PG&E HVAC Tool Validation

Final Report

ET23SWE0060

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Executive Summary

The PG&E HVAC Tool has been developed and managed by Pacific Gas & Electric (PG&E) to enable energy efficiency developers and implementors to estimate savings for retro-commissioning (RCx) measures pursuing various utility energy incentives in commercial buildings in California. However, developers and implementors have been reluctant to use this Tool without additional validation and California Public Utilities Commission (CPUC) approval. The project team hopes that investor-owned utility (IOU) program managers, program implementors, or California Technical Forum (CalTF) staff will implement the recommended tool upgrades. This will increase the likelihood and timeliness of tool acceptance and approval by the CPUC. To validate the performance of this Tool, the project team used EnergyPlus (E+) to generate energy modeling estimates to compare to the Air Side and Hot Water System measures estimates in the Tool.

The project team used the existing commercial Database for Energy Resources (DEER) prototypes for energy modeling and selected four commercial prototypes, including Retail - Multistory Large (Rt3), Office - Large (OfL), Education - Secondary School (ESe), and Manufacturing – Light Industrial (MLI), and three California climate zones (CZ12, CZ14, and CZ16), representing mild, hotter, and colder weather conditions. The project team validated six Air Side System measures and five Hot Water System measures, resulting in 132 model runs in total.

This report provides details about the development of the simulation procedure and calculator input determination process for estimating the savings from the 132 modeling and calculator runs. It details the base case energy consumption and the measure savings comparison, as well as sensitivity analysis results for each measure. It also discusses the possible reasons behind the savings differences between modeling and Tool results under each measure. Additionally, the report summarizes the sources of modeling uncertainty.

The project team recommends that PG&E, CalTF, or future Tool owners potentially improve the Tool for better accuracy and ease of use based on the differences or anomalies identified in the Tool. The recommendations section describes the details for each of them.

Abbreviations and Acronyms

Acronym	Meaning
ACM	Alternative Calculation Method Reference Manual
CalTF	California Technical Forum
CAV	Constant Air Volume
CPUC	California Public Utilities Commission
CZs	Climate Zones
DEER	Database for Energy Resources
DP	Differential Pressure
E+	EnergyPlus
EMS	Energy Management System
ESe	Education - Secondary School
HVAC	Heating, Ventilation and Air Conditioning
HW	Hot Water
HWRT	Hot Water Return Temperature
IOU	Investor-owned utility
M_	Modeling
MLI	Manufacturing – Light Industrial
MS%_	Modeling Savings Percentage
MZVAV	Multi-zone Variable Air Volume
OA	Outdoor Air
OAT	Outdoor Air Temperature

Acronym	Meaning
OfL	Office - Large
PG&E	Pacific Gas and Electric
PG&E HVAC Tool	The Tool
PHWP	Primary-Only Hot Water Pump
PLR	Part-load-ratio
RAT	Return Air Temperature
RCx	Retro-Commissioning
RH	Reheat
Rt3	Retail - Multistory Large
SAT	Supply Air Temperature
SHWT	Supply Hot Water Temperature
SP	Static Pressure
T_	Tool_
TS%_	Tool Savings Percentage
VAV	Variable Air Volume
VFD	Variable Frequency Drive

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Introduction

The “PG&E HVAC Tool”, developed and managed by Pacific Gas and Electric (PG&E), is currently available to energy efficiency developers and implementors to estimate savings for retro-commissioning (RCx) measures pursuing investor-owned utility (IOU) energy incentives in commercial buildings in California. However, other program stakeholders are reluctant to use the Tool without additional validation and California Public Utilities Commission (CPUC) approval. The project team proposed to validate the Air Side System and Hot Water System measures energy savings in the Tool using simulation output generated by EnergyPlus (E+).

