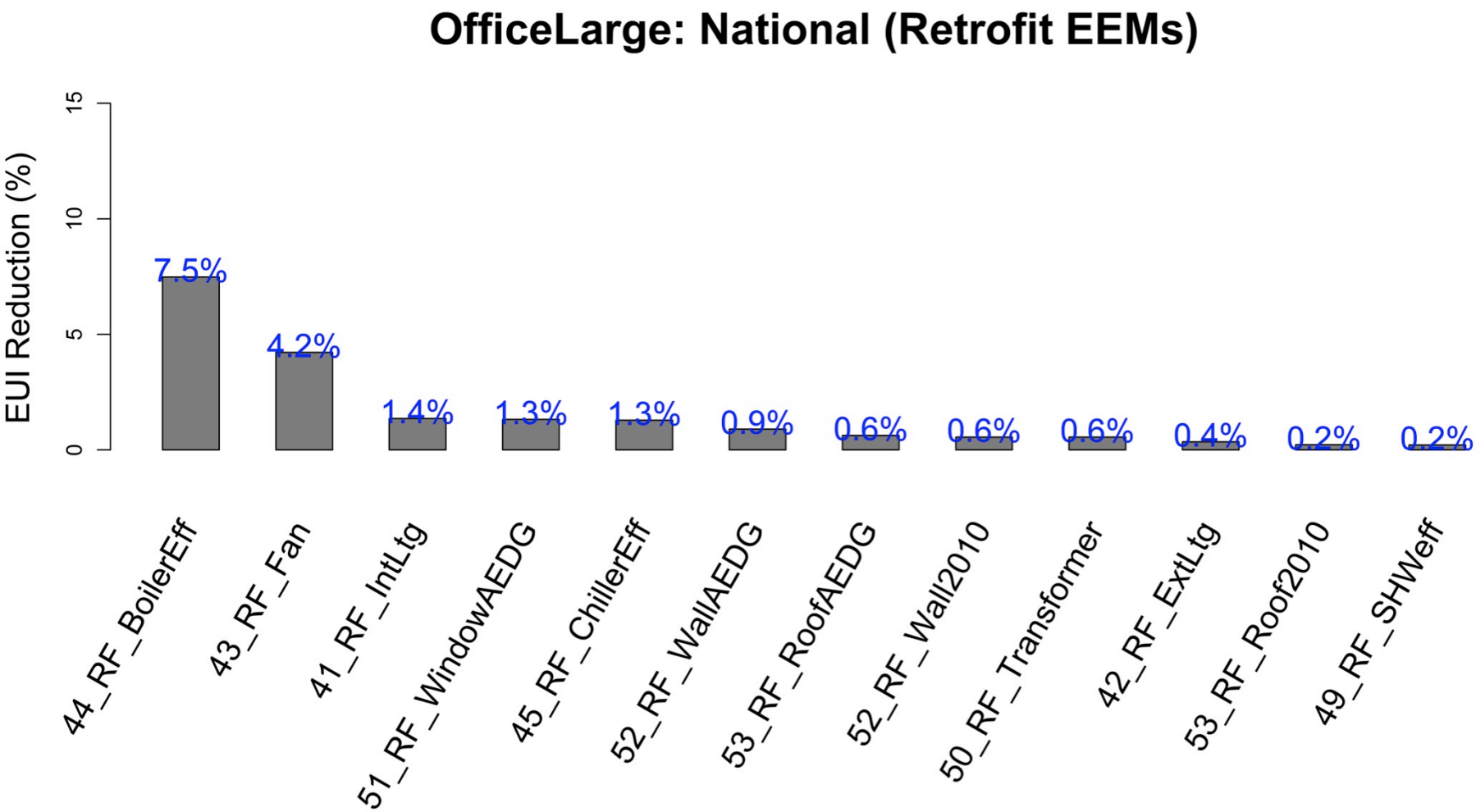
Savings from Top 12 Retrofit Measures: Large Office – Warm/Mixed Climate



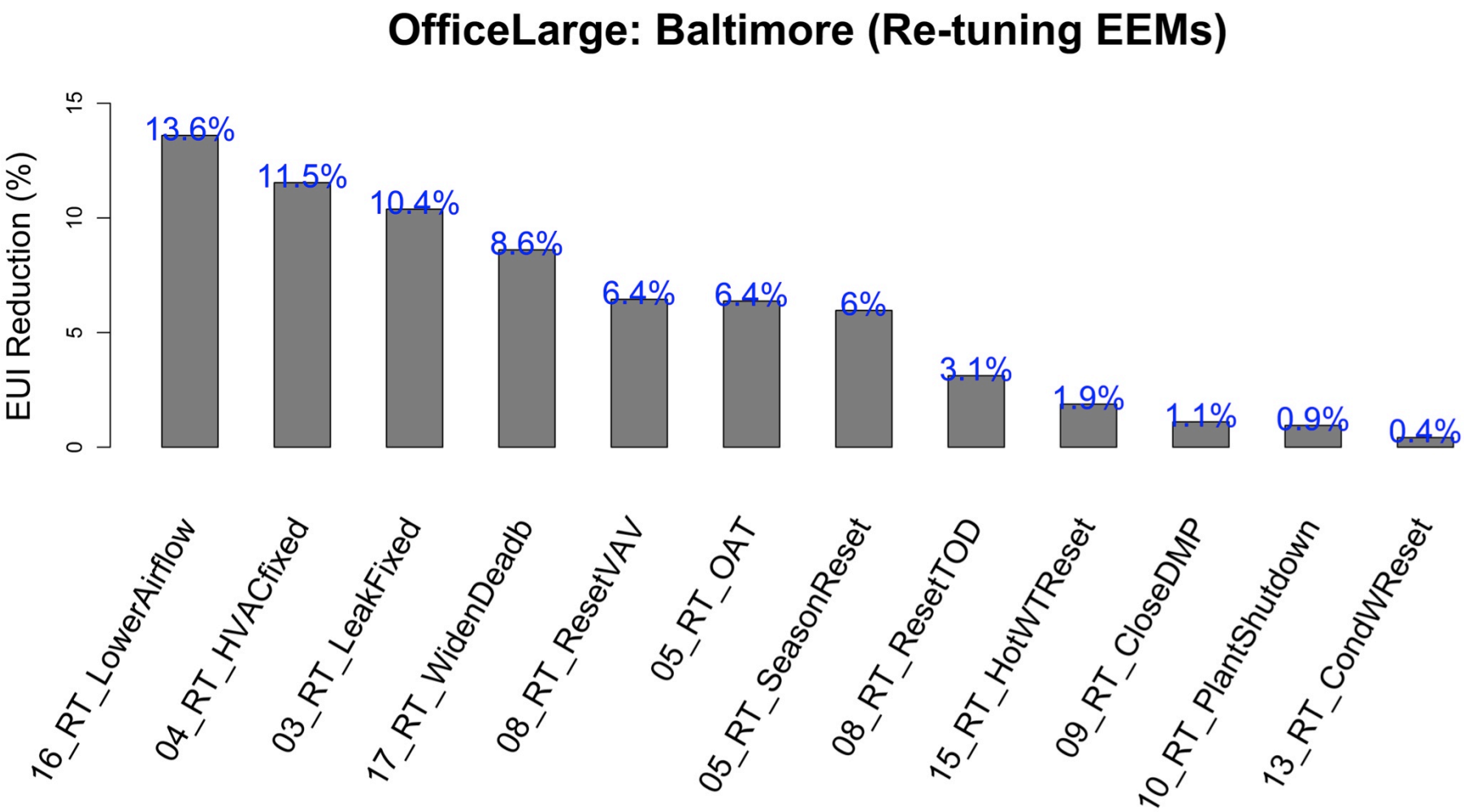
Savings from Top 12 Retrofit Measures: Large Office – Cold Climate



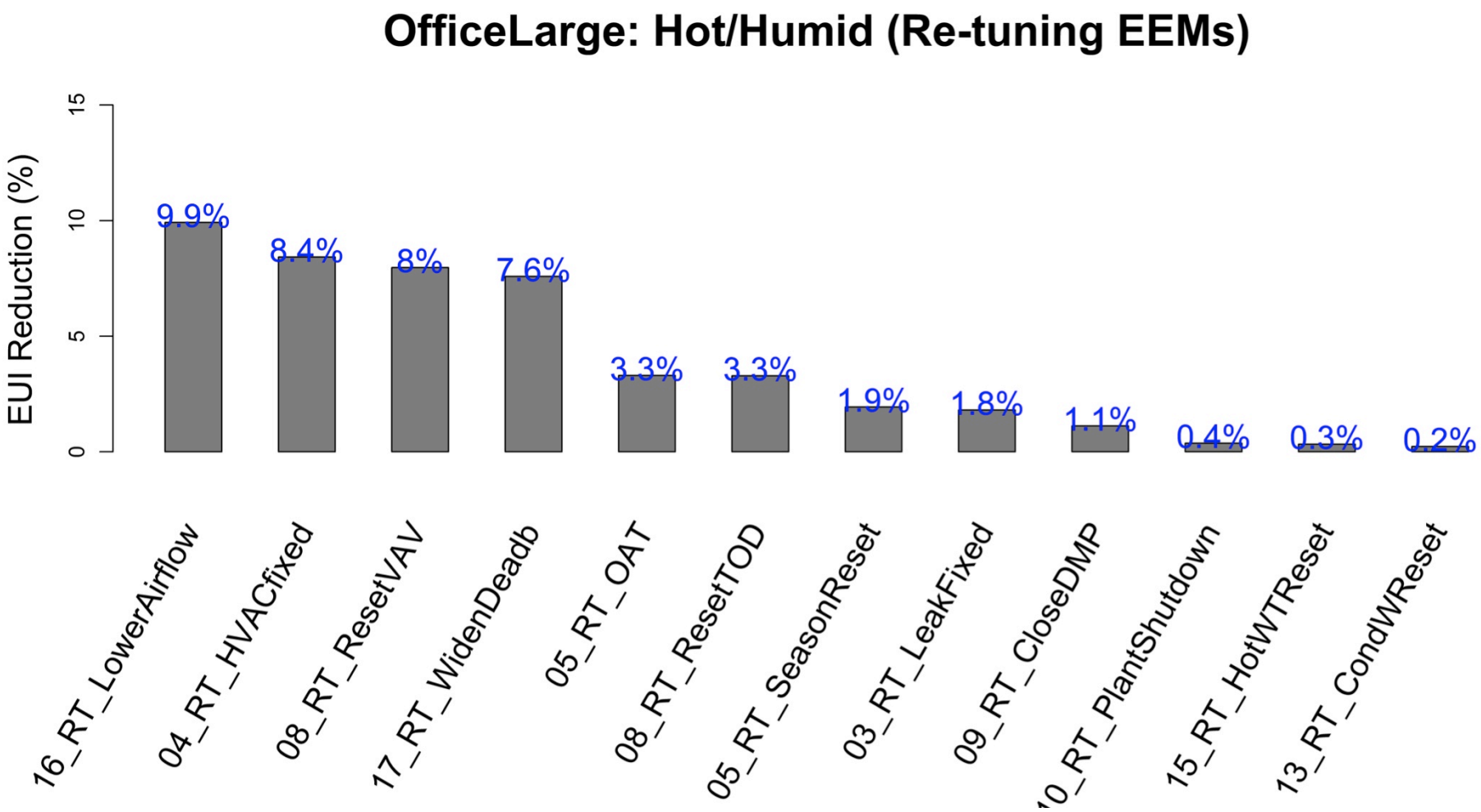
Savings from Top 12 Retrofit Measures: Large Office – National Climate



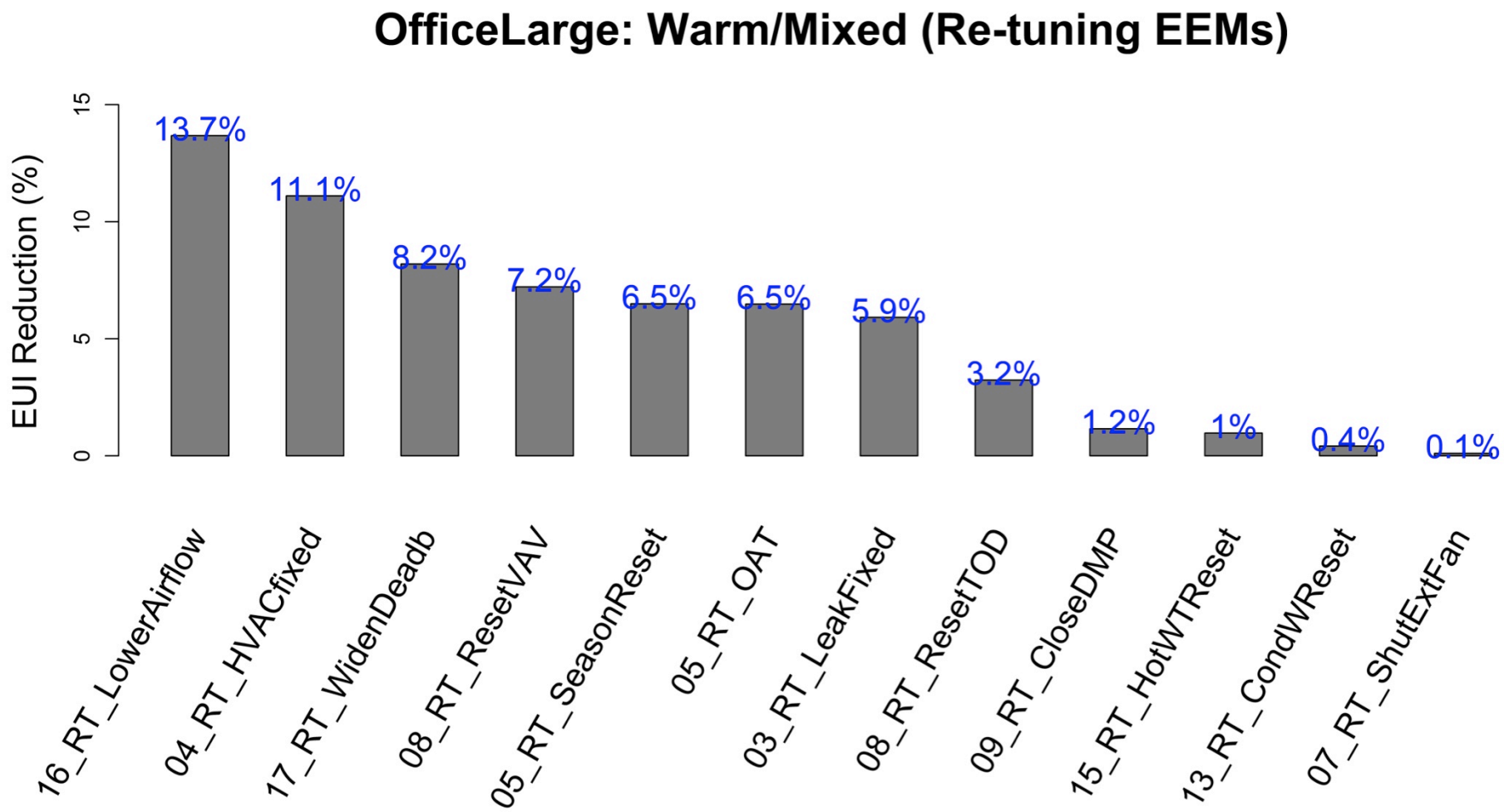
Savings from Top 12 Re-tuning Measures: Large Office – Baltimore



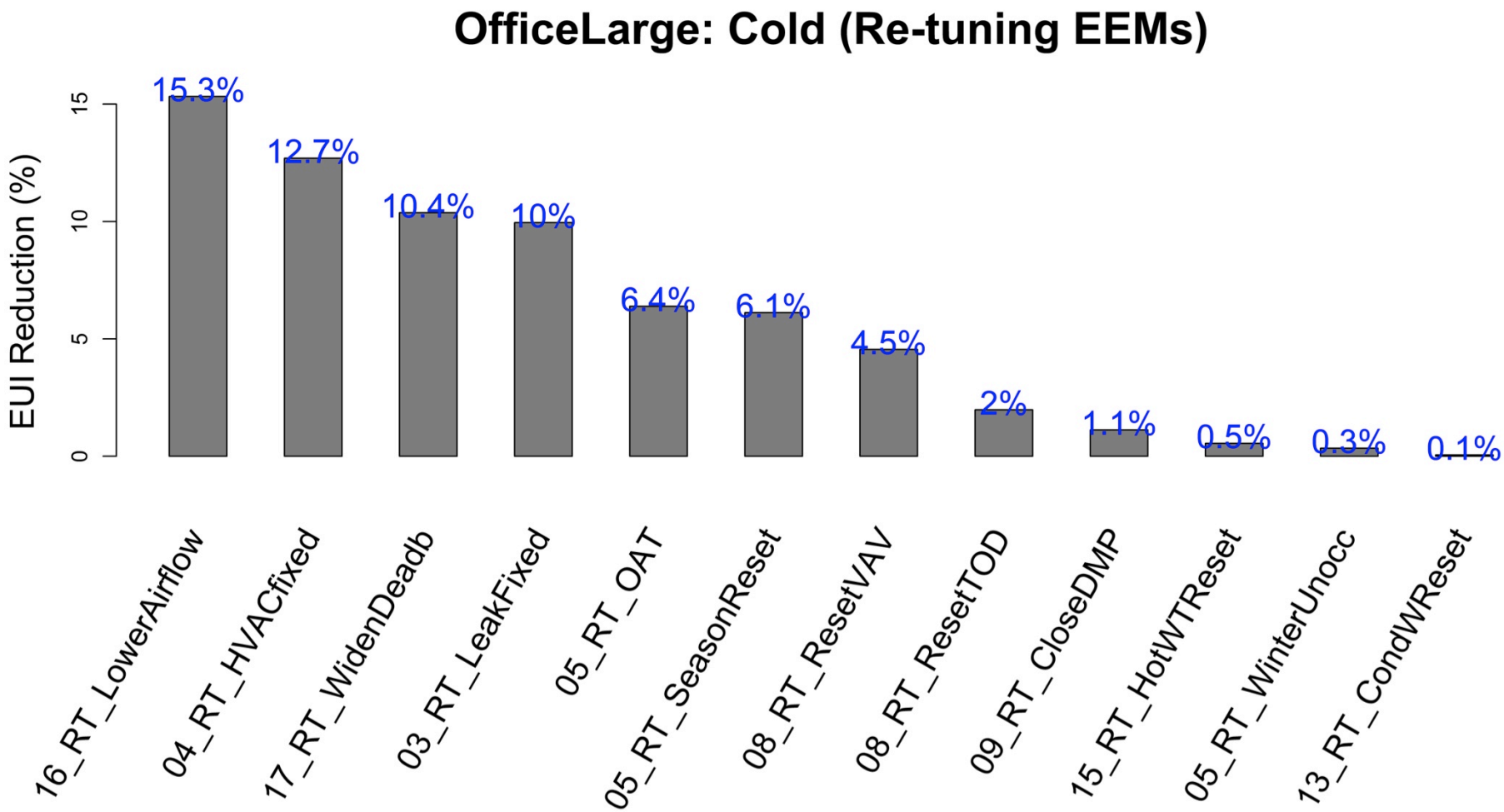
Savings from Top 12 Re-tuning Measures: Large Office – Hot/Humid Climate



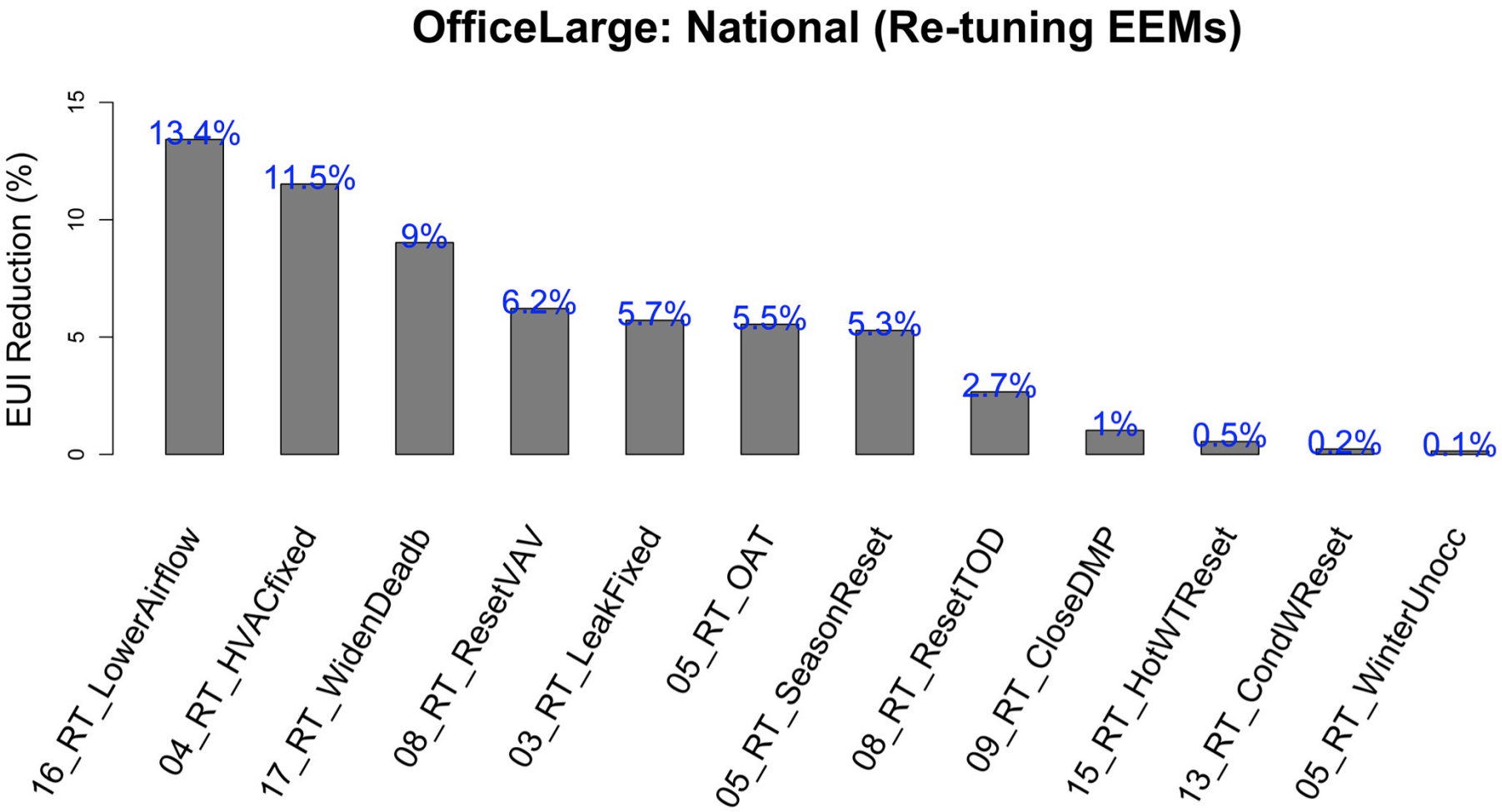
Savings from Top 12 Re-tuning Measures: Large Office – Warm/Mixed Climate



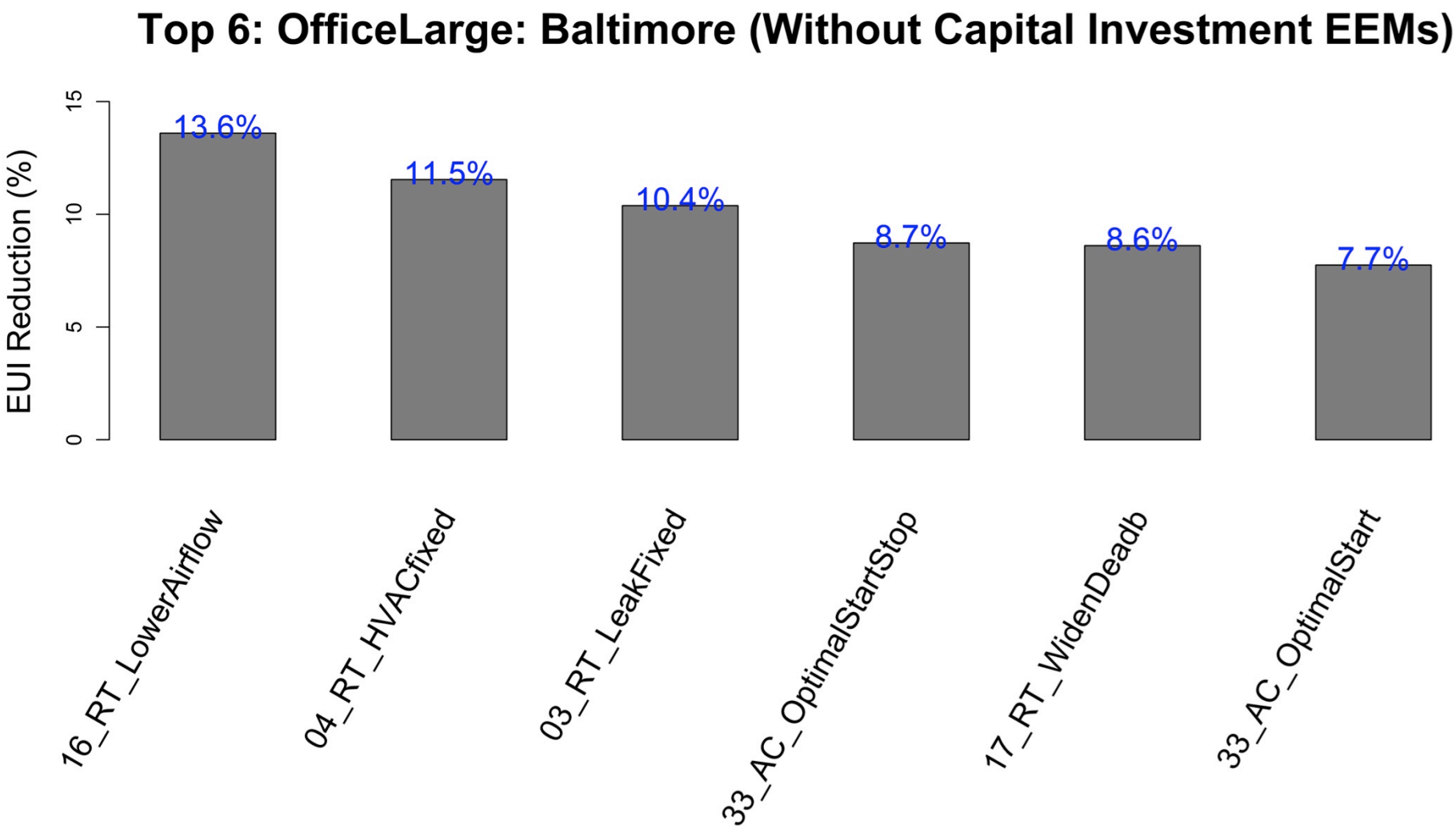
Savings from Top 12 Re-tuning Measures: Large Office – Cold Climate



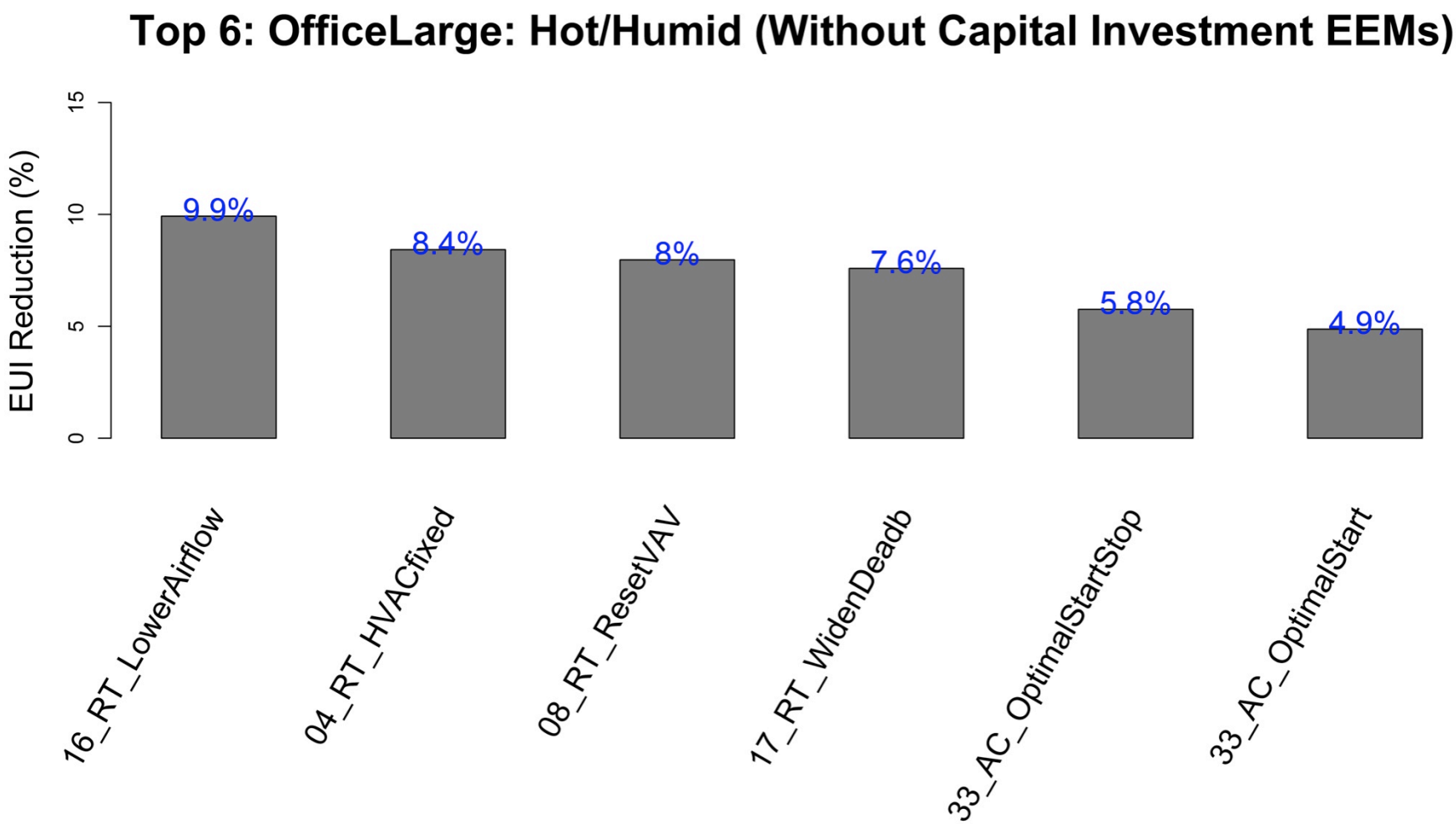
Savings from Top 12 Re-tuning Measures: Large Office – National Climate



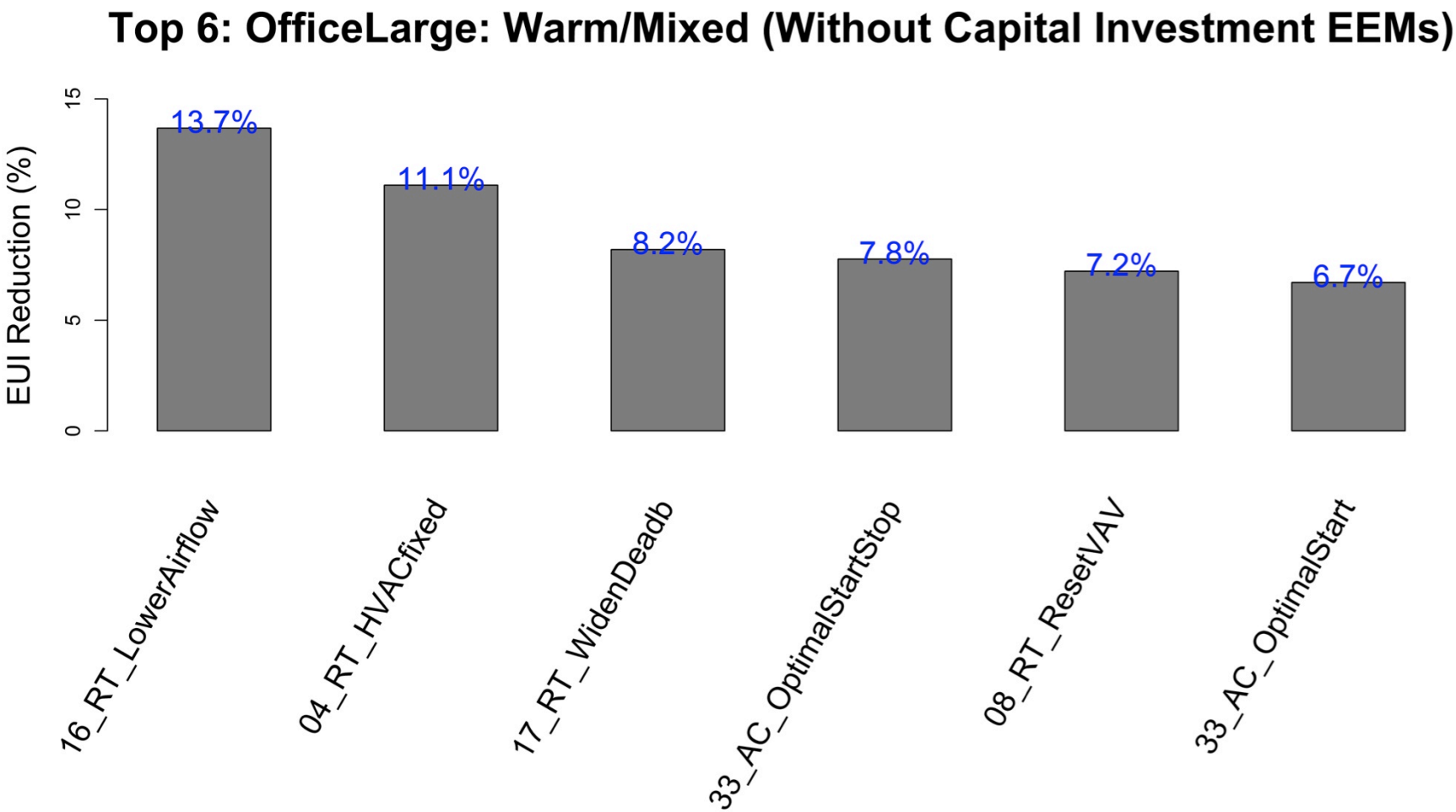
Savings from Top 6 No-Cost Measures: Large Office – Baltimore



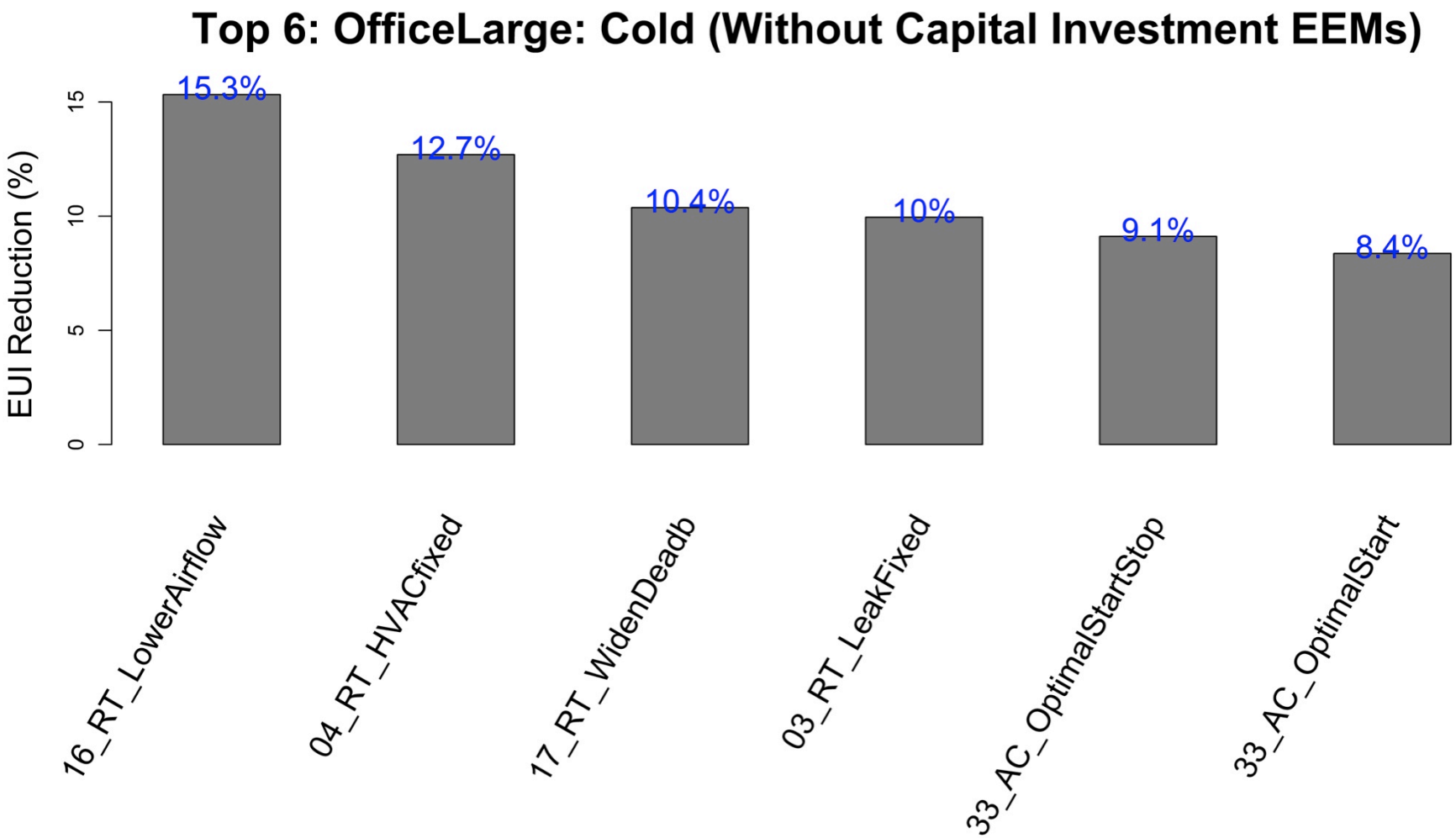
Savings from Top 6 No-Cost Measures: Large Office – Hot/Humid Climate



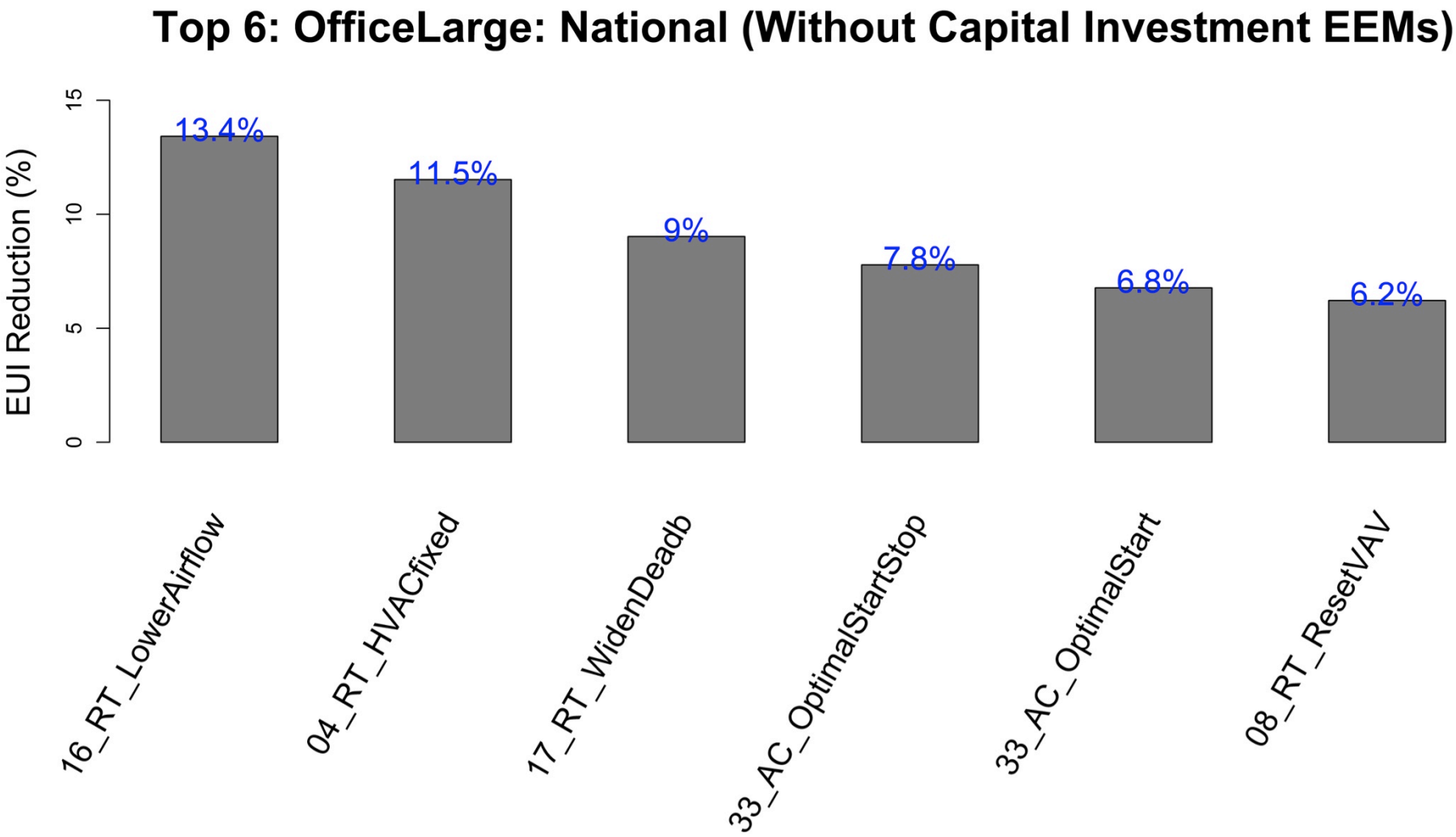
Savings from Top 6 No-Cost Measures: Large Office – Warm/Mixed Climate



Savings from Top 6 No-Cost Measures: Large Office – Cold Climate

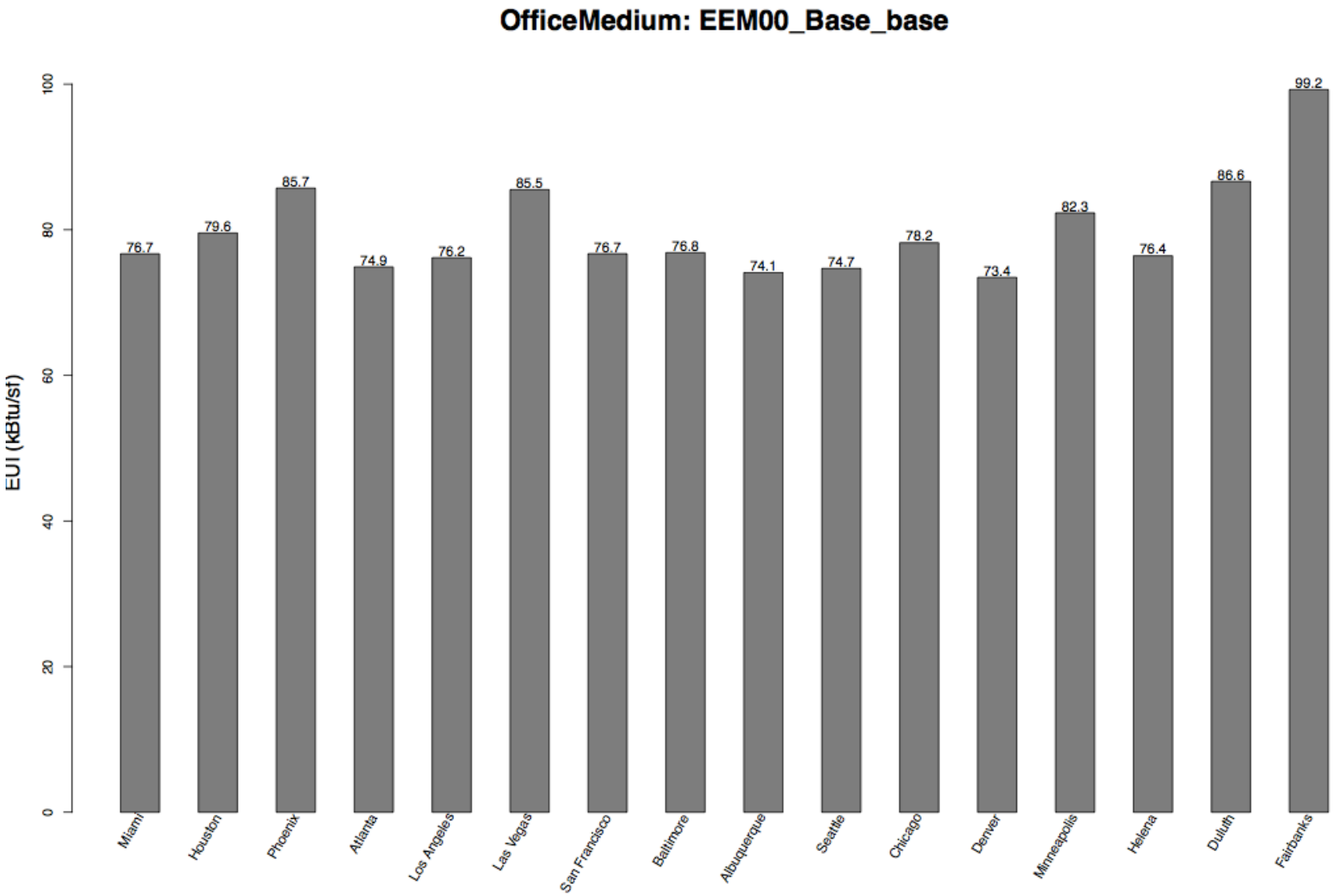


Savings from Top 6 No-Cost Measures: Large Office – National Climate

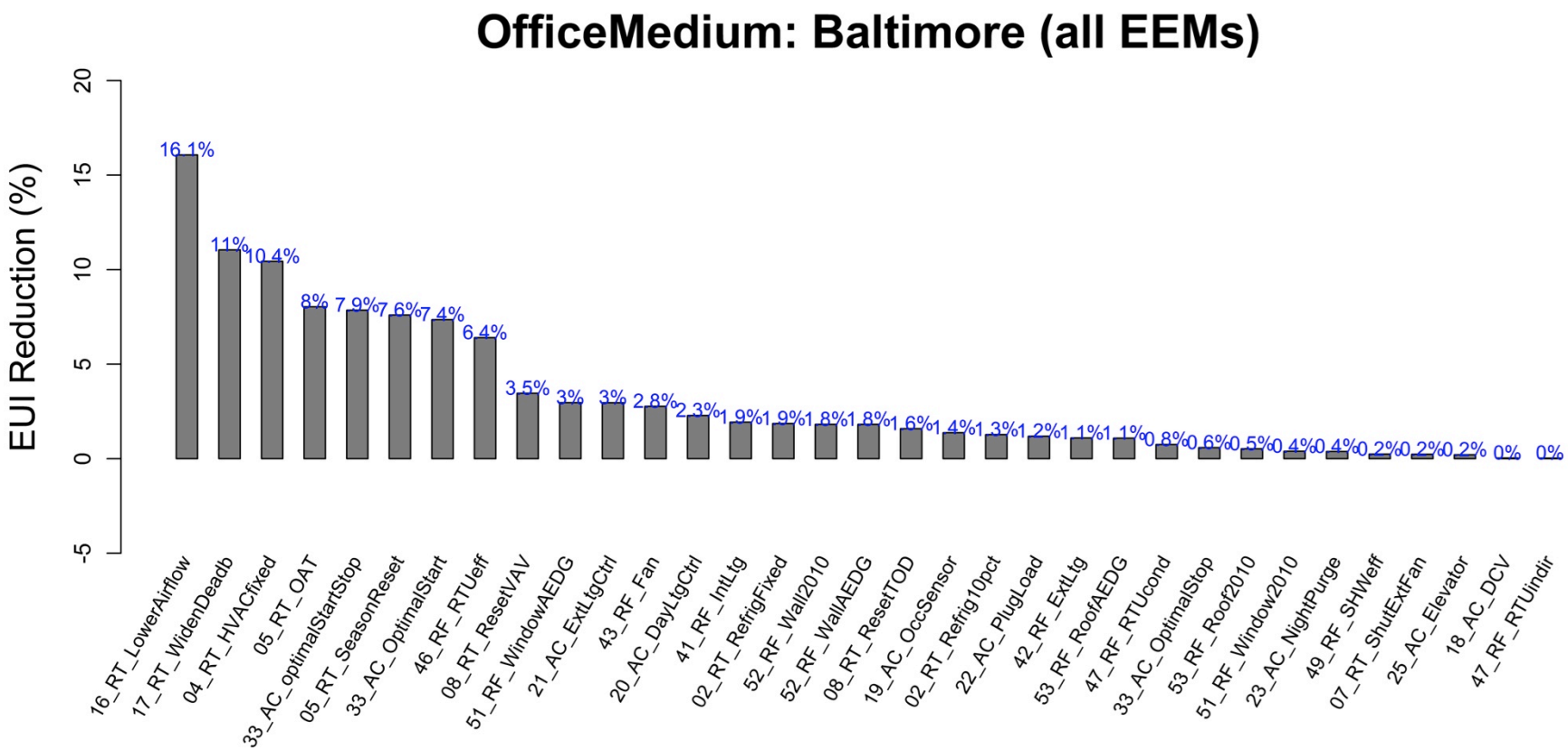


Medium Office Analysis Results

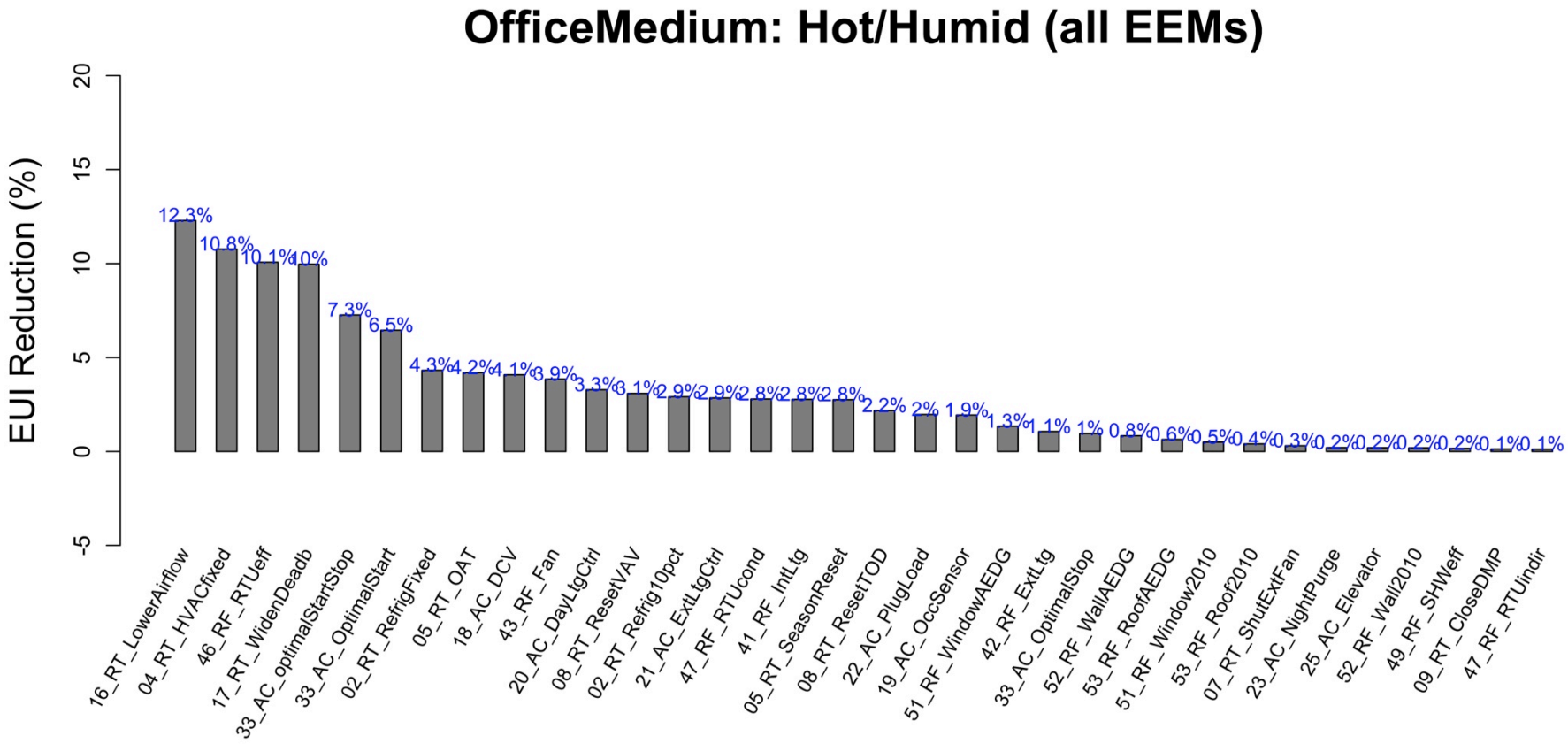
Medium Office Baseline EUIs



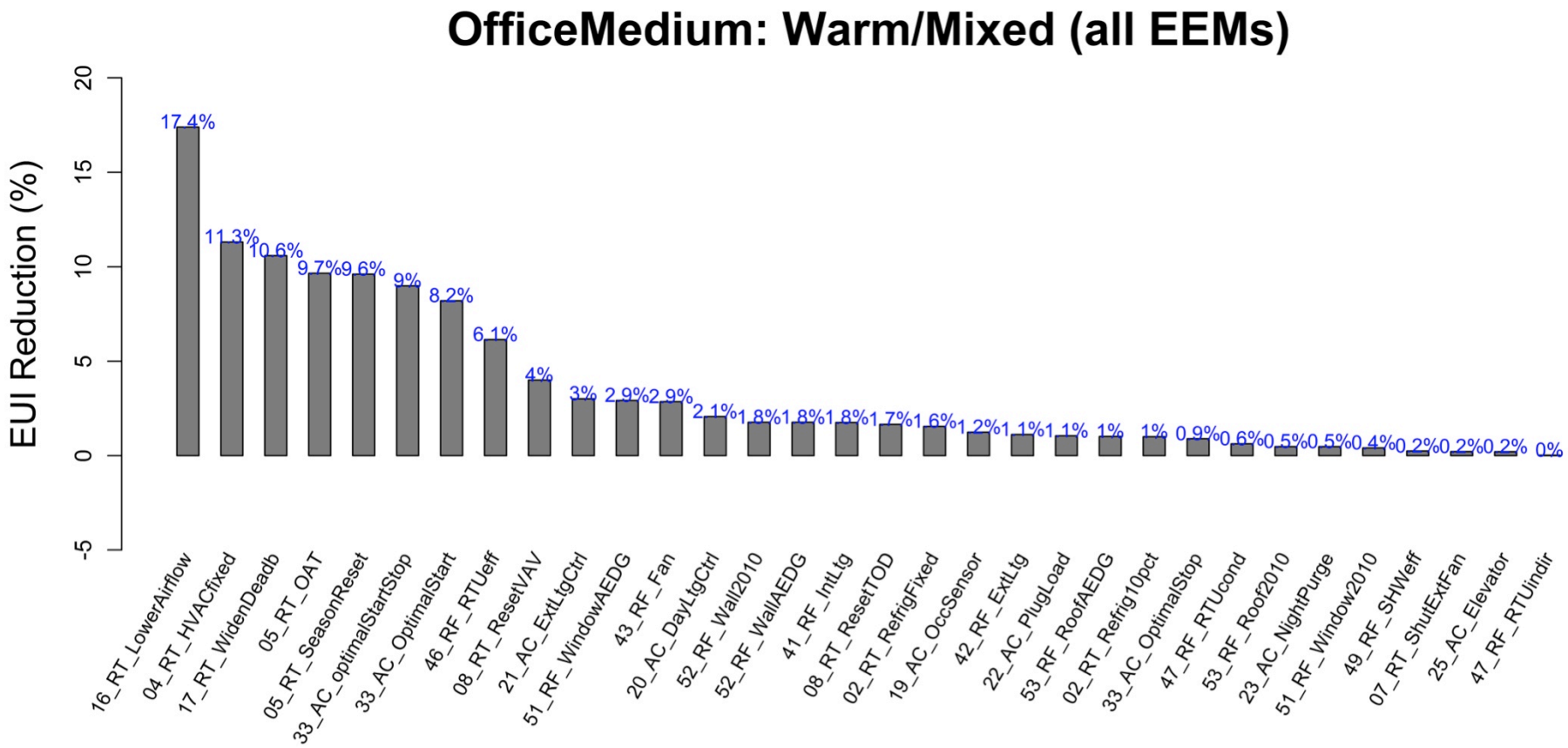
Savings from each Individual Measure: Medium Office - Baltimore



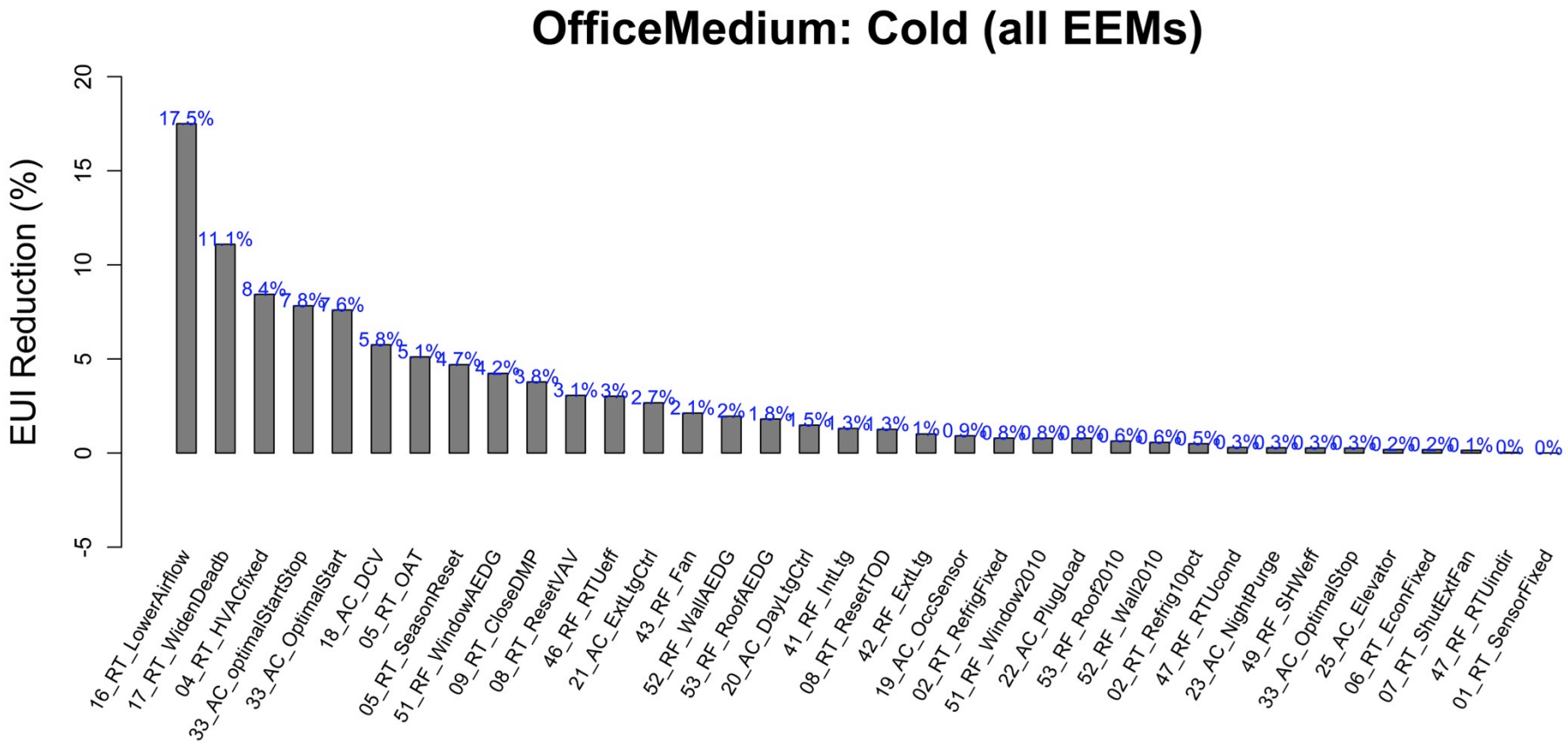
Savings from each Individual Measure: Medium Office – Hot Humid Climate



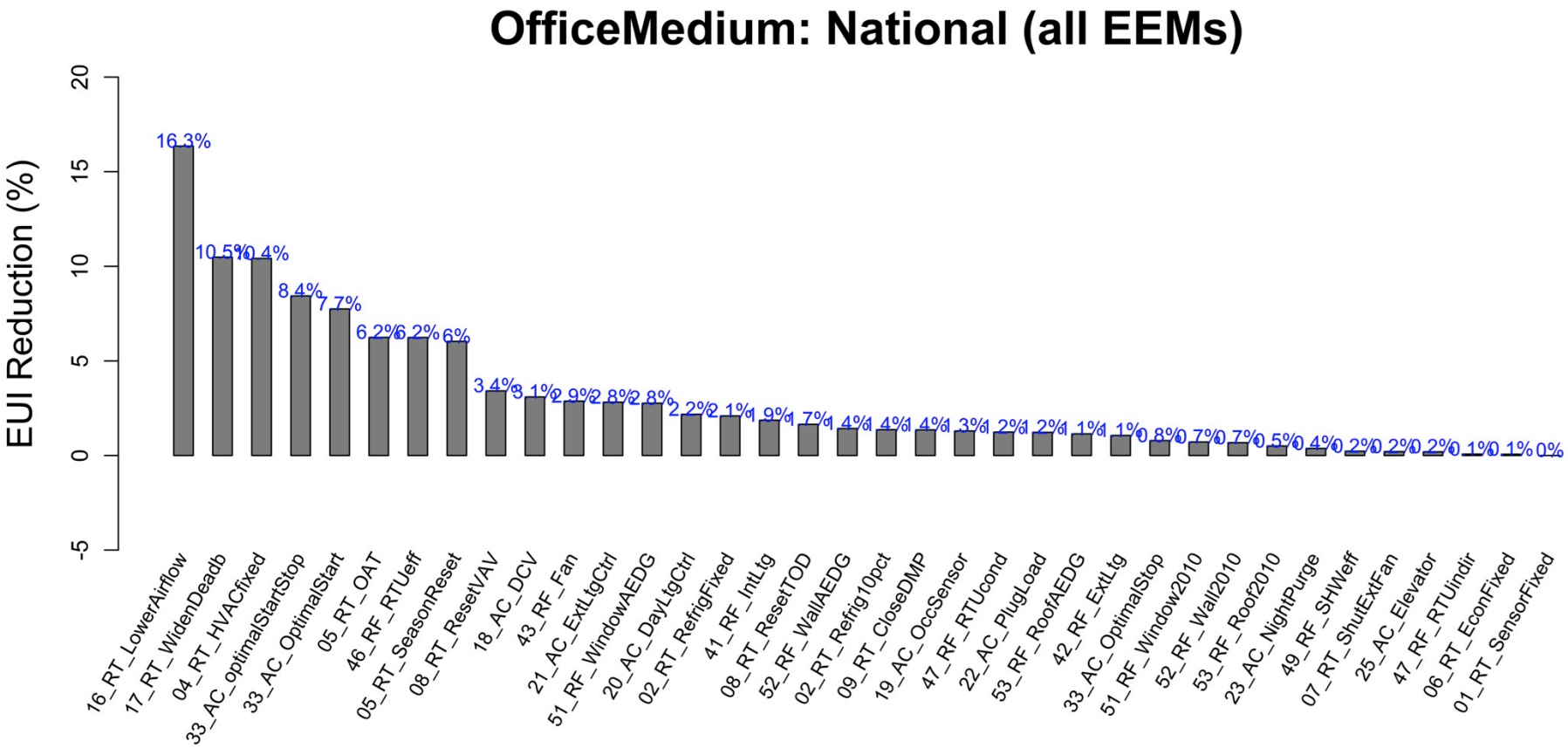
Savings from each Individual Measure: Medium Office – Warm/Mixed Climate



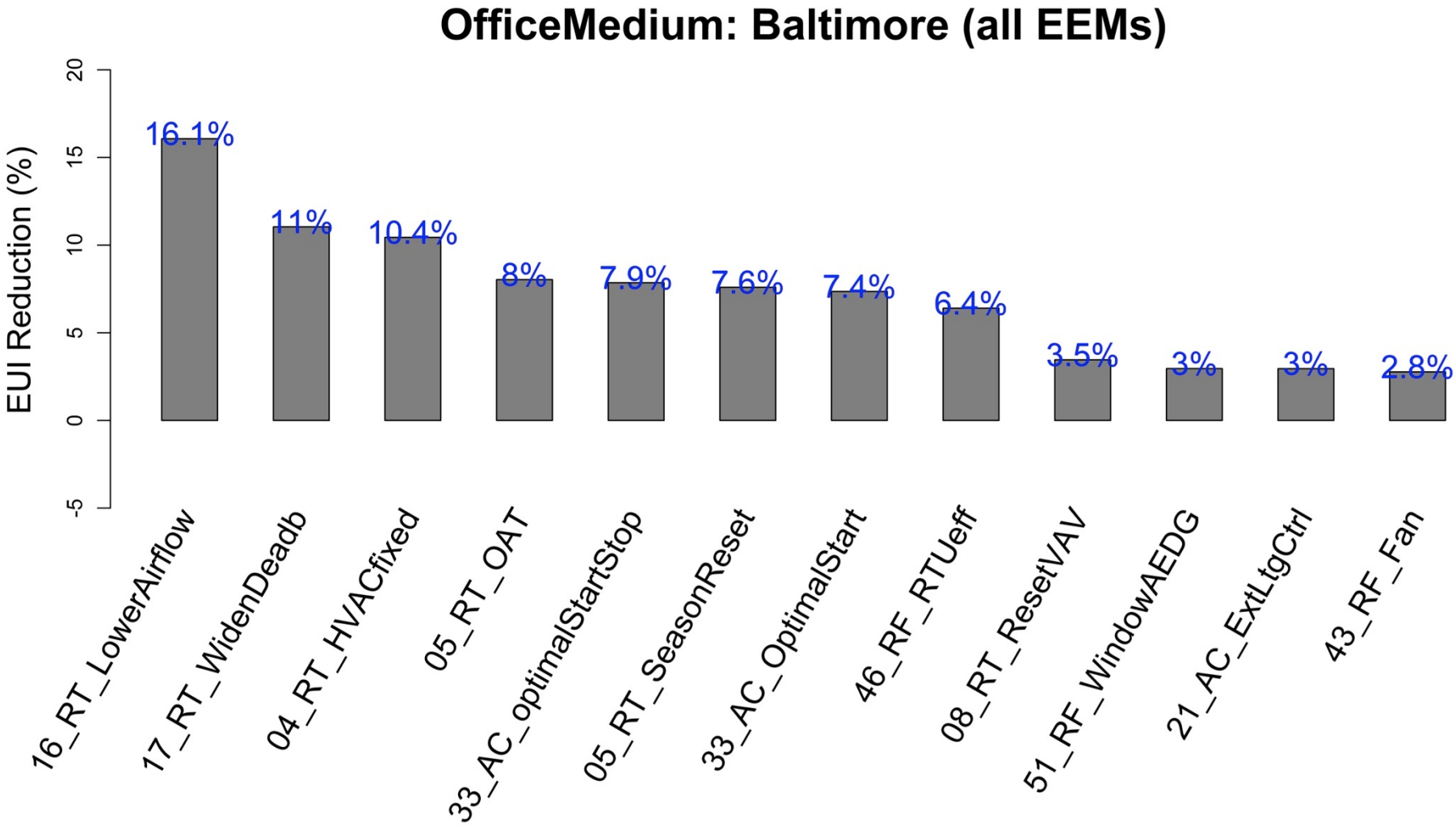
Savings from each Individual Measure: Medium Office – Cold Climate



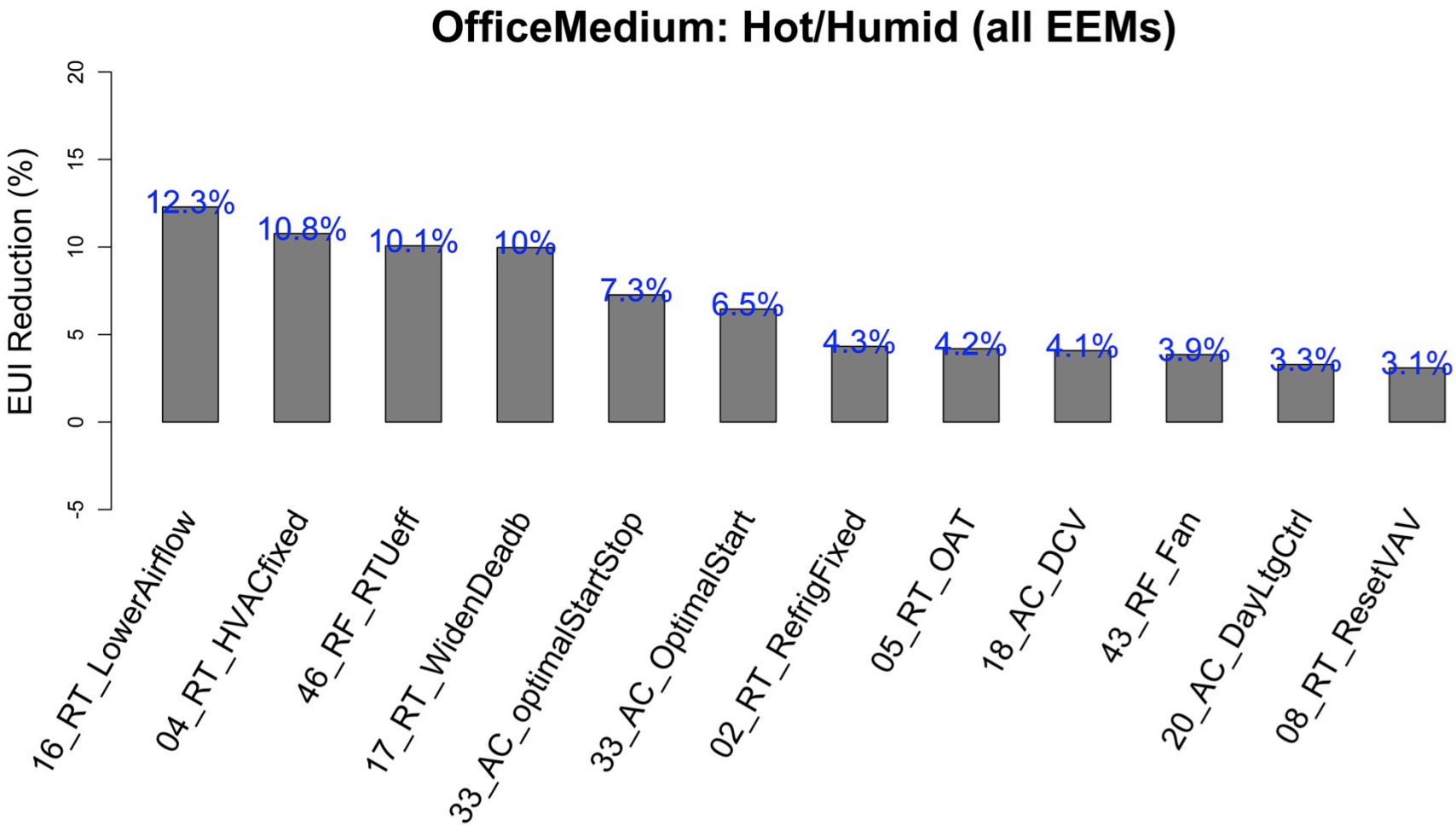
Savings from each Individual Measure: Medium Office – National Climate



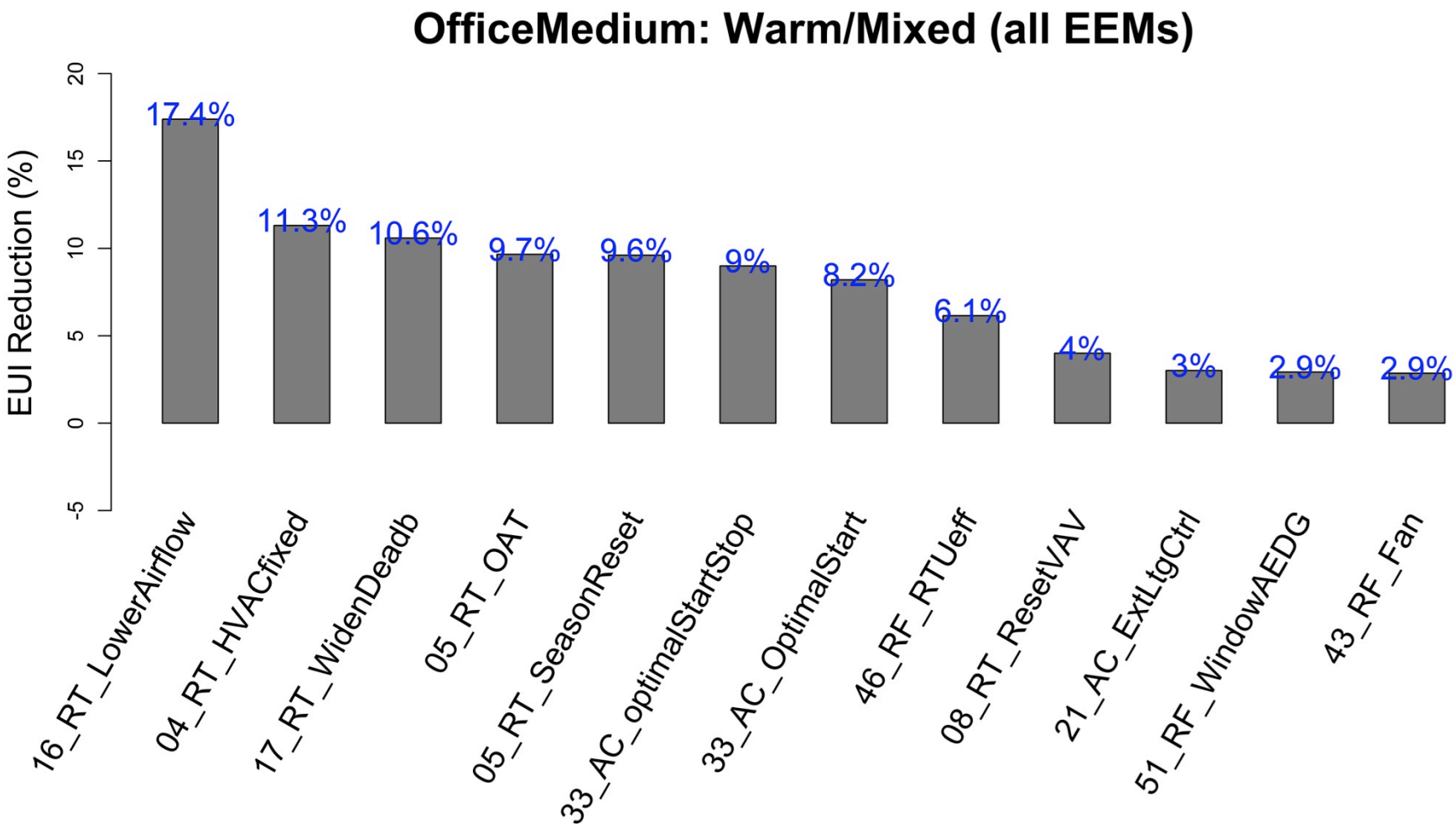
Savings from Top 12 Measures Across all Categories): Medium Office – Baltimore



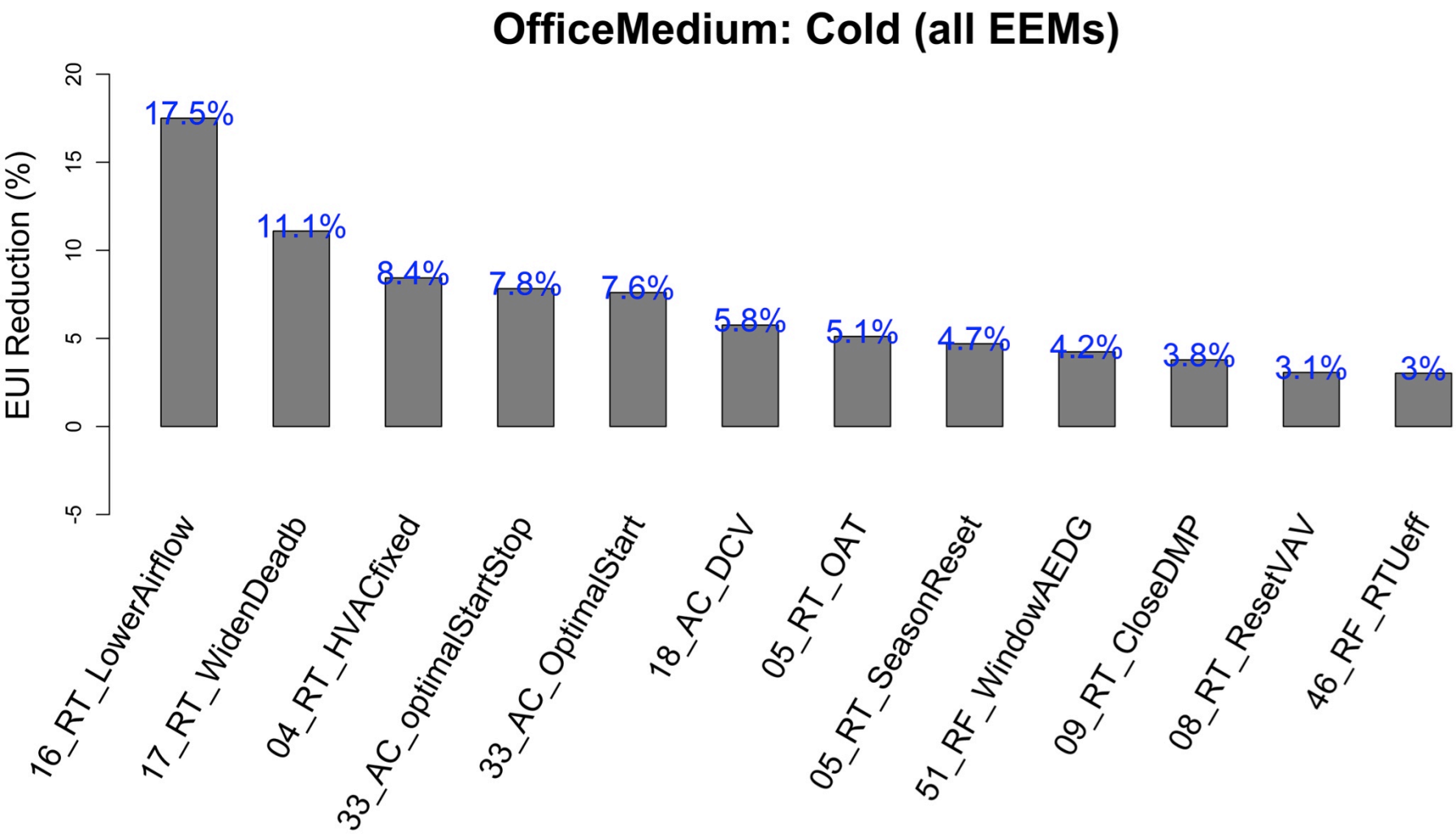
Savings from Top 12 Measures Across all Categories: Medium Office – Hot/Humid Climate



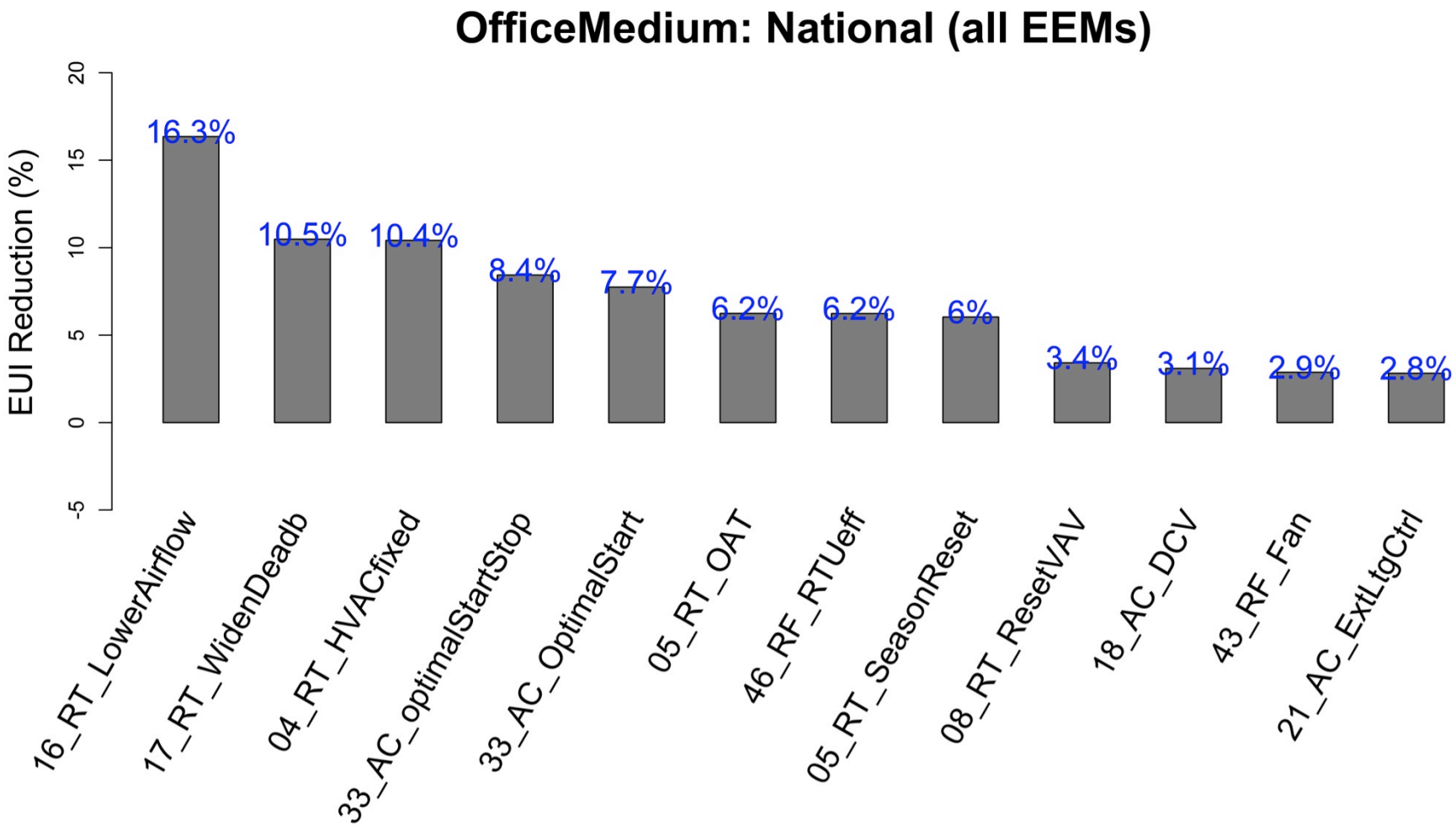
Savings from Top 12 Measures Across all Categories: Medium Office – Warm/Mixed Climate



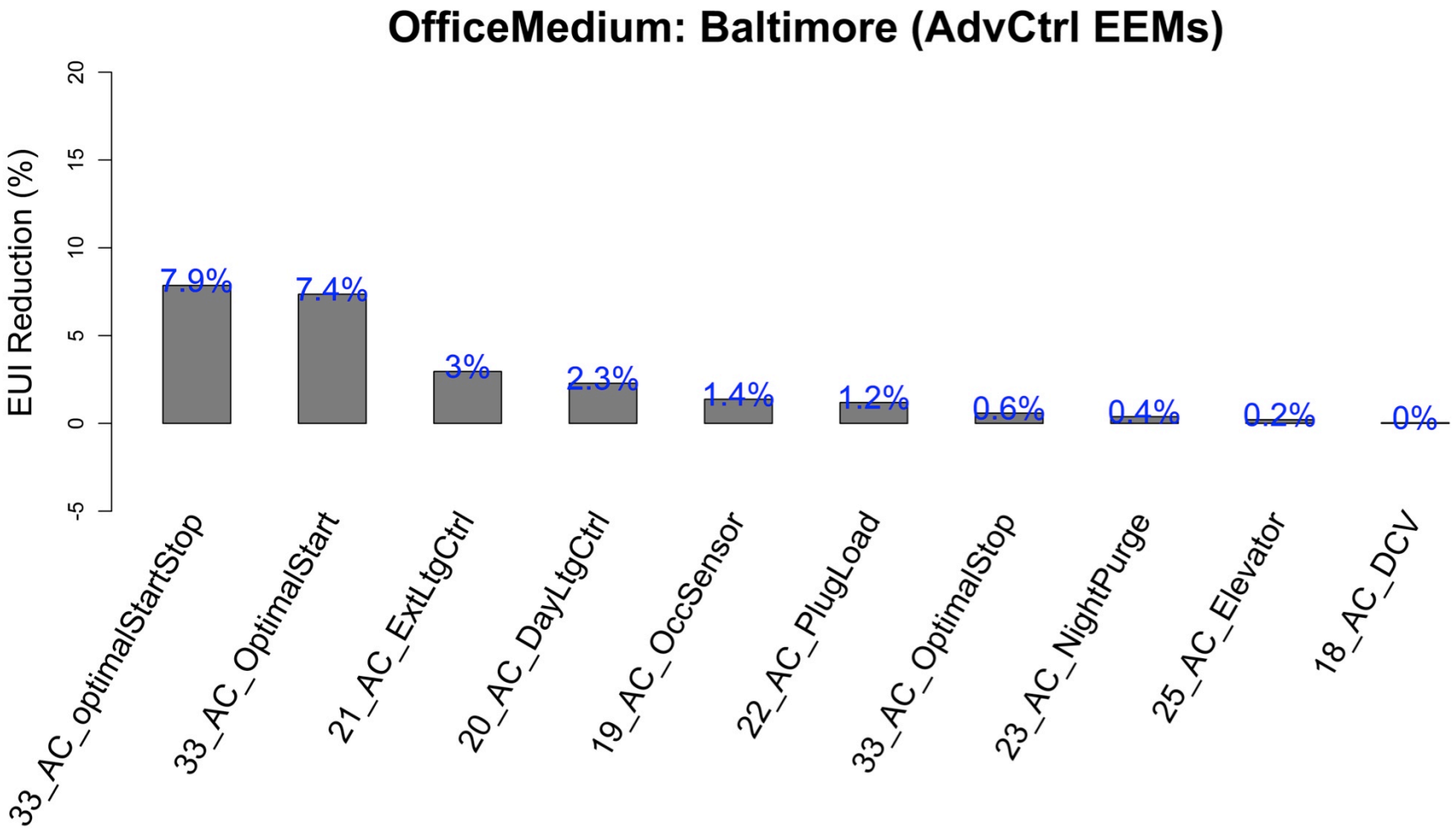
Savings from Top 12 Measures Across all Categories: Medium Office – Cold



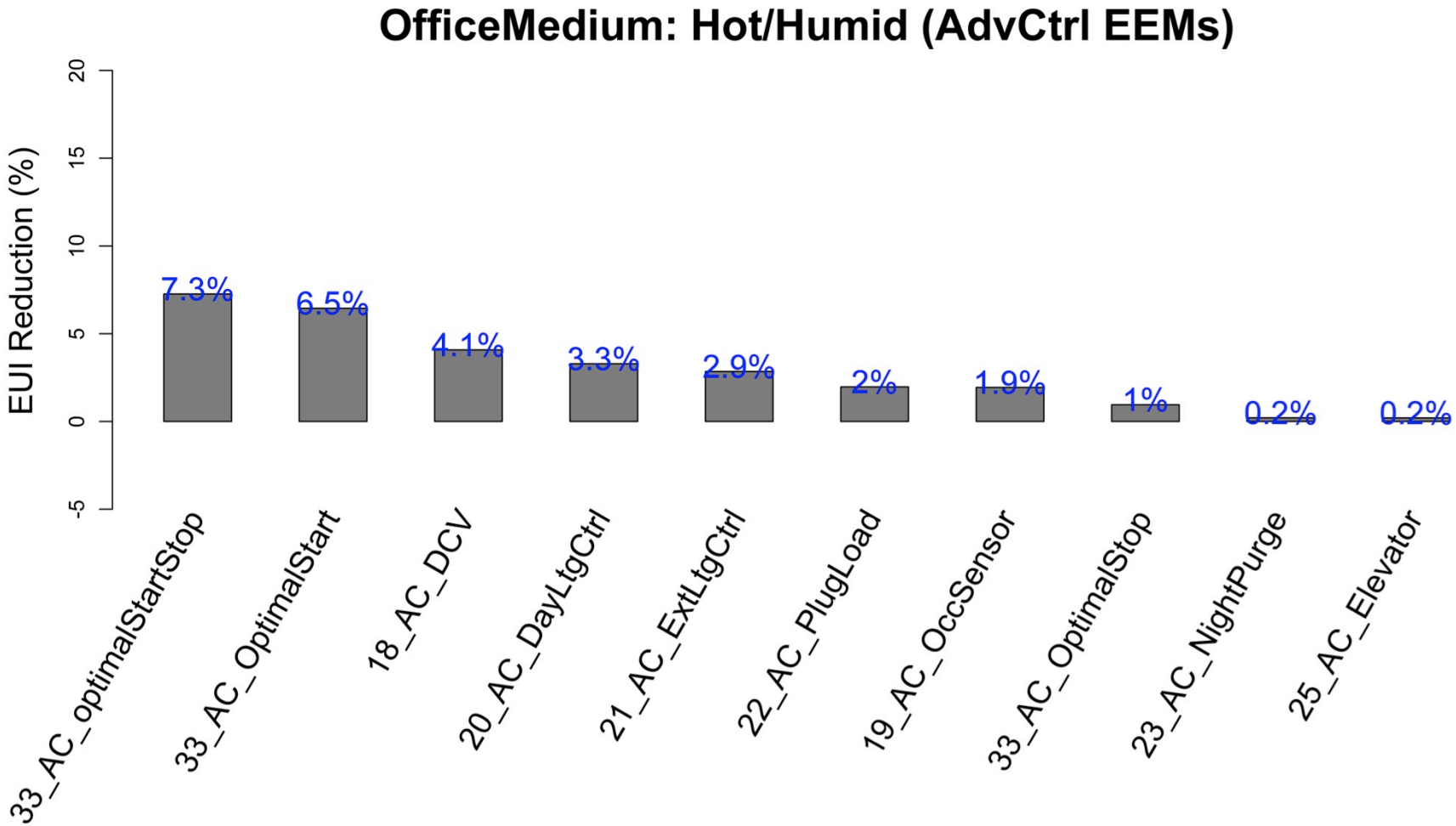
Savings from Top 12 Measures (all categories): Medium Office – National Climate



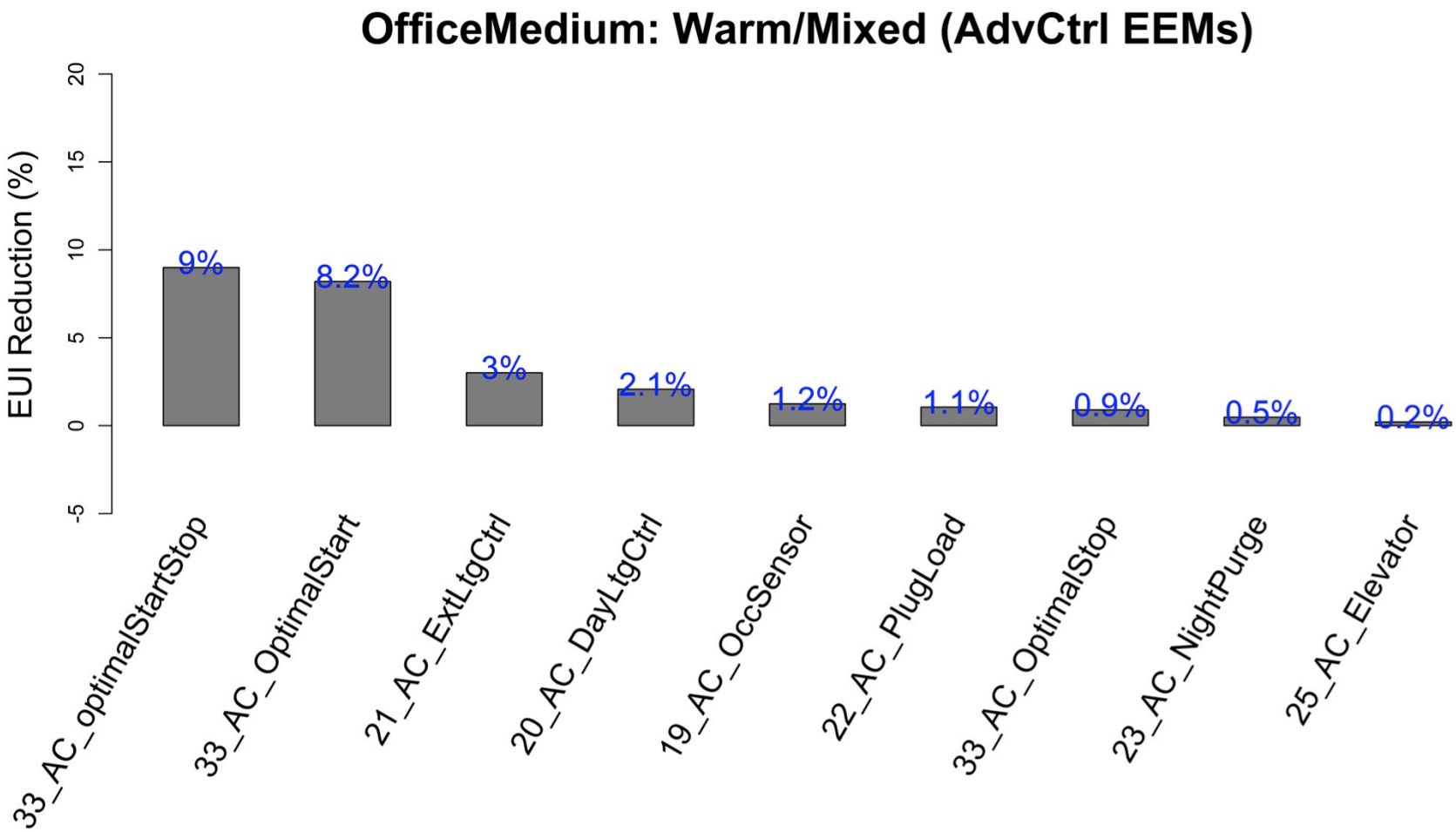
Savings from Top 12 Advanced Controls Measures: Medium Office - Baltimore



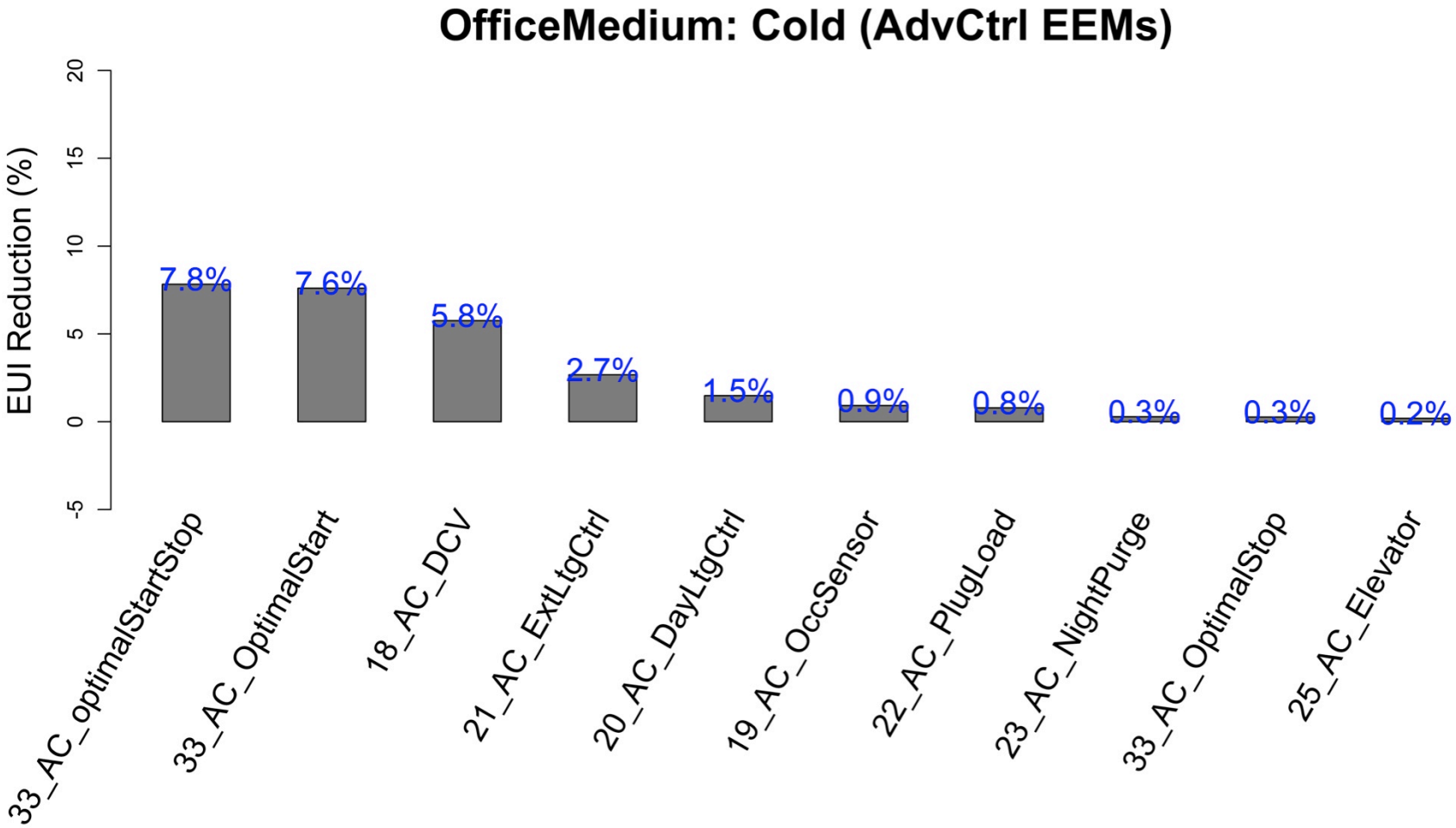
Savings from Top 12 Advanced Controls Measures: Medium Office – Hot/Humid Climate



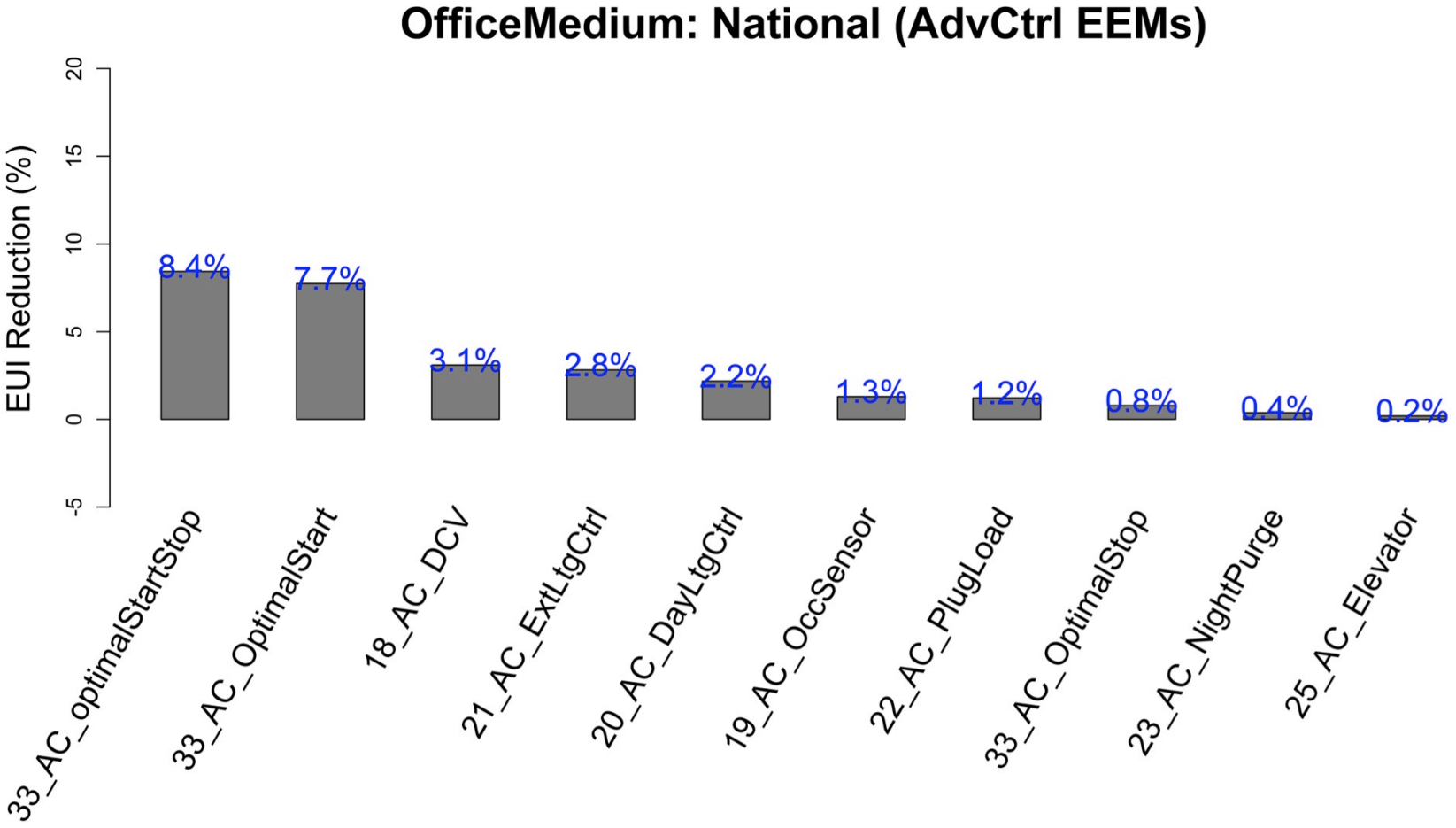
Savings from Top 12 Advanced Controls Measures: Medium Office – Warm/Mixed Climate