Background

To date, the Tool has been developed and managed by PG&E. The California Technical Forum (CalTF)[1] developed an RCx Custom Measure Characterization report[2], in which it proposed using this Tool as the methodology to estimate energy savings for common RCx measures. CalTF solicited stakeholder input on the Tool, and this validation work provides helpful feedback for future use of the Tool statewide. The RCx measures that the Tool can estimate are:

Air Side System Measures

- Equipment Specifications & Replacements
- Scheduling Optimization
- Economizer Optimization
- Static Pressure Reset
- Supply Air Temperature Reset
- Fan and Space Temperature Setbacks

Hot Water System Measures

- Boiler & Pumps Specifications
- Hot Water Plant Lockout Control
- Boiler Staging Sequence (for multi-boiler systems)
- Hot Water Temperature Reset
- Hot Water Pump VFD and Speed Control

Chilled Water System Measures

- Chillers, Cooling Towers & Pumps Specifications
- Chilled Water Plant Lockout Control
- Chiller Staging Sequence Optimization (for multi-chiller systems)
- Chilled Water Temperature Reset

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[1] The California Technical Forum (CalTF) was created in 2014, which is a collaborative of experts who use independent professional judgement and a transparent, technically robust process to review and issue technical information related to California’s integrated demand side management portfolio. More information can be found here: https://www.caltf.org.

[2] Through personal communication, this report is not publicly available yet.

- Condenser Water Temperature Reset
- Water Side Economizer Optimization
- Cooling Tower Staging Sequence Optimization (for multi-CT systems)
- Secondary Chilled Water Pump VFD and Speed Control

The project team details the descriptions and inputs for each measure in the Findings section below. Please note that the Chilled Water System measures validation is beyond the scope of work for this project but would be a good topic for further work.

Objectives

The goal of this project is to accelerate the acceptance of the “PG&E HVAC Tool” as a statewide standard tool by the three IOUs, CalTF, and the CPUC. A statewide RCx tool used by implementors, program administrators, and program evaluators, would provide a common and shared approach to estimating and verifying RCx savings. The results of this work will help all users understand and minimize uncertainties, while reducing the project development and review time when using the Tool to forecast and verify CPUC/IOU energy savings claims and incentives. This will also increase the use of the Tool for the purposes described in CalTF’s new RCx Custom Measure Characterization report.

Methodology & Approach

The Tool uses the bin method based on the concept that the heating, ventilation, and air conditioning (HVAC) component performance or building loads can be expressed as a linear function of the outdoor air dry-bulb temperature. The bin method divides outdoor air temperature ranges into “bins” and calculates building load for each bin by multiplying the number of hours per year that the average outdoor air temperature is contained in a temperature bin by the load in that bin. The bin method does not include a detailed load calculation method, including the envelope heat transfer, internal heat gains, etc., which are time- and temperature-dependent. The Tool will provide energy savings for the measures based on the user inputs. To validate the Air Side System and Hot Water System measures in the Tool, the project team conducted modeling using E+ and then compared the results generated from the simulation with the results output from the Tool. First, the project team selected the existing commercial Database for Energy Resources (DEER) prototypes (California Public Utilities Commission 2024) as the base models. The project team determined the base case and measure case inputs for both the E+ models and the Tool, in order to align the assumptions among them. Second, the project team ran both the E+ models and the Tool to obtain the base case energy consumption and energy savings results for each of these measures. Finally, the project team compared the energy consumption and energy savings results between the two resources and evaluated the model sensitivity of the savings across different prototypes and climate zones (CZs) and sources of modeling uncertainty.

The project team selected four commercial prototypes and three California CZs to cover different types of commercial buildings and weather conditions where the project team expects to see different assumptions and energy usage patterns. The four DEER commercial prototypes include Retail - Multistory Large (Rt3), Office - Large (OfL), Education - Secondary School (ESe), and

Manufacturing – Light Industrial (MLI) which align with four of the 24 commercial building types listed in the Tool (Retail Merchandise/Wholesale, Office, School, and Manufacturing Factories). Table 1 shows the basic building information for these four prototypes. For the three CZs, the project team selected CZ12, CZ14, and CZ16, representing mild, hotter, and colder weather conditions, respectively, depending on the average heating and cooling degree days. There are six Air Side System measures and five Hot Water System measures, resulting in 132 model runs in total.

Table 1: Building Information for the Four Selected Prototypes

Prototypes	Code	Conditioned Area (ft^2)	Floors
Retail – Multi-story Large	Rt3	119,996	3
Office – Large	OfL	174,957	10
Education – Secondary School	ESe	54,455	2
Manufacturing – Light Industrial	MLI	100,018	1

The project team initially chose the Rt3 prototype in CZ12 to develop the simulation procedure and determine the calculator input process and then applied the same procedure and process to all other prototypes and CZs for all Air Side System measures and all Hot Water System measures. To be able to use the same base case model to simulate both the Air Side System and Hot Water System measures, the HVAC system the project team had selected is a Multi-zone Variable Air Volume (MZVAV) with reheat serving the whole building. The heating coils are hot water coils served by a natural gas boiler, and the cooling coils are chilled water coils served by air-cooled chillers. All the Air Side System measures and all the Hot Water System measures share the same base case.

To analyze the modeling and Tool results, the project team first compared the base case energy consumption for the Air Side System measures and Hot Water System measures separately to make sure that the Tool inputs align with modeling assumptions. Then the project team compared the energy savings percentages between the modeling and Tool results for each measure, checked for the sensitivity of the savings across different prototypes and CZs, and discussed the sources of modeling uncertainty. Finally, the project team provided recommendations for potential improvements to the Tool.

Findings

The following subsections summarize 1) the measure input determination process; (under each measure in this section, the project team only listed inputs relevant to that measure. For all other inputs, the project team used the base case inputs from all other measures for calculations in the

Tool and modeling); 2) energy consumption and savings comparison between modeling results and the Tool results for each measure; 3) sensitivity analyses, combining the results across all prototypes and all CZs; and, 4) sources of modeling uncertainty. The approach is to evaluate each measure independently, to identify potential improvements and provide recommendations. The assessment of combinations of measures is not within the scope of this effort.

Air Side System Measures Tool Inputs

Equipment Specifications & Replacements

This measure includes cooling/heating equipment efficiency upgrades or fan control improvement. The Tool inputs under this measure include heating, ventilation, and air conditioning (HVAC) equipment type and sizing. For these inputs, the project team used the auto-sized capacities extracted from E+ output tables. These auto-sized capacities vary for different prototypes and CZs.

Under this measure, there could be multiple sub-measures, including upgrading chiller efficiency, fan control, etc. The sub-measure case the project team selected was to upgrade the non-condensing boiler efficiency from 0.80 in the base case to 0.87 in the measure case[3] based on subject matter expert discussion and product research. Table 2 summarizes the inputs under this measure.

Table 2: Tool Inputs under Air Side System: Equipment Specifications & Replacements Measure

Parameters[4]	Base Case	Measure Case	Source
Equipment Name	AHU-1	Same as base case	Tool default
Seasonal average kW/Ton	0.89	Same as base case	E+ output tables
Source of Heating	Gas	Same as base case	DEER prototype default
Gas Efficiency	0.80	0.87	DEER prototype default
Heating Lockout Temp (°F)	103 for CZ12 and CZ16 109 for CZ14	Same as base case	Design cooling outdoor air temperature (OAT)[5]

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[3] This measure could also be under the Hot Water System Measures – Boilers & Pumps Specifications, but we didn't test that.

[4] The parameters' names came from the Tool. Detailed descriptions can be found in the manual of the Tool. The Tool and Tool manual are available upon request <YChu@trccompanies.com> through 12/31/2024. Thereafter, refer to <www.calnext.com>

[5] We used the cooling and heating design OAT from the Tool, which also aligns with the design day data for California cities in 2022 Building Energy Efficiency Standards Appendix JA2-4 Table 2-3 (California Energy Commission 2022).

Parameters[4]	Base Case	Measure Case	Source
Cooling Lockout Temp (°F)	30 for CZ12 29 for CZ14 16 for CZ16	Same as base case	Design heating OAT[6]
Supply Fan (HP)	Varies for each prototype and each CZ	Same as base case	E+ output tables
Supply Fan (CFM)	Varies for each prototype and each CZ	Same as base case	E+ output tables
Supply Fan Control	Variable Frequency Drive (VFD)	Same as base case	DEER prototype default
Return Fan (HP)	Varies for each prototype and each CZ	Same as base case	E+ output tables
Return Fan (CFM)	Varies for each prototype and each CZ	Same as base case	E+ output tables
Return Fan Control	VFD	Same as base case	DEER prototype default
Return Fan % of Supply	100%	Same as base case	DEER prototype default
System Type (Constant Air Volume (CAV)/Variable Air Volume (VAV))	Variable Air Volume	Same as base case	DEER prototype default
Return Fan (HP)	Varies for each prototype and each CZ	Same as base case	E+ output tables

[6] Ibid.