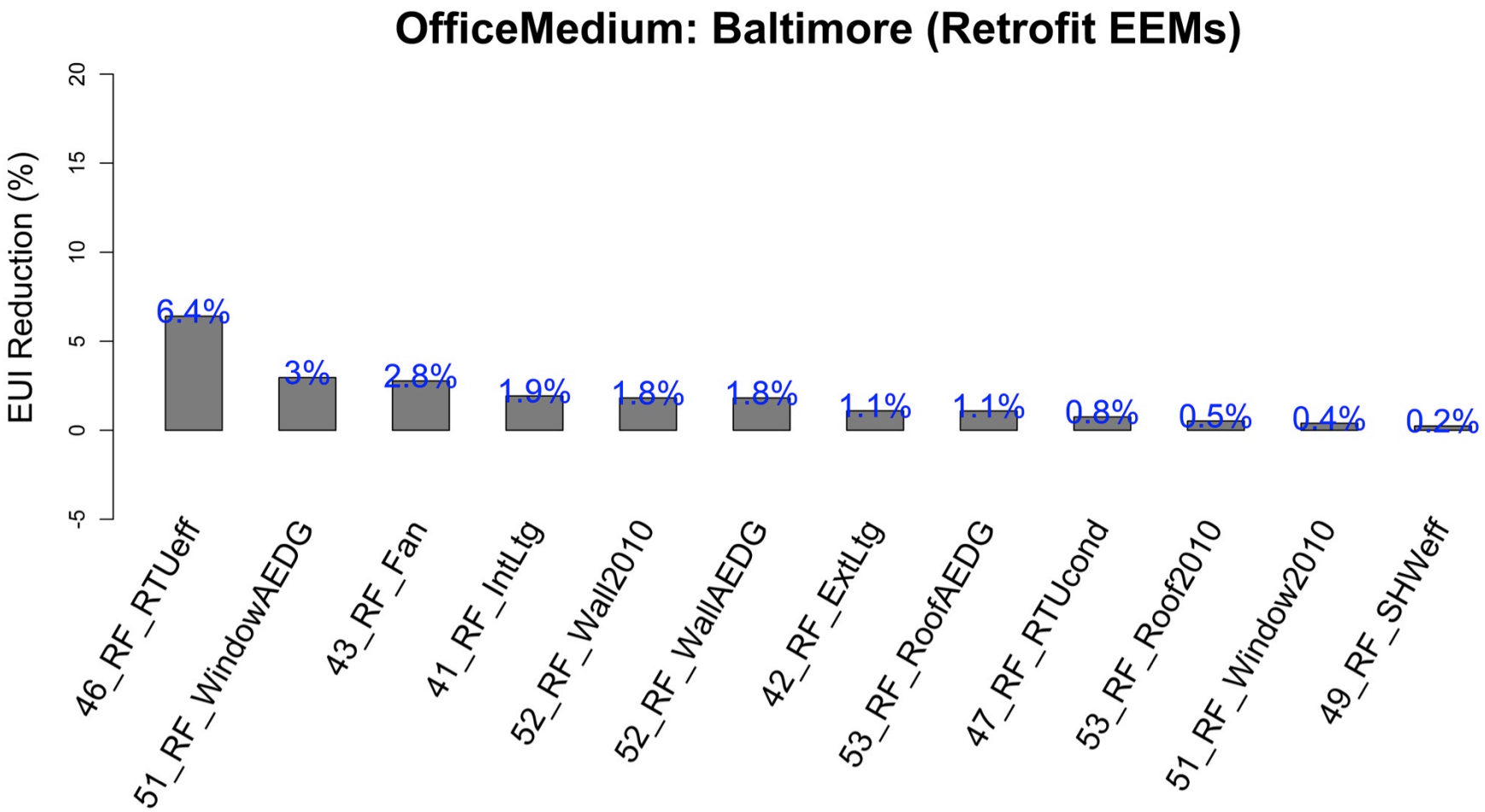
Savings from Top 12 Advanced Controls Measures: Medium Office – Cold Climate



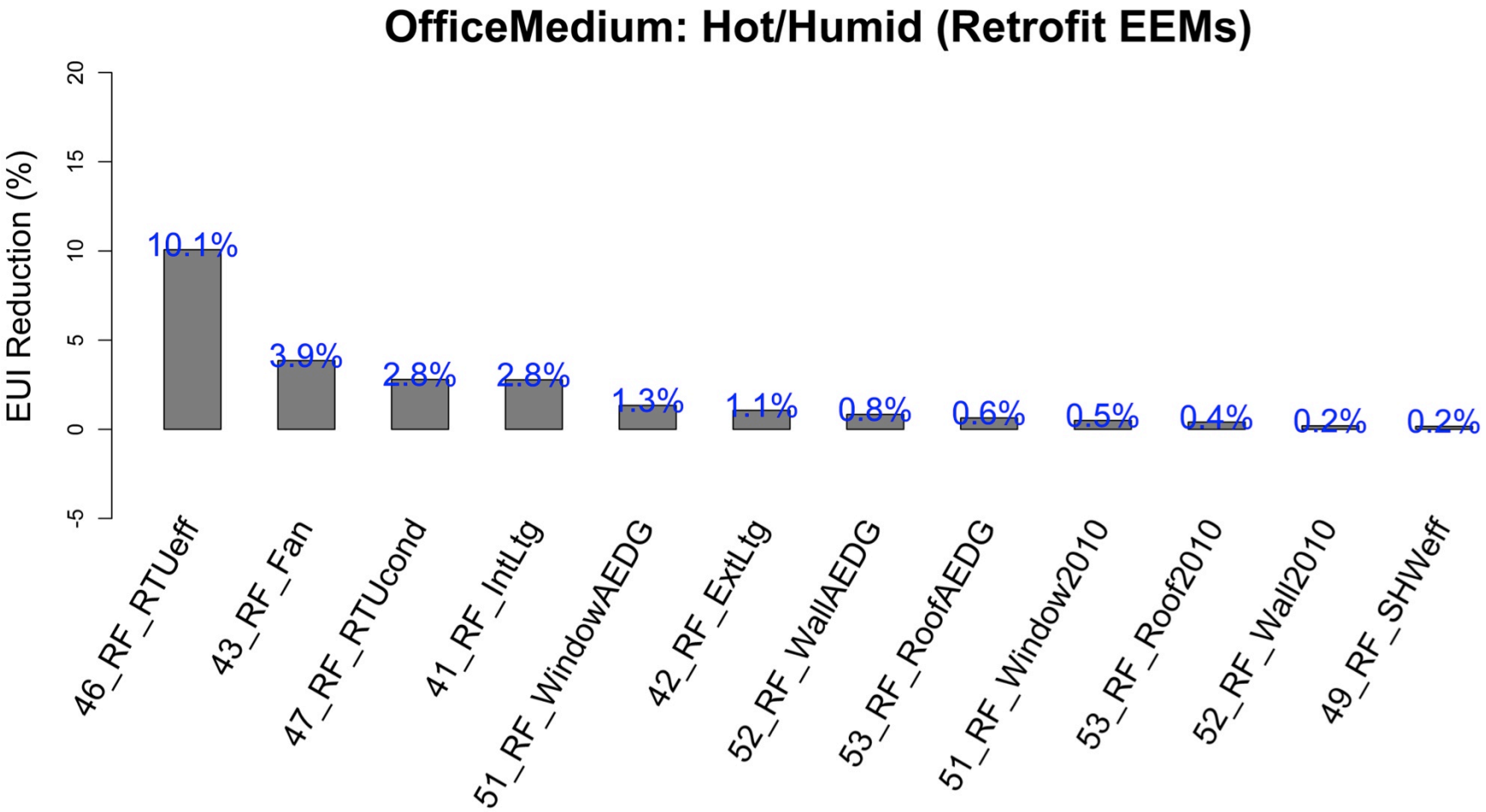
Savings from Top 12 Advanced Controls Measures: Medium Office – National Climate



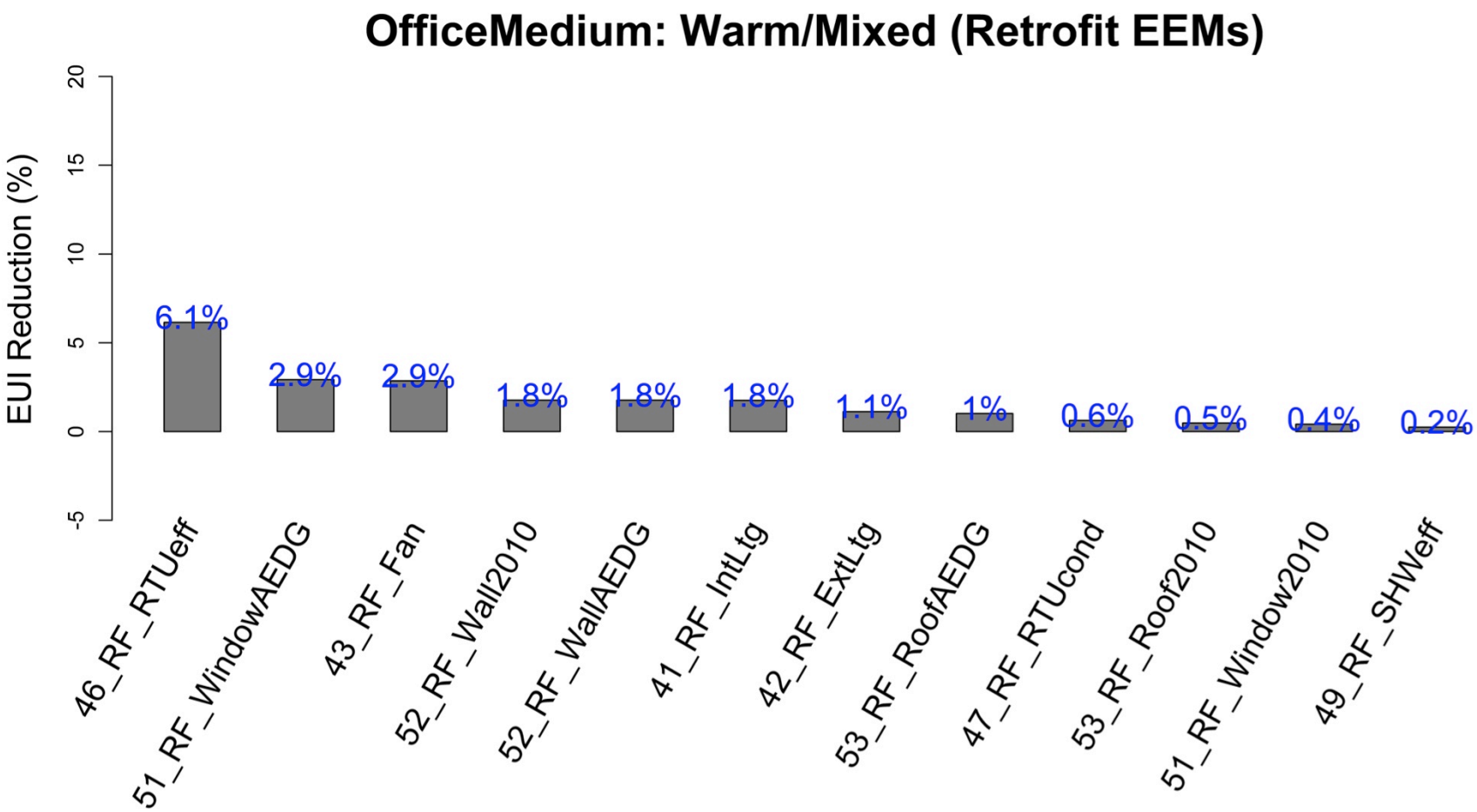
Savings from Top 12 Retrofit Measures: Medium Office – Baltimore



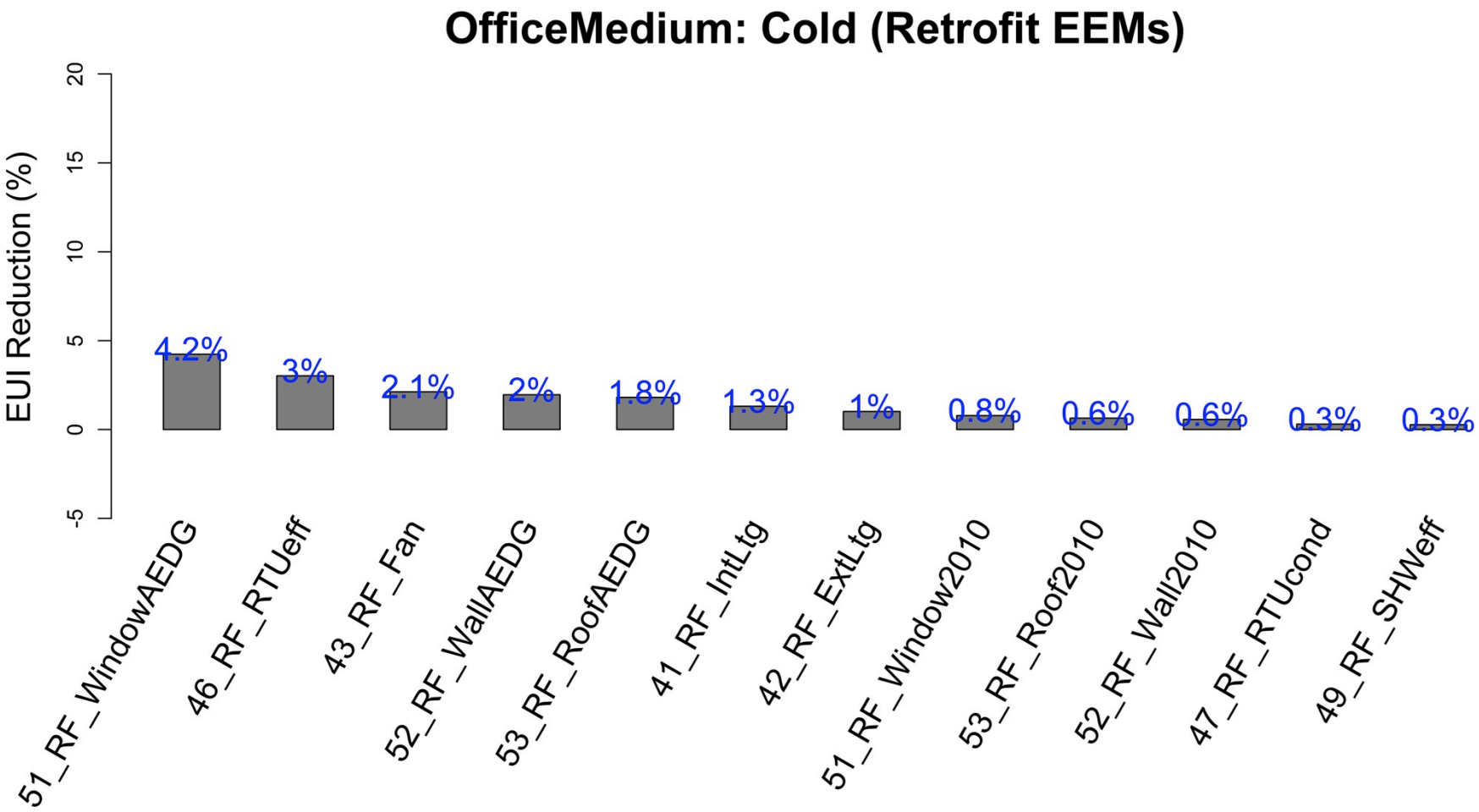
Savings from Top 12 Retrofit Measures: Medium Office – Hot/Humid Climate



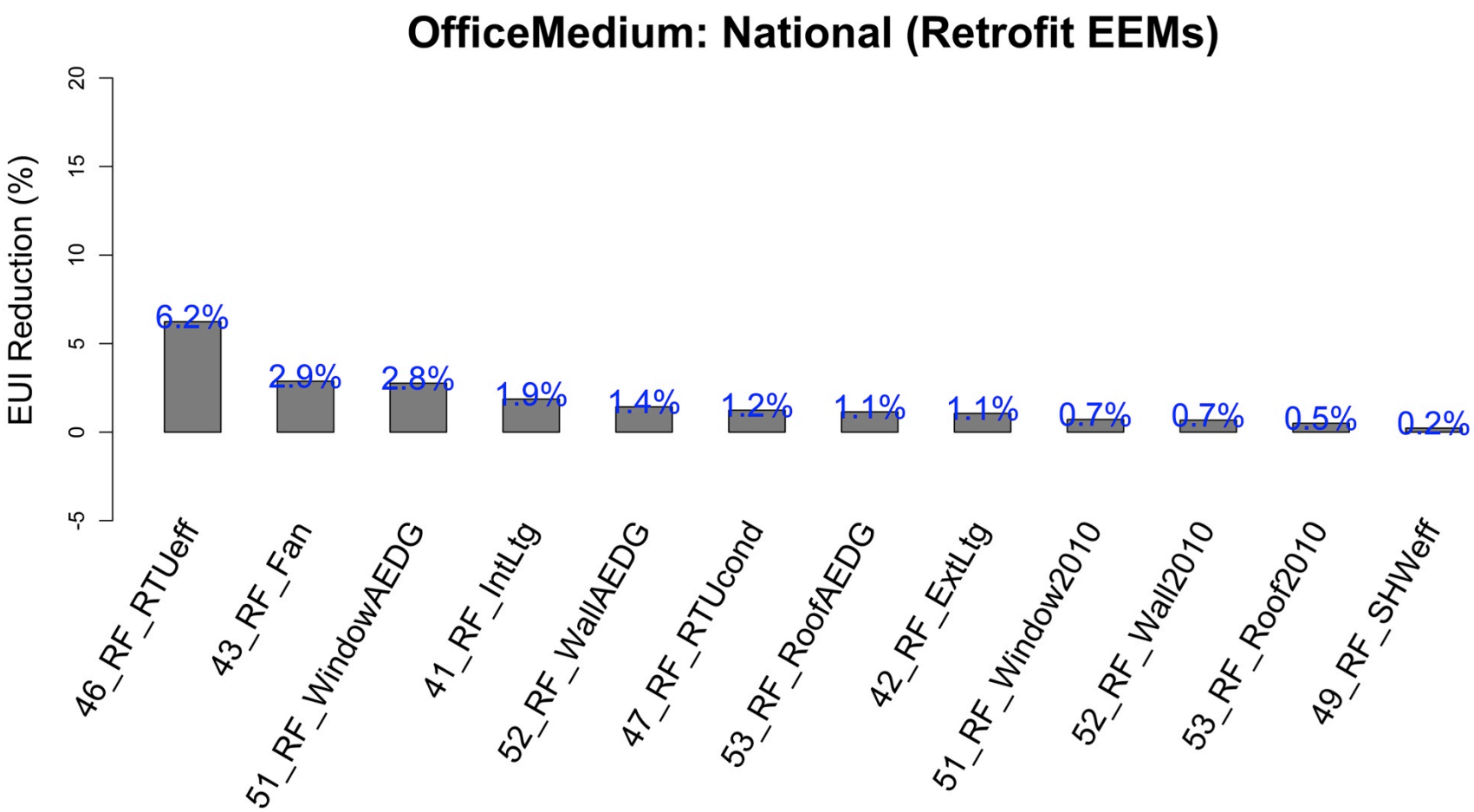
Savings from Top 12 Retrofit Measures: Medium Office – Warm/Mixed Climate



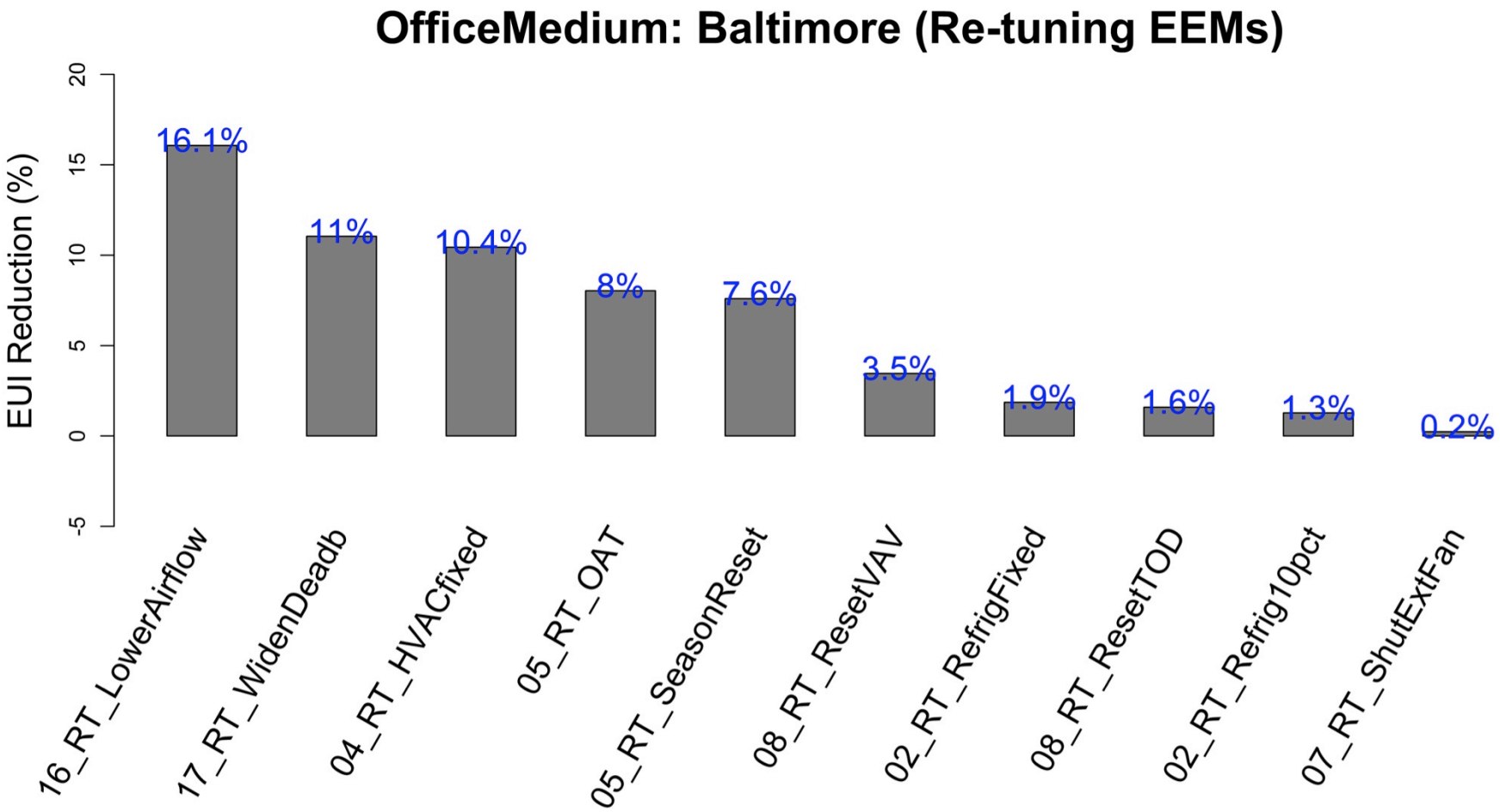
Savings from Top 12 Retrofit Measures: Medium Office – Cold Climate



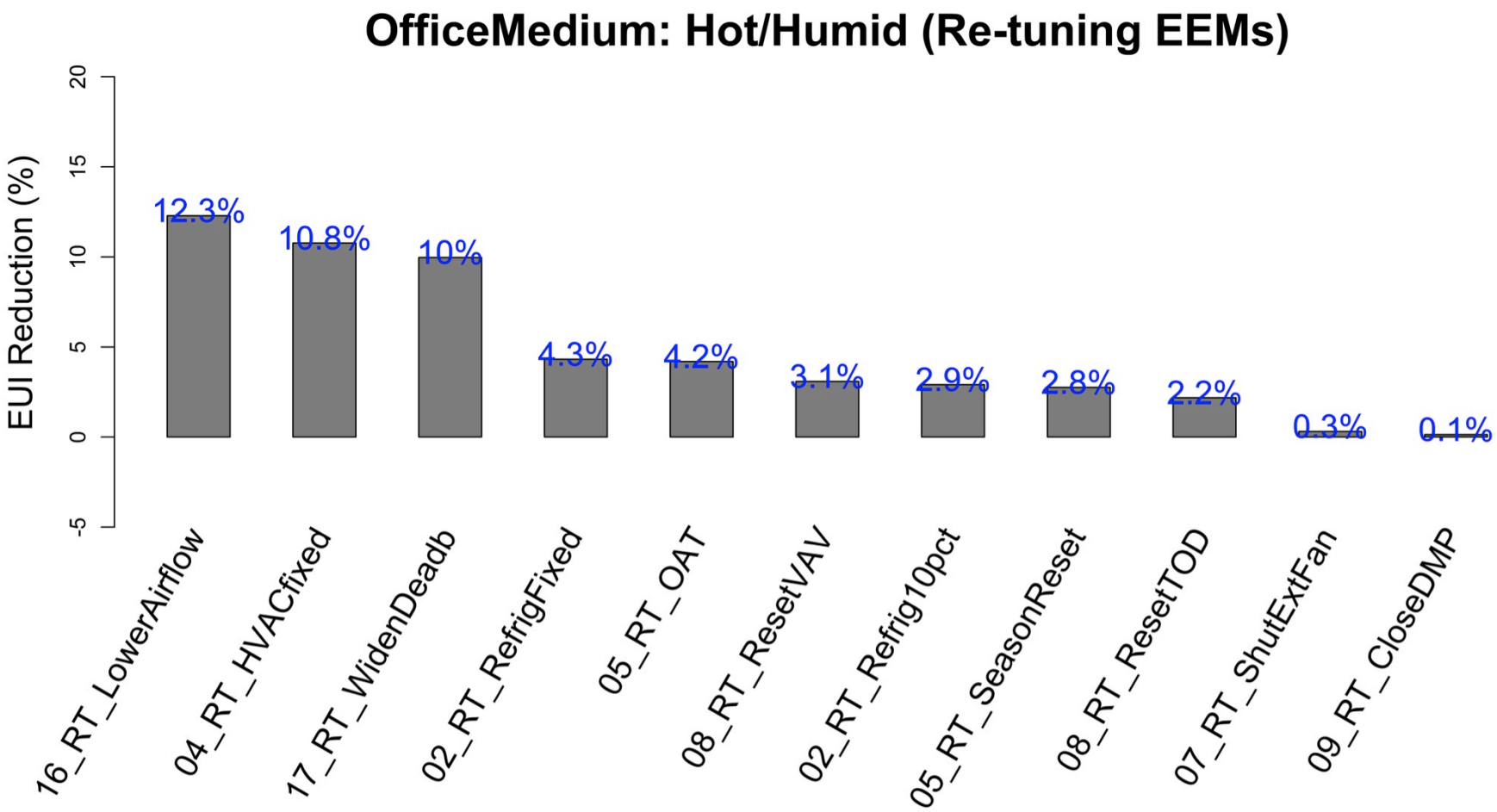
Savings from Top 12 Retrofit Measures: Medium Office – National Climate



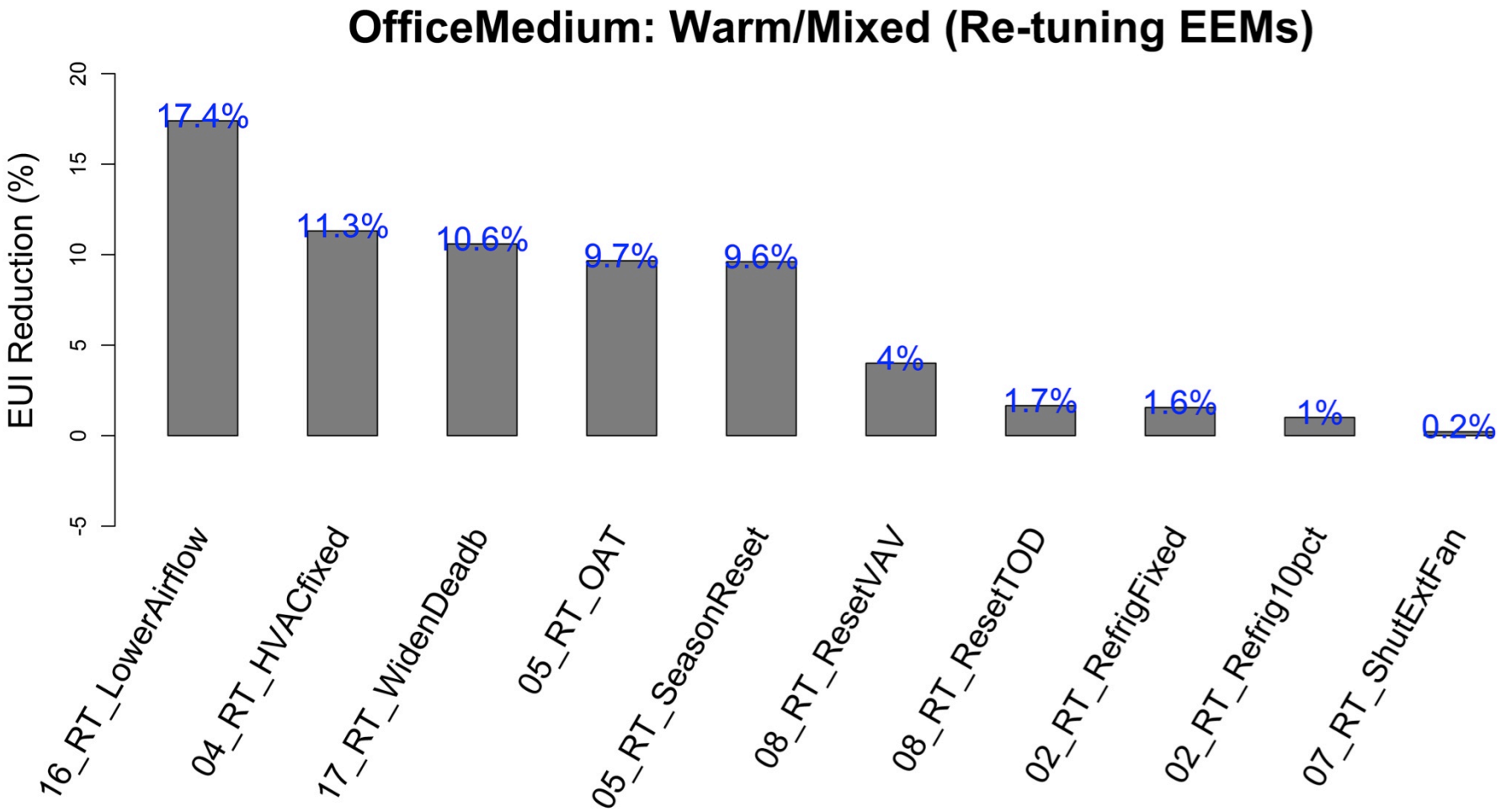
Savings from Top 12 Re-tuning Measures: Medium Office – Baltimore



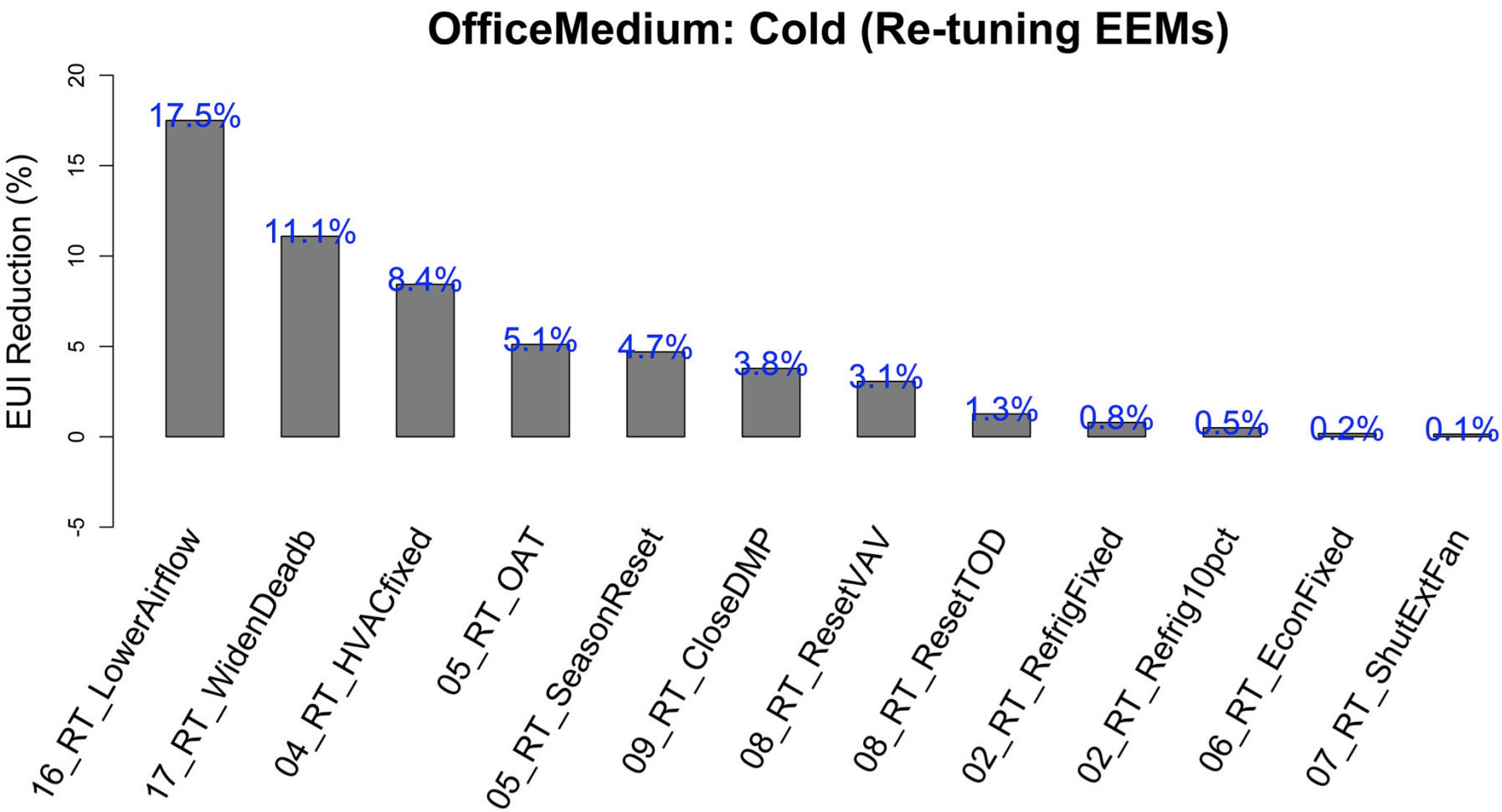
Savings from Top 12 Re-tuning Measures: Medium Office – Hot/Humid Climate



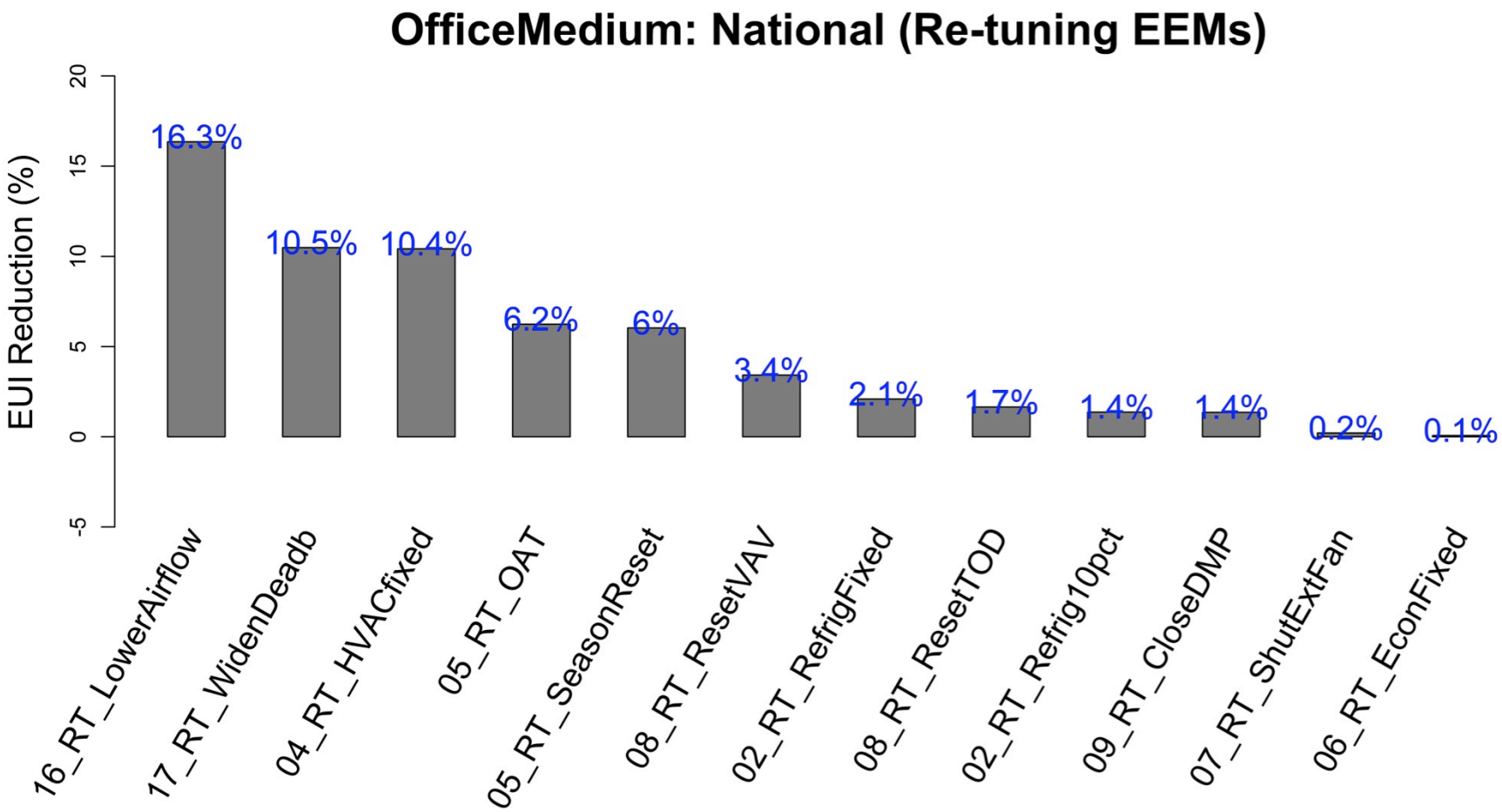
Savings from Top 12 Re-tuning Measures: Medium Office – Warm/Mixed Climate



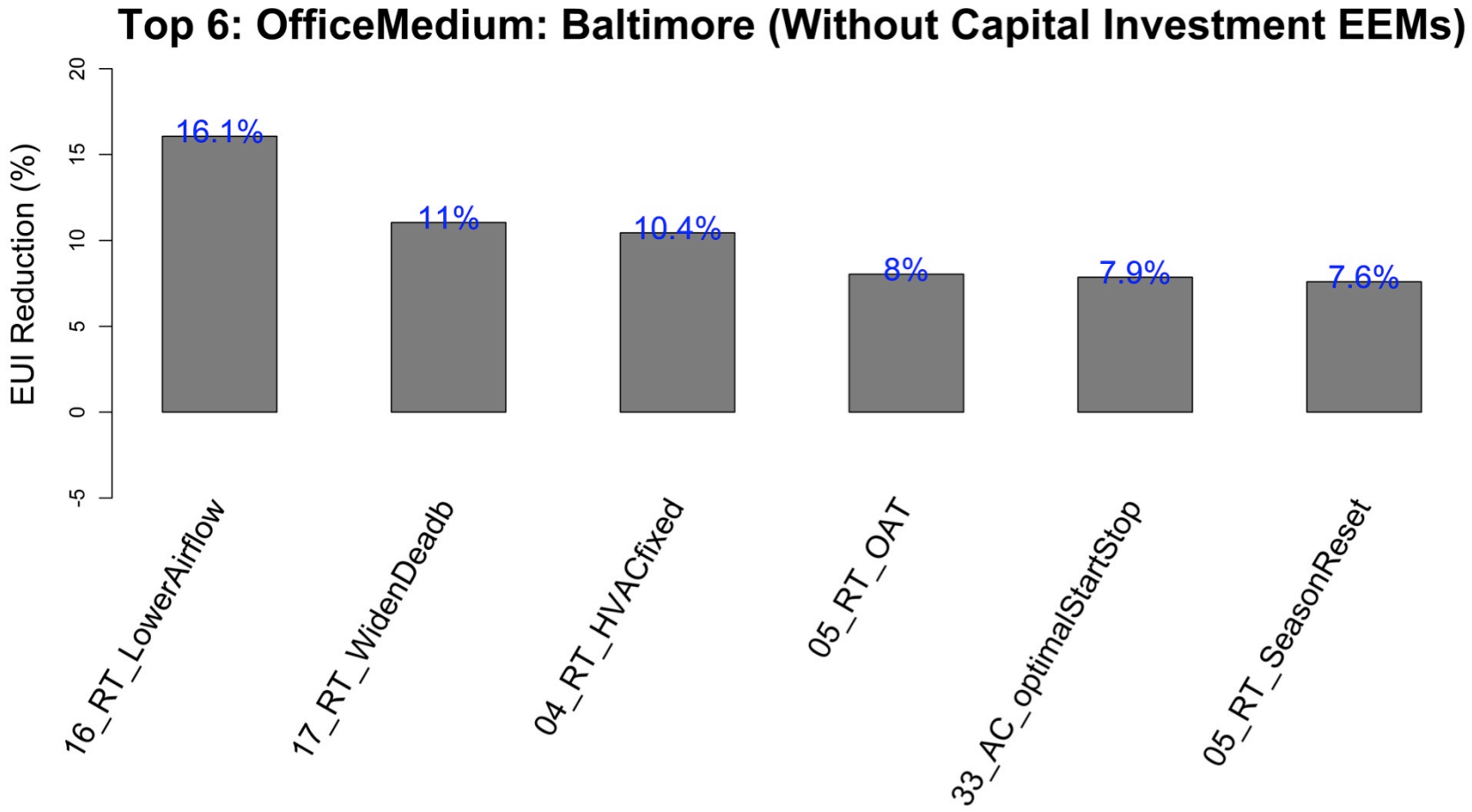
Savings from Top 12 Re-tuning Measures: Medium Office – Cold Climate



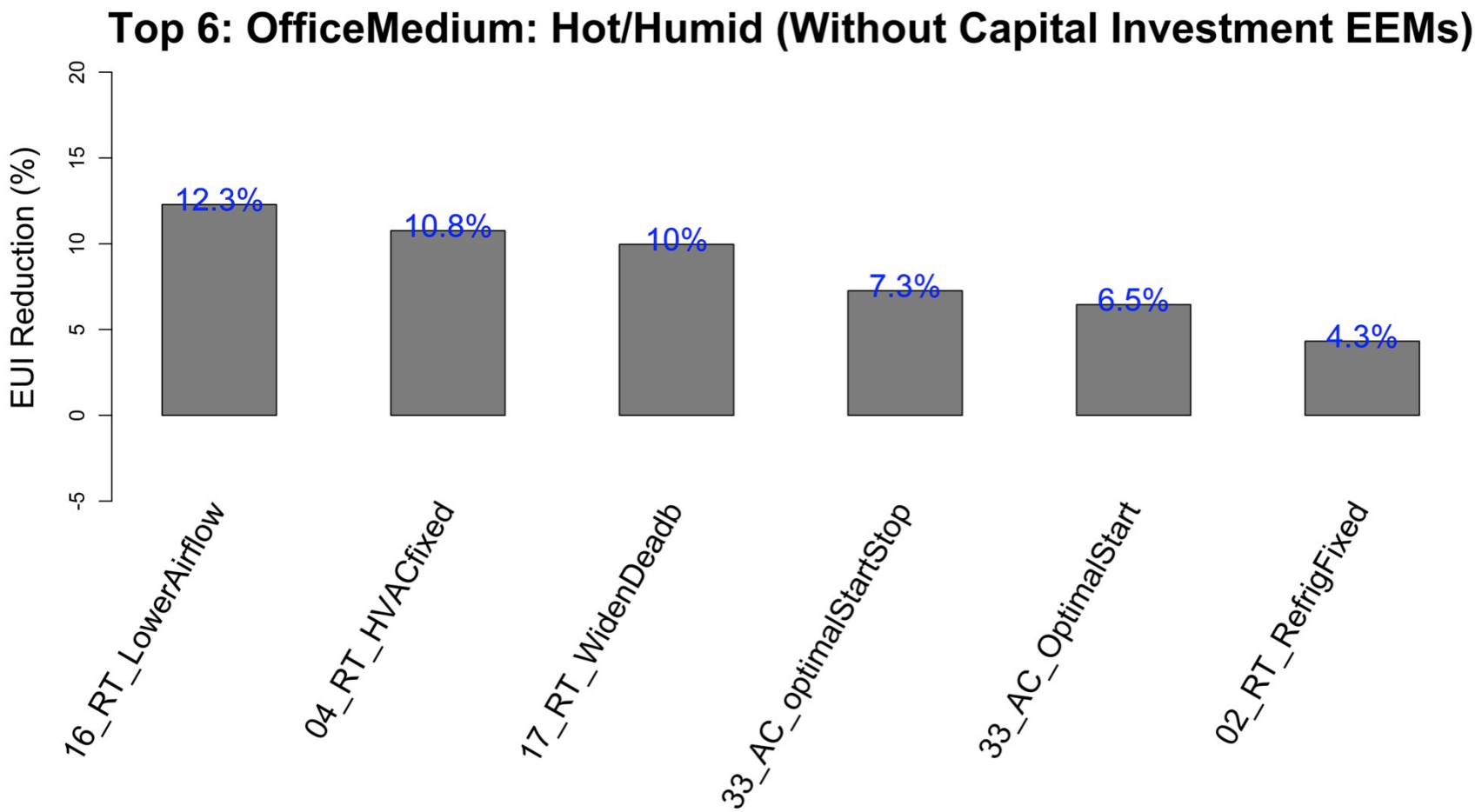
Savings from Top 12 Re-tuning Measures: Medium Office – National Climate



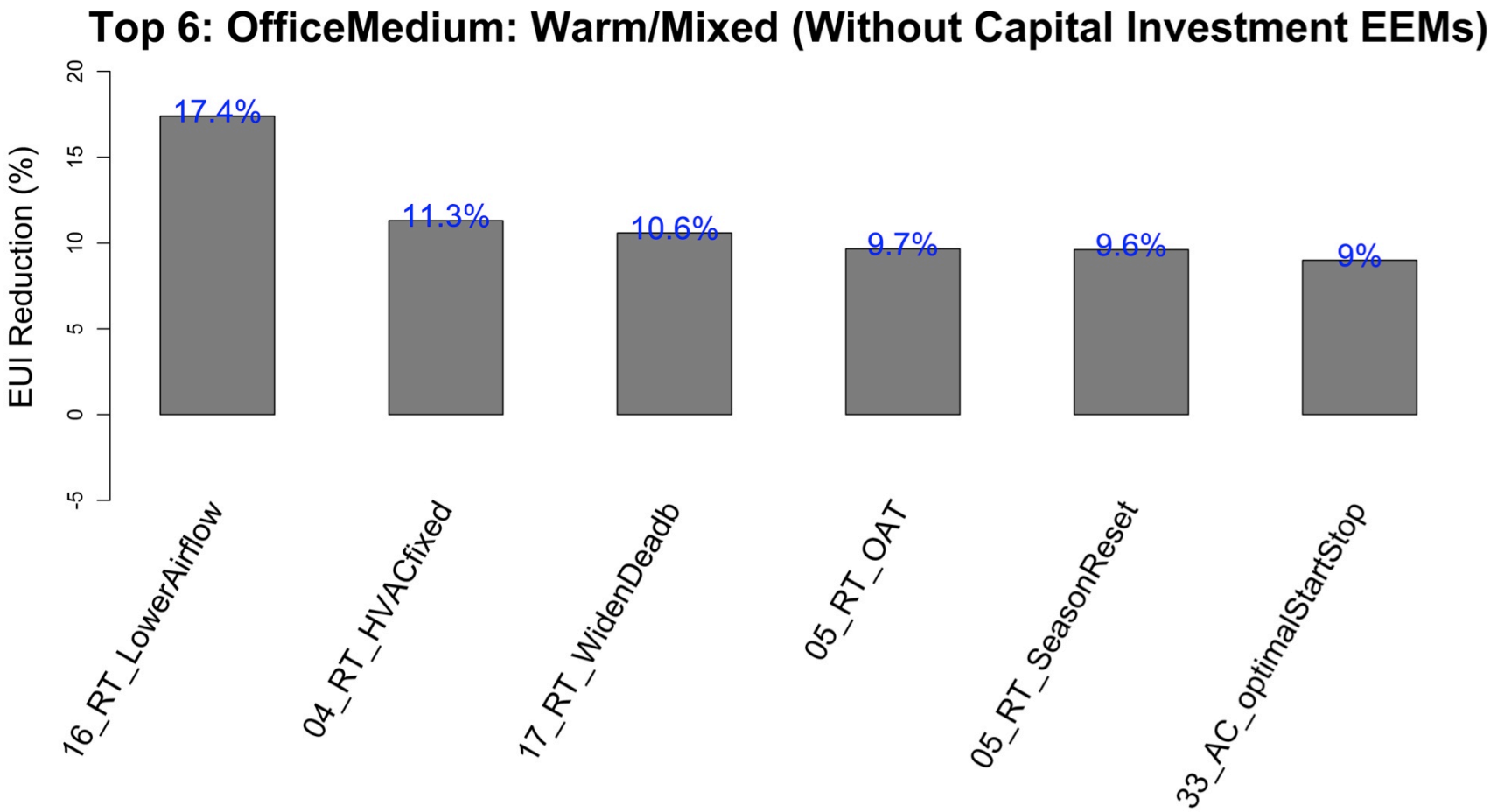
Savings from Top 6 No-Cost Measures: Medium Office – Baltimore



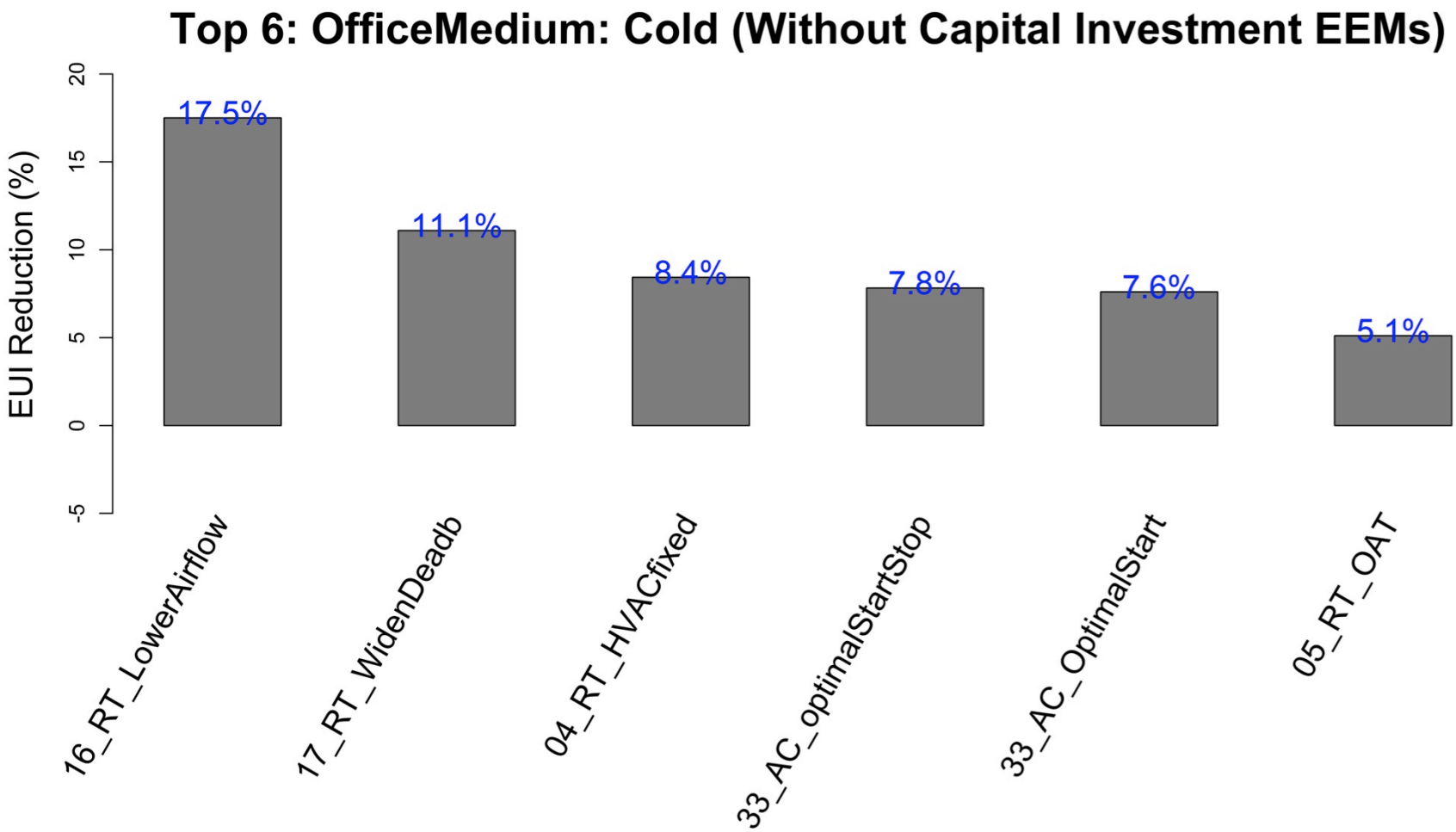
Savings from Top 6 No-Cost Measures: Medium Office – Hot/Humid Climate