Scheduling Optimization

This measure changes the operation schedule of the HVAC equipment to better align with the building occupancy schedule. The project team used the DEER prototype default schedule as the base case. For the measure case, the project team assumed that the HVAC system would stop operating one hour ahead to conservatively estimate savings from this measure. The project team also assumed temperature setbacks for unoccupied periods along with this measure to capture reasonable savings. Table 3 lists the inputs under this measure.

Table 3: Tool Inputs Under Air Side System: Scheduling Optimization

Parameters	Base Case	Measure Case
Weekday HVAC Operation Schedule	6 a.m. – 9 p.m. as an example Varies for each prototype	6 a.m. – 8 p.m. as an example Varies for each prototype
Saturday HVAC Operation Schedule	6 a.m. – 10 p.m. as an example Varies for each prototype	6 a.m. – 9 p.m. as an example Varies for each prototype
Sunday HVAC Operation Schedule	8 a.m. – 7 p.m. as an example Varies for each prototype	8 a.m. – 6 p.m. as an example Varies for each prototype
Heating Setpoint Temperature (°F)	Occupied: 70 Unoccupied: 65	Same as base case
Cooling Setpoint Temperature (°F)	Occupied: 75 Unoccupied: 80	Same as base case

Economizer Optimization

Economizer operation allows the introduction of more outdoor air (OA) to enable free cooling to save HVAC cooling energy. The base case assumes there is no economizer, while the measure case uses an economizer with fixed dry bulb control, which is the standard design strategy in the 2022 Nonresidential and Multifamily Alternative Calculation Method Reference Manual (ACM) (California Energy Commission 2022). The project team then determined the economizer high limit, varying by CZ, following Table 140.4-G in the 2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (California Energy Commission 2022). The project team extracted the OA percentage range from the E+ hourly variable output: Air System Outdoor Air Fraction during both Occupied and Unoccupied periods and used that for the Occupied OA percentage range and Unoccupied OA percentage range in the Tool. Table 4 shows the inputs under this measure.

Table 4: Tool Inputs Under Air Side System: Economizer Optimization

Parameters	Base Case	Measure Case	Source
Data Type*	Simple Data	Same as base case	Tool default
Occupied OA %	Constant OA % Varies for each prototype and CZ (Range: 15% to 34%)	Min OA % (Same as base case) to 100%	E+ hourly variable output: Air System Outdoor Air Fraction
Occupied Enable OAT (°F)	75	Same as base case	2022 Building Energy Efficiency Standard
Unoccupied OA %	0%	0% to 100%	E+ hourly variable output: Air System Outdoor Air Fraction
Unoccupied Enable OAT (°F)	75	Same as base case	2022 Building Energy Efficiency Standard

*The Tool has two options when providing inputs: "Simple Data" and "Trend Data". By using "Simple Data", the calculator will always select the optimal OA percentage within the bounds of the minimum and maximum percentages that are entered for maximum free cooling based on OAT, return air temperature (RAT), and supply air temperature (SAT). For "Trend Data", the user needs to provide detailed OA percentage trend data that has been binned in each corresponding OAT bin. To simplify the process, the project team chose the "Simple Data" method for all Data Types where that is applicable.

Static Pressure (SP) Reset

SP reset is a control strategy that helps minimize fan energy in VAV systems by resetting the SP based on the flow demand. The project team assume that there is no SP reset in the base case with a constant SP setpoint of 1.5 inches. Measure case assumes static pressure reset with a minimum SP setpoint of 0.5 inches. The Tool will select the corresponding fan curve associated with different SP setpoints (in. Water min and max which are the Tool inputs) from DOE-2. For the base case, the Tool used the fan curve without reset, while for the measure case, it used the fan curve with good reset.

Table 5 lists the inputs under this measure.

Table 5: Tool Inputs Under Air Side System: SP Rese

Parameters	Base Case	Measure Case	Source
in. Water min	1.5	0.5	Tool default Fan curve with good reset
in. Water max	1.5	Same as base case	Tool default Fan curve without reset

Supply Air Temperature (SAT) Reset

This measure increases SAT to allow reduced compressor energy and reheat energy with decreasing OAT but may increase fan energy in a VAV system. The Tool uses the OA Reset method for this measure, where SAT will reset based on the OAT. The base case for this measure is an air system without OA Reset, i.e., constant SAT, and the measure case includes the OA Reset strategy. The supply temperature and OA range with reset are from the DEER prototype default. Table 6 shows the inputs for this measure.