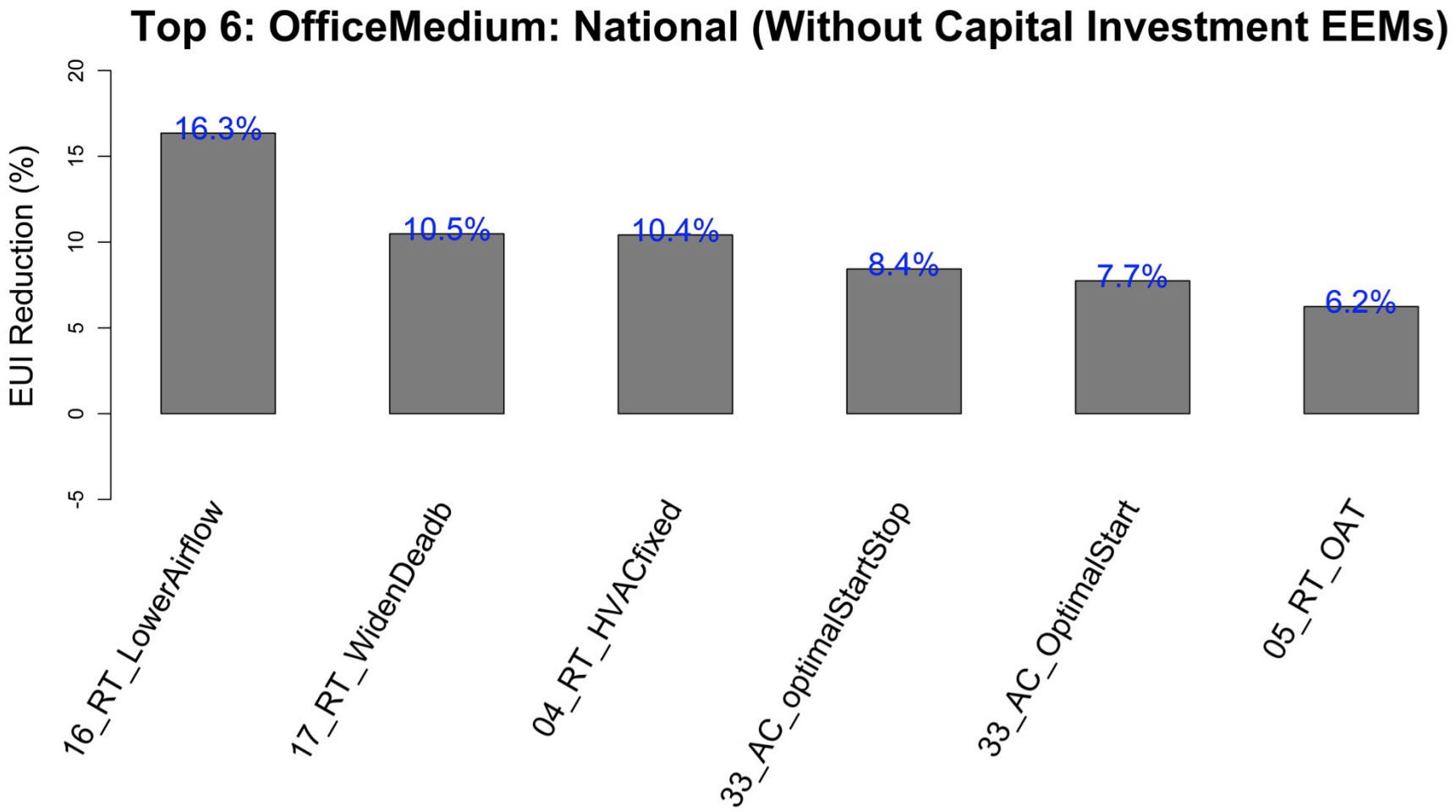
Savings from Top 6 No-Cost Measures: Medium Office – Warm/Mixed Climate



Savings from Top 6 No-Cost Measures: Medium Office – Cold Climate

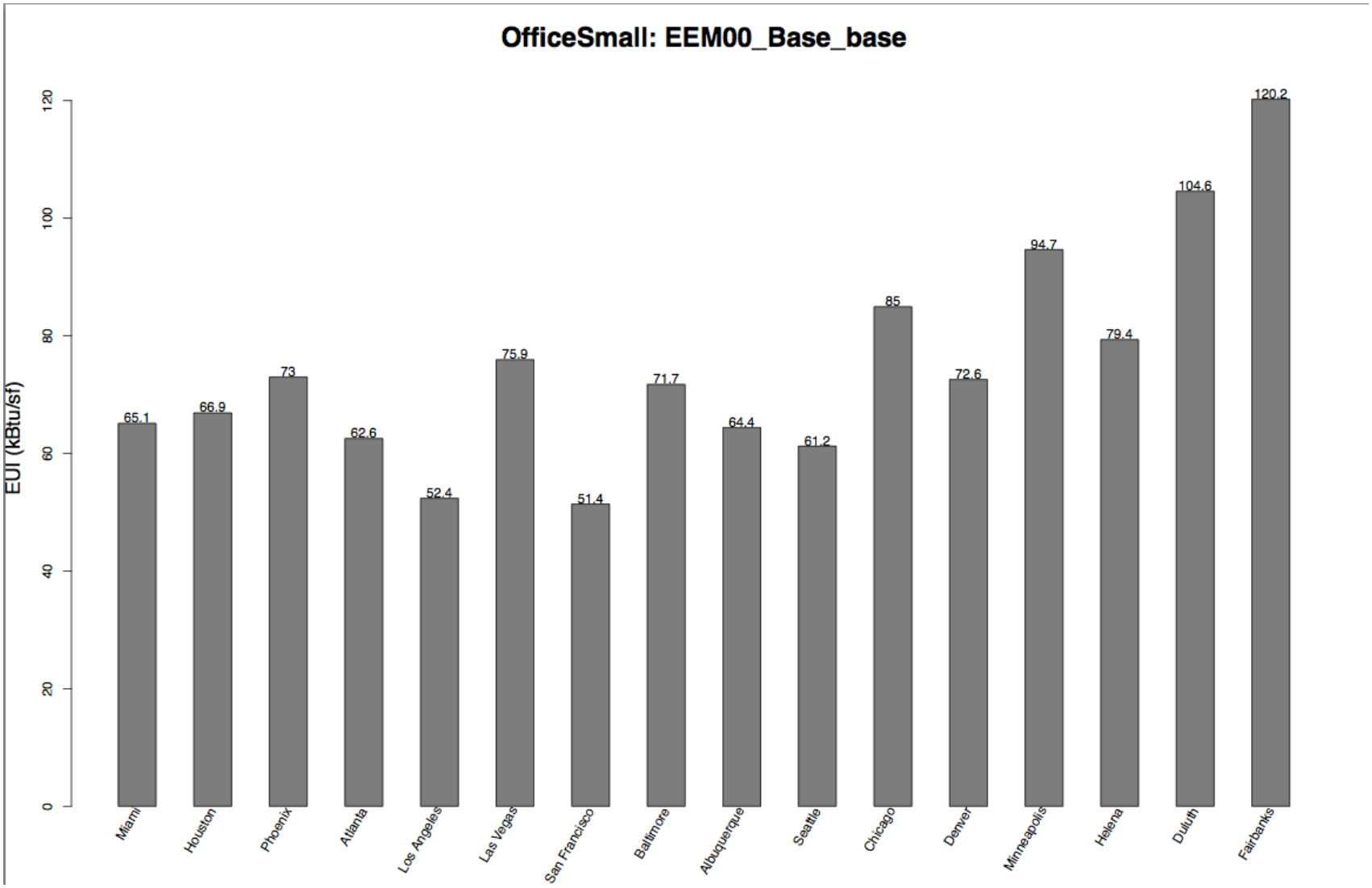


Savings from Top 6 No-Cost Measures: Medium Office – National Climate

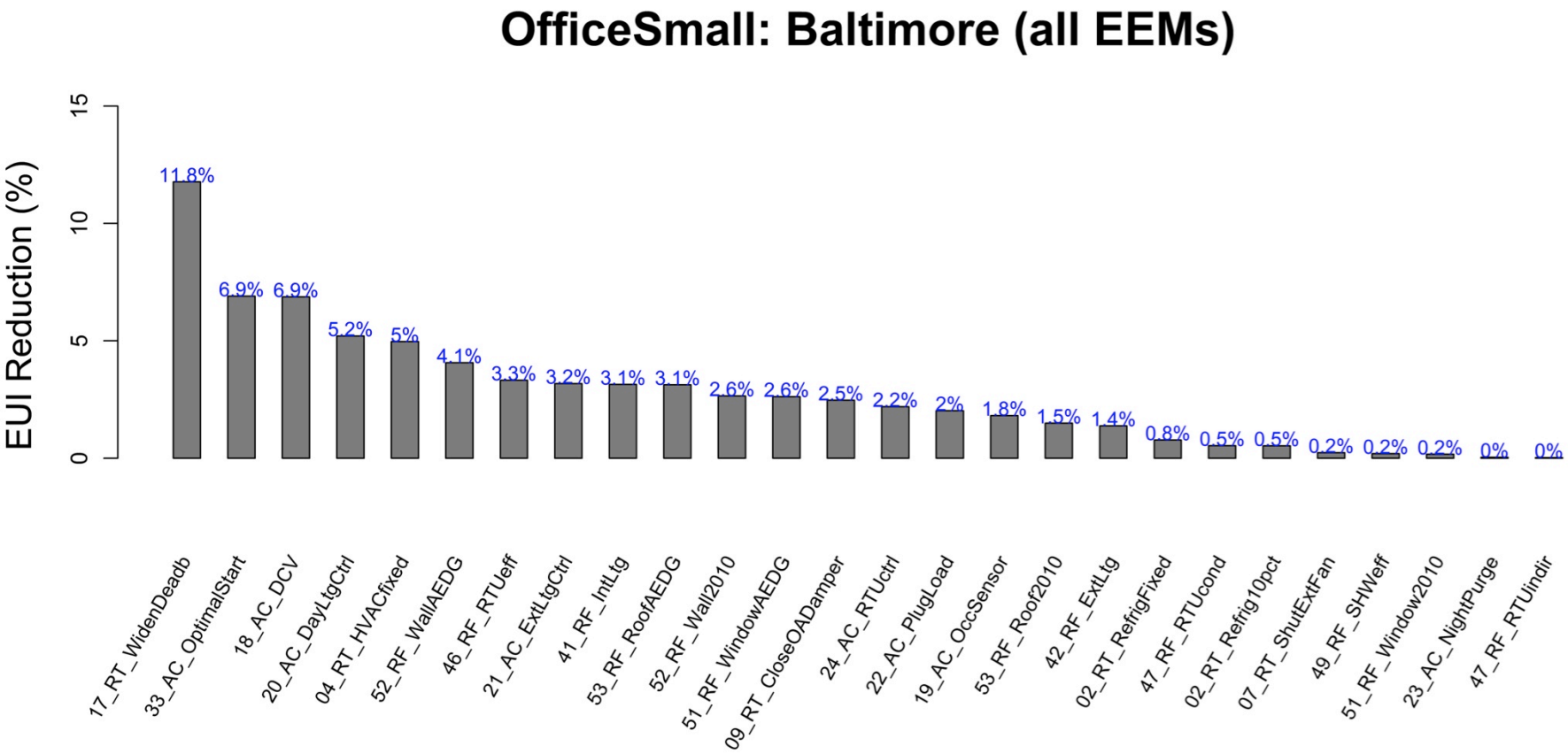


Small Office Analysis Results

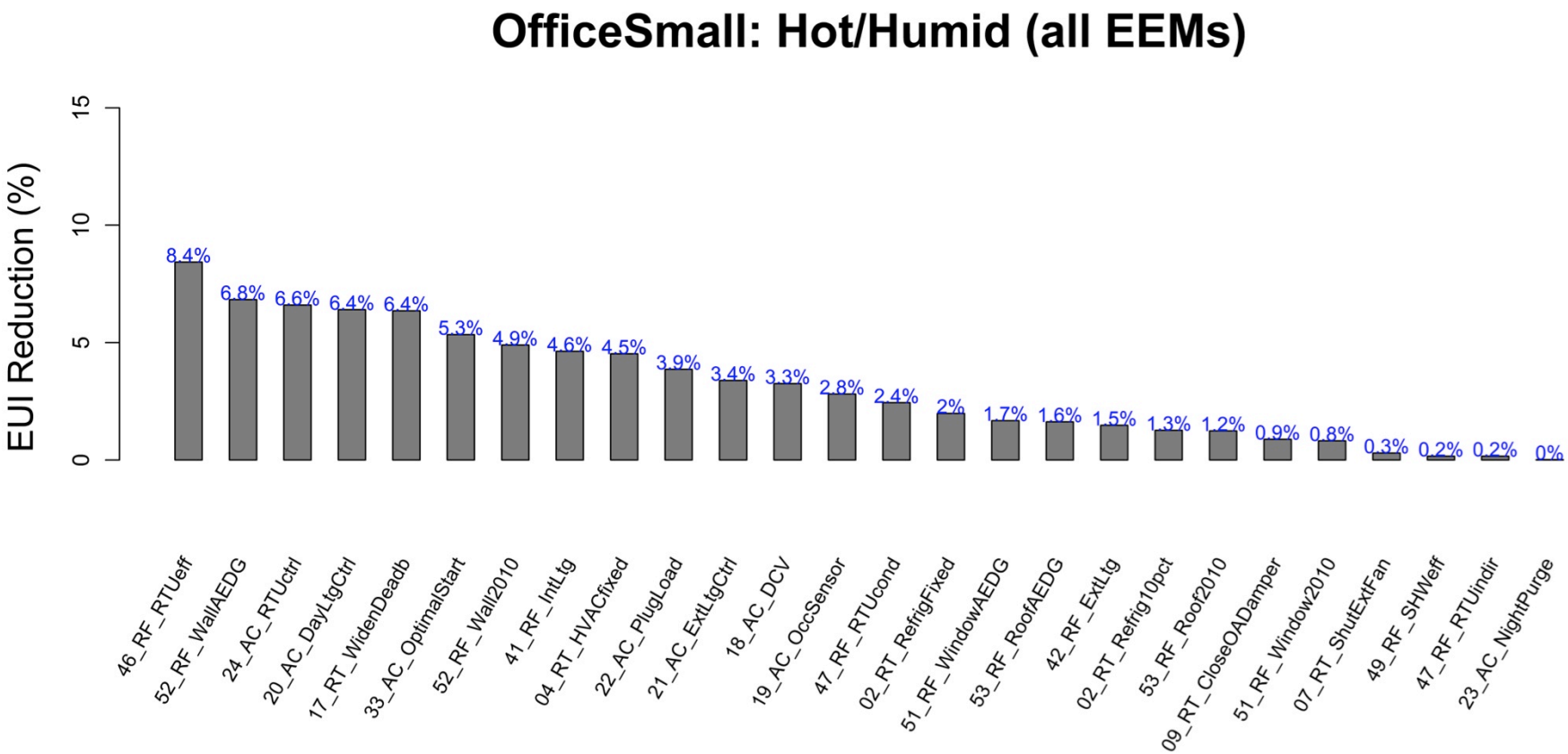
Small Office Baseline EUIs



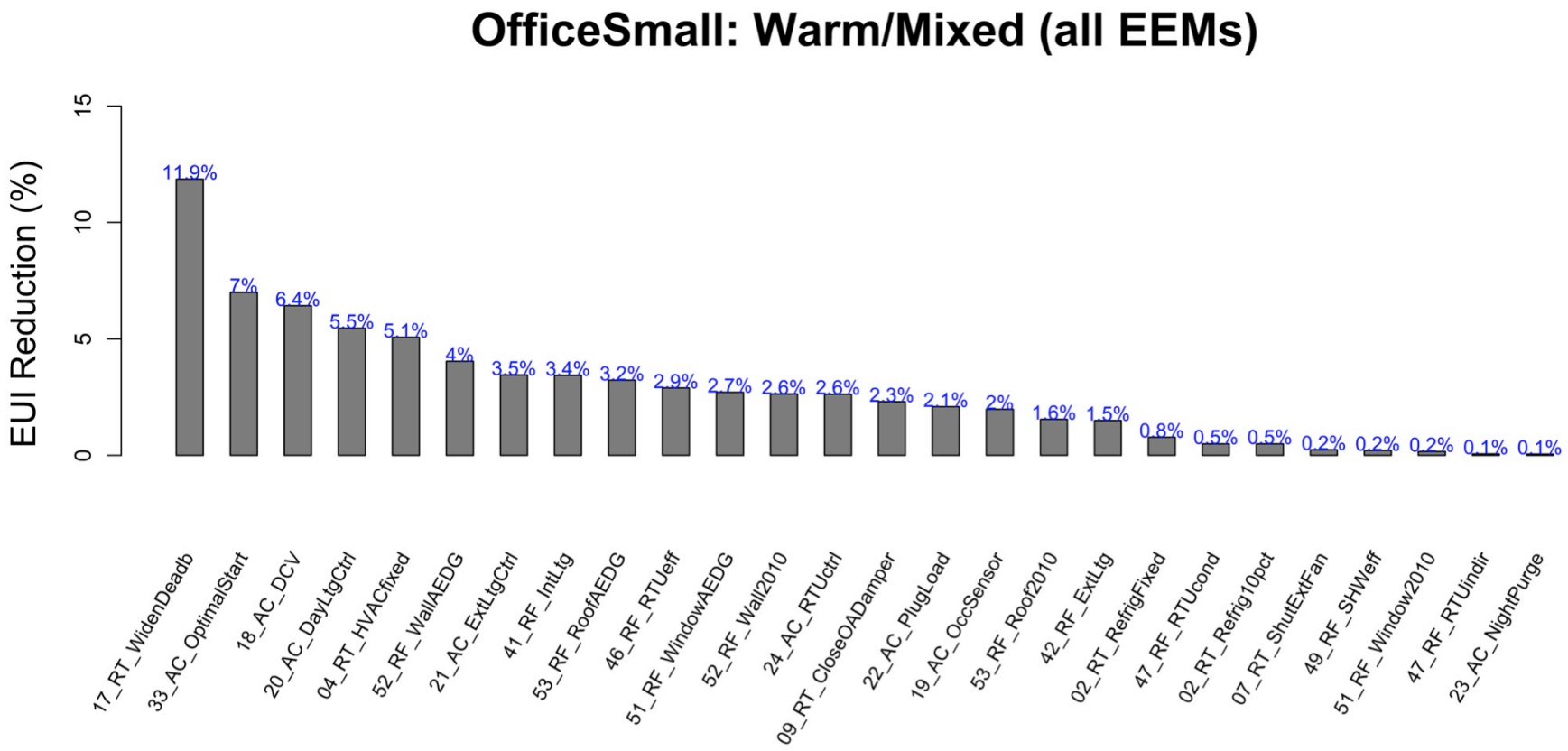
Savings from each Individual Measure: Small Office - Baltimore



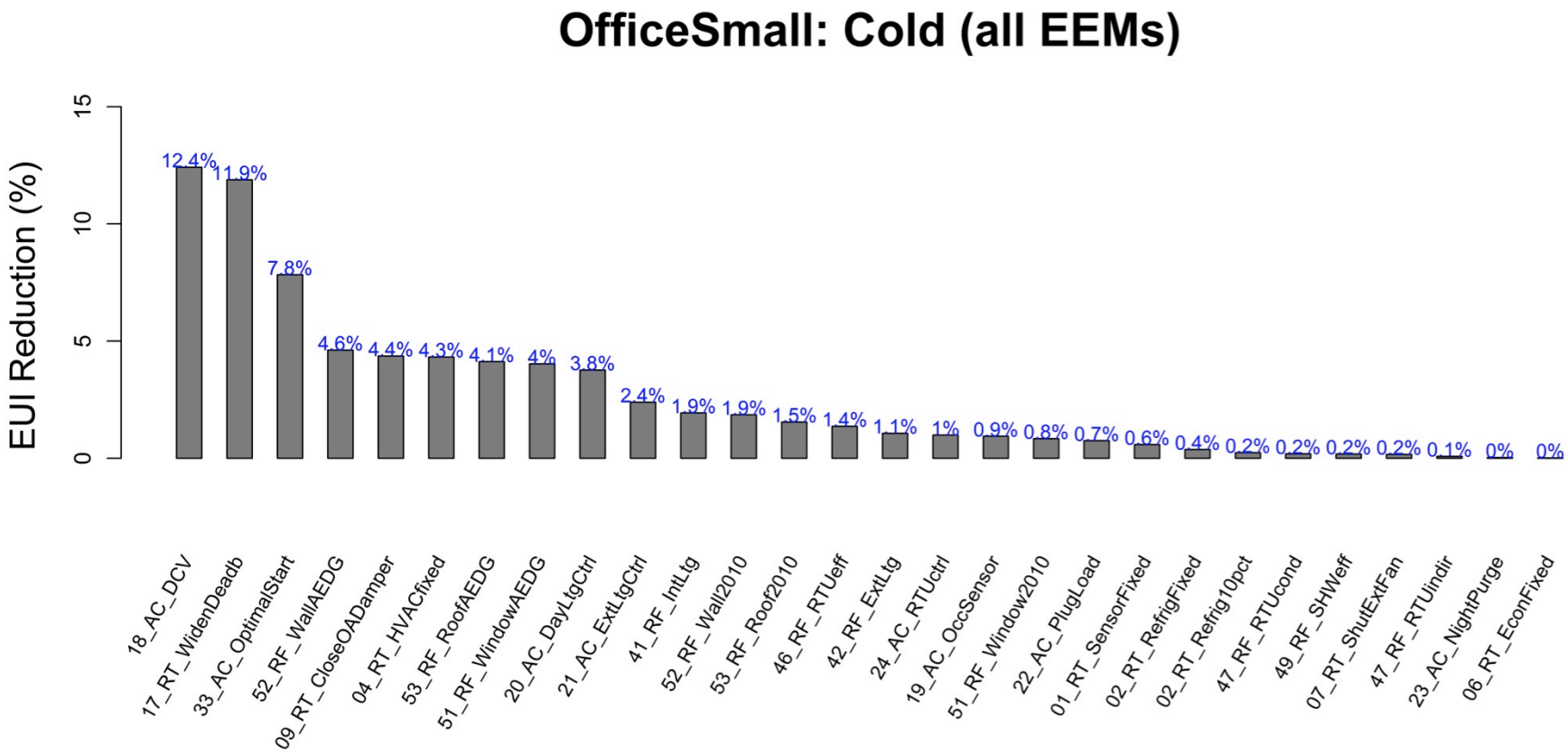
Savings from each Individual Measure: Small Office – Hot/Humid Climate



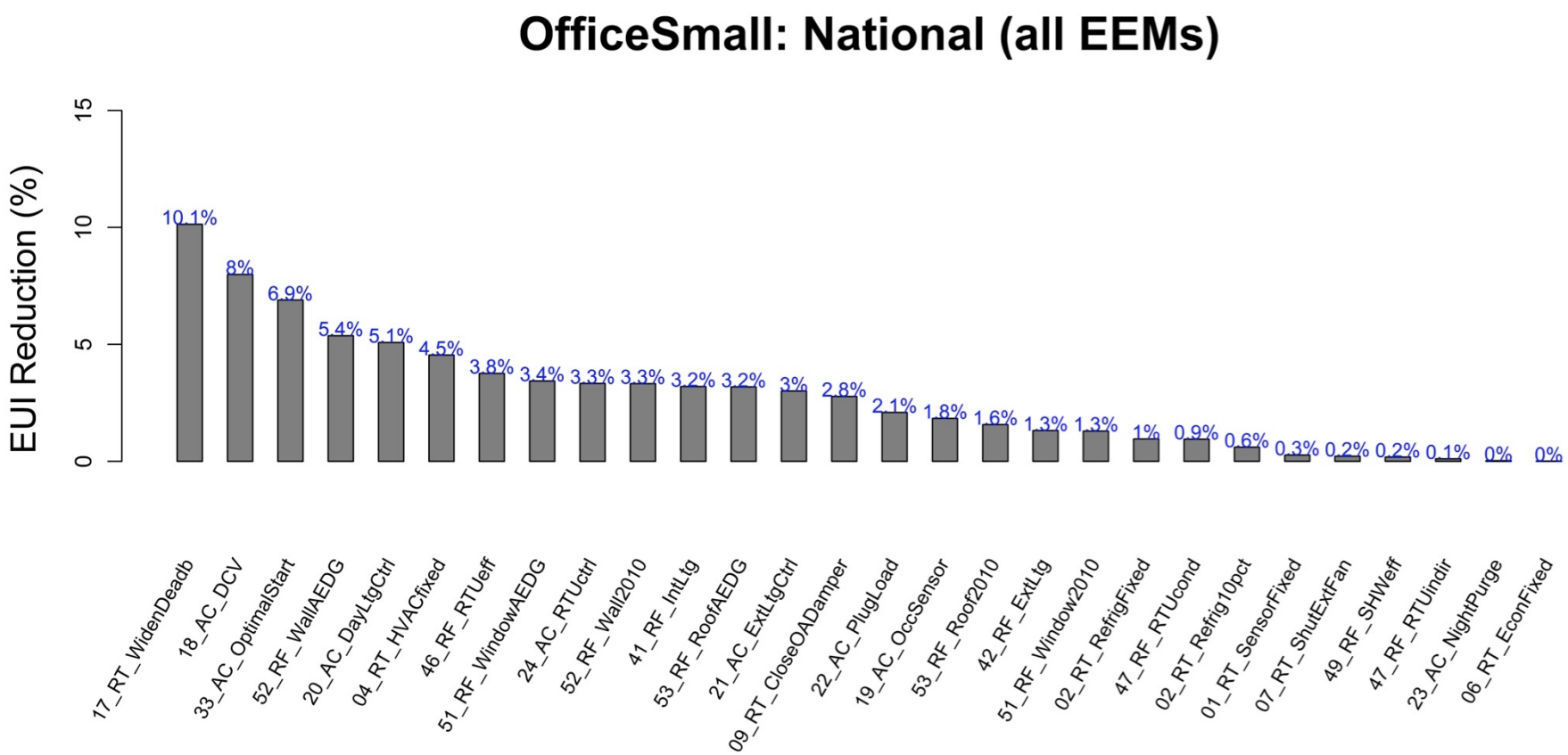
Savings from each Individual Measure: Small Office – Warm/Mixed Climate



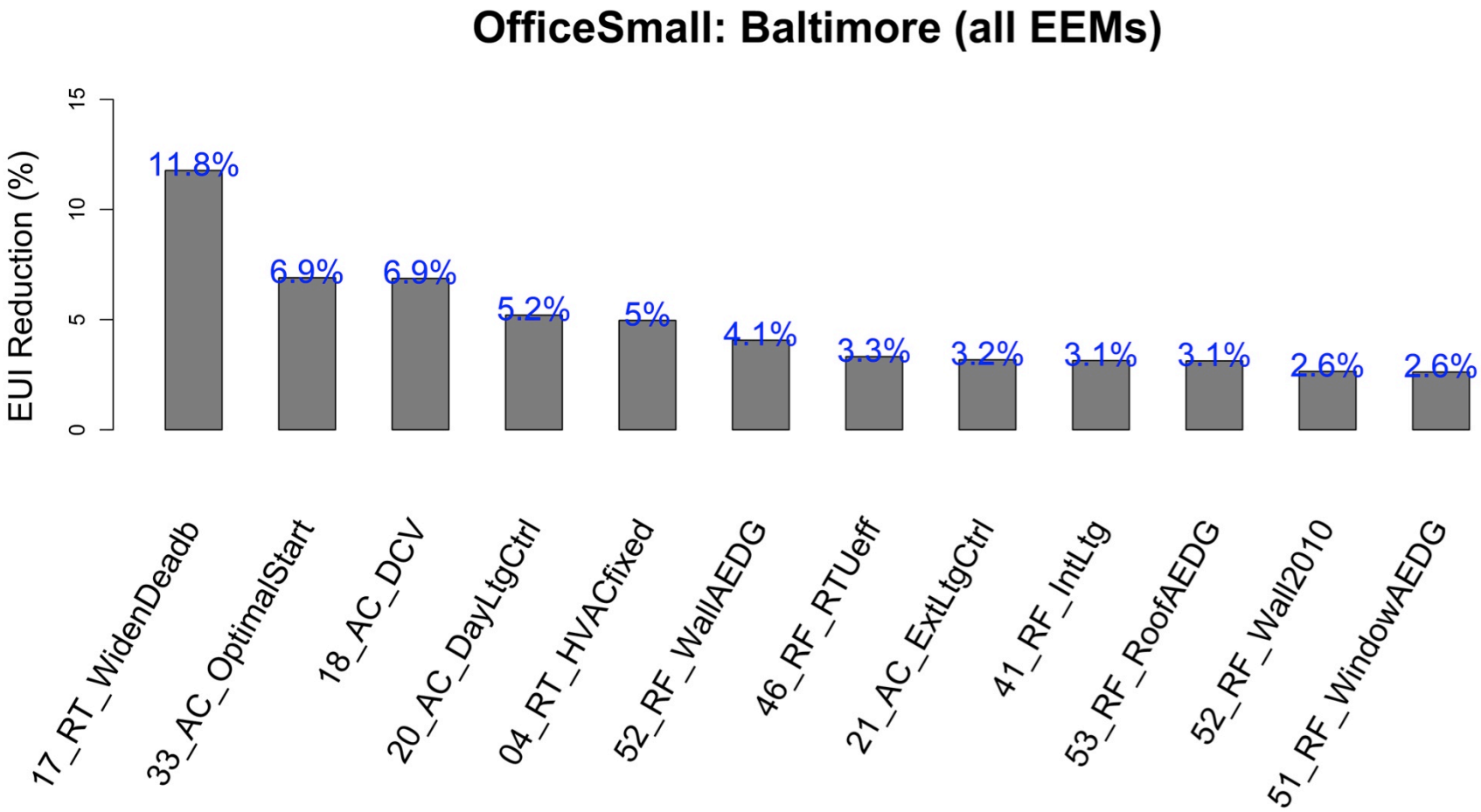
Savings from each Individual Measure: Small Office – Cold Climate



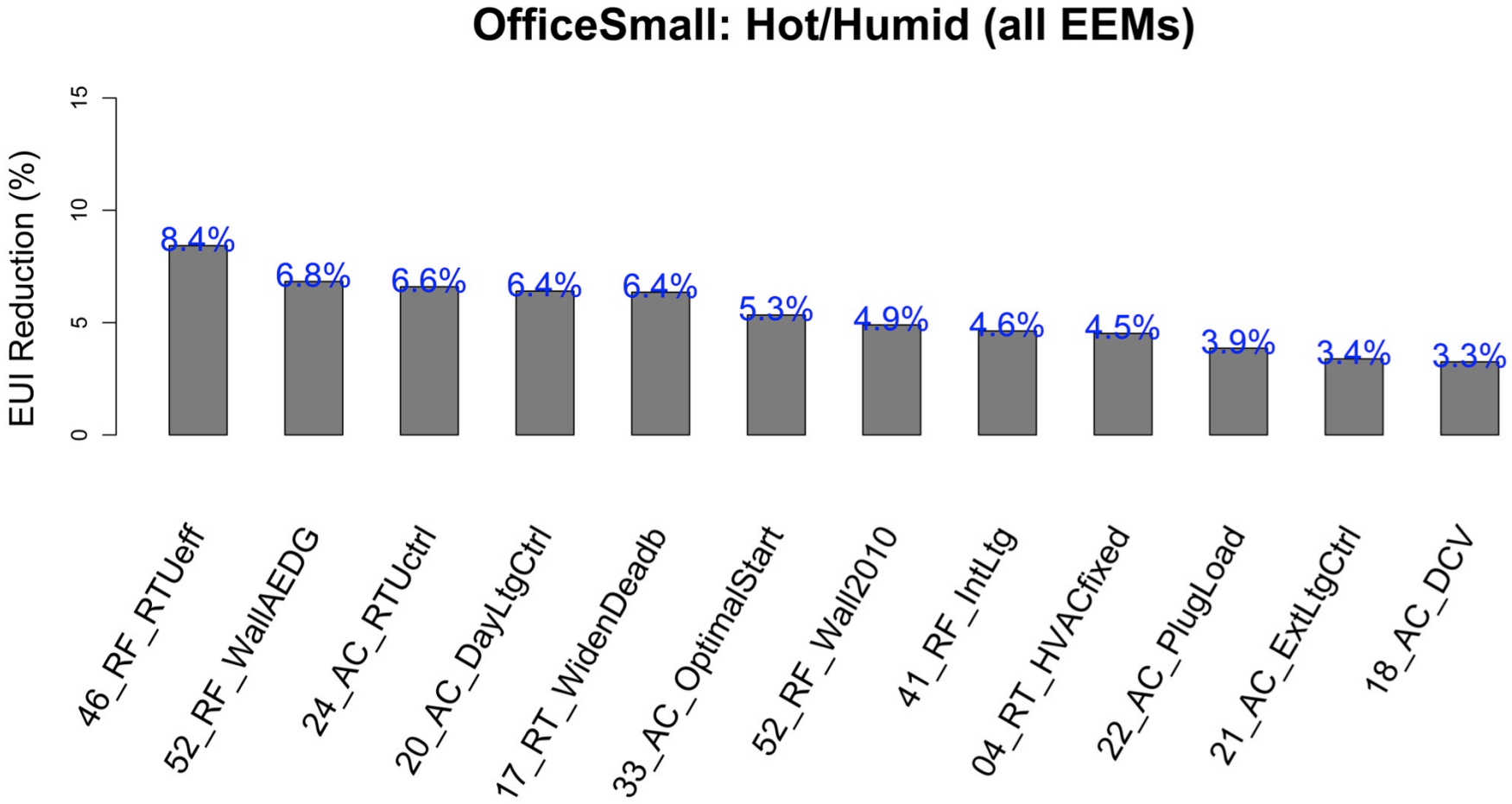
Savings from each Individual Measure: Small Office – National Climate



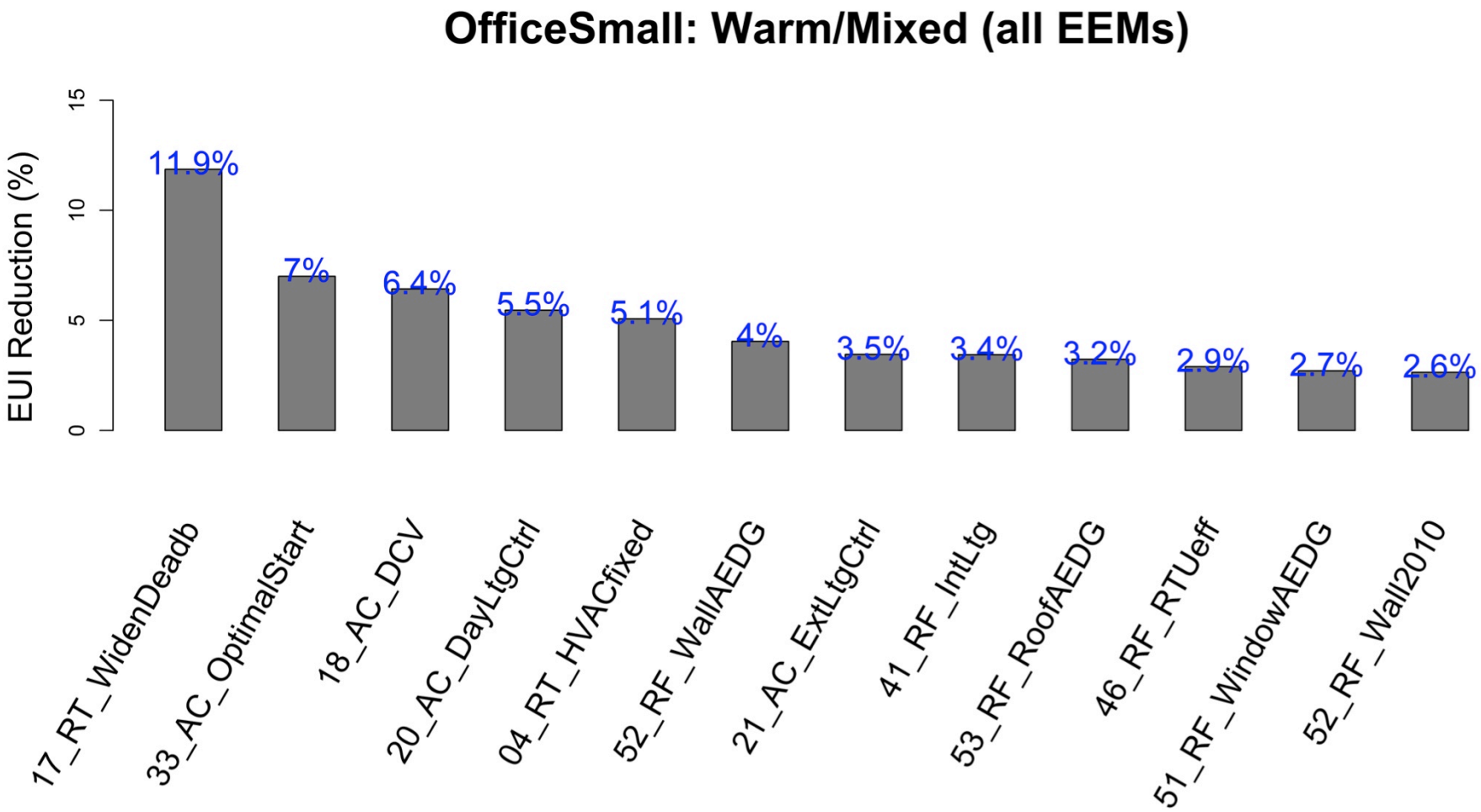
Savings from Top 12 Measures Across all Categories: Small Office – Baltimore



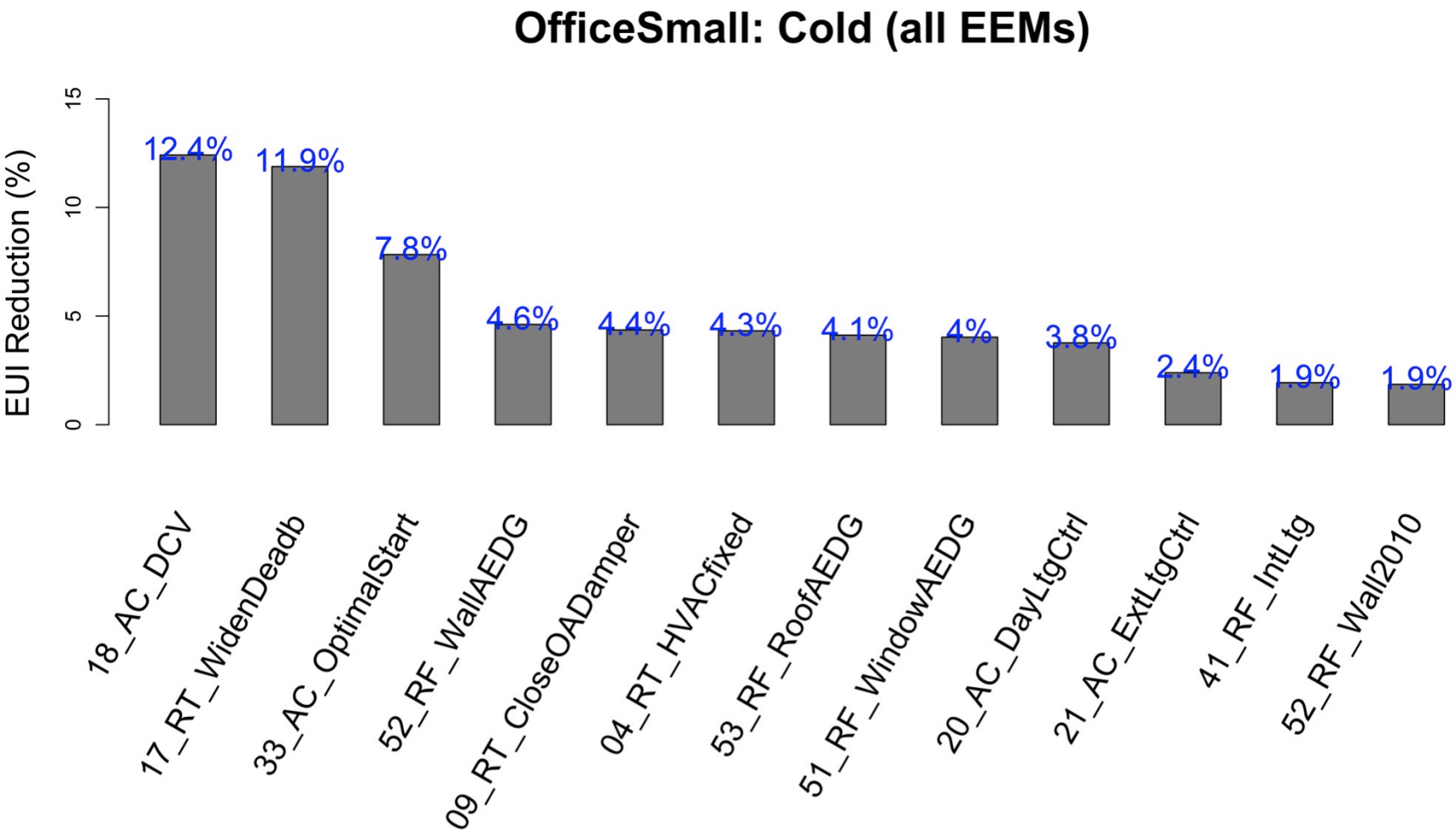
Savings from Top 12 Measures Across all Categories: Small Office – Hot/Humid Climate



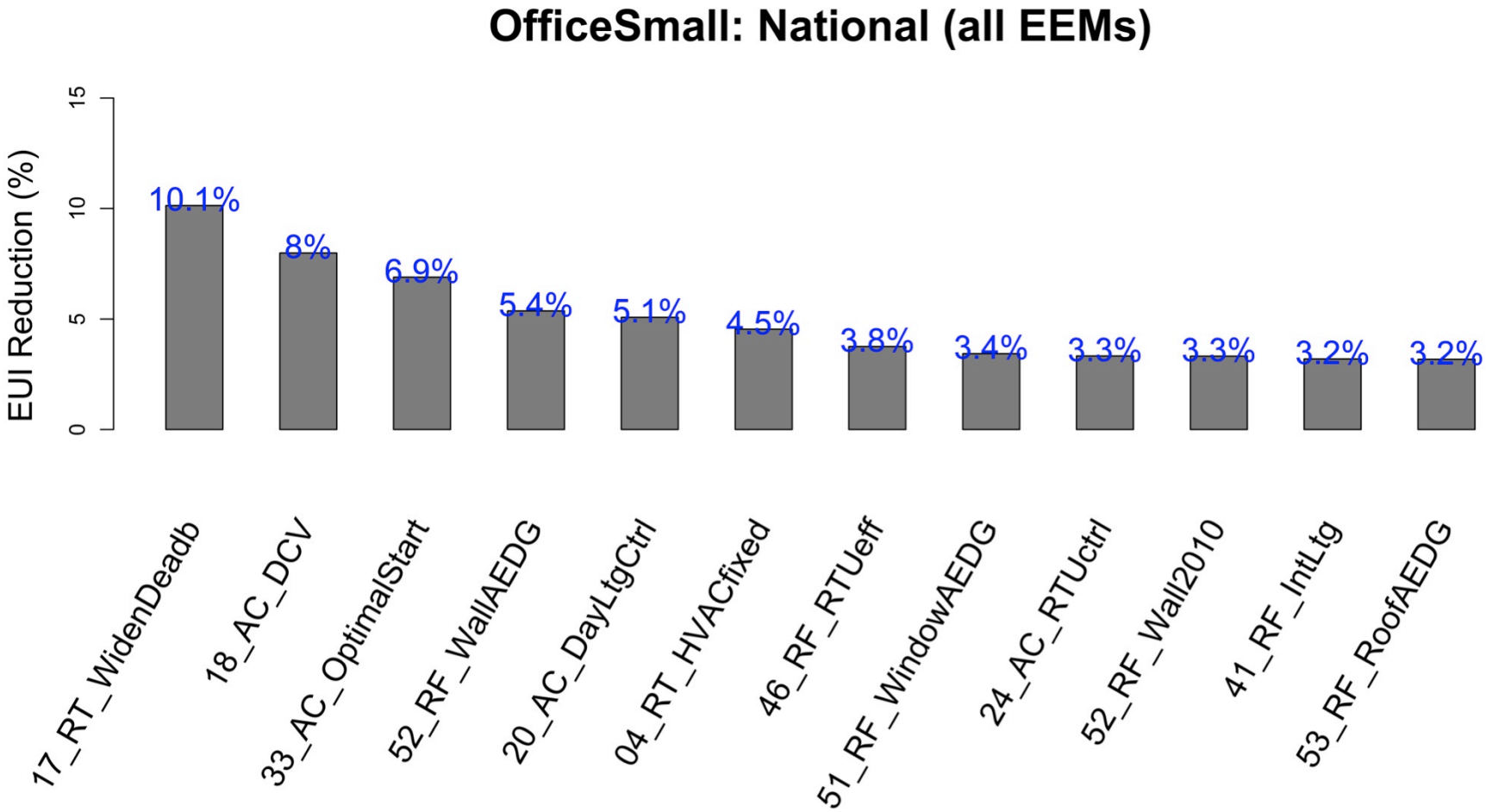
Savings from Top 12 Measures Across all Categories: Small Office – Warm/Mixed Climate



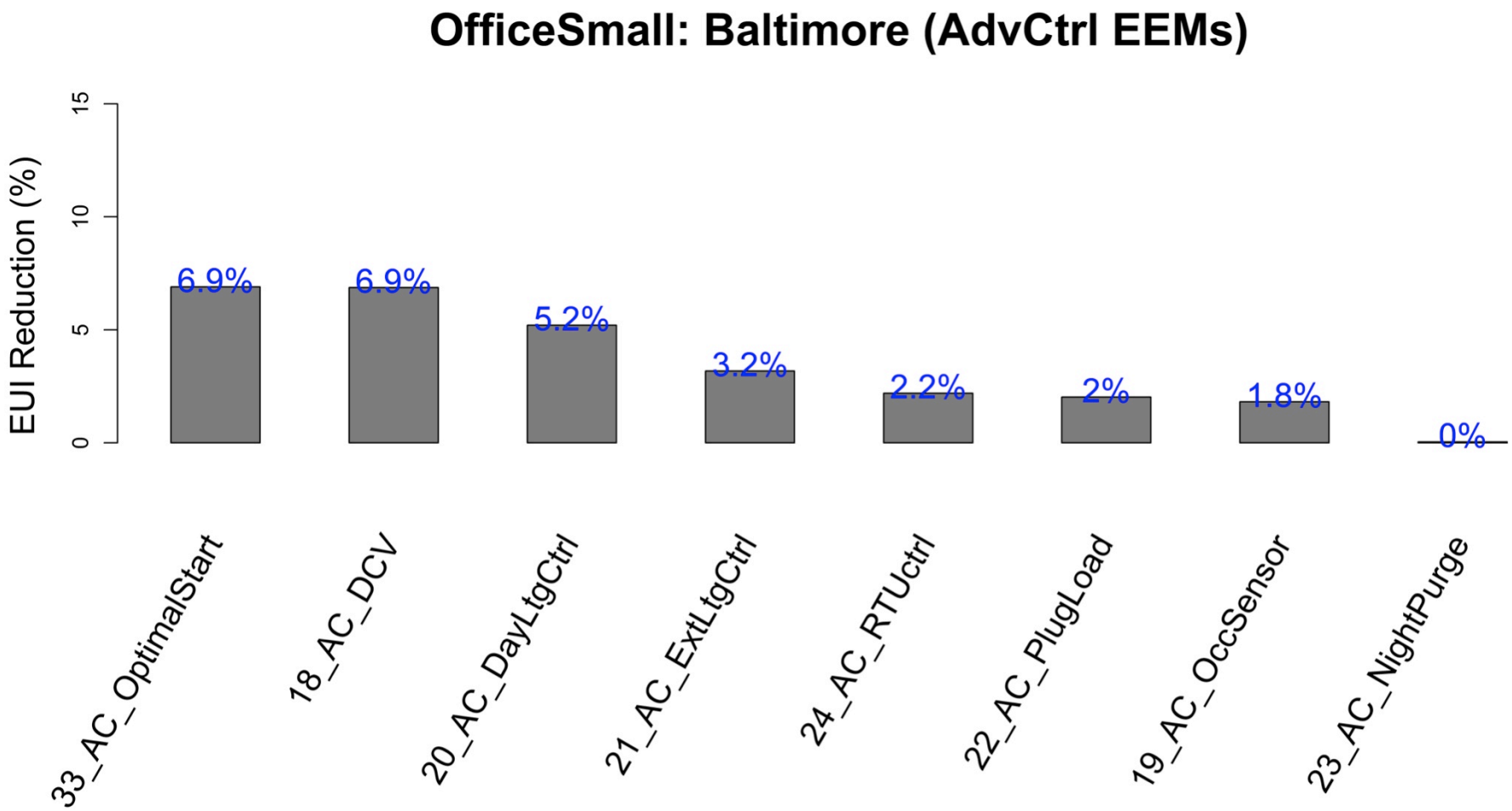
Savings from Top 12 Measures Across all Categories: Small Office – Cold Climate



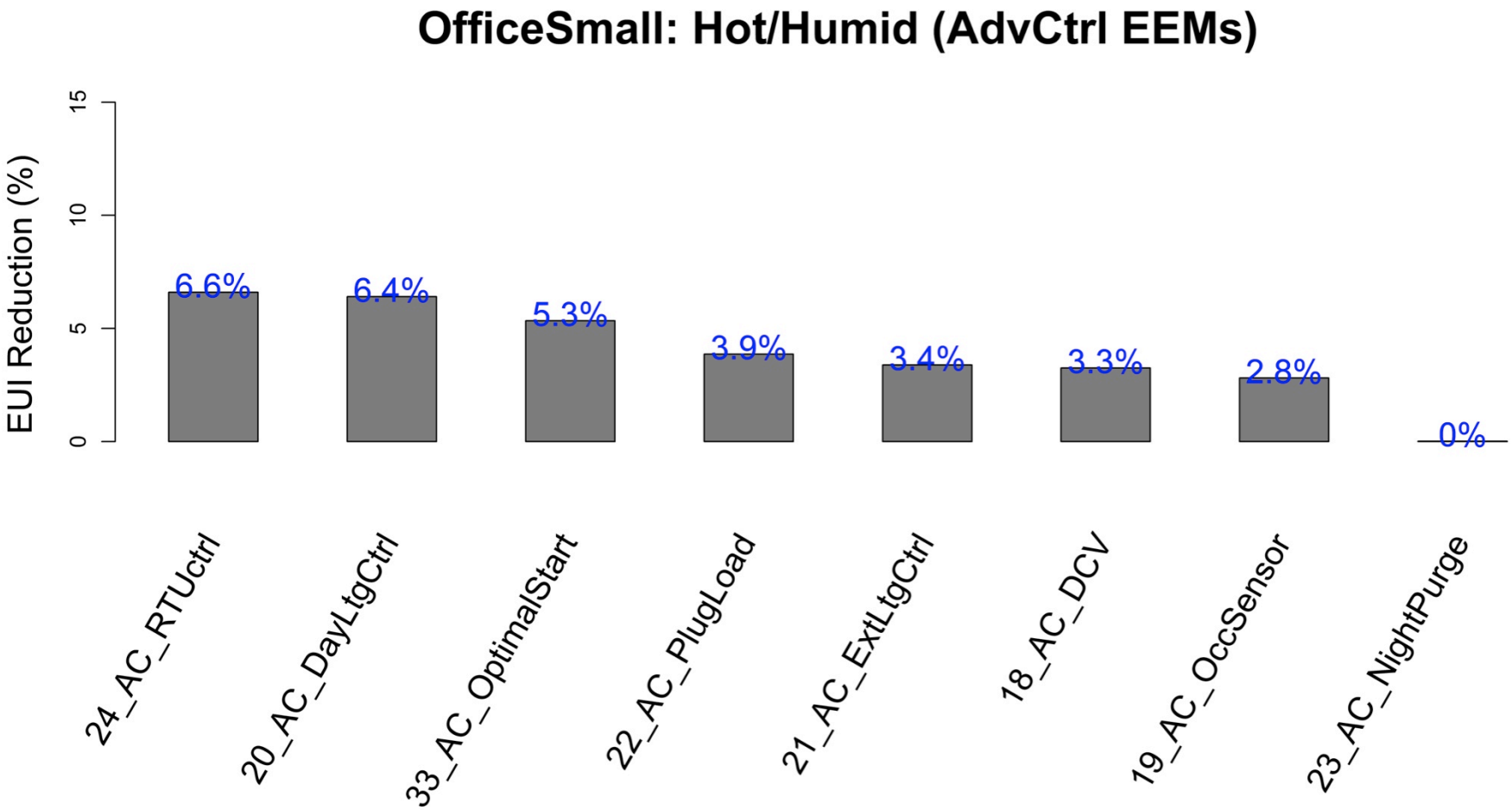
Savings from Top 12 Measures Across all Categories: Small Office – National Climate



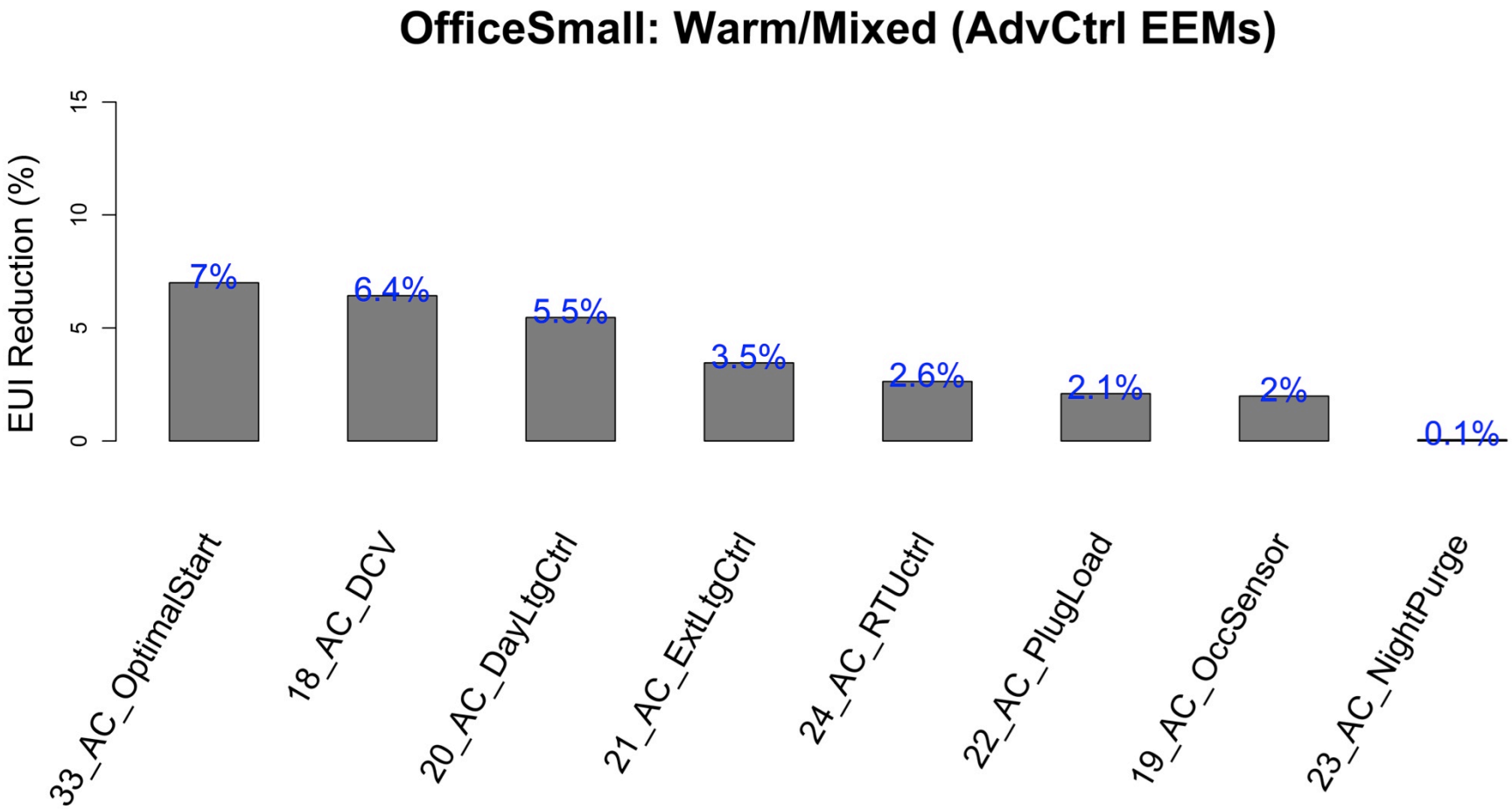
Savings from Top 12 Advanced Controls Measures: Small Office - Baltimore



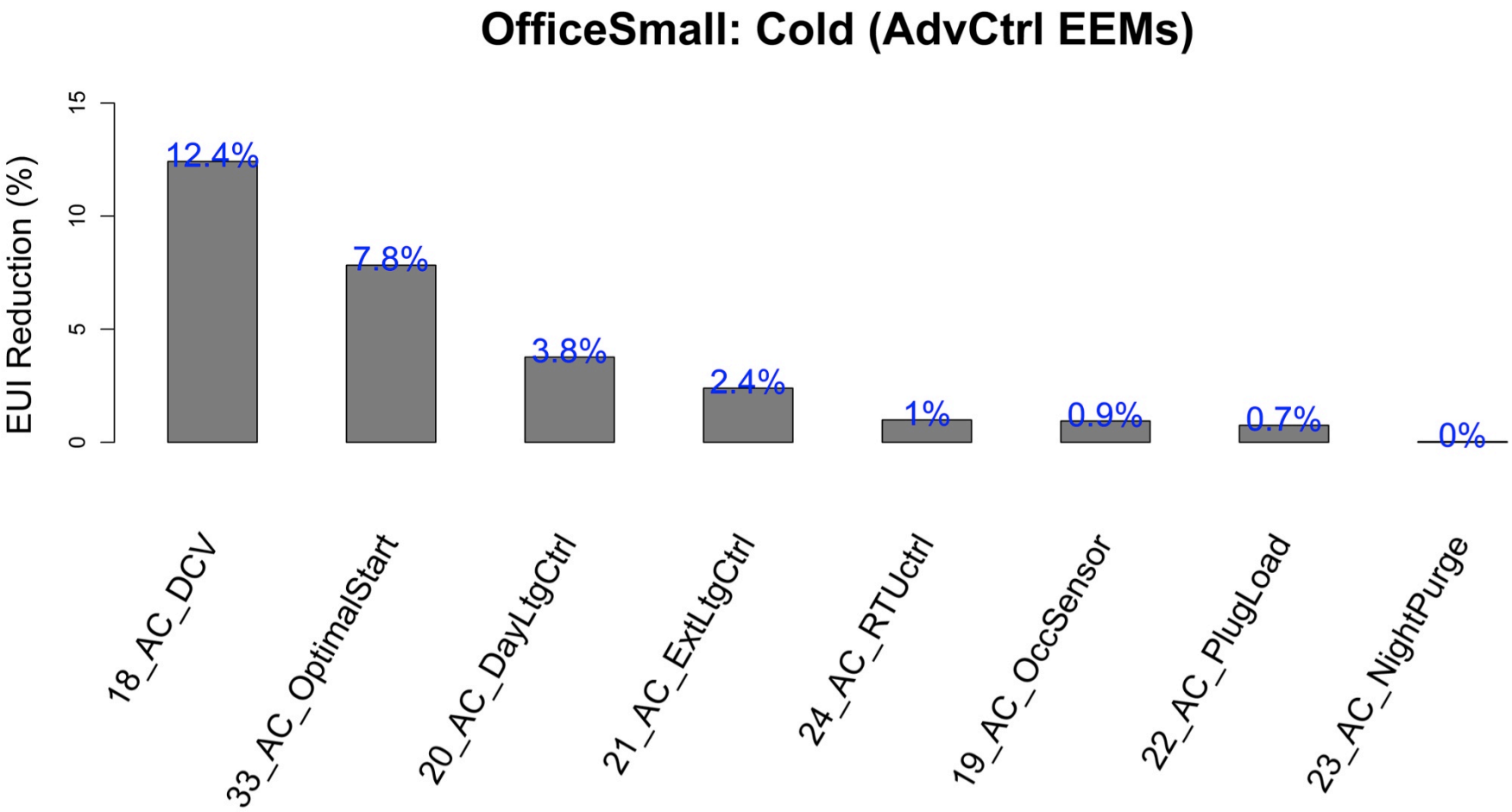
Savings from Top 12 Advanced Controls Measures: Small Office – Hot/Humid Climate



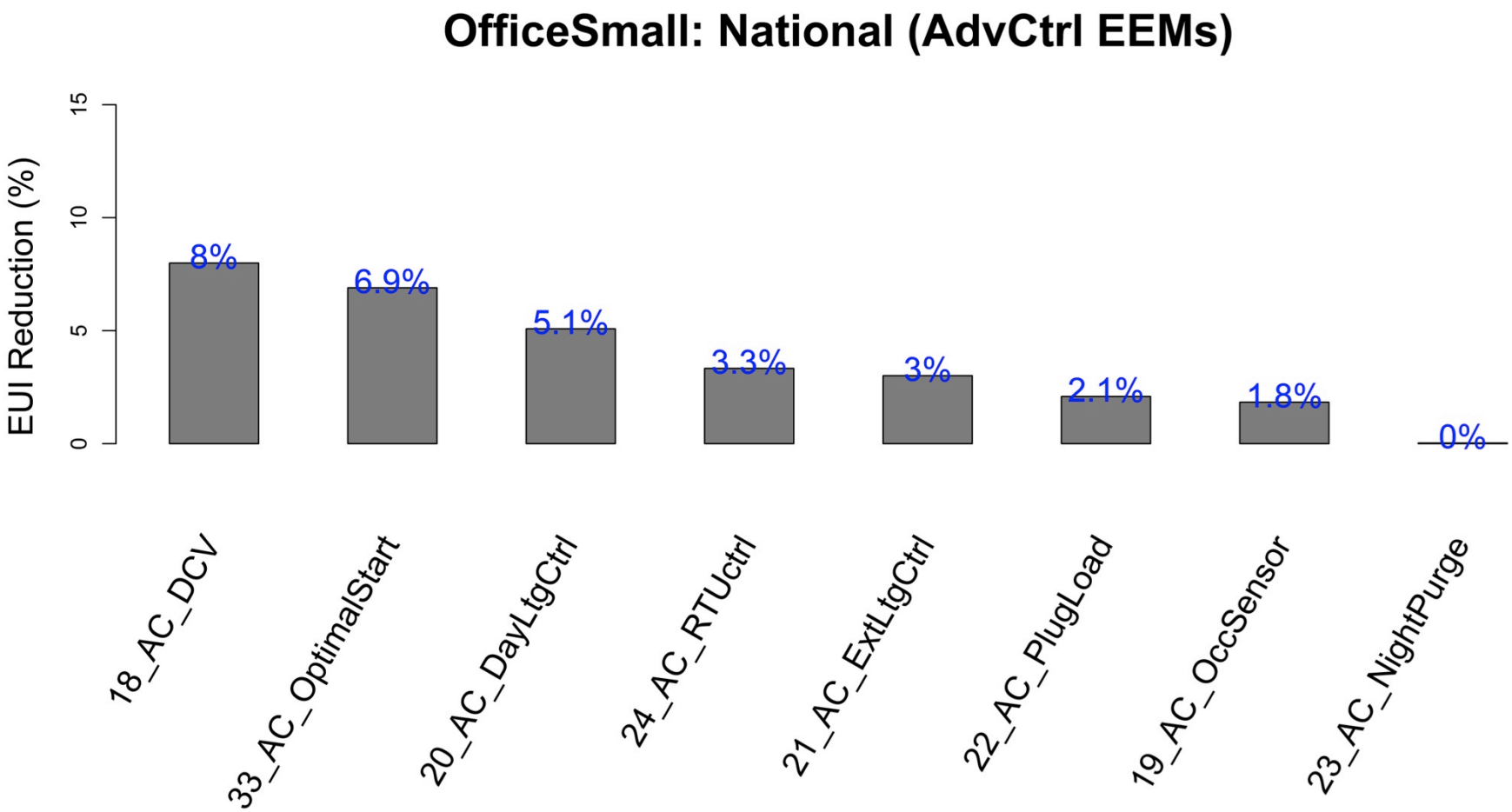
Savings from Top 12 Advanced Controls Measures: Small Office – Warm/Mixed Climate



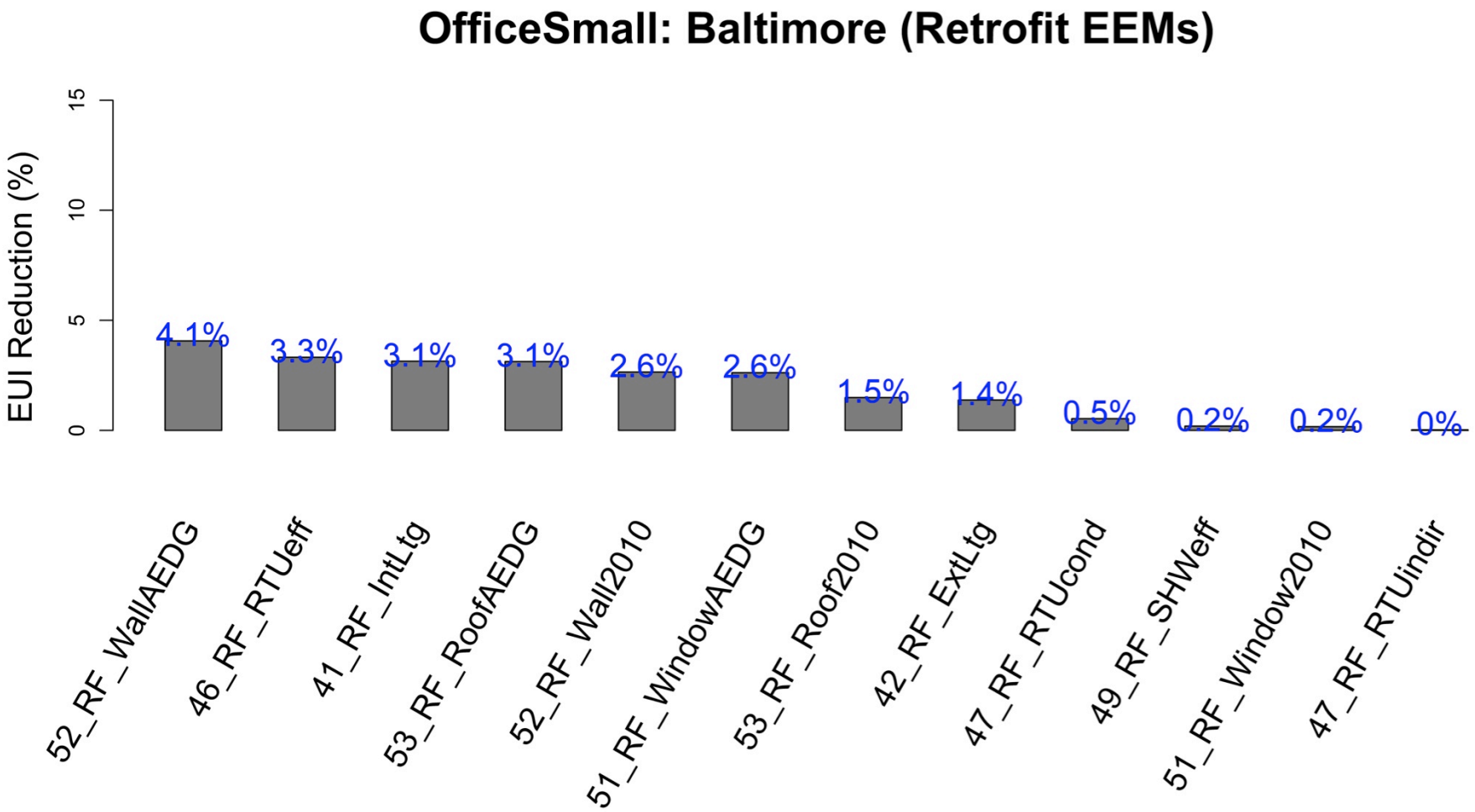
Savings from Top 12 Advanced Controls Measures: Small Office – Cold Climate



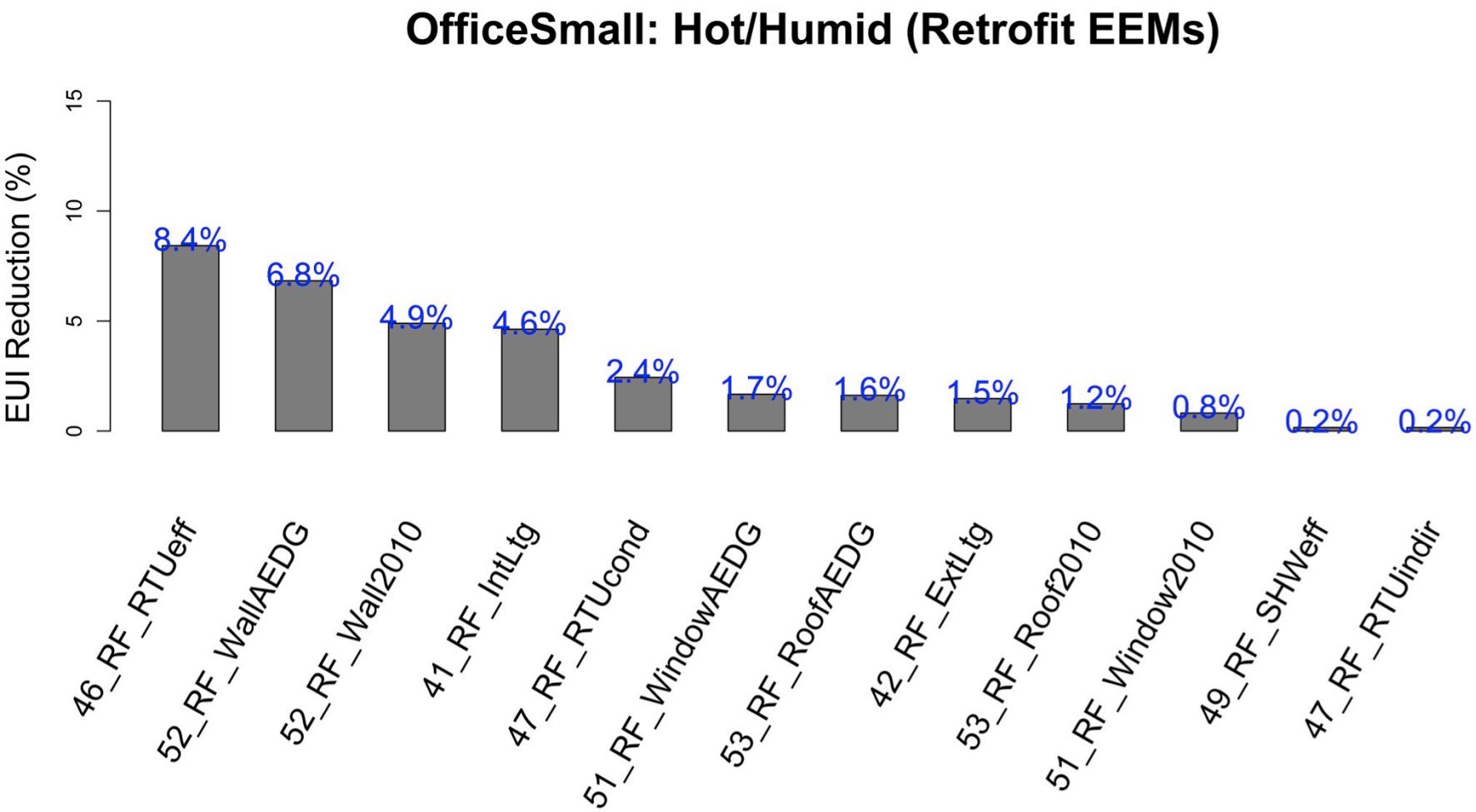
Savings from Top 12 Advanced Controls Measures: Small Office – National Climate



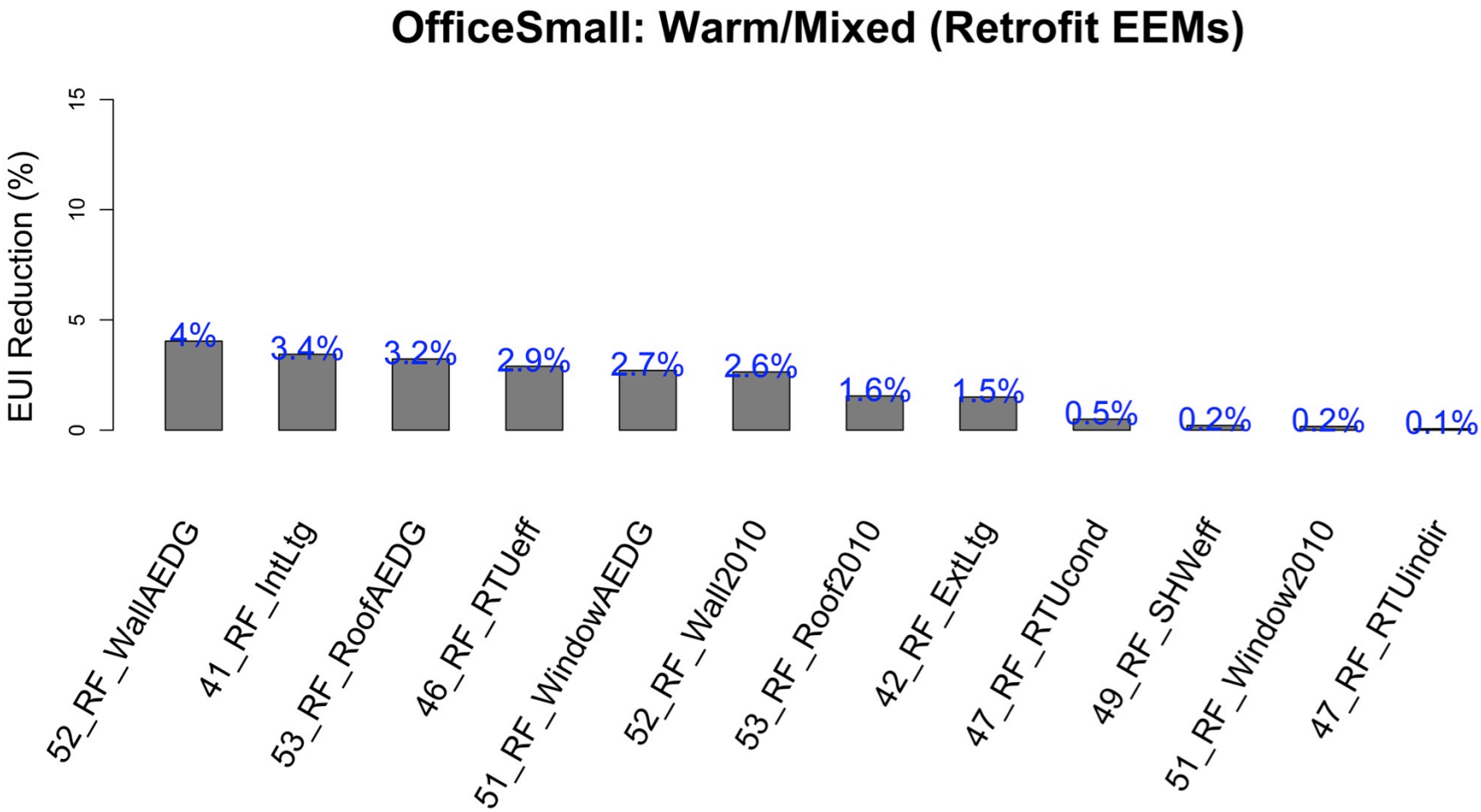
Savings from Top 12 Retrofit Measures: Small Office – Baltimore



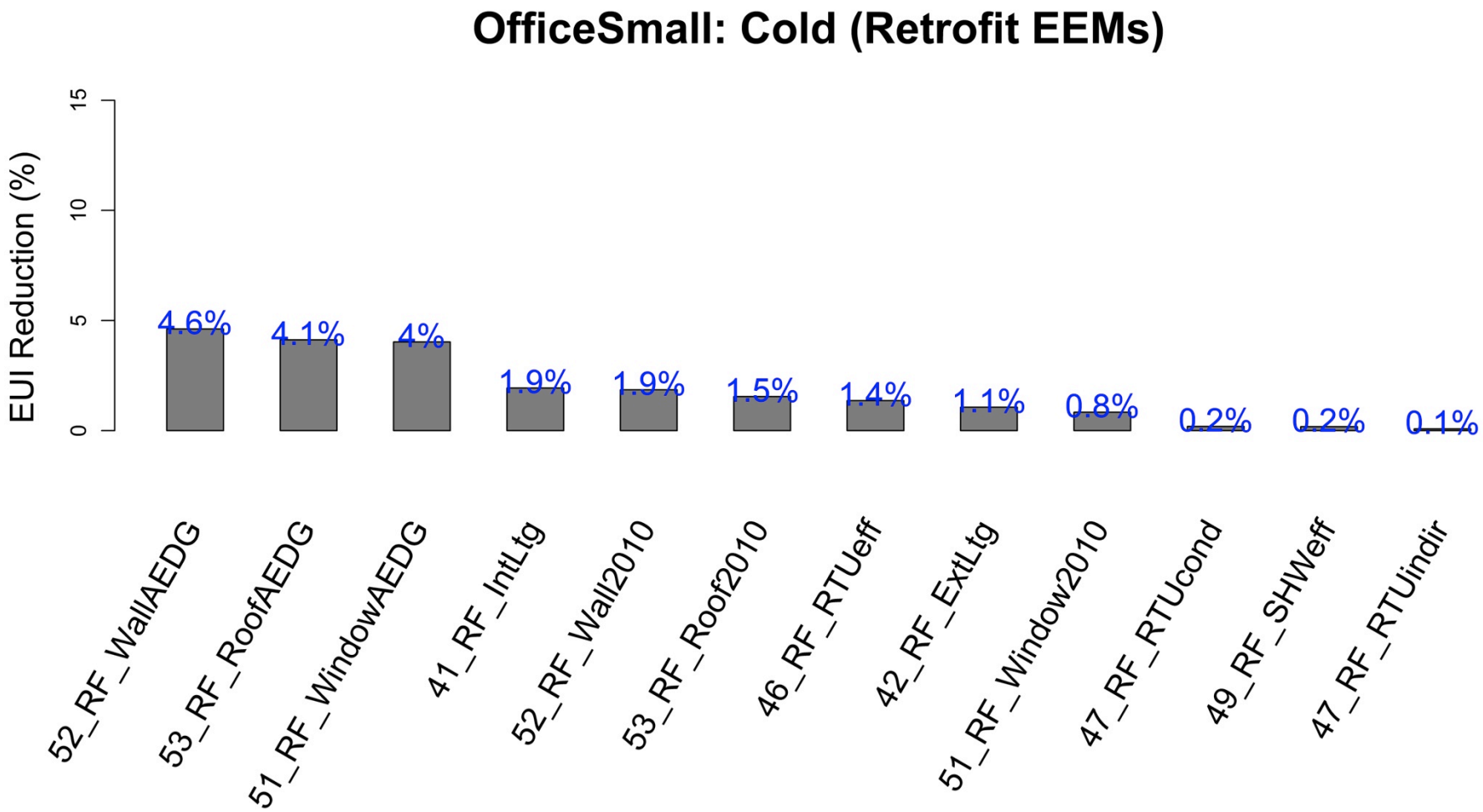
Savings from Top 12 Retrofit Measures: Small Office – Hot/Humid Climate



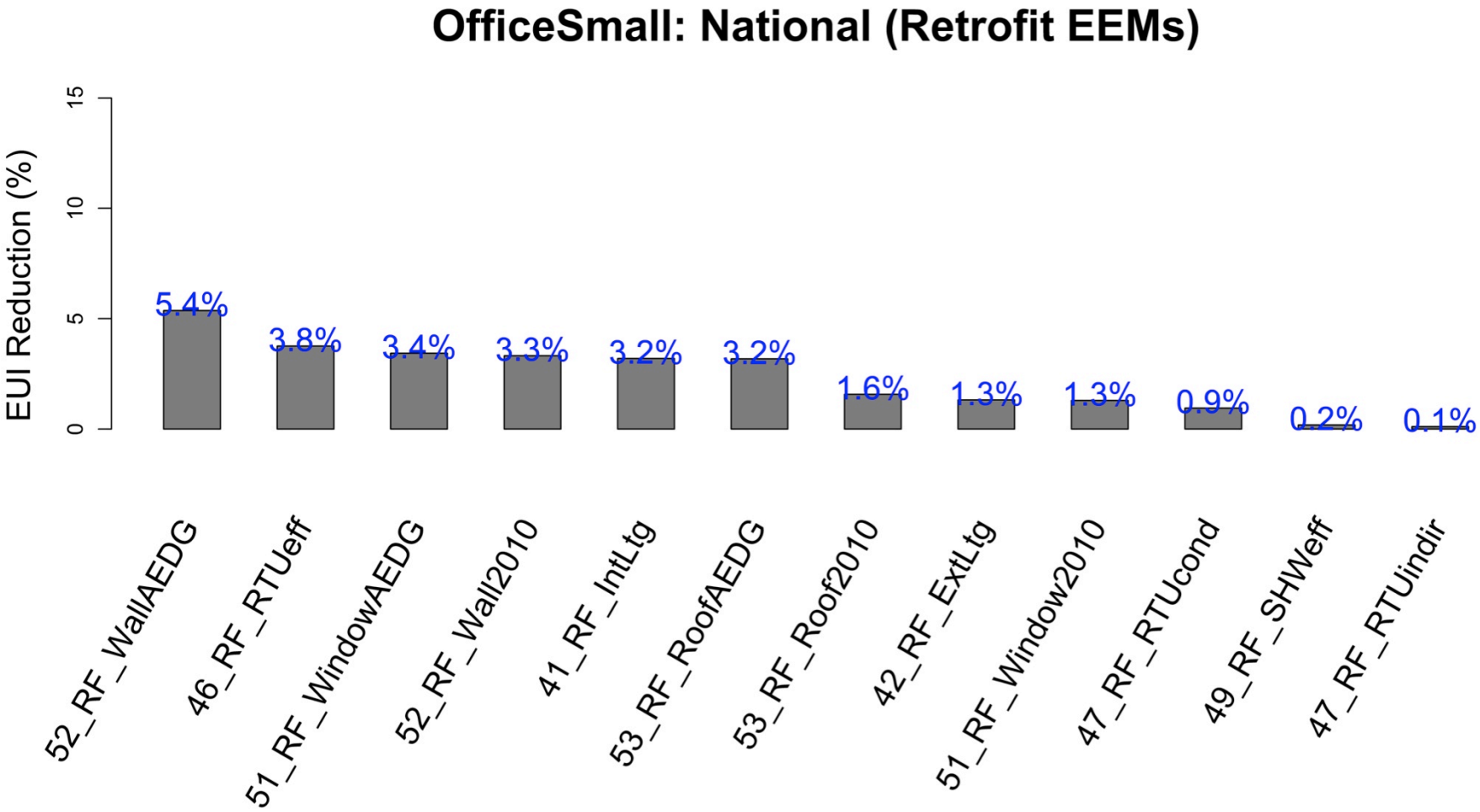
Savings from Top 12 Retrofit Measures: Small Office – Warm/Mixed Climate



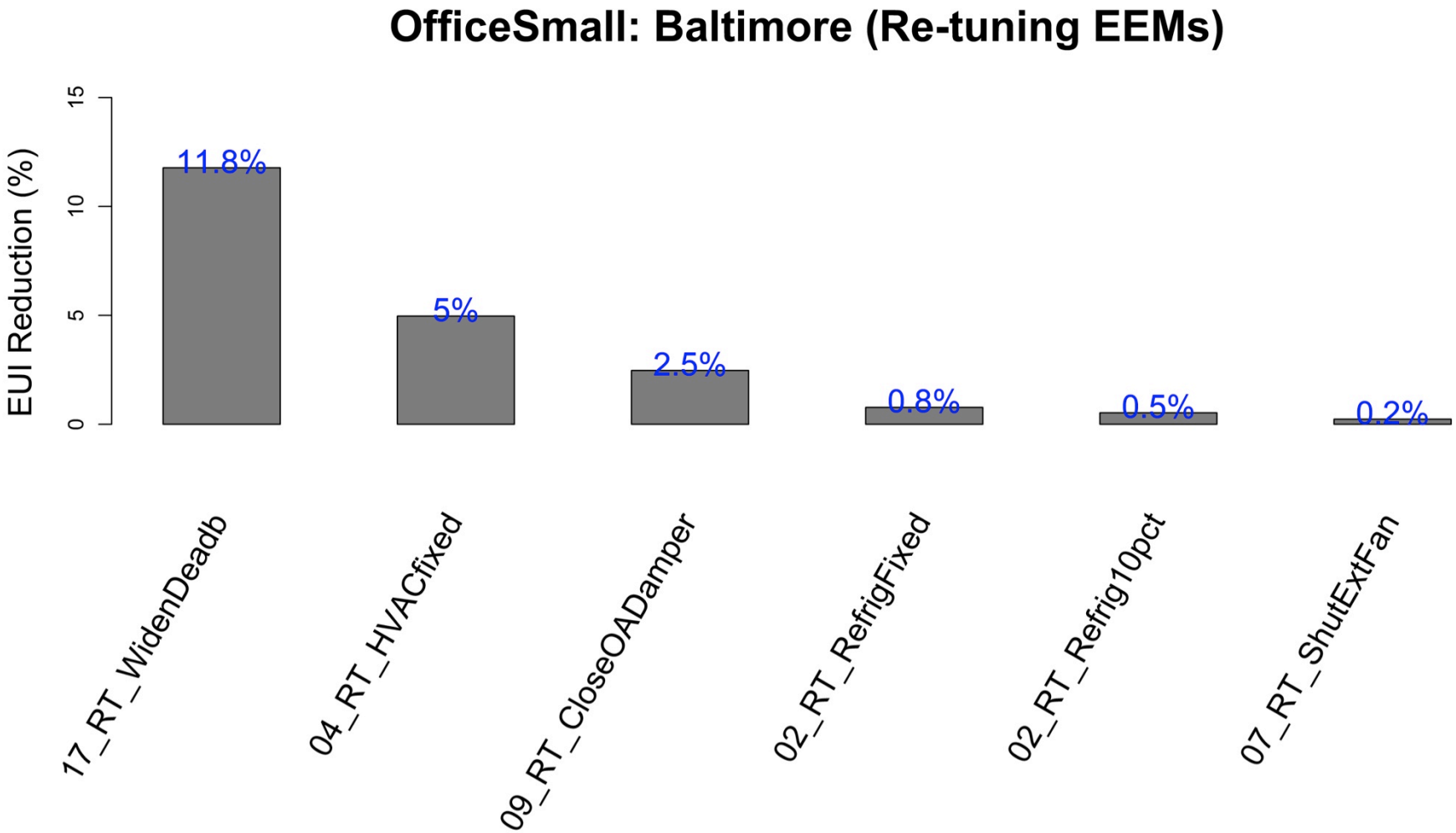
Savings from Top 12 Retrofit Measures: Small Office – Cold Climate



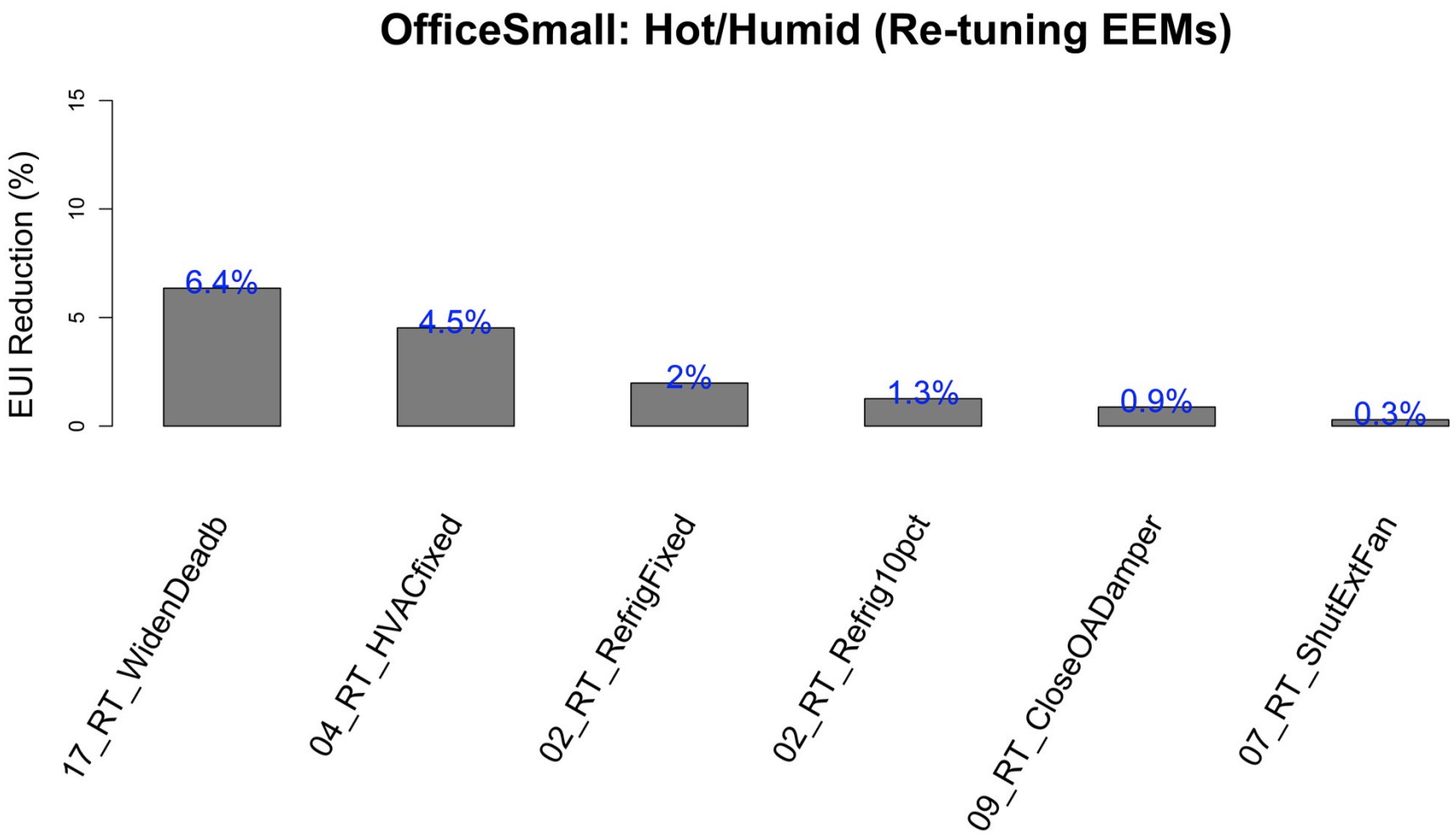
Savings from Top 12 Retrofit Measures: Small Office – National Climate



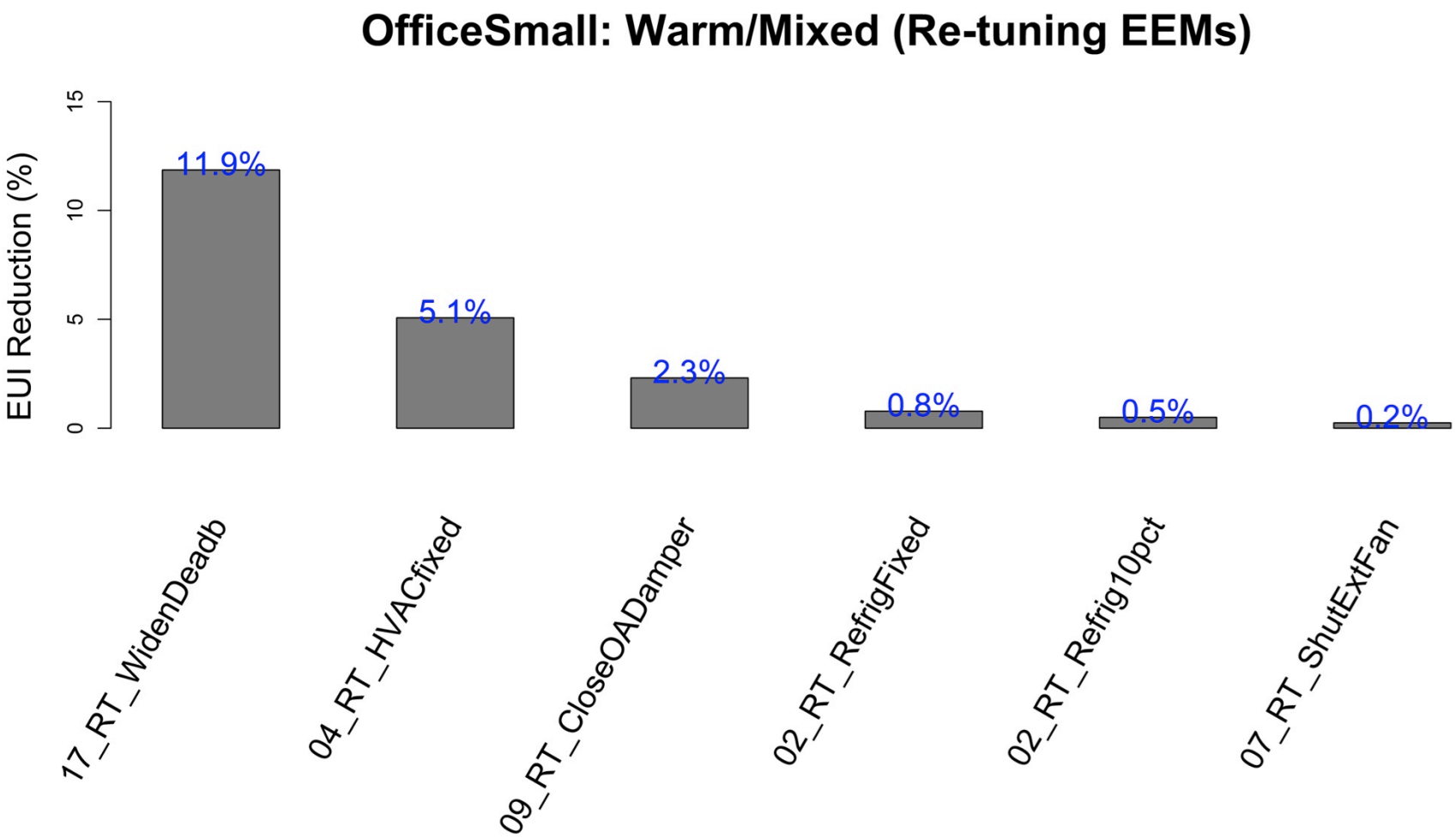
Savings from Top 12 Re-tuning Measures: Small Office – Baltimore



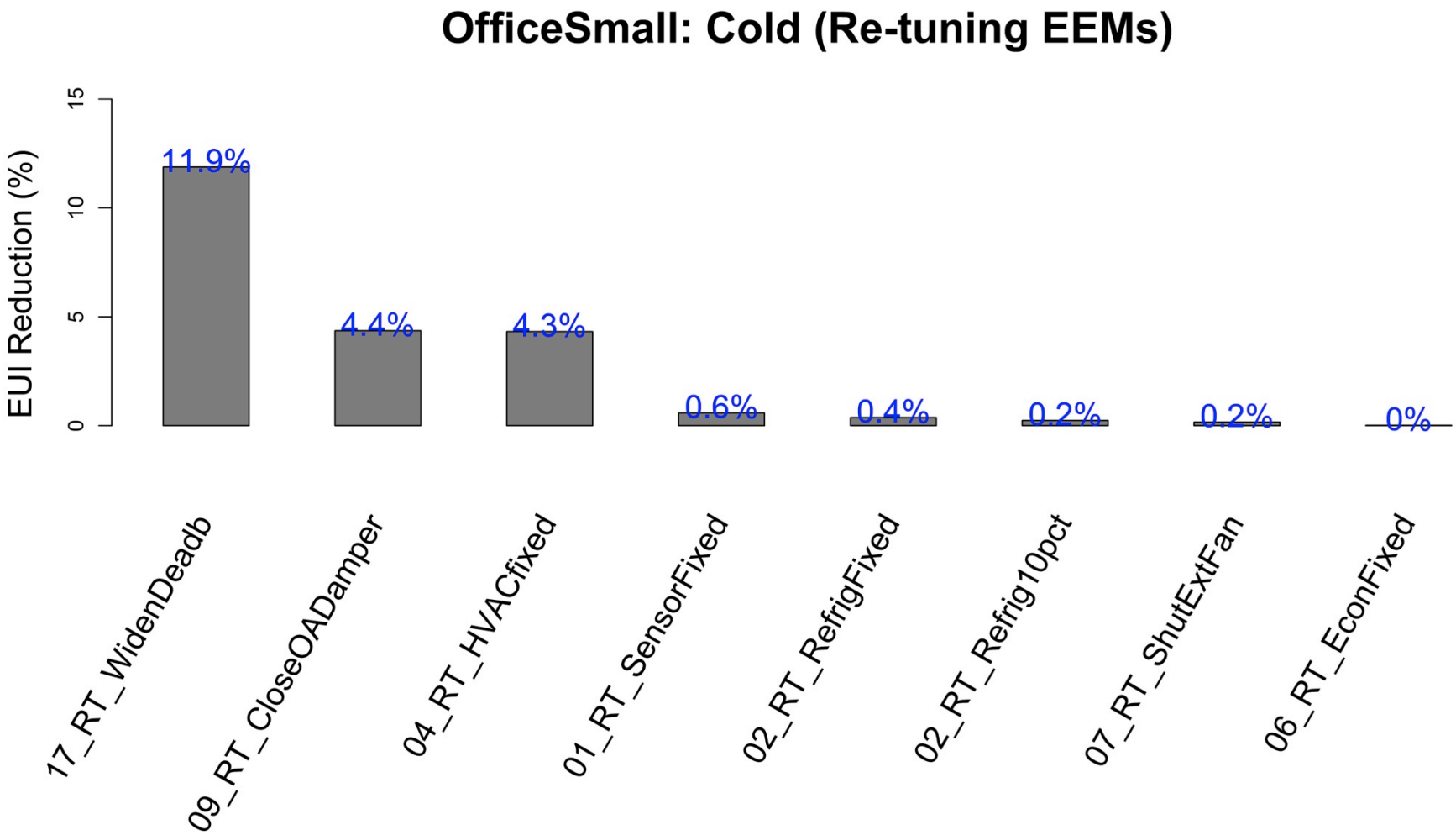
Savings from Top 12 Re-tuning Measures: Small Office – Hot/Humid Climate



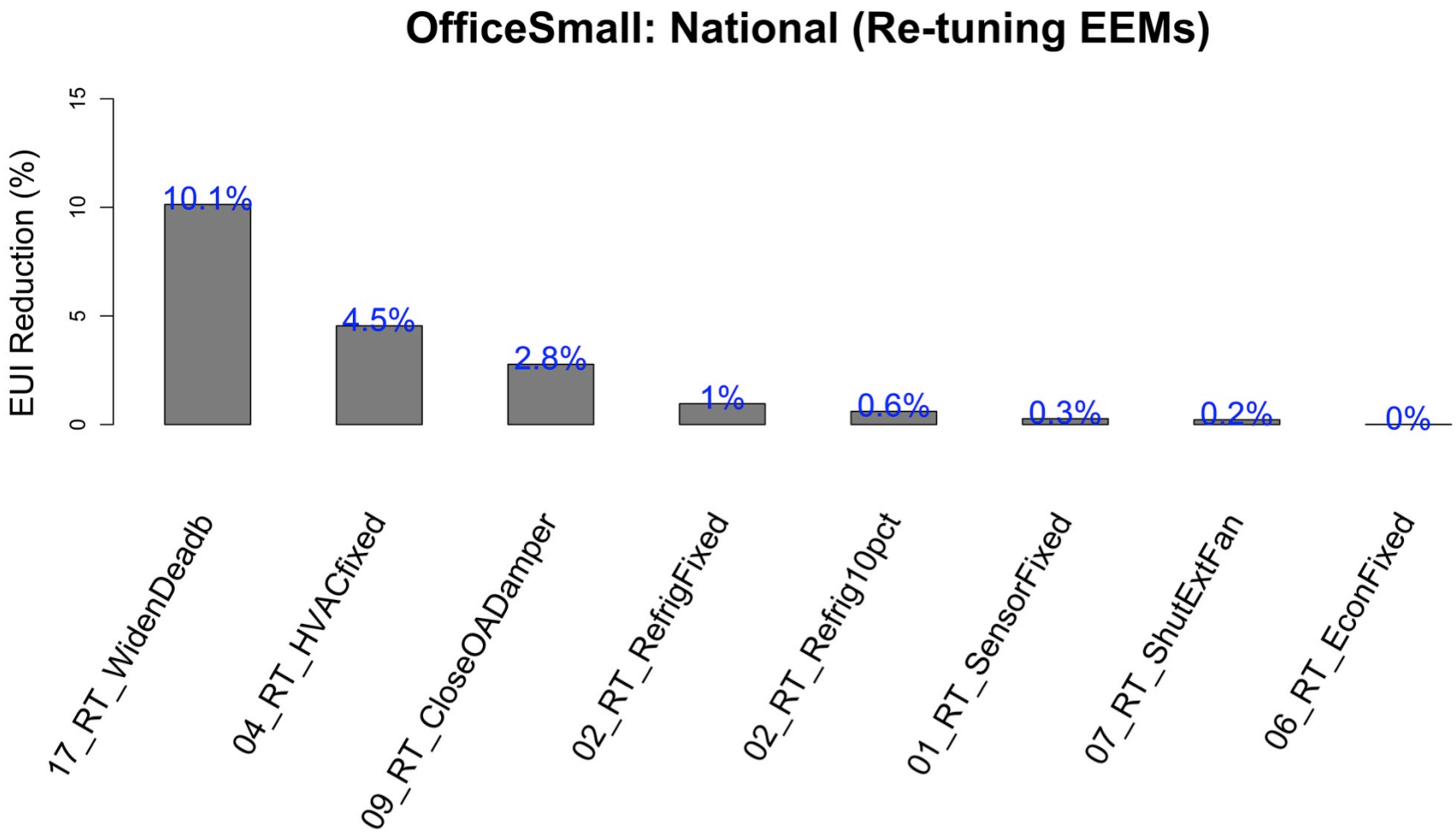
Savings from Top 12 Re-tuning Measures: Small Office – Warm/Mixed Climate