Table 6: Tool Inputs Under Air Side System: SAT Reset

Parameters	Base Case	Measure Case	Source
Data Type	Simple Data	Same as base case	Tool default
Supply Air Temp	55	60 to 55	DEER prototype default
@ OAT	50 to 75	Same as base case	DEER prototype default
Pre-Heat Coil?	No	Same as base case	DEER prototype default

Fan and Space Temperature Setbacks

This measure includes two sub-measures: the first is the fan setback where the user can reduce the VAV box minimum flow, and the other is the space temperature setback where the user can increase the deadband for the zone space temperature setpoints when the space is unoccupied. The project team analyzed the two sub-measures separately.

For the fan setback sub-measure, the project team assumed the baseline model input for the minimum supply fan air flow ratio is 0.3, while it is 0.2 for the measure case. The project team then obtained the actual minimum supply fan air flow percentages from the E+ hourly variable output: Air System Supply Fan Airflow during both occupied and unoccupied periods for both cooling and heating, which account for minimum ventilation rates, and used that for the occupied and unoccupied fan flow range during both cooling and heating in the Tool.

Table 7 summarizes the inputs for the fan setback sub-measure. The occupied OA cooling and heating temperature ranges are slightly different due to our workarounds to make the slope of the supply fan flow percentages vs. OAT for cooling the same between the base case (30 percent minimum) and the measure case (20 percent minimum). The unoccupied fan flow percentage and temperature ranges are different from the occupied periods due to fan cycling, resulting in different fan flow patterns.

For the space temperature setback sub-measure, the project team assumed there is no setback applied in the base case, and there are setbacks in the measure case. The project team used the DEER prototype default schedules for the heating and cooling space temperature setpoints. Table 8 provides the inputs for the space temperature setback sub-measure.

Table 7: Tool Inputs Under Air Side System: Fan Setbacks

Parameters	Base Case	Measure Case	Source
Data Type (Supply Fan Flow)	Simple Data	Same as base case	Tool default
Occ Fan Flow % - Cool	30% (increases in some zones to meet minimum ventilation requirements) - 100% Varies for each prototype and CZ	20% (increases in some zones to meet minimum ventilation requirements) - 100% Varies for each prototype and CZ	E+ hourly variable output: Air System Supply Fan Airflow
Occ OA Cooling Temp Range (°F)	60°F to Design cooling OAT Varies for each CZ	53°F to Design cooling OAT Varies for each CZ	The low end is a rule-of-thumb number The high end is the design cooling temperature
Occ Fan Flow % - Heat	30% with increases in some zones to meet minimum ventilation requirements	20% with increases in some zones to meet minimum for ventilation requirements	E+ hourly variable output: Air System Supply Fan Airflow

Parameters	Base Case	Measure Case	Source
Occ OA Heating Temp Range (°F)	Design heating OAT to 55 Varies for each CZ	Design heating OAT to 50 Varies for each CZ	The high end is a rule-of-thumb number. The low end is the design heating temperature
Unocc Fan Flow % - Cool	0% to Maximum Unocc Cooling Fan Flow Varies for each prototype and CZ	Same as base case	E+ hourly variable output: Air System Supply Fan Airflow
Unocc OA Cooling Temp Range (°F)	60 to Design cooling OAT Varies for each CZ	Same as base case	The low end is a rule-of-thumb number. The high end is the design cooling temperature
Unocc Fan Flow % - Heat	0% to Maximum Unocc Heating Fan Flow Varies for each prototype and CZ	Same as base case	E+ hourly variable output: Air System Supply Fan Airflow
Unocc OA Heating Temp Range (°F)	50 to 45	Same as base case	The high end is a rule-of-thumb number. The low end is the high end minus 5 °F.
Data Type (VAV Reheat)	Simple Data	Same as base case	Tool default
Fraction of Zones with Reheat (RH)	100%	Same as base case	E+ default assumption
@ OAT (No RH) (°F)	55	Same as base case	Derived from E+ hourly results
Select Closest City	Stockton AP for CZ12 Daggett AP for CZ14 Bishop AP for CZ16	Same as base case	CZ2022 weather files
Design Heating OAT Lookup (°F)	Design heating OAT Varies for each CZ	Same as base case	Rule of thumb