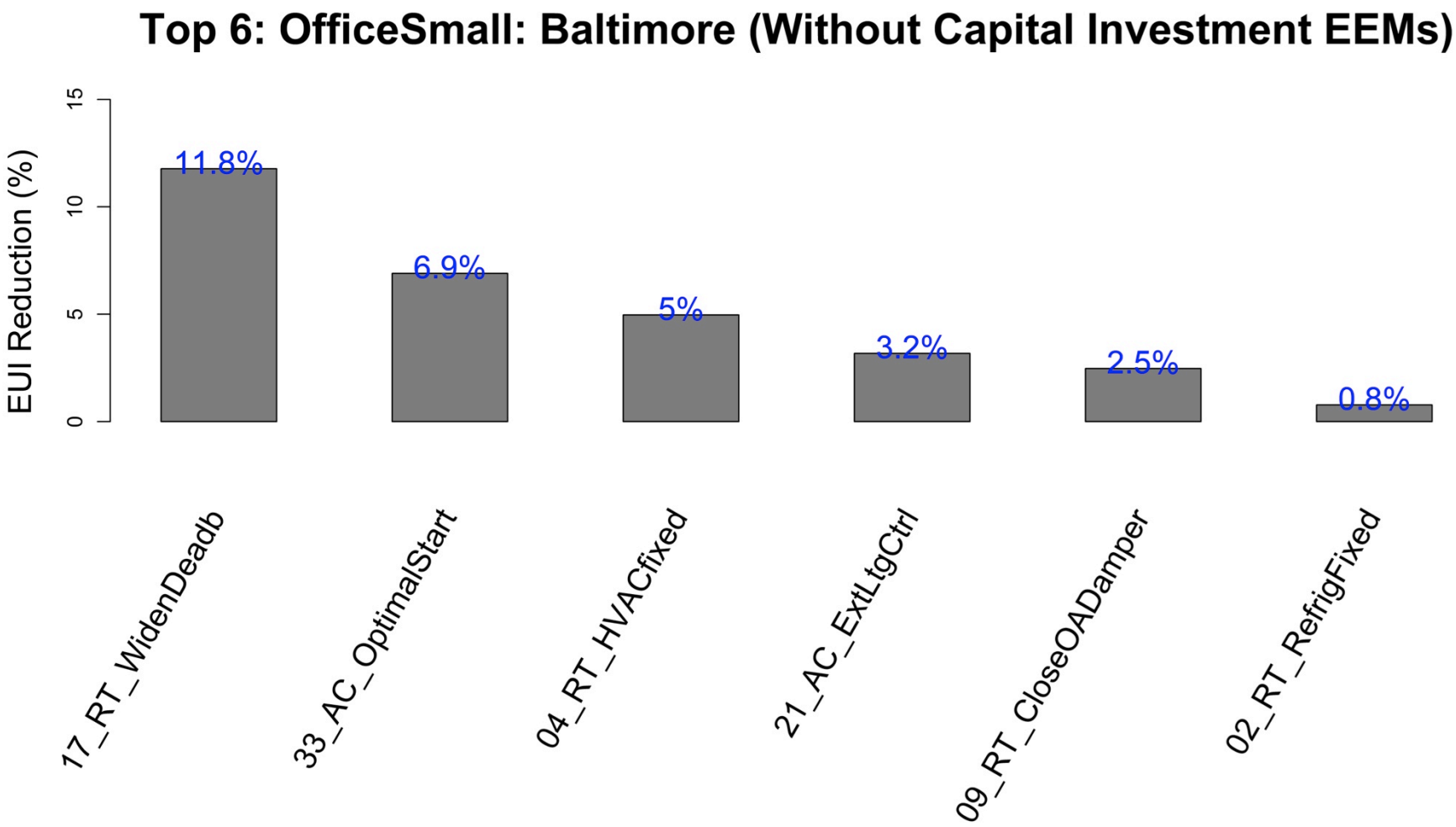
Savings from Top 12 Re-tuning Measures: Small Office – Cold Climate



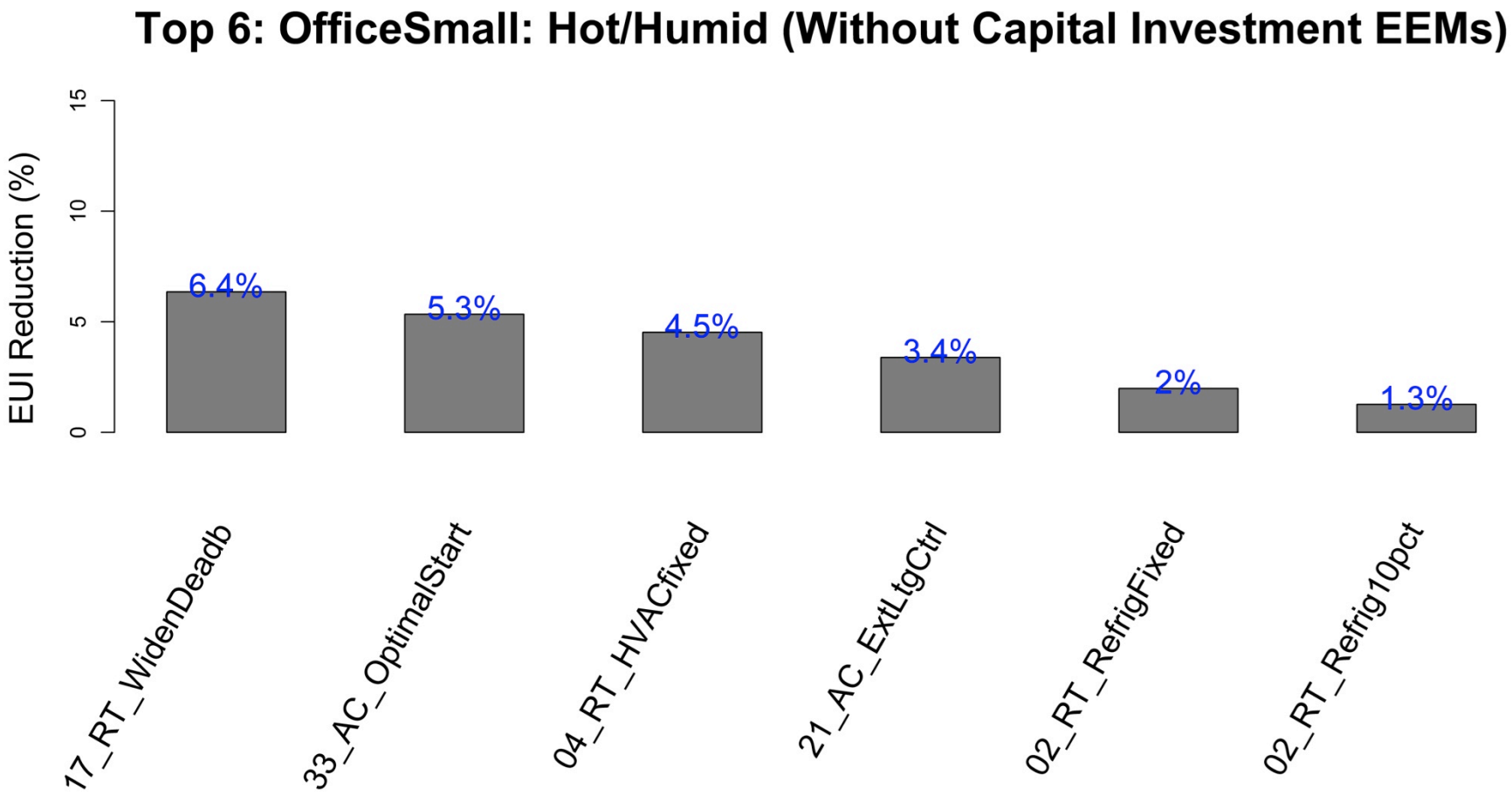
Savings from Top 12 Re-tuning Measures: Small Office – National Climate



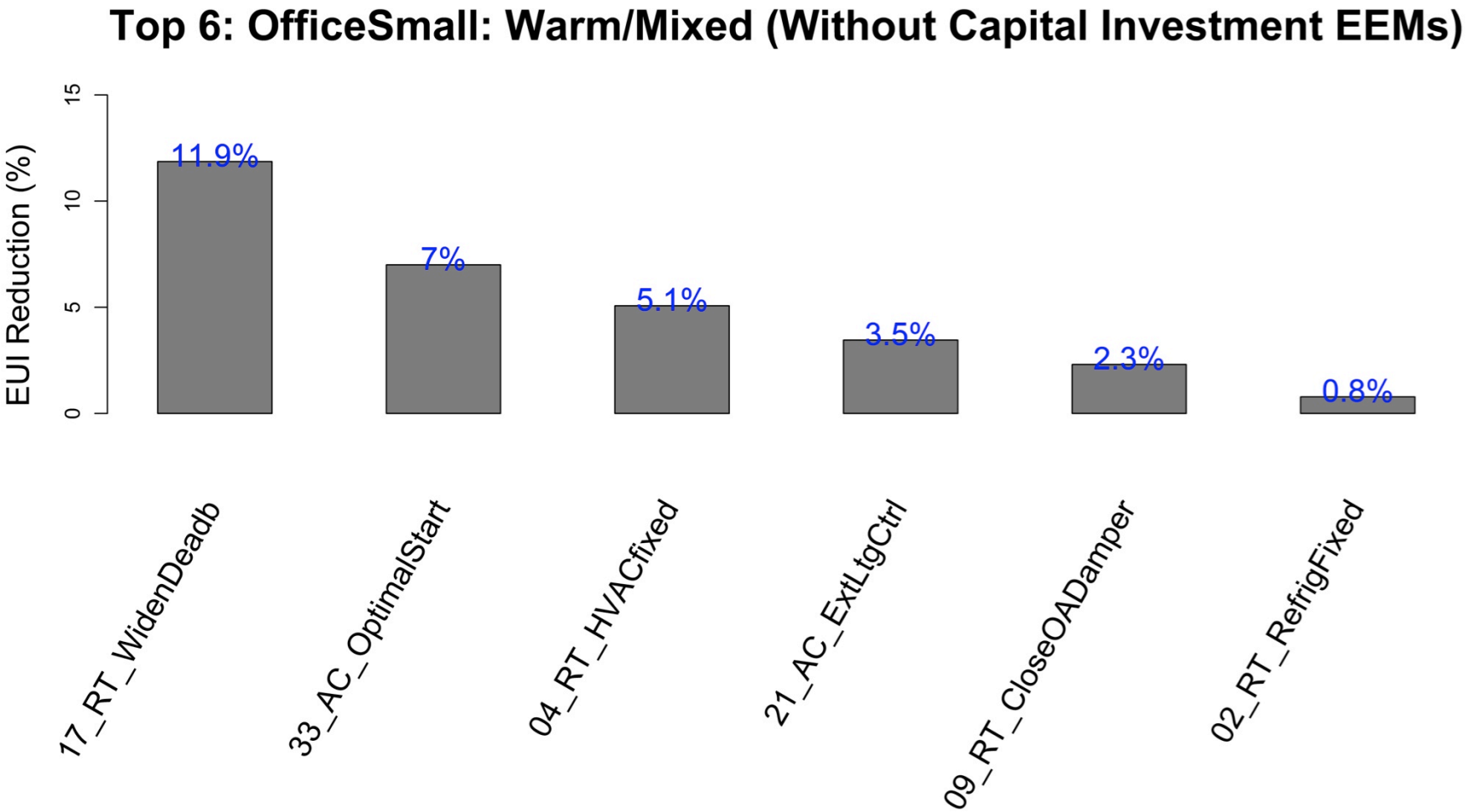
Savings from Top 6 No-Cost Measures: Small Office – Baltimore



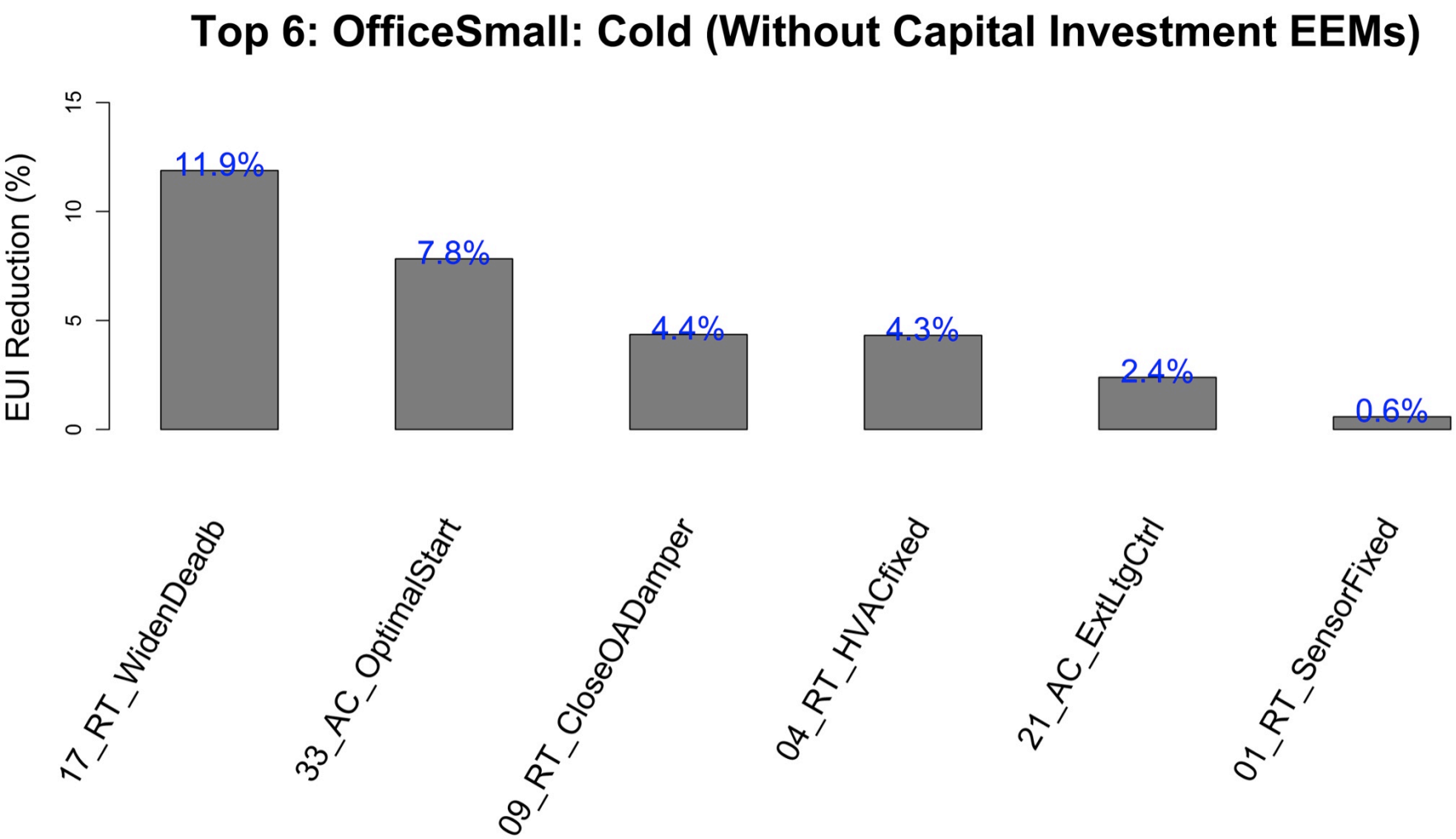
Savings from Top 6 No-Cost Measures: Small Office – Hot/Humid Climate



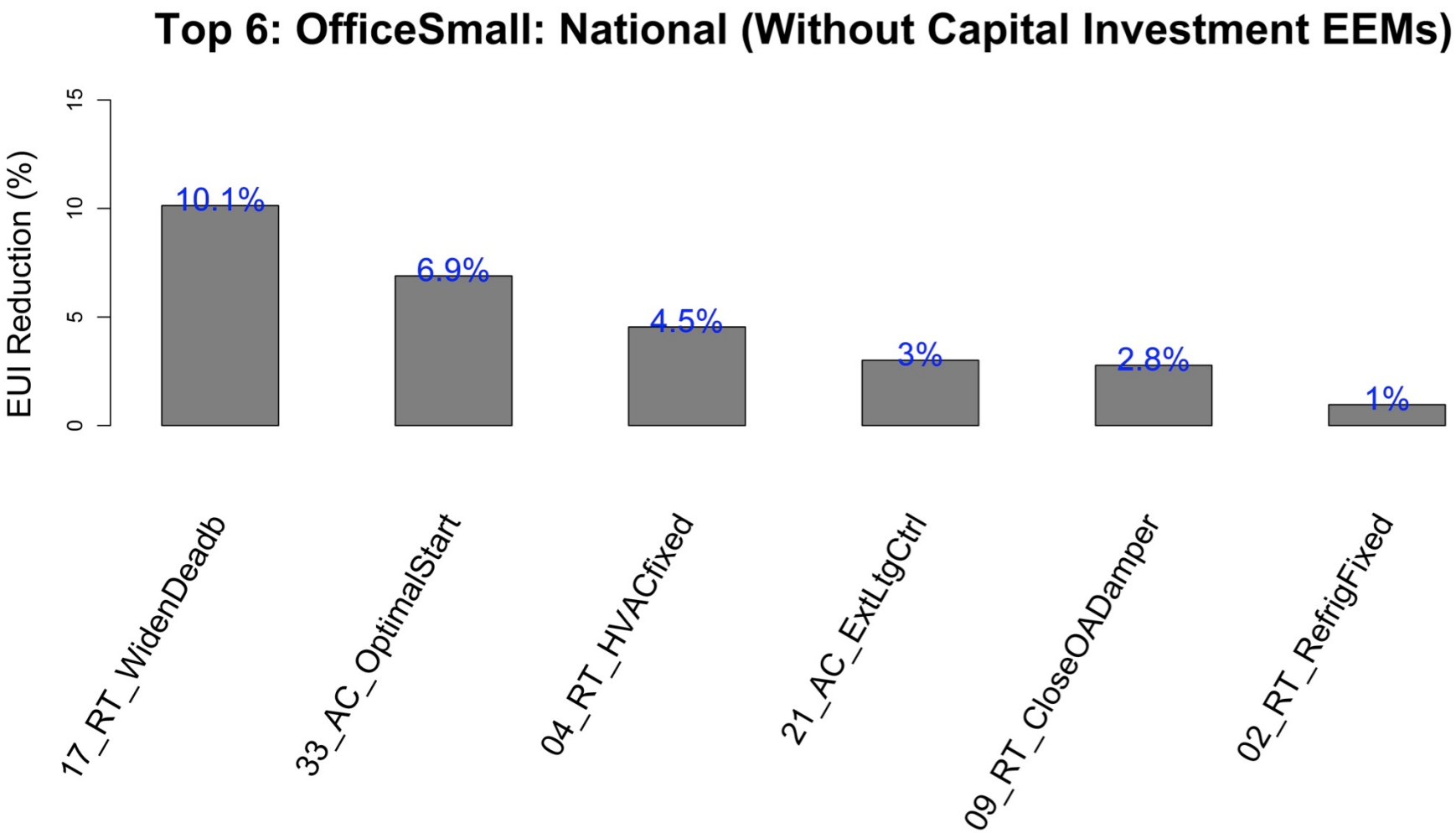
Savings from Top 6 No-Cost Measures: Small Office – Warm/Mixed Climate



Savings from Top 6 No-Cost Measures: Small Office – Cold Climate



Savings from Top 6 No-Cost Measures: Small Office – National Climate



Efficiency Package Results

Efficiency Packages of Measures

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- A1. Preventive maintenance and fixing operational faults – low severity
  - Sensor calibration (sensor faults) (LO, MO, SO)
  - Correct refrigerant charge (MO, SO)
  - Fix water coil valve leakages (LO)
  - Correcting HVAC operation schedules (LO, MO, SO)
  - Economizer, damper leakage (LO, MO, SO)
- A2. Preventive maintenance and fixing operational faults – moderate severity
- A3. Preventive maintenance and fixing operational faults – high severity

- B1. Re-tuning and building control for energy savings - requires no capital investment or BAS re-programming
  - Supply air temperature set point reset (seasonal reset) (LO, MO)
  - Exhaust fan shut down during unoccupied periods (LO, MO, SO)
  - Static pressure reset (based on schedule) (LO, MO)
  - Close outdoor air damper during unoccupied periods (LO, MO, SO)
  - Chilled water supply temperature reset (seasonal reset) (LO)
  - Lower minimum air flow rate for VAV terminals (LO, MO)
  - Widen thermostat set point dead band (LO, MO, SO)
  - Exterior lighting control (LO, MO, SO)

Efficiency Packages of Measures (cont.)

Pacific Northwest NATIONAL LABORATORY
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- B2. Re-tuning and building control for energy savings - requires re-programming on BAS, but no capital project investment
  - Supply air temperature set point reset (based on OA temperature) (LO, MO)
  - Exhaust fan shut down during unoccupied periods (LO, MO, SO)
  - Static pressure reset (based on damper) (LO, MO)
  - Close outdoor air damper during unoccupied periods (LO, MO, SO)
  - Chilled water supply temperature reset (seasonal reset) (LO)
  - Lower minimum air flow rate for VAV terminals (LO, MO)
  - Widen thermostat set point dead band (LO, MO, SO)
  - Exterior lighting control (LO, MO, SO)
  - Plant shut down when there is no load (LO)
  - Chilled water pump differential pressure reset (LO)
  - Condenser water temperature reset (LO)
  - Hot water pump differential pressure reset (LO)
  - Hot water supply temperature reset (LO)
  - Optimal start (LO, MO, SO)

Efficiency Packages of Measures (cont.)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- B3. Re-tuning and building control for energy savings - requires advanced BAS re-programming and capital project investment
  - Supply air temperature set point reset (based on OA temperature) (LO, MO)
  - Exhaust fan shut down during unoccupied periods (LO, MO, SO)
  - Static pressure reset (based on damper) (LO, MO)
  - Close outdoor air damper during unoccupied periods (LO, MO, SO)
  - Chilled water supply temperature reset (seasonal reset) (LO)
  - Lower minimum air flow rate for VAV terminals (LO, MO)
  - Widen thermostat set point dead band (LO, MO, SO)
  - Exterior lighting control (LO, MO, SO)
  - Plant shut down when there is no load (LO)
  - Chilled water pump differential pressure reset (LO)
  - Condenser water temperature reset (LO)
  - Hot water pump differential pressure reset (LO)
  - Hot water supply temperature reset (LO)
  - Optimal start (LO, MO, SO)
  - Occupancy sensor for lighting control (LO, MO, SO)
  - Demand-controlled ventilation (LO, MO, SO)
  - Daylight control (LO, MO, SO)
  - Advanced on/off control for plug loads (LO, MO, SO)
  - Night purge ventilation (LO, MO, SO)
  - Advanced rooftop unit (RTU) controls (SO)
  - Elevator cab lighting and ventilation control (LO, MO)
  - Water-side economizer (LO)
  - Cooling tower controls (variable-speed fan) (LO)

Efficiency Packages of Measures (cont.)

Pacific Northwest NATIONAL LABORATORY
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- C1. Energy efficiency upgrade retrofits – envelope
  - Replace windows (LO, MO, SO)
  - Add wall insulation (LO, MO, SO)
  - Add roof insulation (LO, MO, SO)
- C2. Energy efficiency upgrade retrofits – HVAC and lighting
  - Interior lighting retrofit to reduce lighting power density (LPD) (LO, MO, SO)
  - Exterior lighting fixtures retrofit (LO, MO, SO)
  - Replace supply fan motor and variable frequency drive (VFD) (for variable-speed fans) (LO, MO)
  - Replace boilers with higher efficiency models (LO)
  - Replace chillers with higher efficiency models (LO)
  - Replace RTUs with higher efficiency units (MO, SO)
  - Replace RTUs with units that use evaporative cooling (MO, SO)
  - Replace RTUs with air-to-air heat pumps (SO)
  - Increase efficiency of service hot water system (LO, MO, SO)
  - Retrofit electric transformers with higher efficiency models (LO, MO)

Efficiency Packages of Measures

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- C3. Energy efficiency upgrade retrofits – envelope, HVAC and lighting
  - Interior lighting retrofit to reduce lighting power density (LPD) (LO, MO, SO)
  - Exterior lighting fixtures retrofit (LO, MO, SO)
  - Replace supply fan motor and variable frequency drive (VFD) (for variable-sped fans) (LO, MO)
  - Replace boilers with higher efficiency models (LO)
  - Replace chillers with higher efficiency models (LO)
  - Replace RTUs with higher efficiency units (MO, SO)
  - Replace RTUs with units that use evaporative cooling (MO, SO)
  - Replace RTUs with air-to-air heat pumps (SO)
  - Increase efficiency of service hot water system (LO, MO, SO)
  - Retrofit electric transformers with higher efficiency models (LO, MO)
  - Replace windows (LO, MO, SO)
  - Add wall insulation (LO, MO, SO)
  - Add roof insulation (LO, MO, SO)

Efficiency Packages of Measures

- D1. Demand response – peak reduction reactive
  - Thermostat set points reset (LO, MO, SO)
  - Duty cycle (LO, MO, SO)
  - Lighting controls (LO, MO, SO)
  - Chilled water temperature control with fan controls (LO)
- D2. Demand response – peak reduction anticipatory
  - Duty cycle (LO, MO, SO)
  - Pre-cooling (LO, MO, SO)
  - Lighting controls (LO, MO, SO)
  - Chilled water temperature control with fan controls (LO)

Most Likely Package of Measures – Large Office

- Sensor calibration (sensor faults)
- Fix water coil valve leakages
- Correcting HVAC operation schedules
- Economizer, damper leakage
- Supply air temperature set point reset (based on OA temperature)
- Exhaust fan shut down during unoccupied periods
- Static pressure reset (based on damper)
- Plant shut down when there is no load
- Chilled water pump differential pressure reset
- Chilled water supply temperature reset (seasonal reset)
- Condenser water temperature reset
- Hot water supply temperature reset
- Lower minimum air flow rate for VAVterminals
- Widen thermostat set point dead band
- Occupancy sensor for lighting control
- Exterior lighting control
- Optimal start
- Cooling tower controls (variable-speed fan)

Most Likely Package of Measures – Medium Office

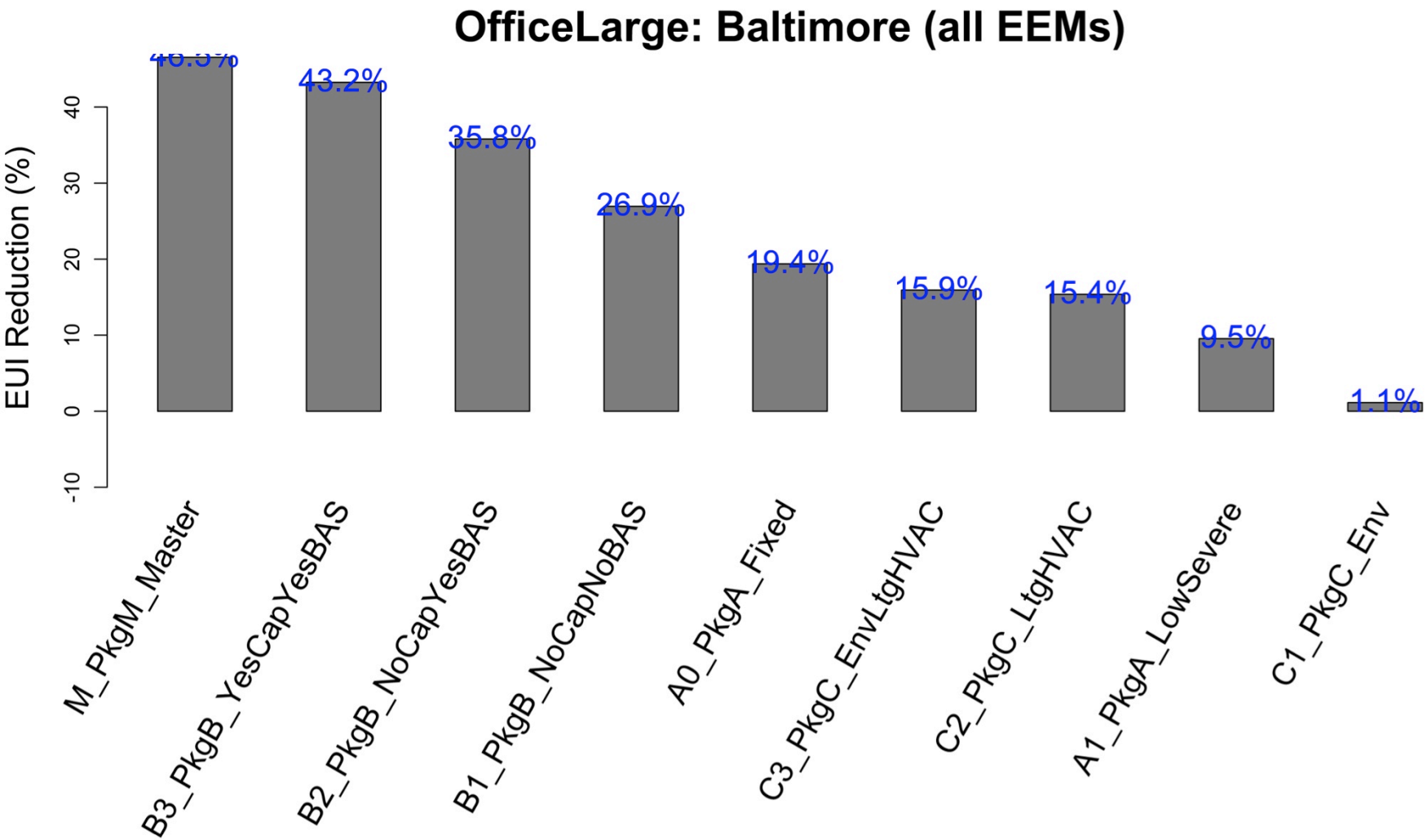
- Sensor calibration (sensor faults)
- Correcting HVAC operation schedules
- Economizer, damper leakage
- Supply air temperature set point reset (based on OA temperature)
- Exhaust fan shut down during unoccupied periods
- Static pressure reset (based on damper)
- Close outdoor air damper during unoccupied periods
- Lower minimum air flow rate for VAV terminals
- Widen thermostat set point dead band
- Occupancy sensor for lighting control
- Daylight control
- Exterior lighting control
- Optimal start
- Night purge ventilation

Most Likely Package of Measures – Small Office

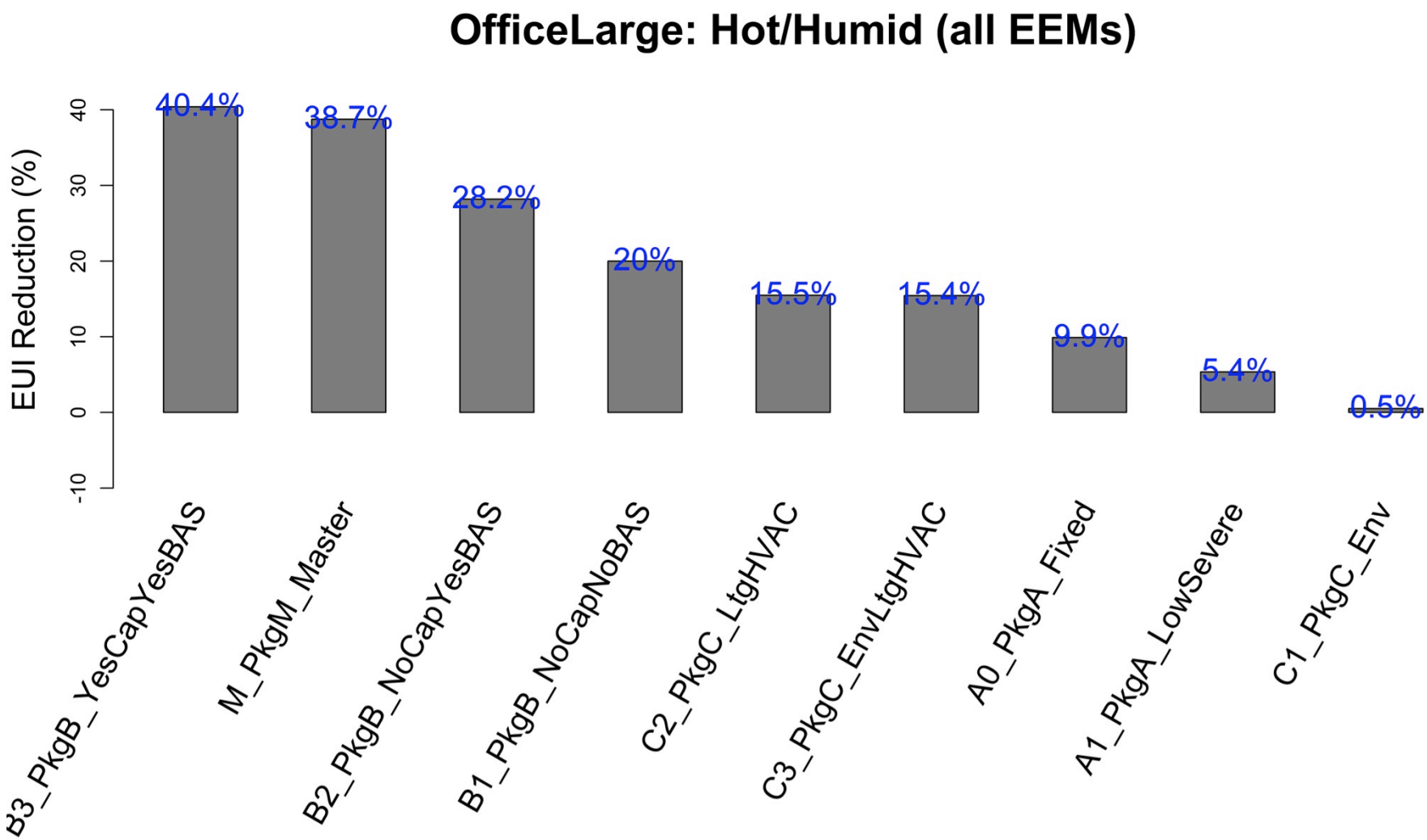
- Sensor calibration (sensor faults)
- Correcting HVAC operation schedules
- Economizer, damper leakage
- Exhaust fan shut down during unoccupied periods
- Close outdoor air damper during unoccupied periods
- Widen thermostat set point dead band
- Occupancy sensor for lighting control
- Demand-controlled ventilation
- Daylight control
- Exterior lighting control
- Optimal start
- Advanced rooftop unit (RTU) control

Efficiency Package Results – Large Office

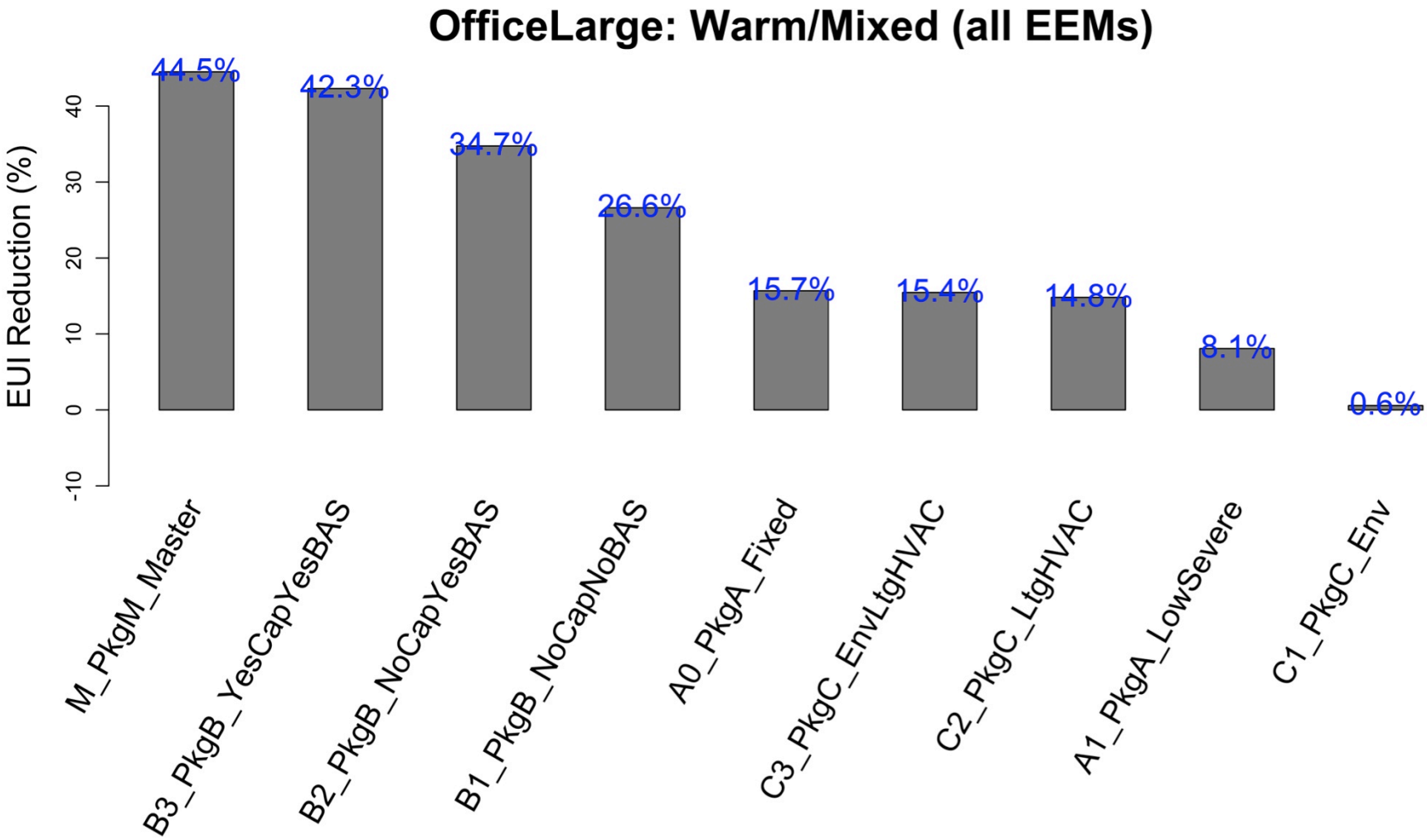
Savings from Package for Measures: Large Office - Baltimore



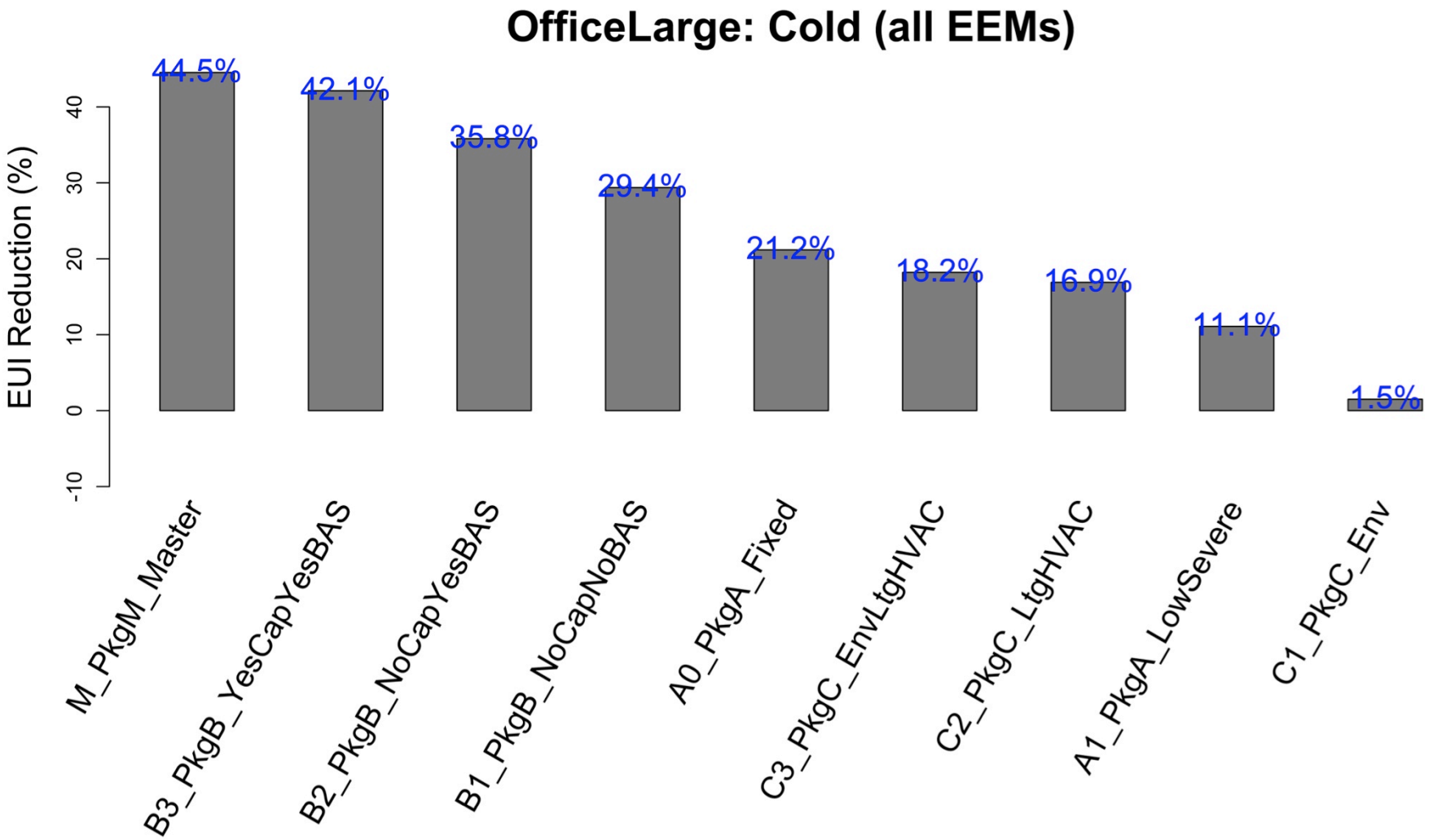
Savings from Package for Measures: Large Office – Hot/Humid Climate



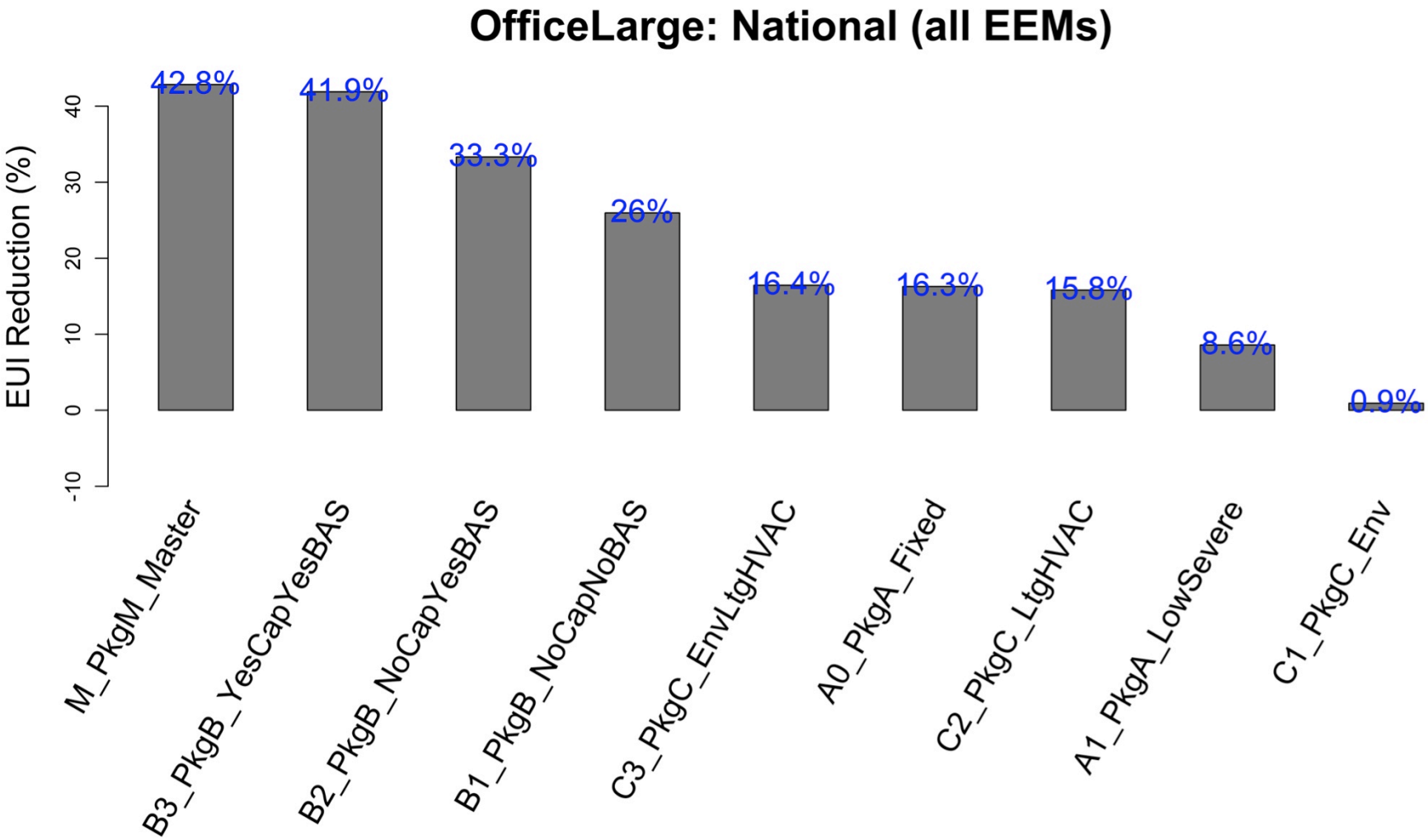
Savings from Package for Measures: Large Office – Warm/Mixed Climate



Savings from Package for Measures: Large Office – Cold Climate

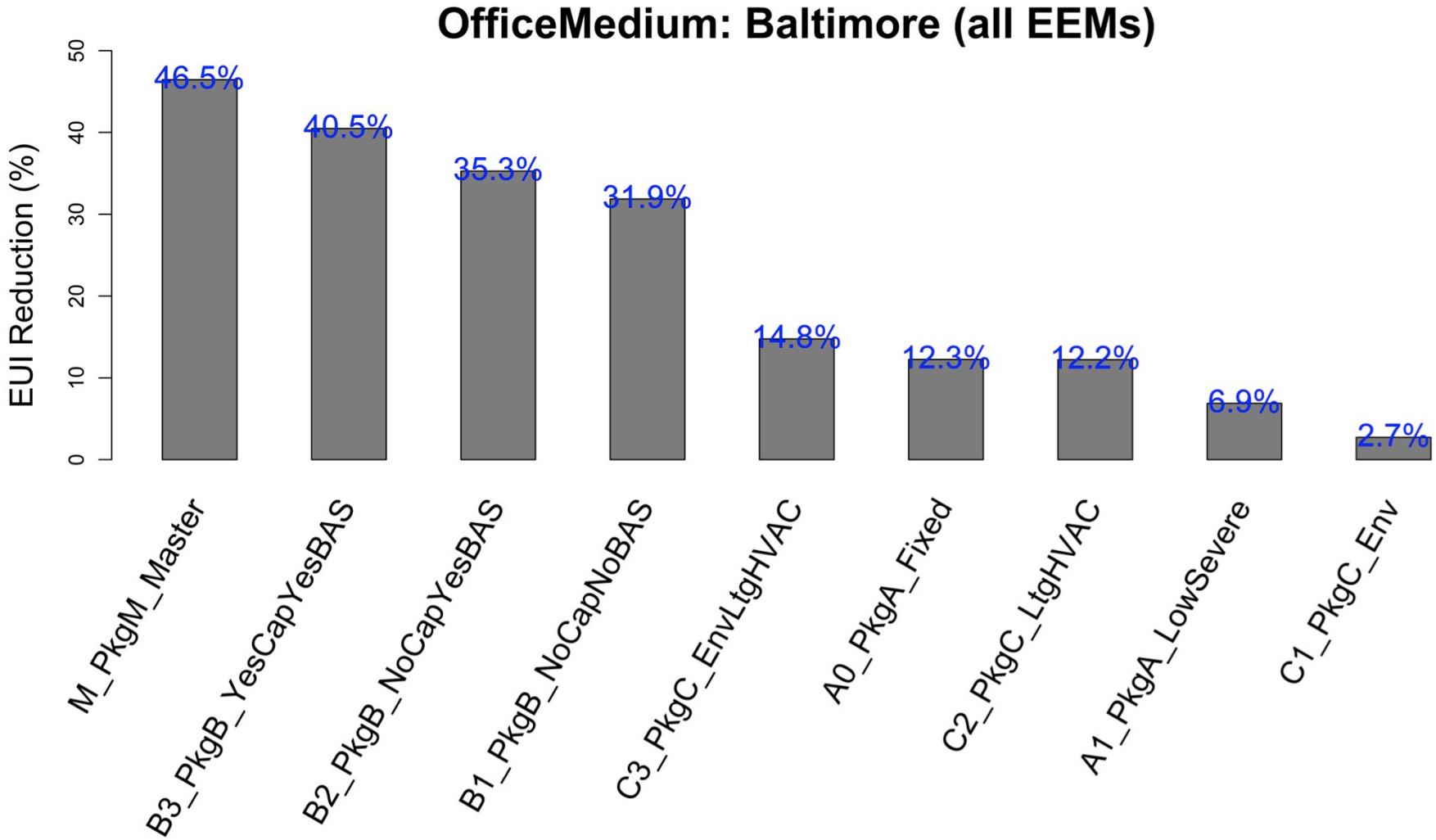


Savings from Package for Measures: Large Office – National Climate

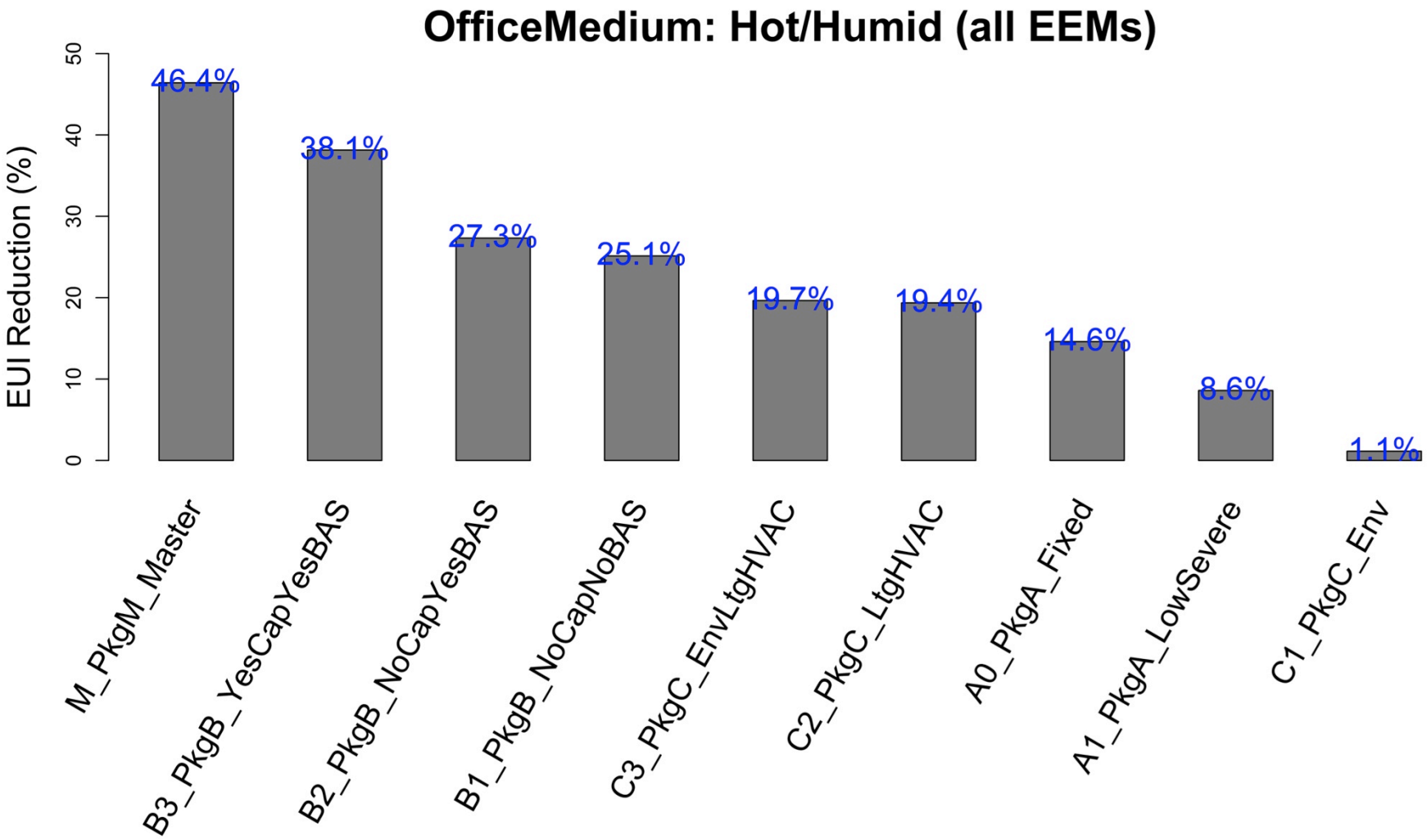


Efficiency Package Results – Medium Office

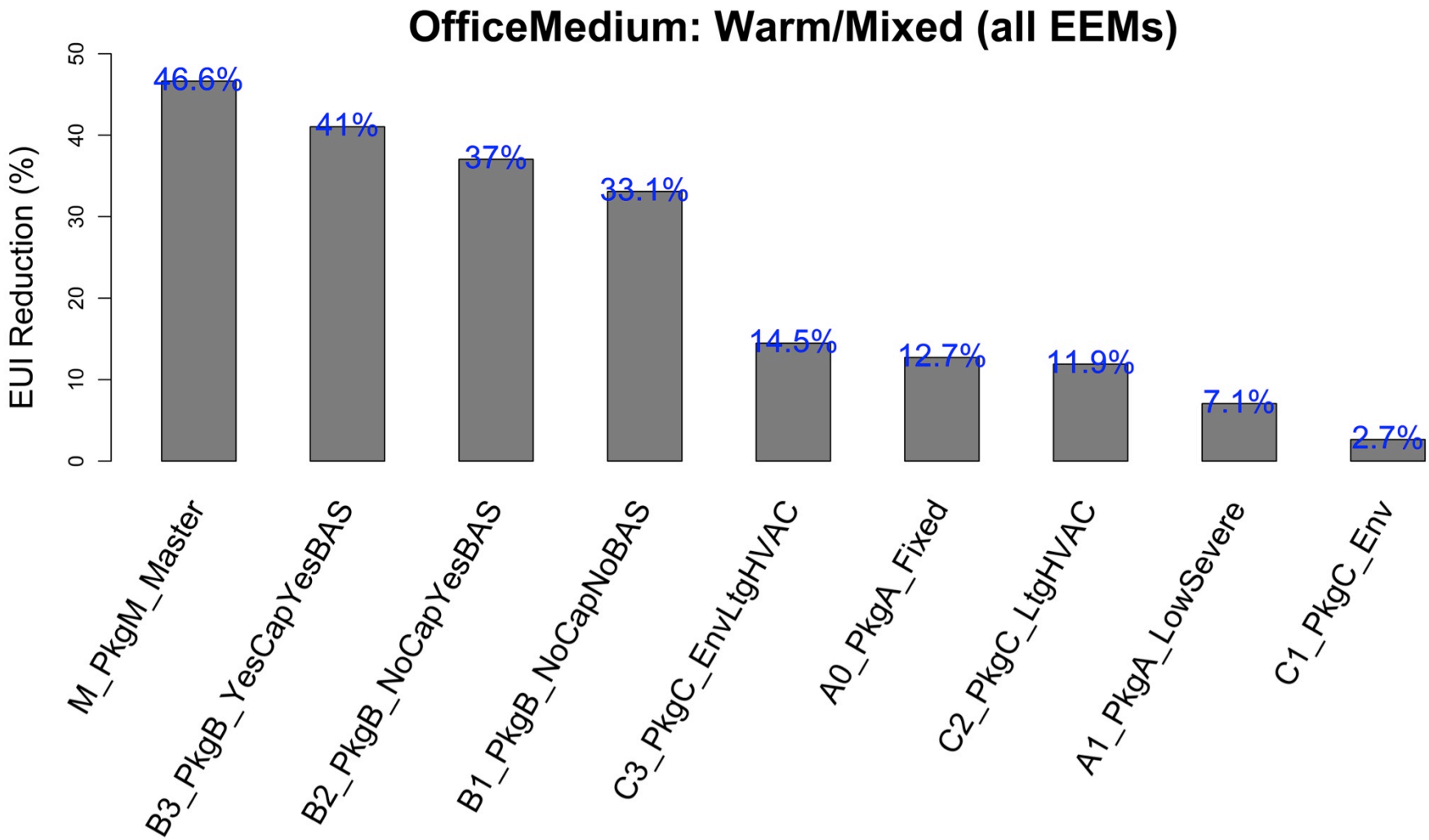
Savings from Package for Measures: Medium Office – Baltimore



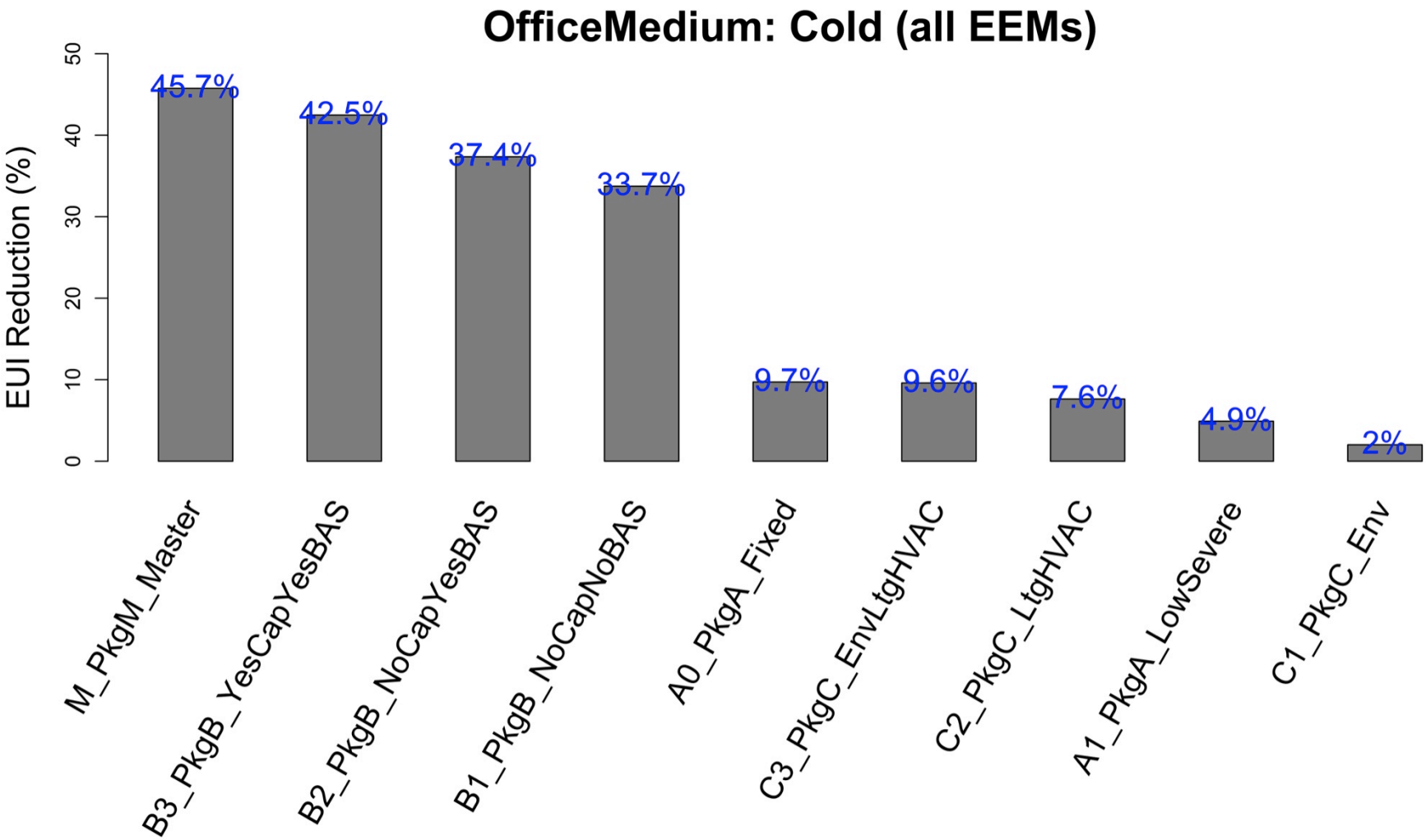
Savings from Package for Measures: Medium Office – Hot/Humid Climate



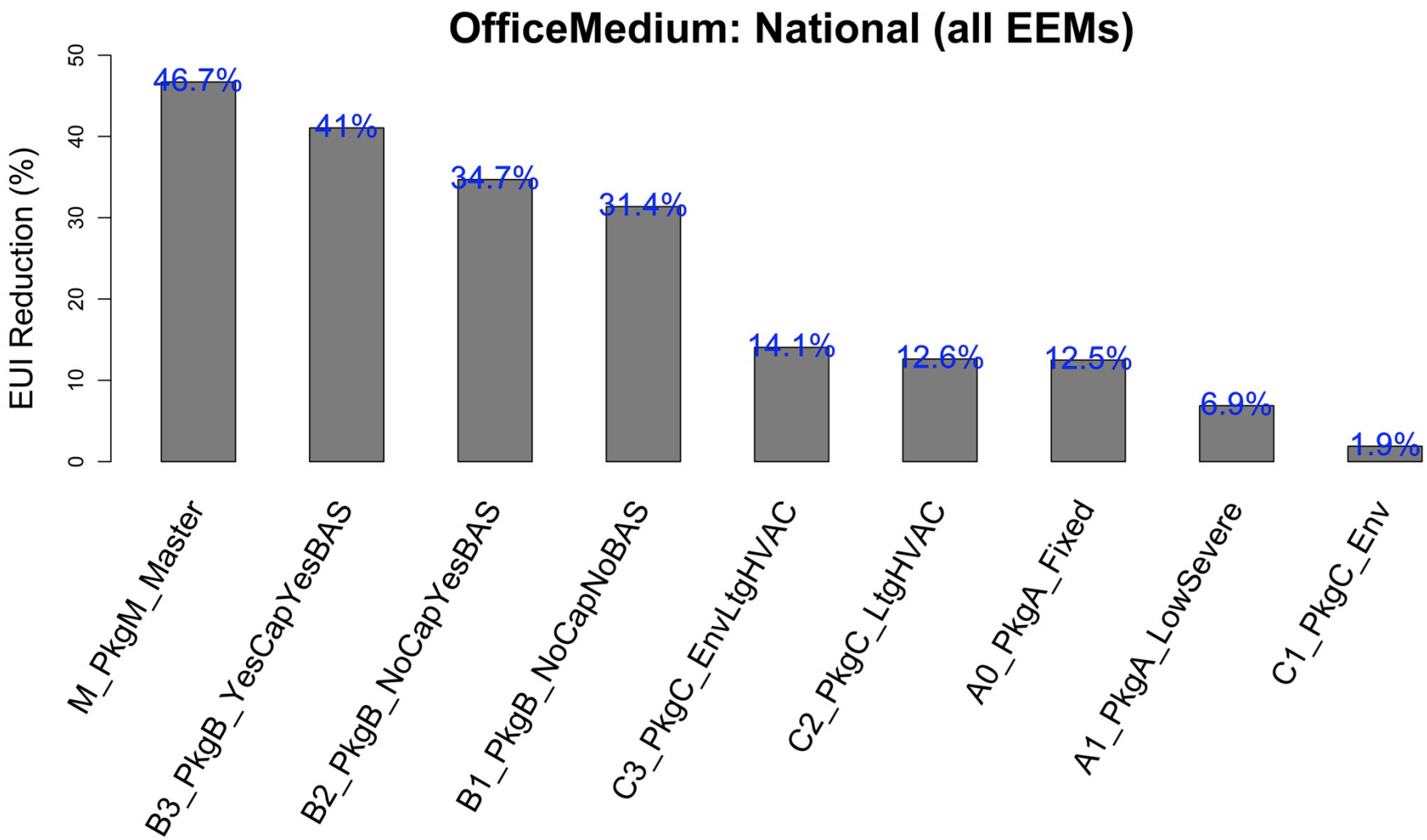
Savings from Package for Measures: Medium Office – Warm/Mixed Climate



Savings from Package for Measures: Medium Office – Cold Climate

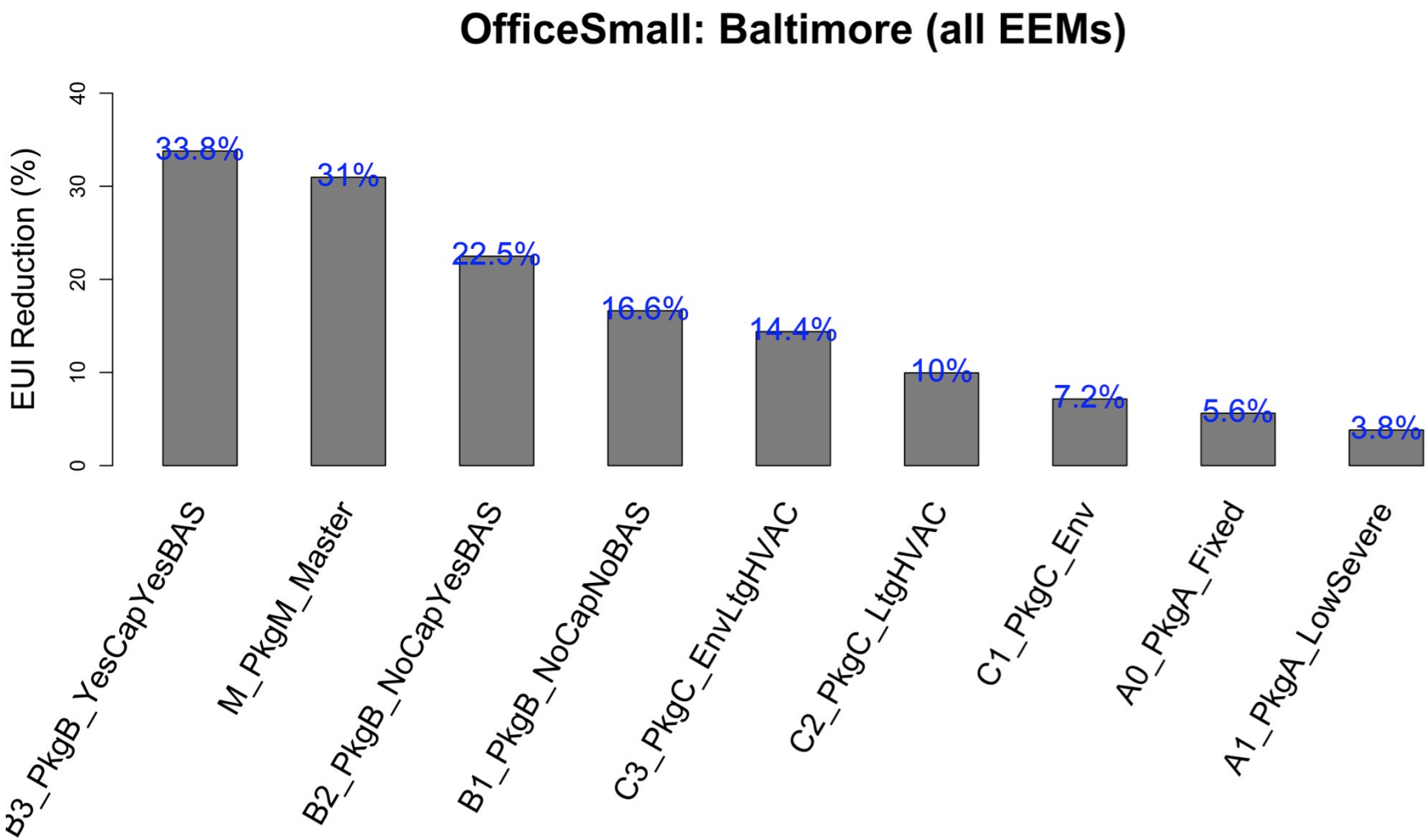


Savings from Package for Measures: Medium Office – National Climate

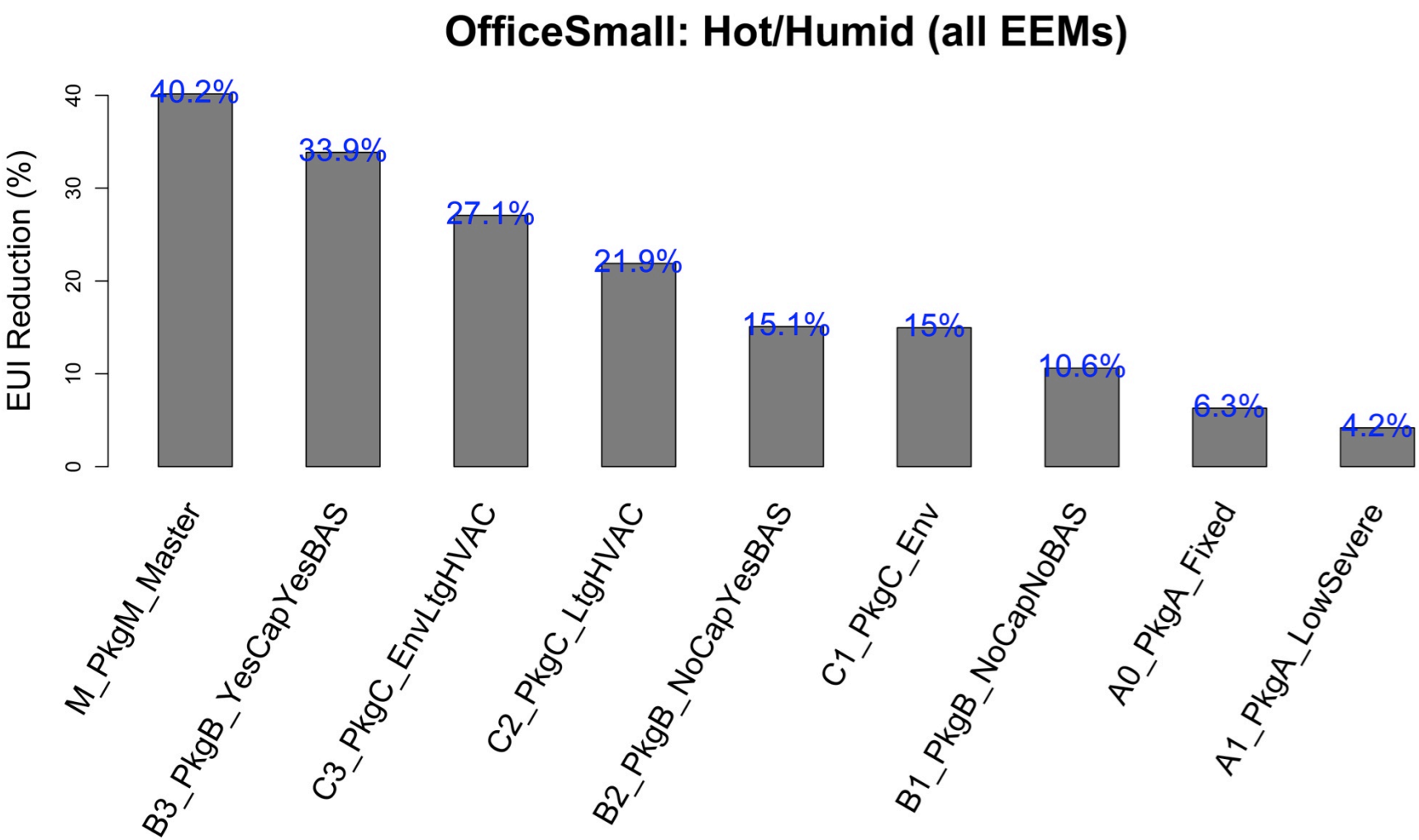


Efficiency Package Results – Small Office

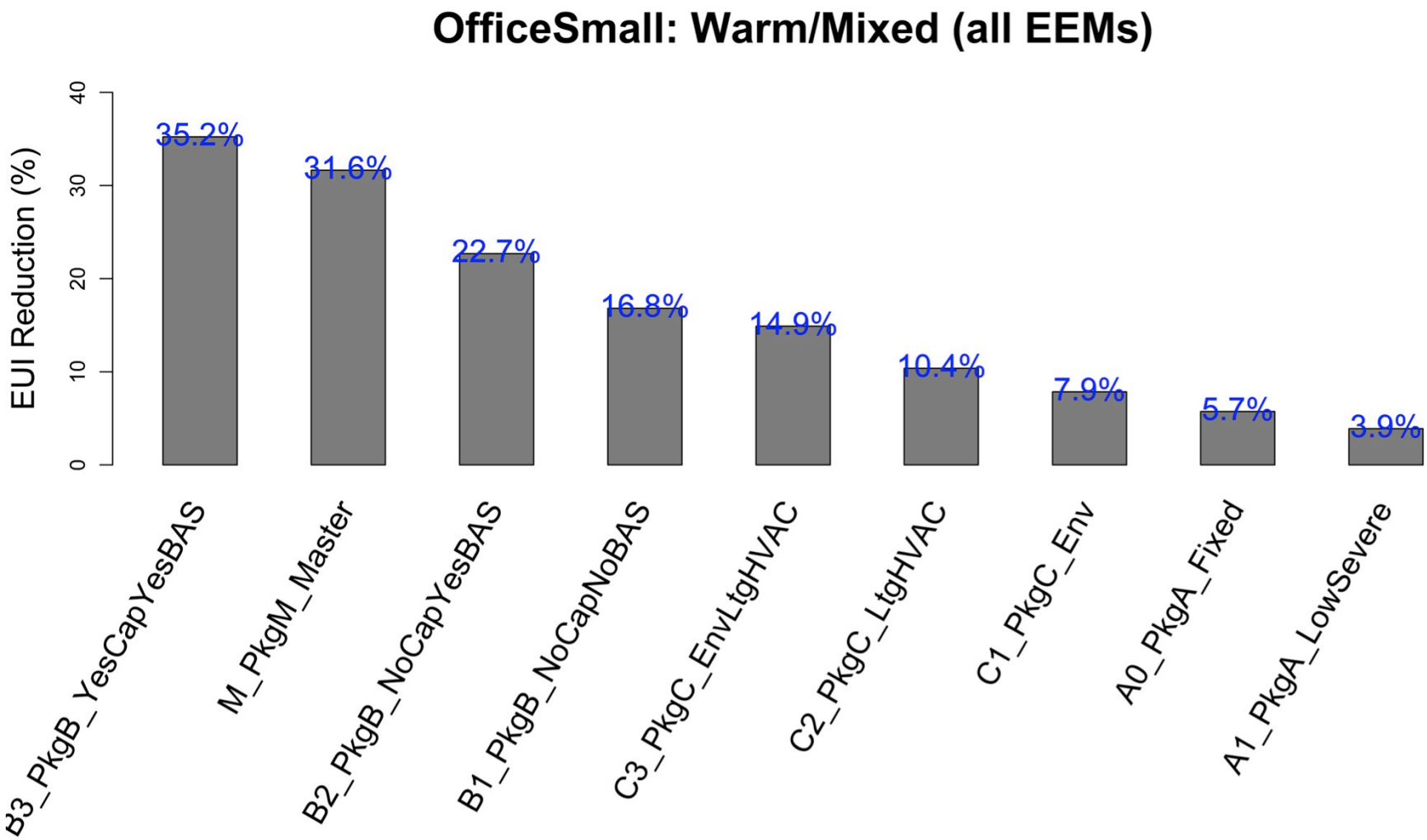
Savings from Package for Measures: Small Office – Baltimore



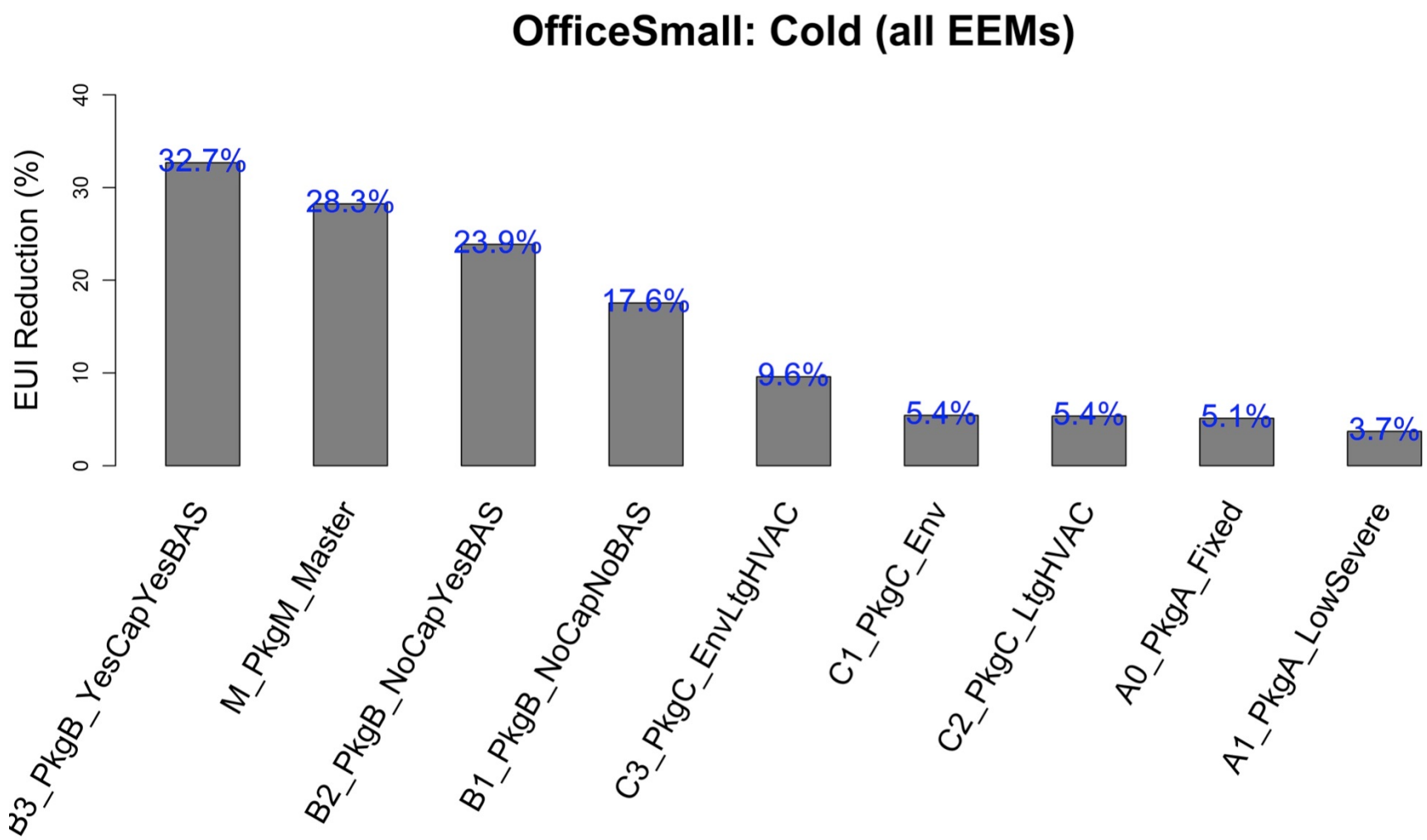
Savings from Package for Measures: Small Office – Hot/Humid Climate



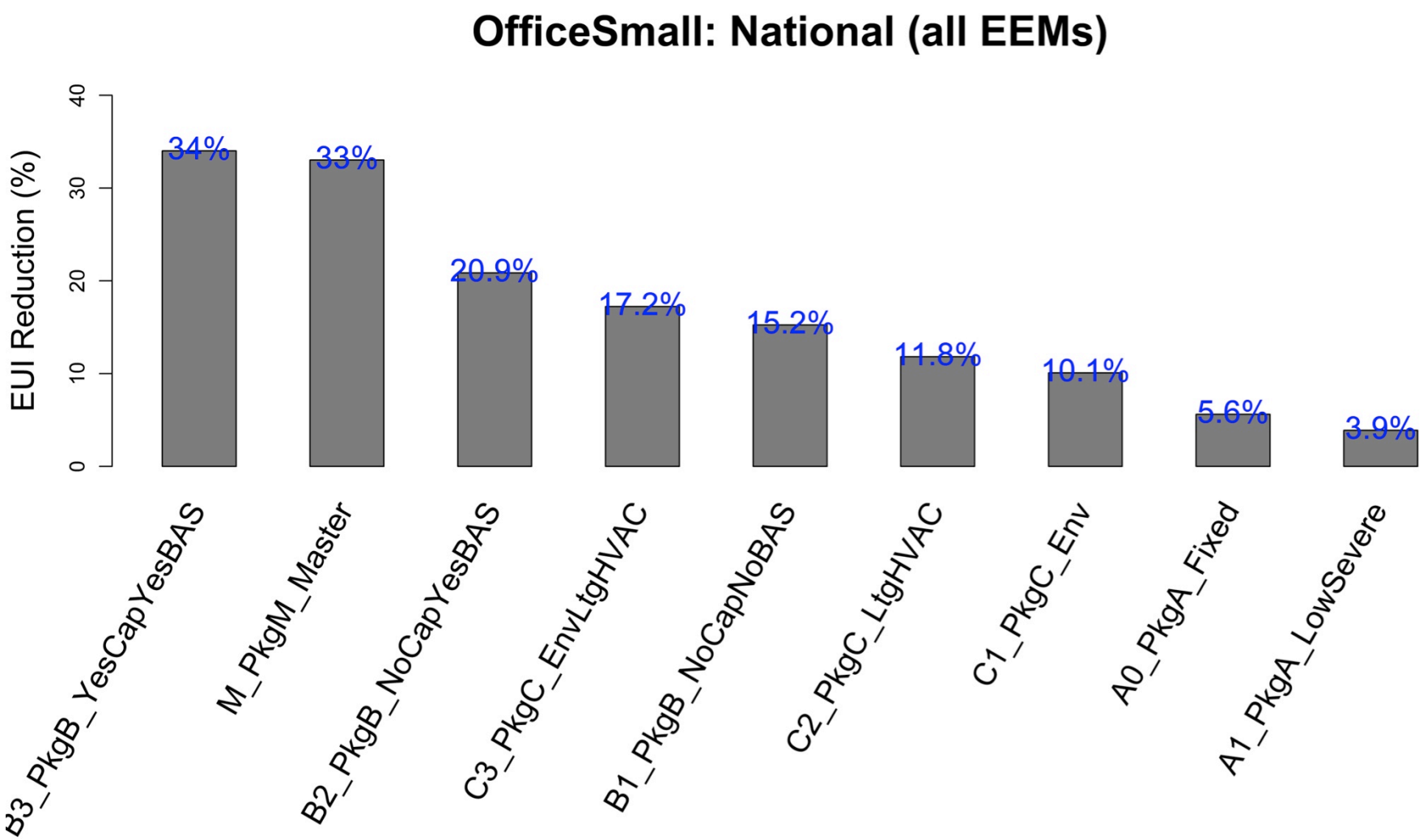
Savings from Package for Measures: Small Office – Warm/Mixed Climate



Savings from Package for Measures: Small Office – Cold Climate



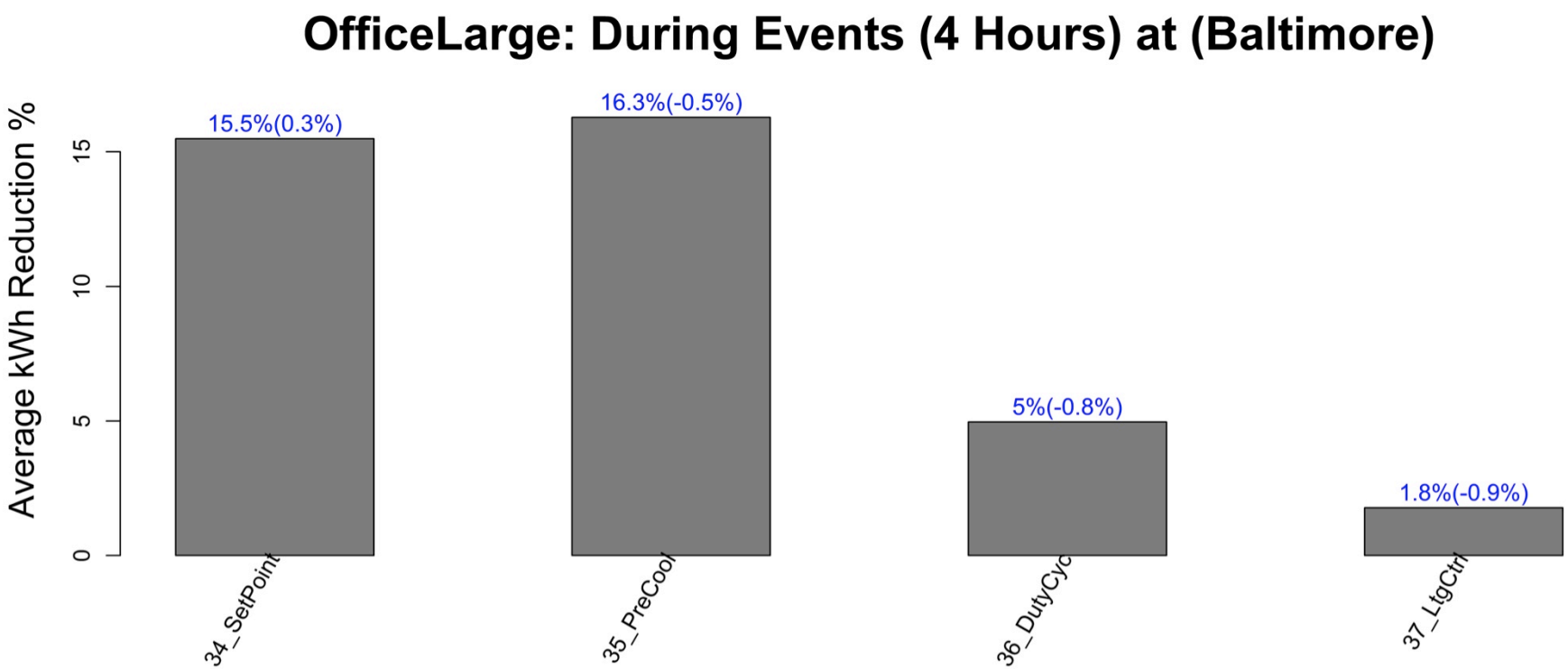
Savings from Package for Measures: Small Office – National Climate



Demand Response Results

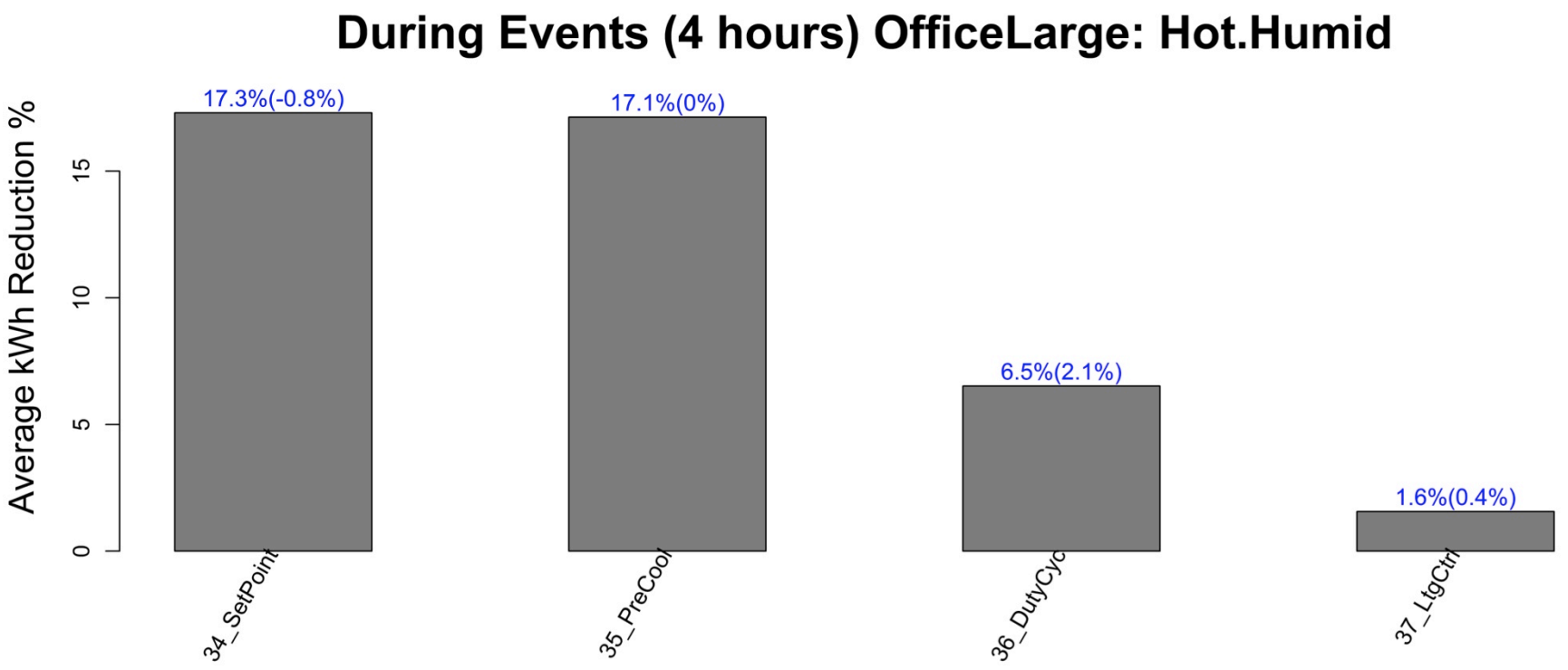
Average kWh Reduction from Demand Response Measures: Large Office – Baltimore

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



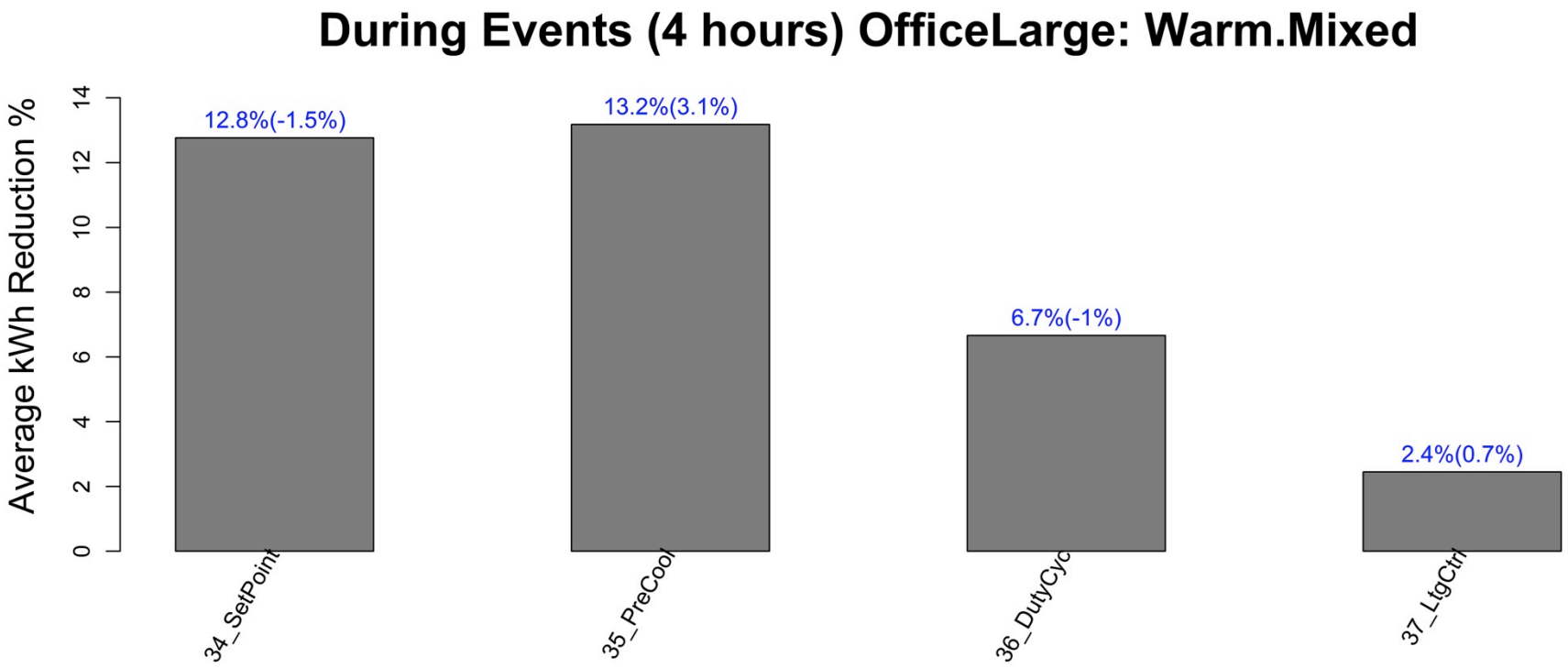
Average kWh Reduction from Demand Response Measures: Large Office – Hot/Humid

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



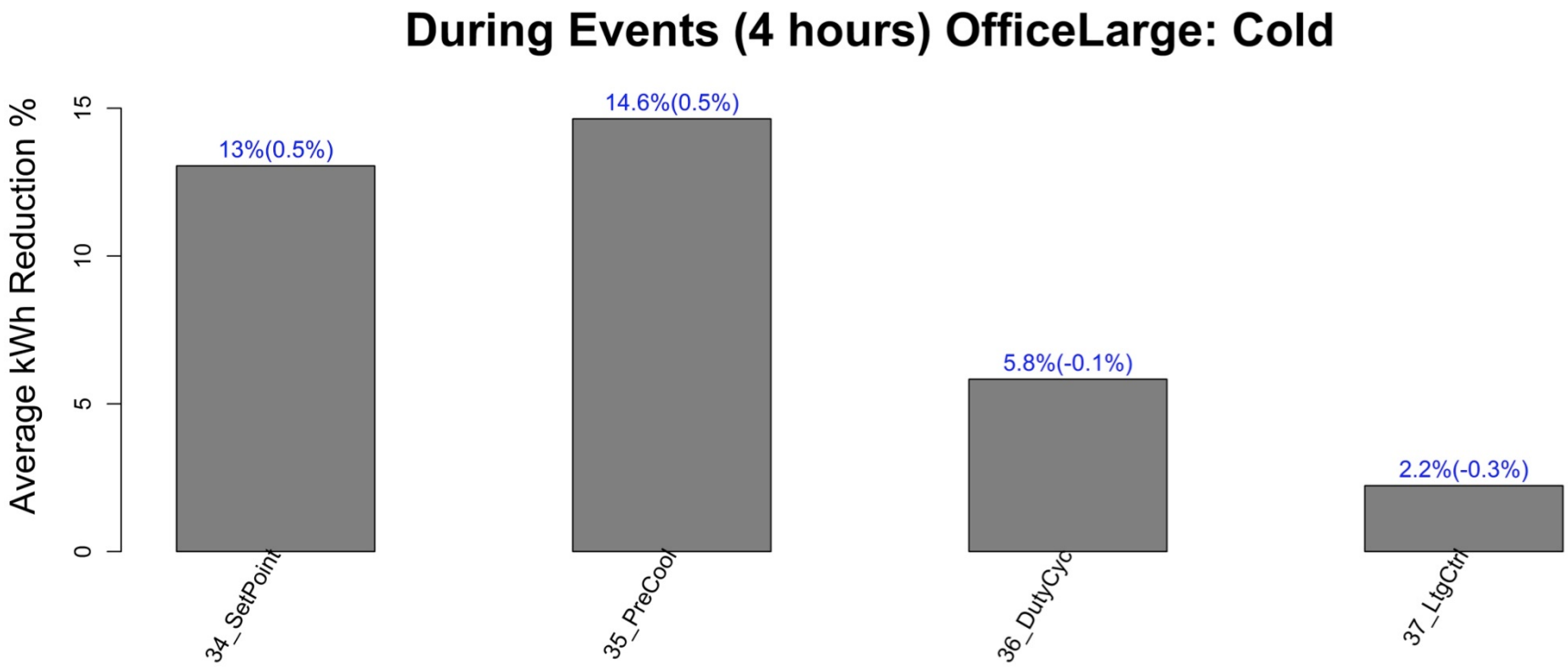
Average kWh Reduction from Demand Response Measures: Large Office – Warm/Mixed

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



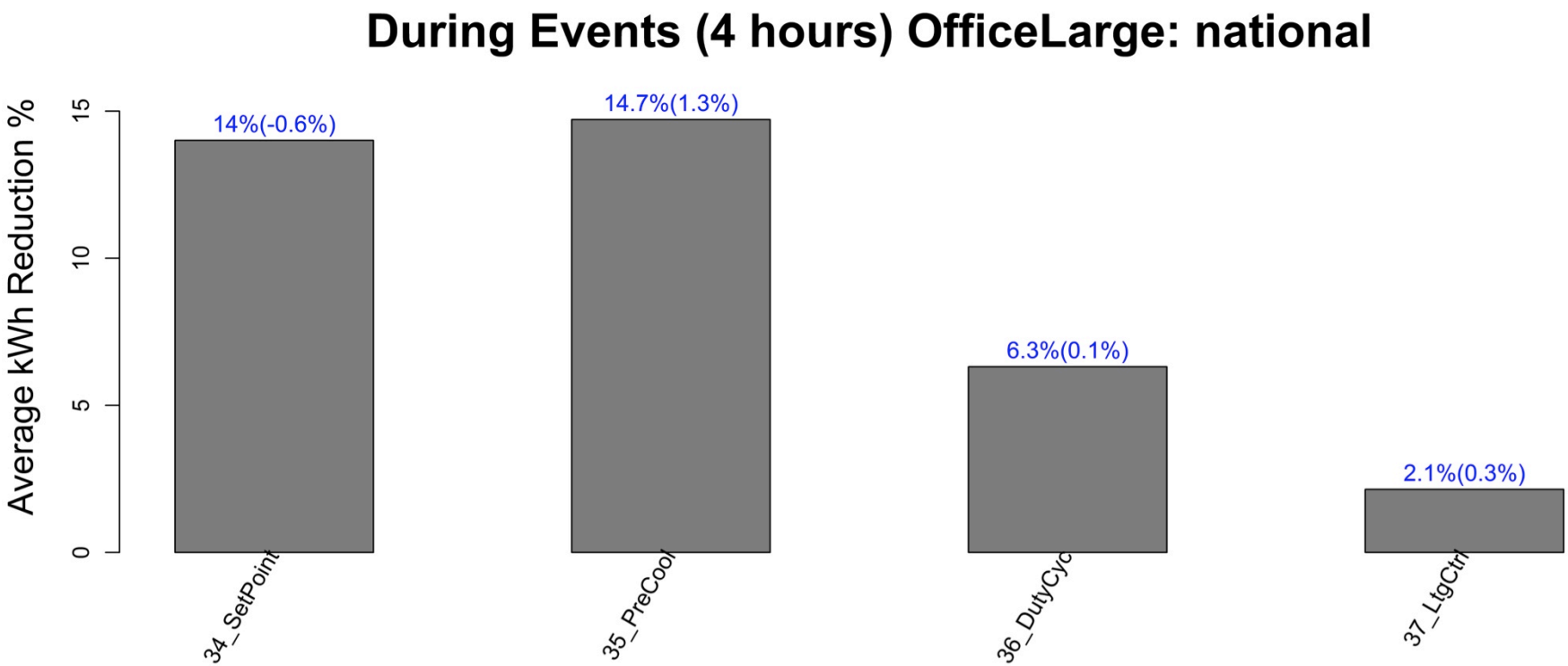
Average kWh Reduction from Demand Response Measures: Large Office – Cold

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



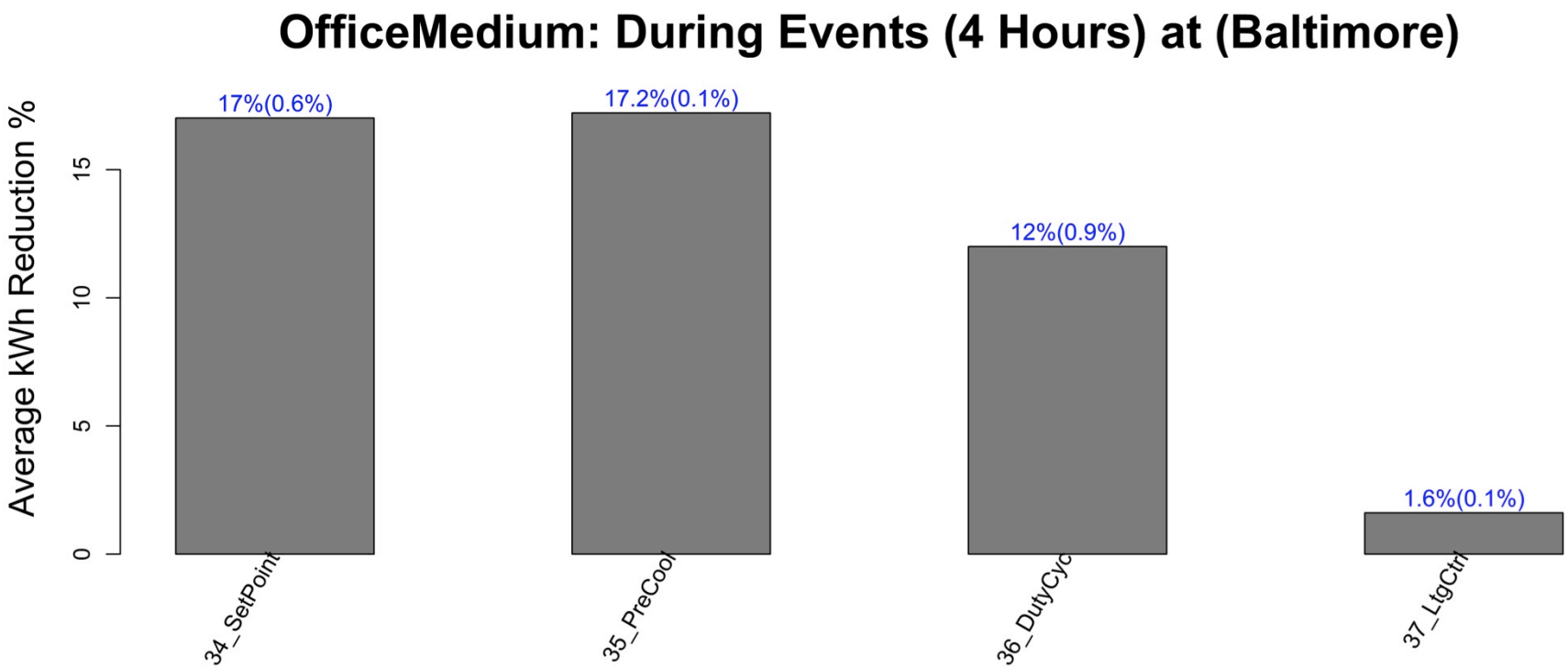
Average kWh Reduction from Demand Response Measures: Large Office – National