Parameters	Base Case	Measure Case	Source
Override Lookup?	No	Same as base case	Tool default
Max DAT (Avg of All RH Boxes) (°F)	Occupied: Varies for each prototype and CZ Unoccupied: Varies for each prototype and CZ	Same as base case	E+ hourly variable output: Air System Discharged Air Temperature
RH VAV Flow & DAT Profile	NA	Auto Calc	Tool default

Table 8: Inputs Under Air Side System: Space Temperature Setbacks

Parameters	Base Case	Measure Case	Source
Occ Space Temp (°F)	Heating: 70 Cooling: 75	Same as base case	DEER prototype default
Unocc Space Temp (°F)	Heating: 70 Cooling: 75	Heating: 65 Cooling: 80	DEER prototype default
Return Air Temp	Use Space Temp	Same as base case	DEER prototype default

Air Side System Measures Results

Base Case Energy Consumption Comparison

First, the project team compared the base case energy consumption between the Tool and modeling (Figure 1 and Figure 2). Figure 1 shows that the hottest CZ (CZ14) has the highest cooling loads, and the coldest CZ (CZ16) has the highest heating loads for all prototypes (Figure 2). Under the same CZ, the loads are different for each prototype depending on the building size and characteristics. Taking the modeling results as the denominator, the percentage difference ranges are minus 28 percent to 28 percent, and minus 46 percent to 73 percent between modeling and the Tool for total electricity and total heating consumption, respectively, across all prototypes and CZs (

Table 9). The average percentage differences are four percent and minus 15 percent for total electricity and total heating consumption.

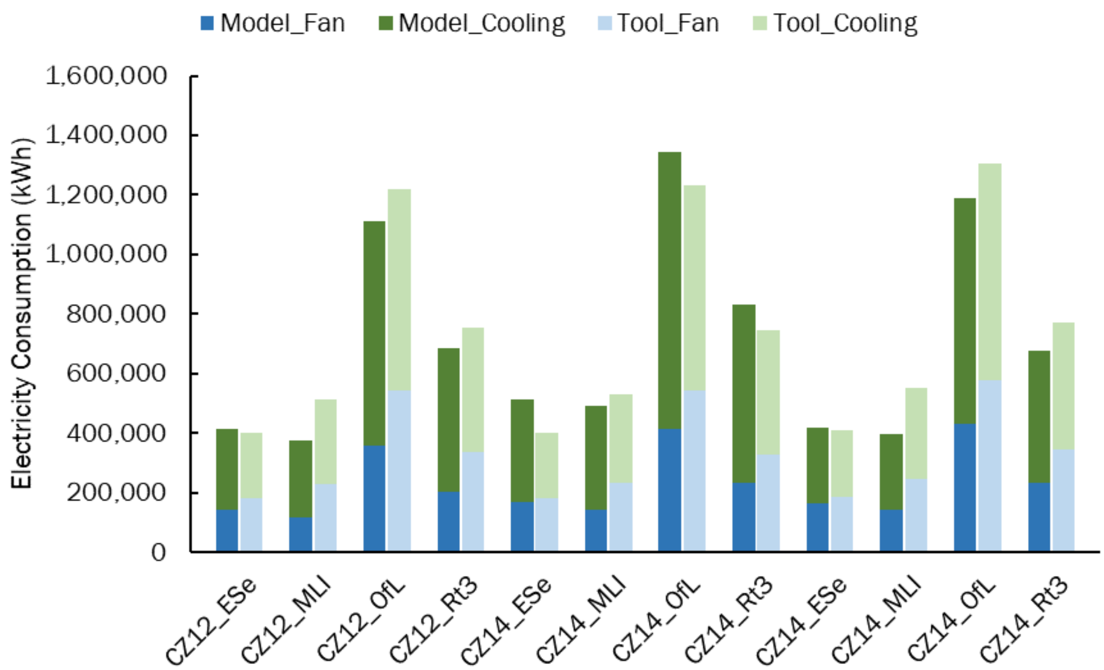

Figure 1: Base case fan and cooling electricity consumptions comparison for air side system measures.