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



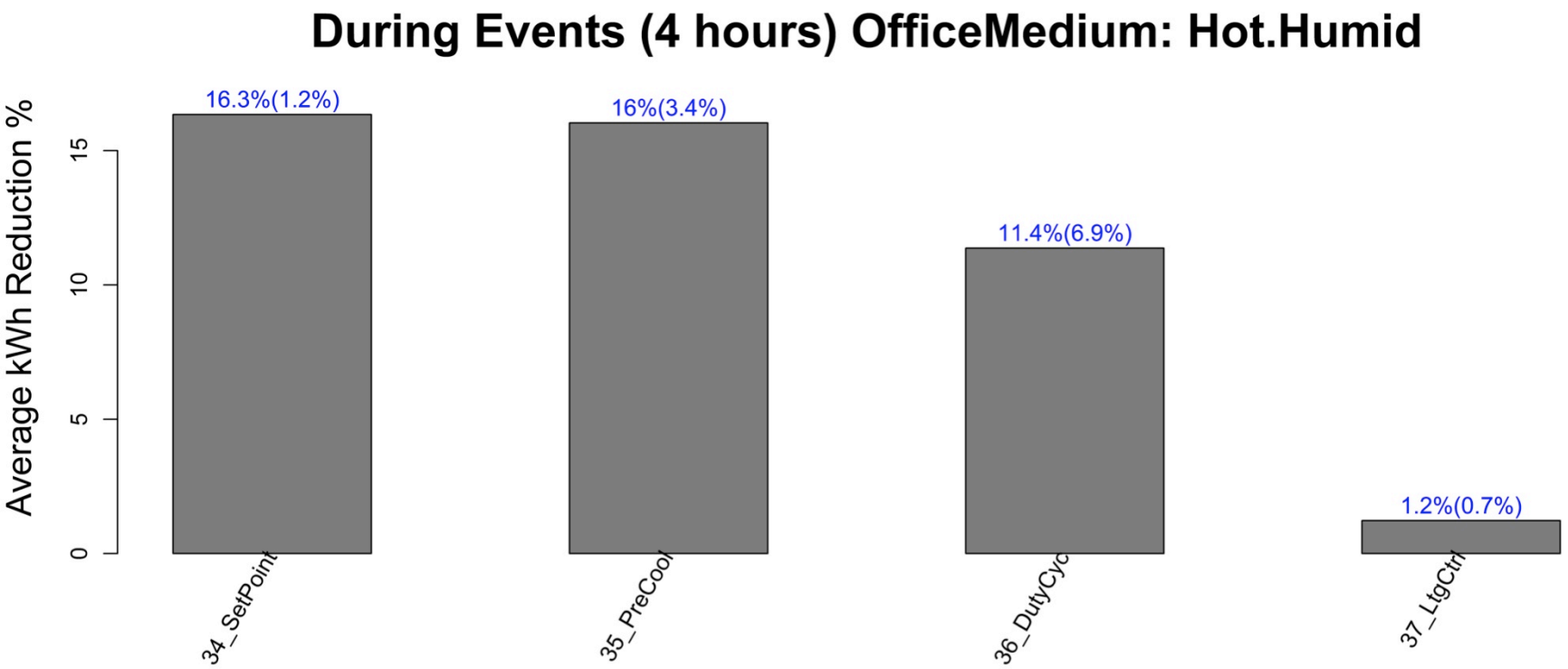
Average kWh Reduction from Demand Response Measures: Medium Office – Baltimore

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



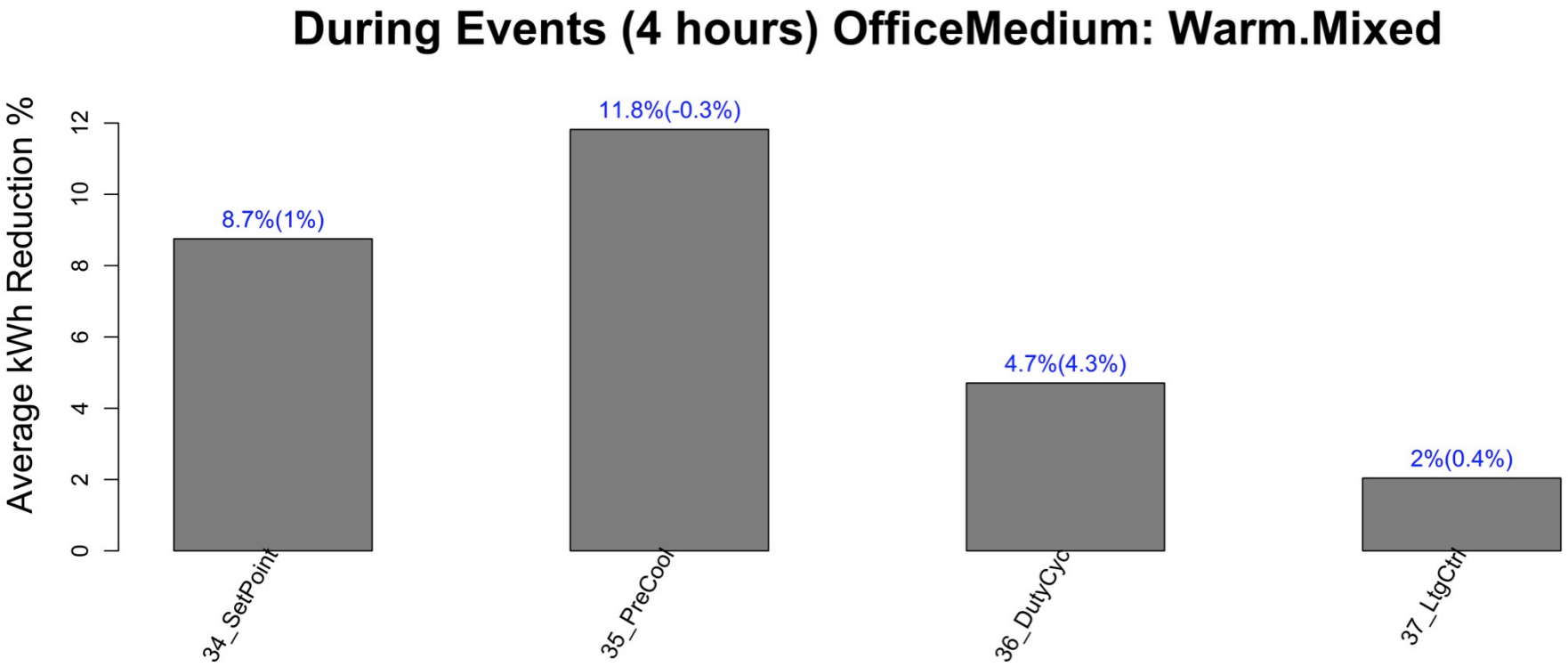
Average kWh Reduction from Demand Response Measures: Medium Office – Hot/Humid

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



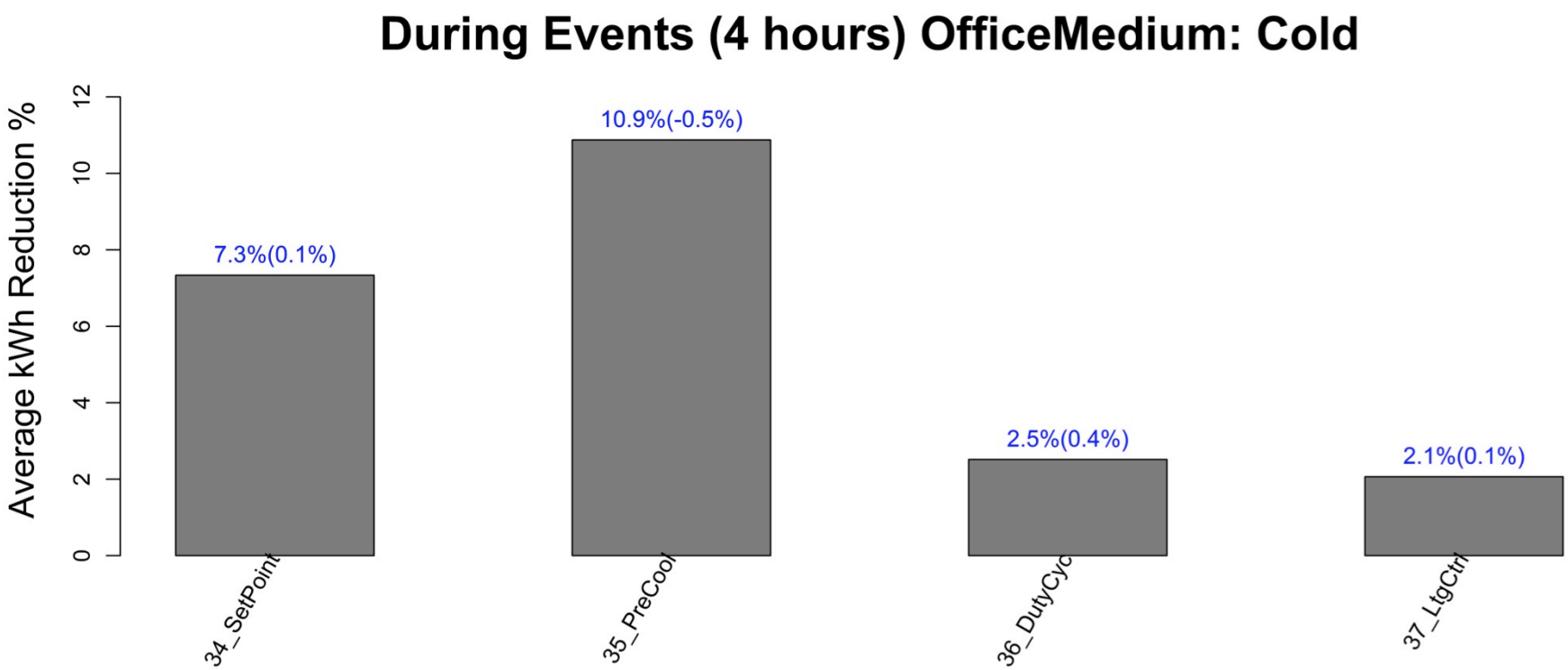
Average kWh Reduction from Demand Response Measures: Medium Office – Warm/Mixed

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



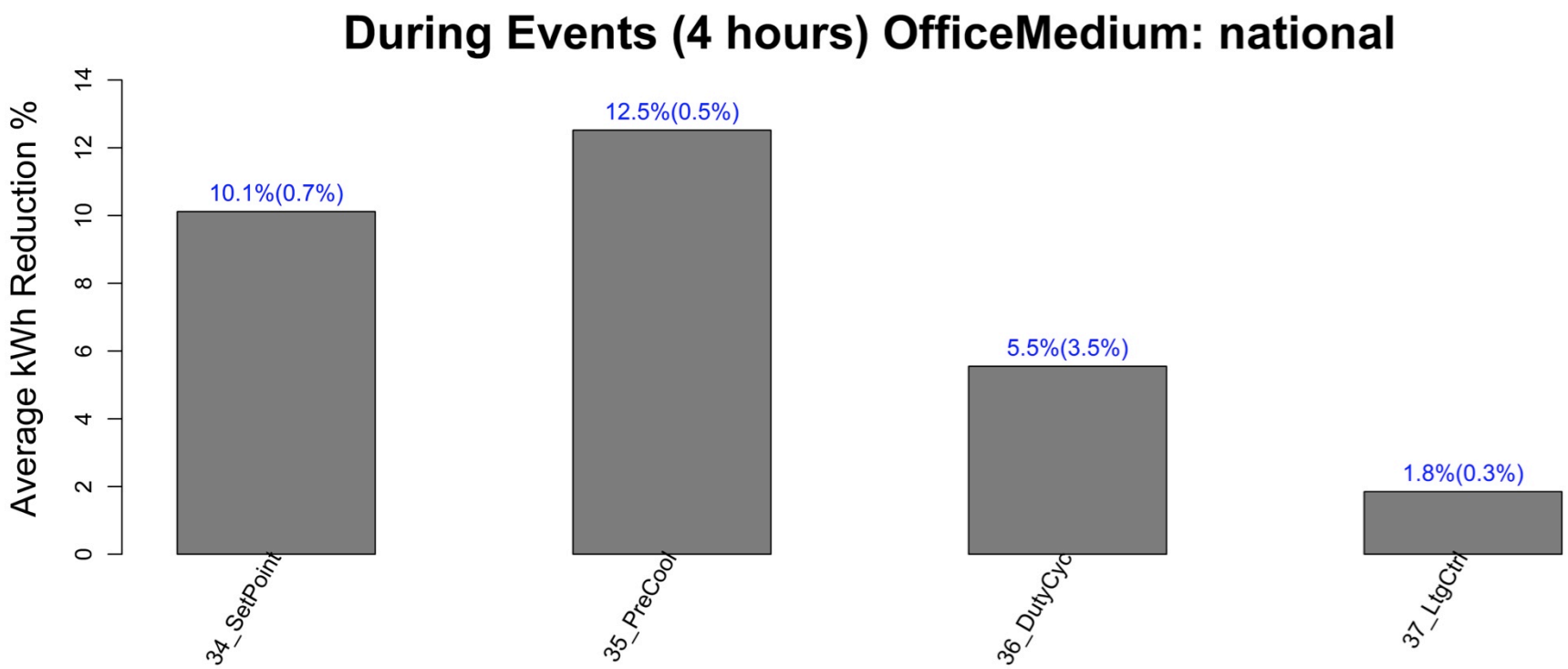
Average kWh Reduction from Demand Response Measures: Medium Office – Cold

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



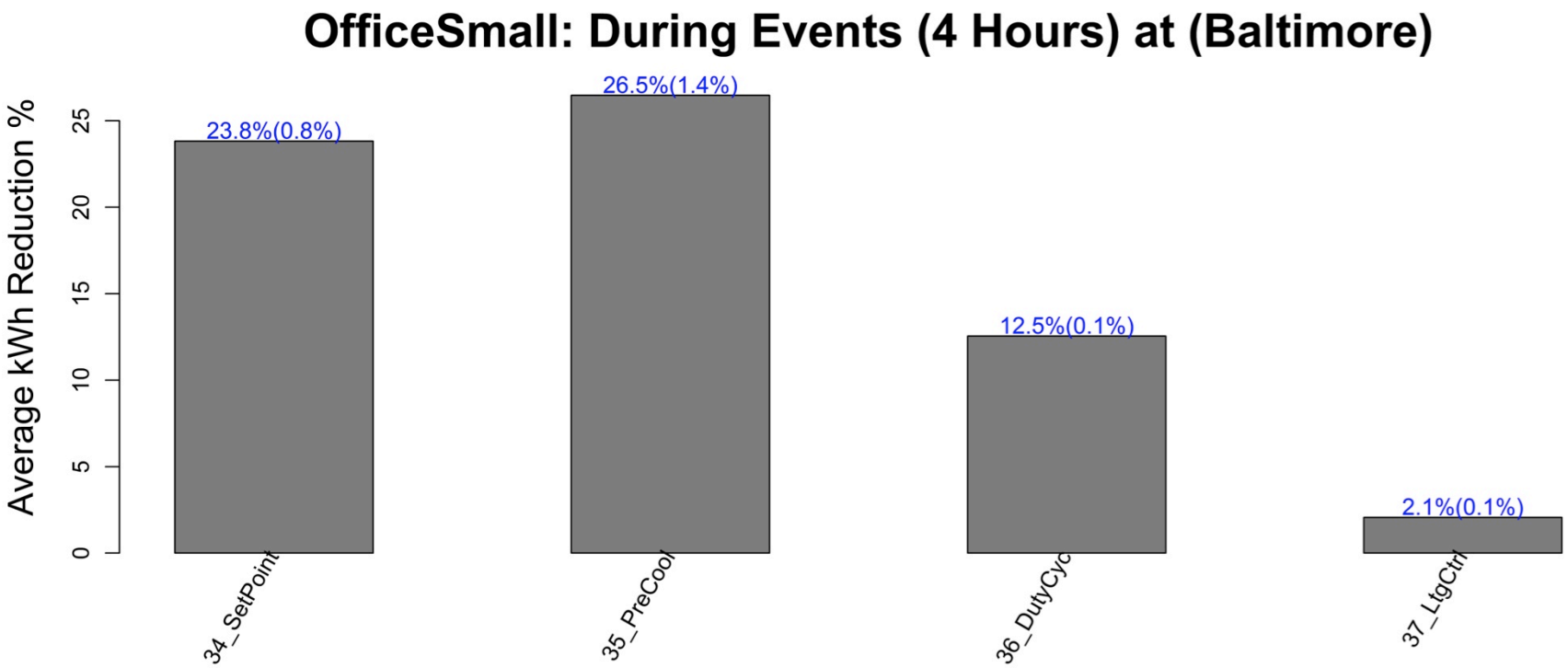
Average kWh Reduction from Demand Response Measures: Medium Office – National

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



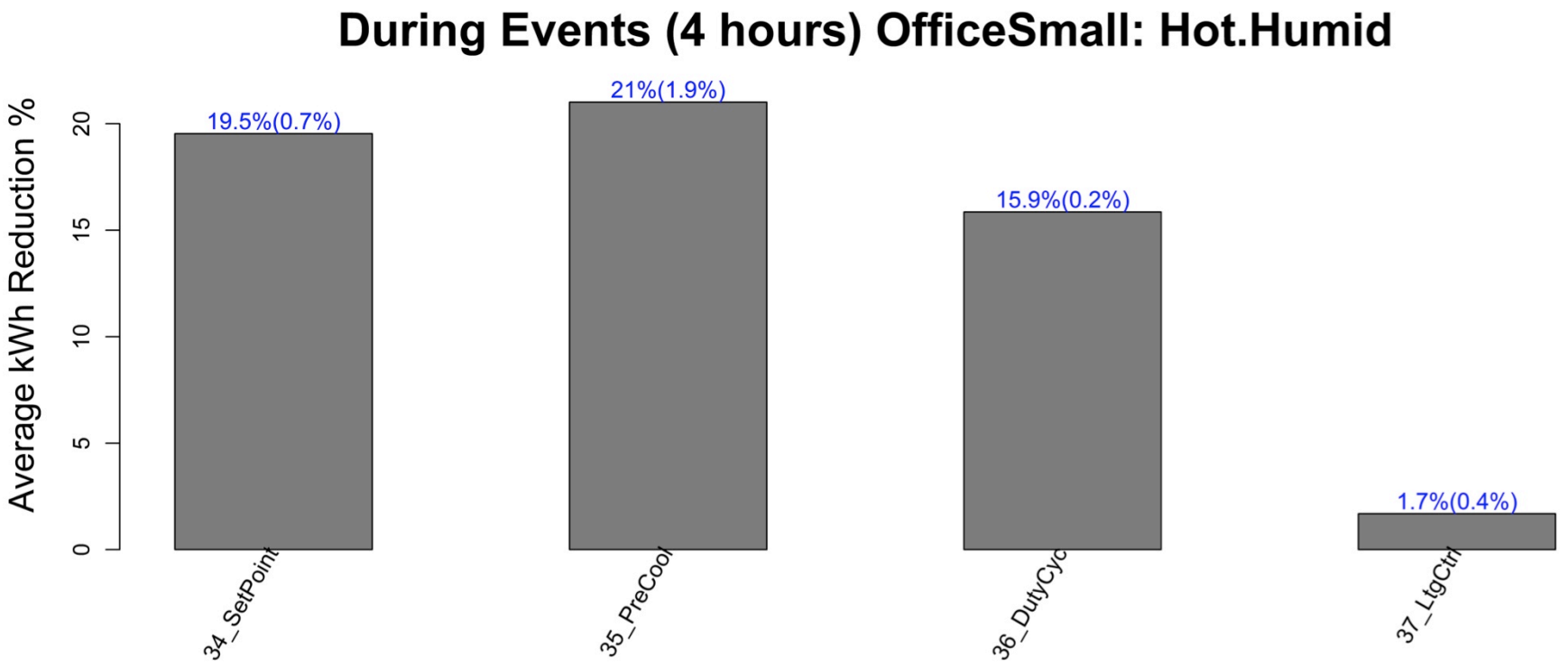
Average kWh Reduction from Demand Response Measures: Small Office – Baltimore

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



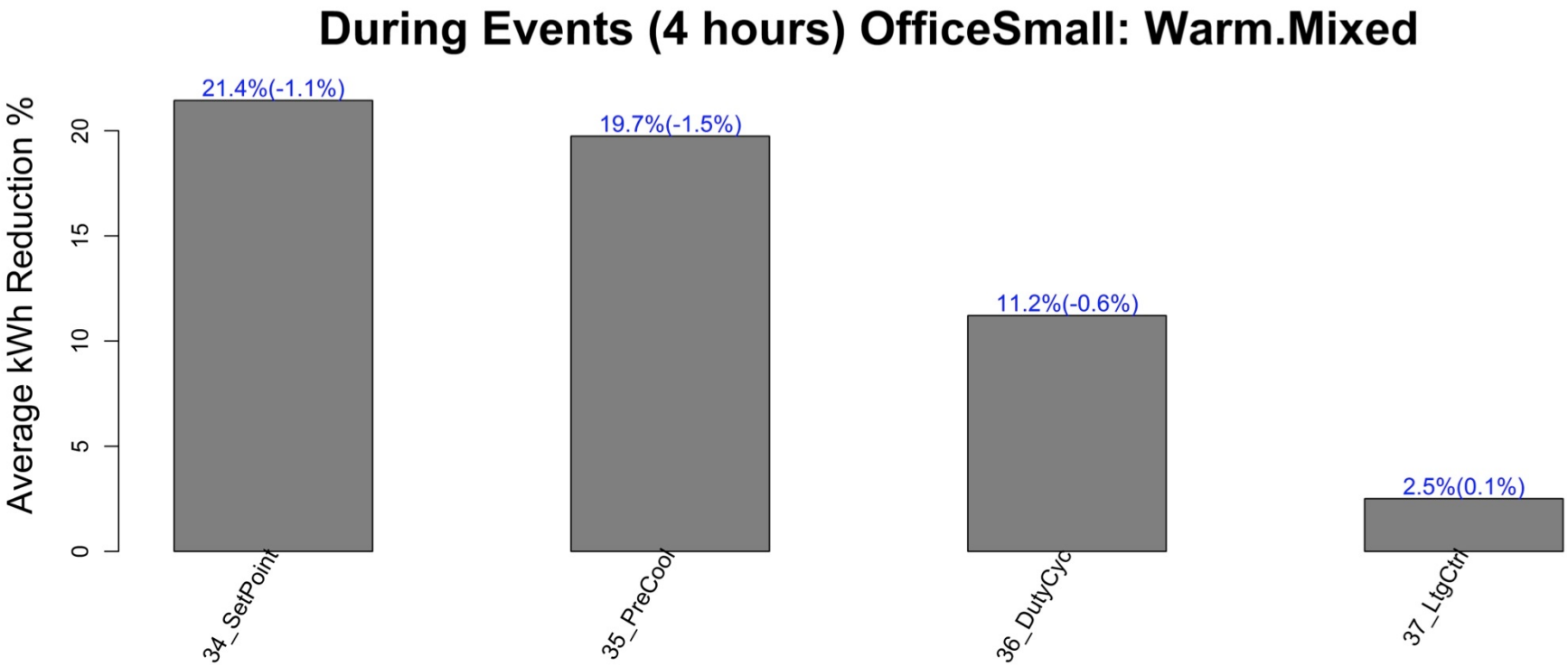
Average kWh Reduction from Demand Response Measures: Small Office – Hot/Humid

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



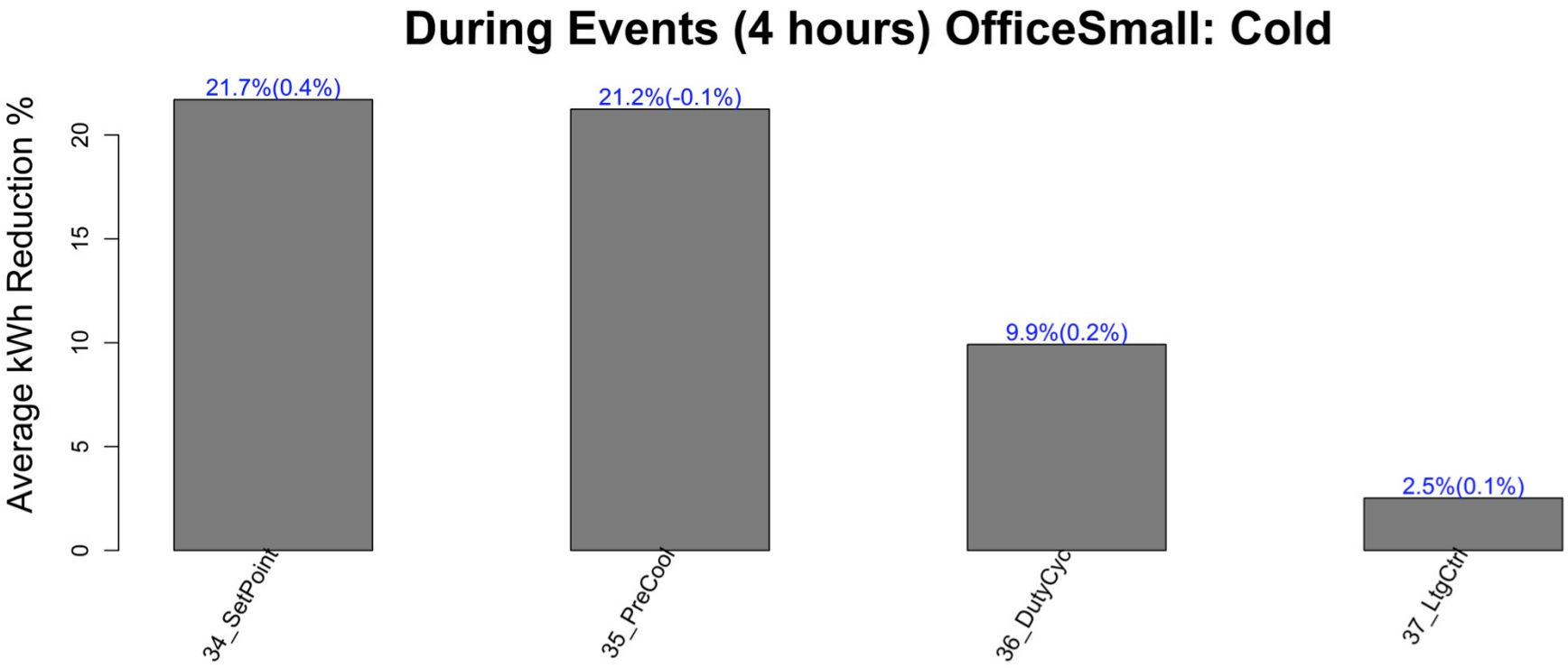
Average kWh Reduction from Demand Response Measures: Small Office – Warm/Mixed

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



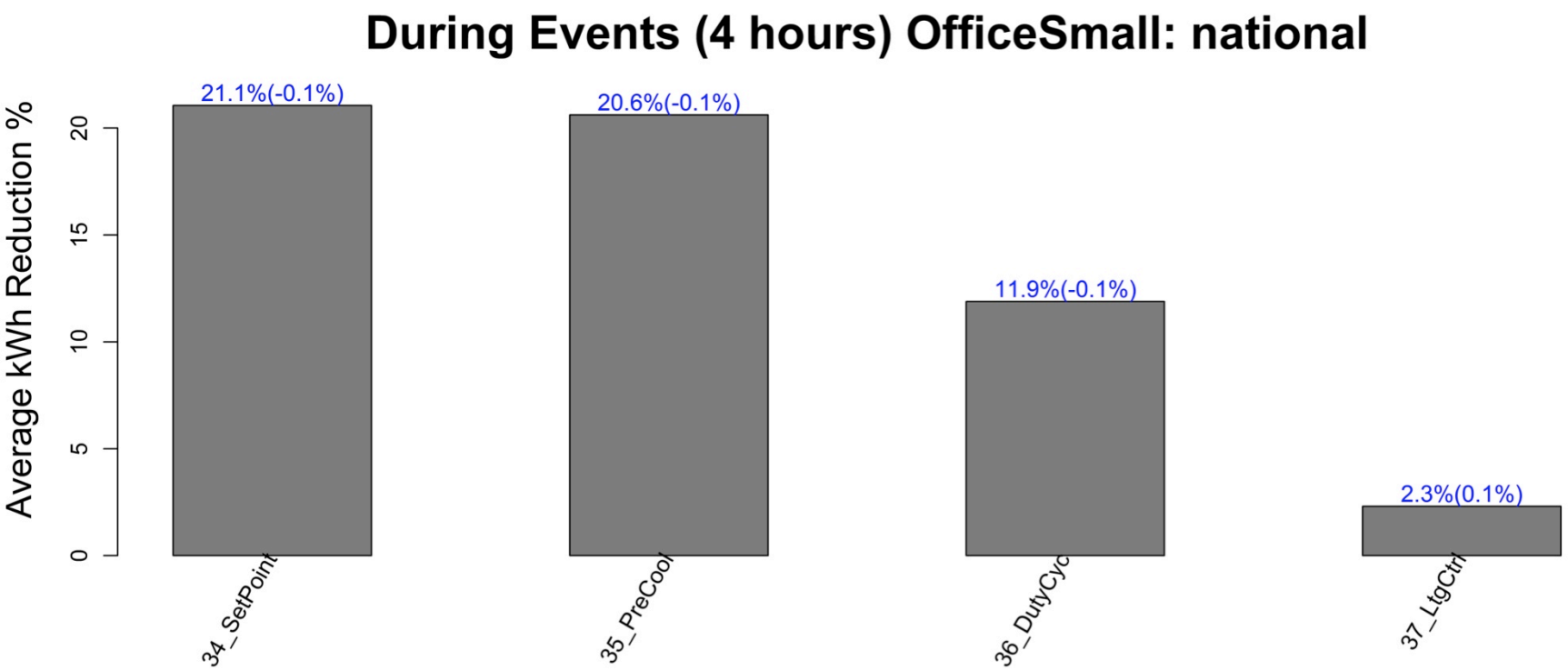
Average kWh Reduction from Demand Response Measures: Small Office – Cold

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



Average kWh Reduction from Demand Response Measures: Small Office – National

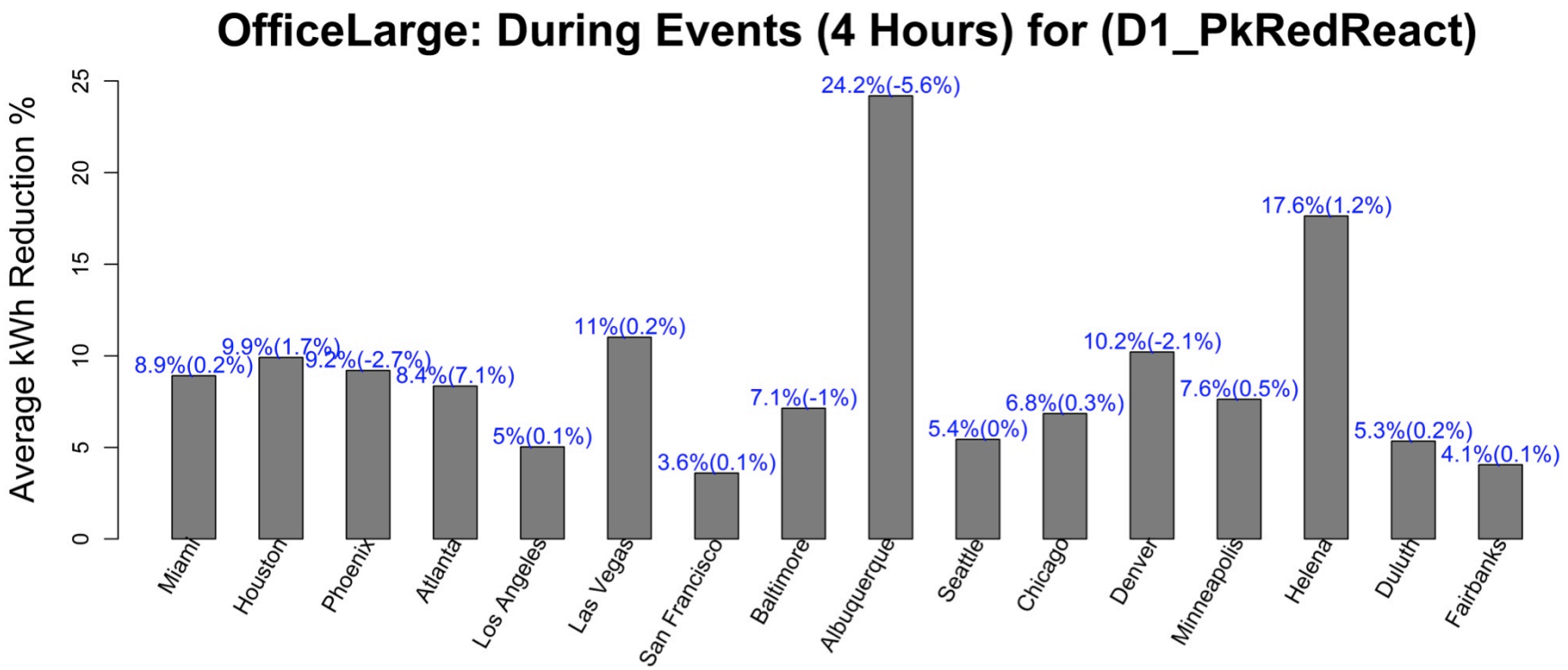
(during 4 hour event; values in the parentheses are over the 24 hour period; negative reduction = increased consumption)



Demand Response Package Results

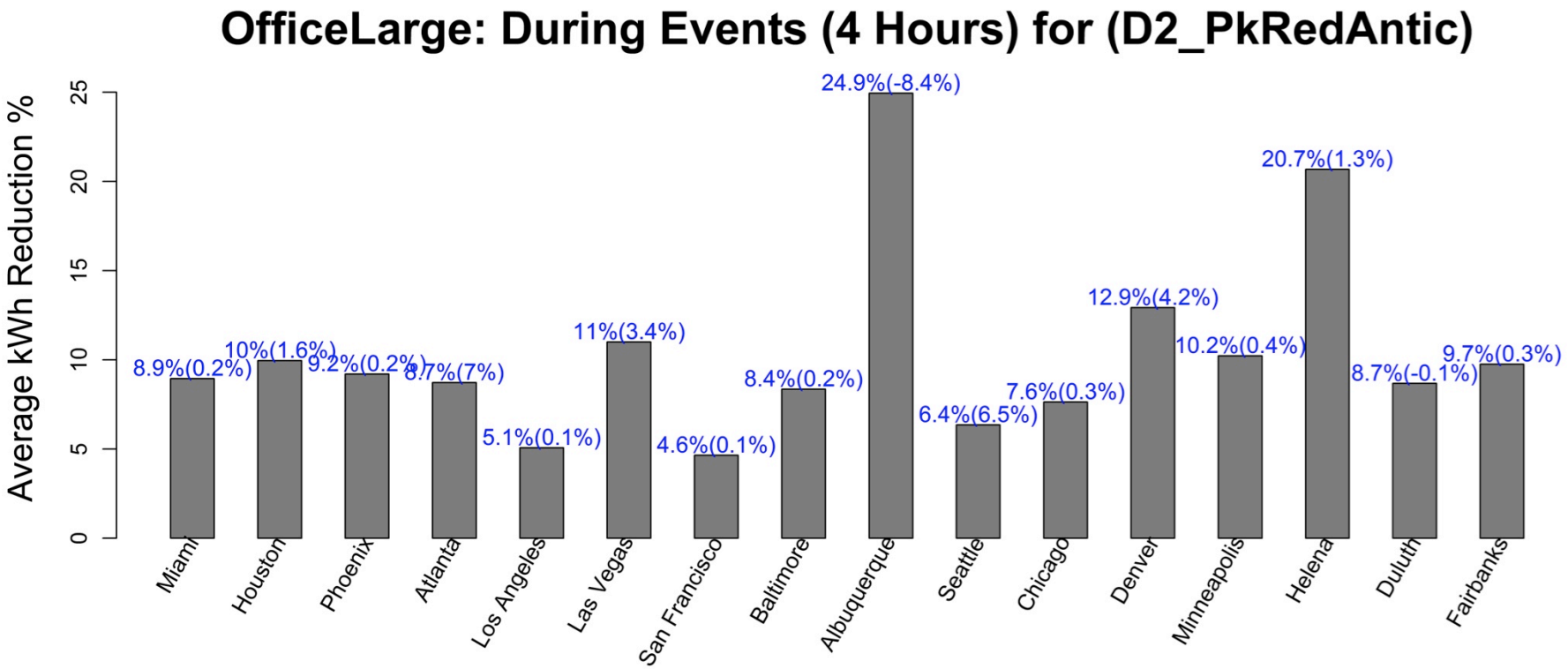
Average kWh Reduction from Demand Response Package D1: Large Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



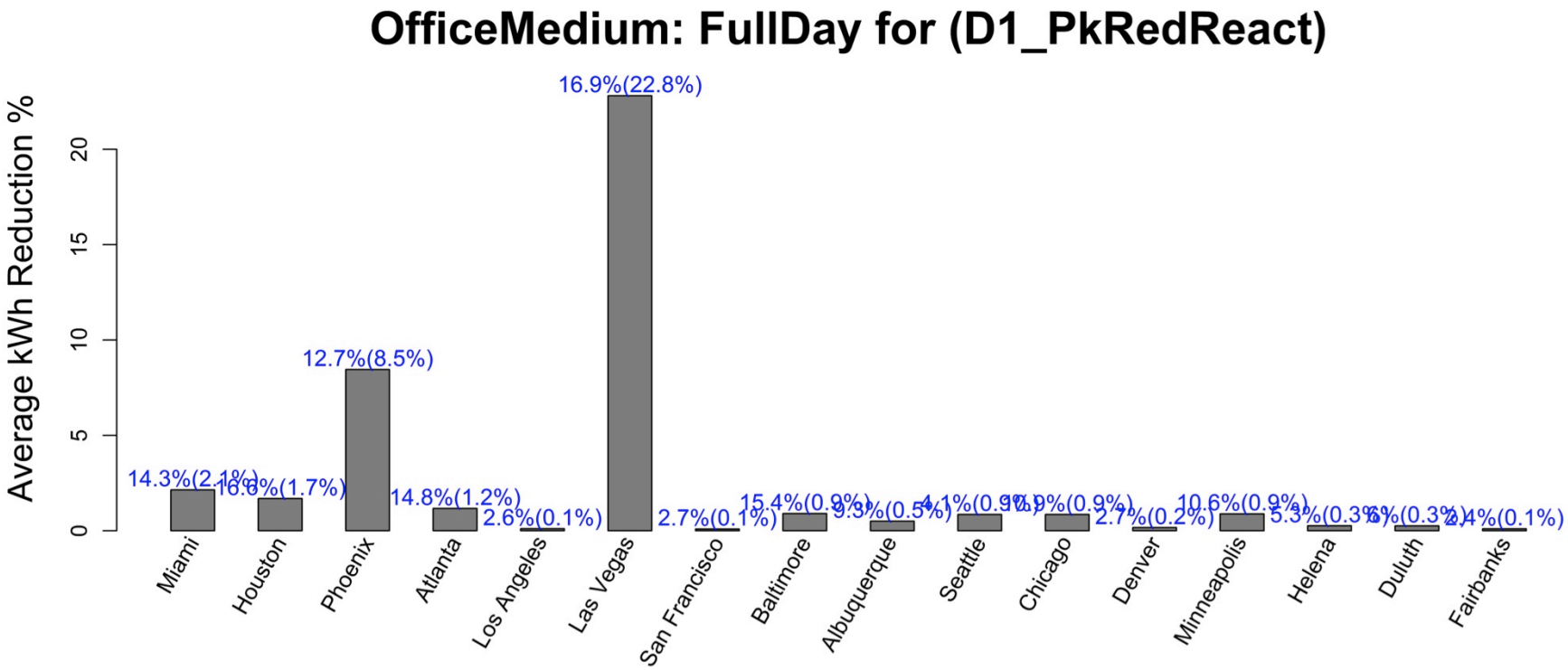
Average kWh Reduction from Demand Response Package D2: Large Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



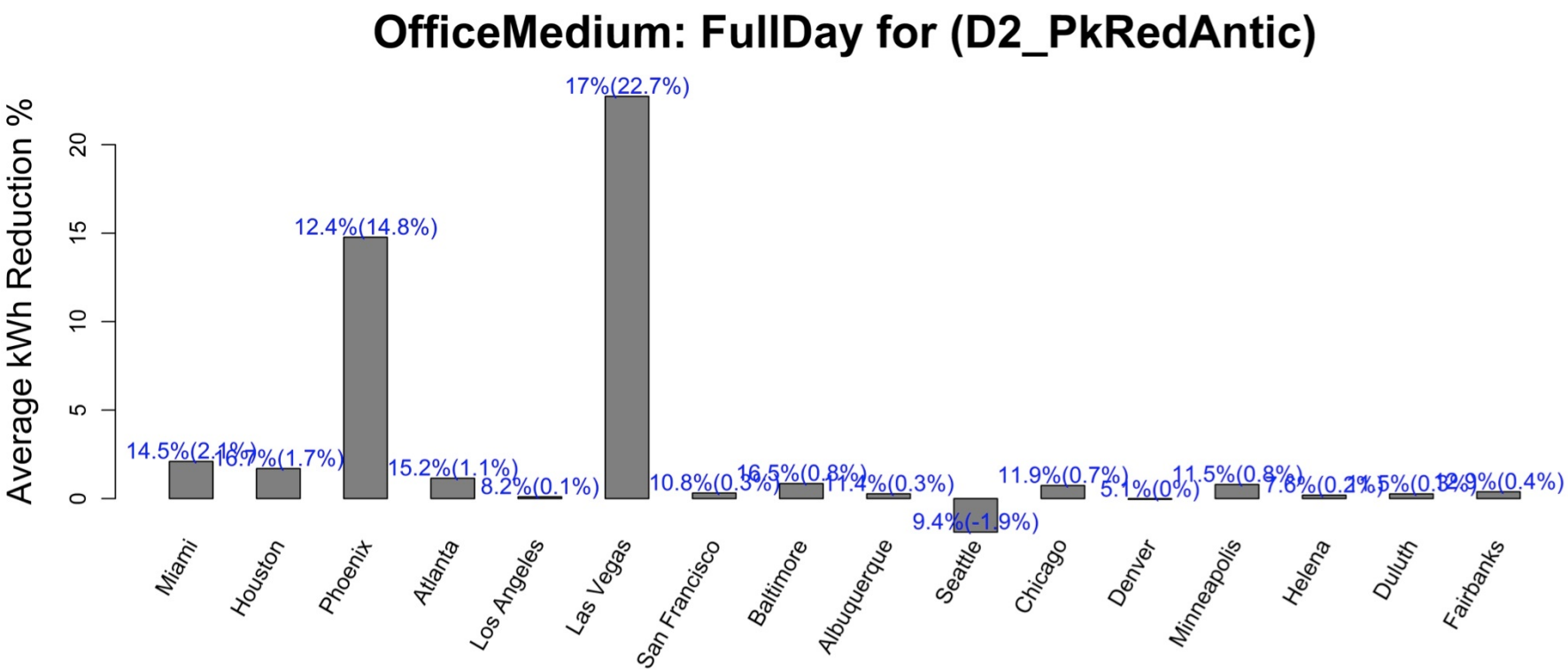
Average kWh Reduction from Demand Response Package D1: Medium Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



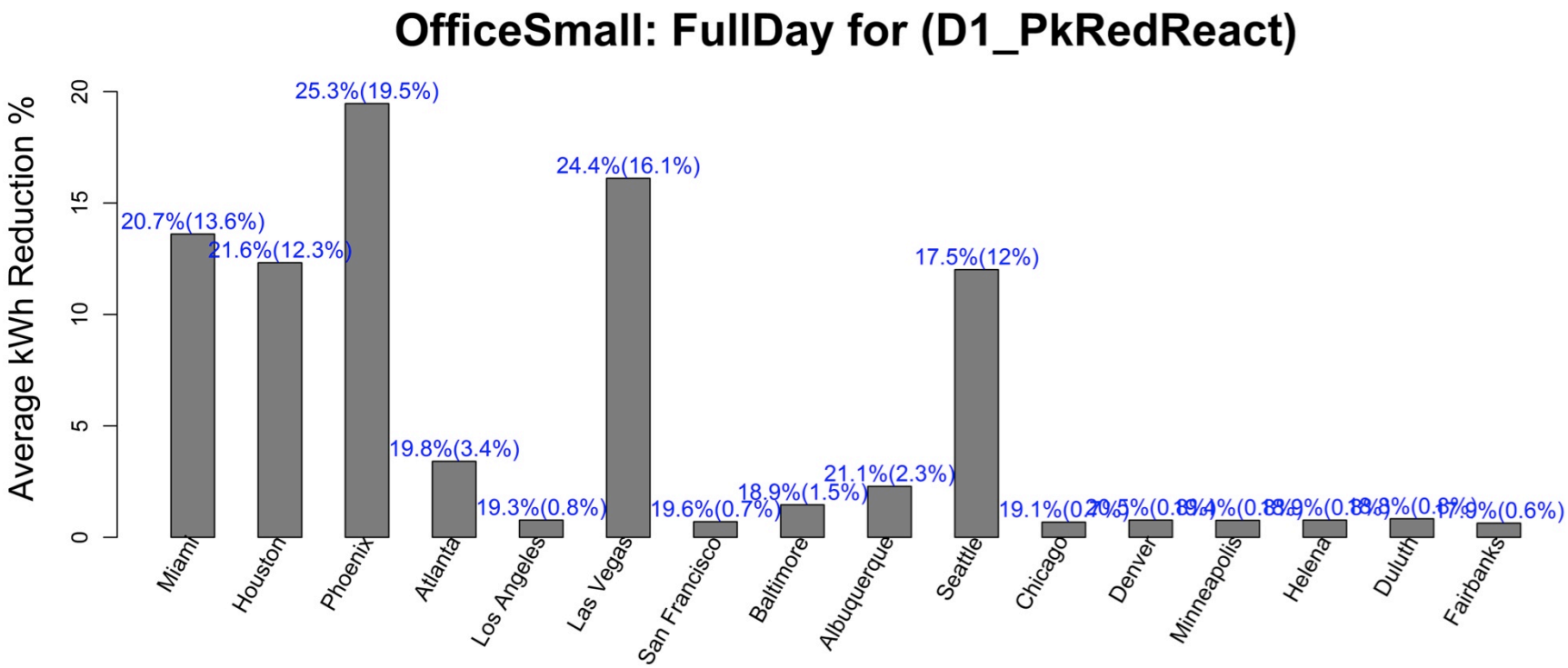
Average kWh Reduction from Demand Response Package D2: Medium Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



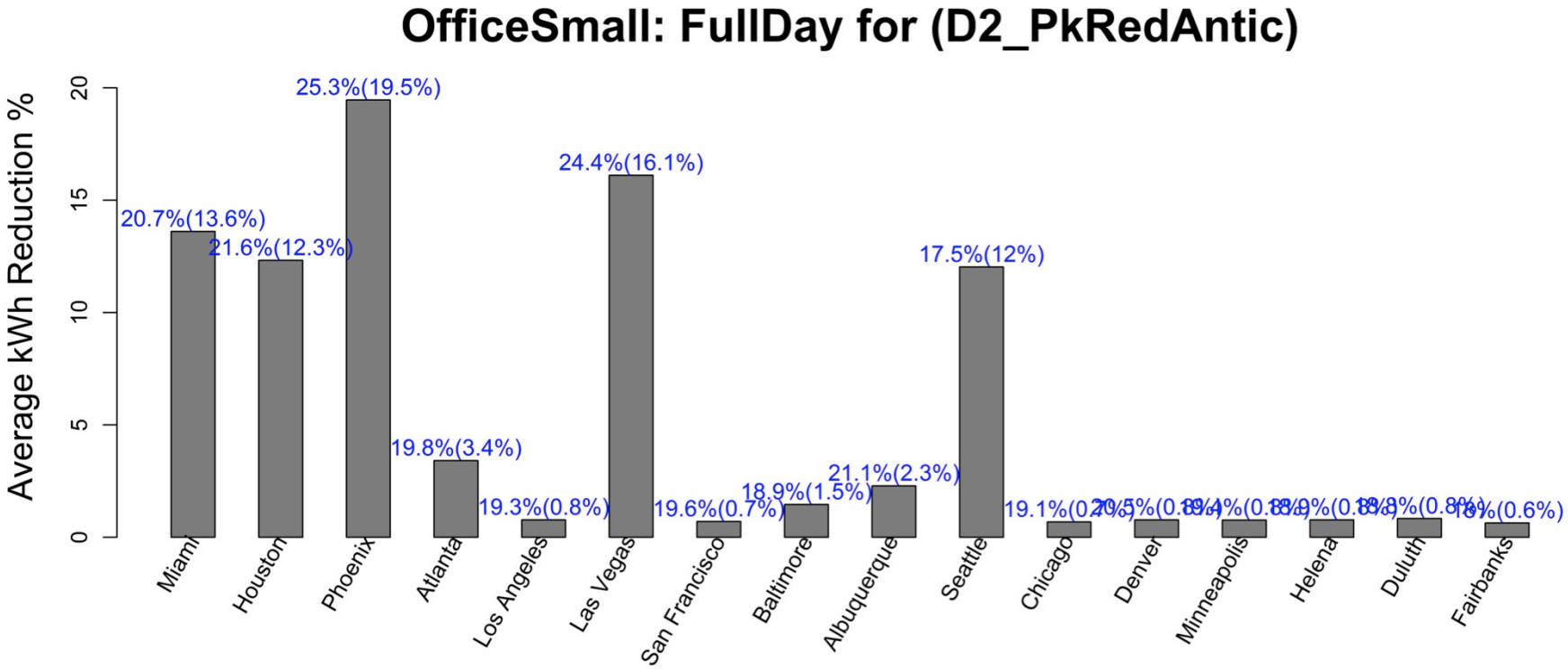
Average kWh Reduction from Demand Response Package D1: Small Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



Average kWh Reduction from Demand Response Package D2: Small Office

(during 4 hour event; values in the parentheses are over the 24 hour period; negative reductions = increased consumption)



Summary of Results

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- The savings for the individual measures ranged from 0% to 17% of the total building consumption
- The savings from packages ranged from 1% to 46% of the total building consumption
- The savings for the most likely package, which has a small capital requirement, would yield over 30% savings in most climate locations
- The average demand reduction during the demand response event (4 hour period) ranged between 2% and 20%
- **In FY15, PNNL plans to extend this analysis to cover additional buildings types.**

Concluding Remarks

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- Complete the review of simulation results, validate models and update models, if needed
- Complete the presentation with supporting information to support the analysis effort
- The analysis can be used to estimate the potential benefits of sensors, controls and diagnostics in the commercial building sector
- Because there aren't any documented studies that state the prevalence of problems
  - The "most-likely" package is our best guess of what we think is reasonable with little capital investment
- The analysis required a number of assumption, if someone doesn't like the assumption, they can certainly use their assumption to re-estimate the national potential by exercising the reference models
- Some of measures that were identified were not modeled, either because of limitations of EnergyPlus (some sensor faults, ancillary services) or the complexity of modeling (thermal storage)