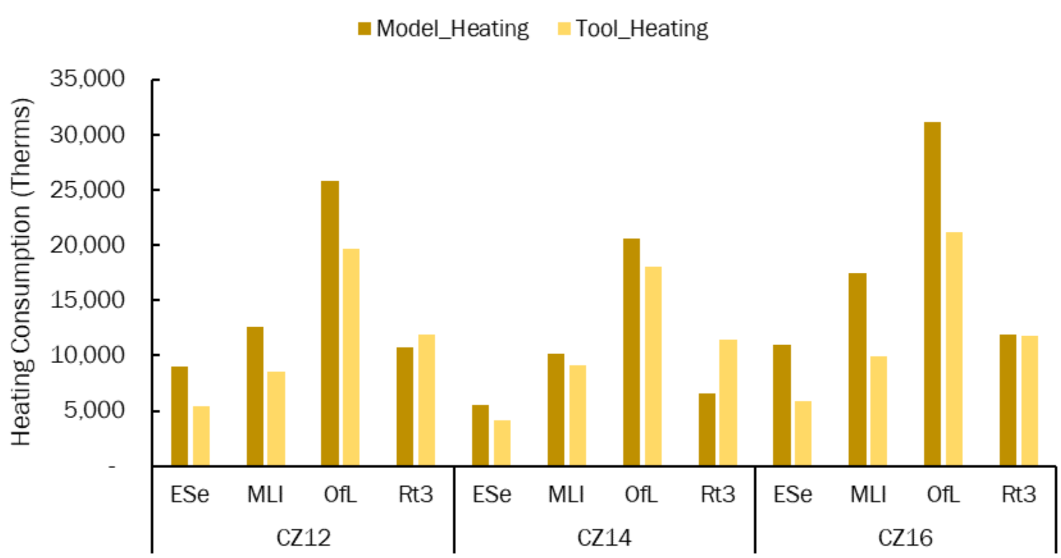

Figure 2: Base case heating energy consumptions comparison for air side system measures.

Table 9: Percentage Differences for Total Electricity and Heating Summary for Air Side System Measures

CZ	Prototype	Total Electricity_% difference	Total Heating_% difference
CZ12	ESe	-3%	-40%
CZ12	MLI	27%	-32%
CZ12	OfL	9%	-24%
CZ12	Rt3	9%	11%
CZ14	ESe	-28%	-26%
CZ14	MLI	8%	-11%
CZ14	OfL	-9%	-12%
CZ14	Rt3	-11%	73%
CZ16	ESe	-2%	-46%
CZ16	MLI	28%	-43%
CZ16	OfL	9%	-32%
CZ16	Rt3	12%	-1%
Mean	-	4%	-15%

Measure Cases Energy Savings Comparison and Sensitivity Analysis

Then the project team calculated the energy savings and energy savings percentages for each measure and compared the results from the Tool and modeling, checking for the sensitivity of the savings across different prototypes and CZs.

EQUIPMENT SPECIFICATIONS & REPLACEMENT

There are no fan and cooling savings for this measure. The minimum savings happened for Ese in CZ14, while the maximum savings were for OfL in CZ16. The heating savings percentages are approximately eight percent for both modeling and Tool results across all prototypes and CZs, which is expected due to the boiler efficiency improvement.

SCHEDULING OPTIMIZATION

There are fan, cooling, and heating savings for this measure. Table 10 summarizes the range and mean of the measure savings for both the modeling and the Tool results across all prototypes and CZs. Overall, the Tool seems to overestimate the cooling and fan savings and underestimate the heating savings for this measure, compared with the modeling results. One possible reason could be that the model is looking at an hour that has a lower load, however, the Tool does not account for the internal load differences between hours of the day. Figure 3 summarizes measure savings percentages (percent of base consumption) from both modeling and Tool results for each prototype and each CZ, where "MS%_" refers to modeling savings percentage, and "TS%_" refers to Tool savings percentage. For heating, the savings are higher from the modeling results for all prototypes except for MLI. One possible reason is that all other three prototypes are larger buildings where the reheat effect in core zones plays a significant role during cooling seasons, which are not considered in the Tool.

Table 10: Scheduling Optimization Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	0.3% - 0.6 %	0.8% - 1.1%	0.4%	1.0%
Cooling (kWh)	0.4% - 0.8 %	1.2% - 1.9%	0.6%	1.7%
Total (kWh)	0.9% - 1.3 %	2% - 3.1%	1.1%	2.7%
Heating (Therms)	1.9% - 7.9 %	-0.4% - 3.7%	5.0%	1.9%

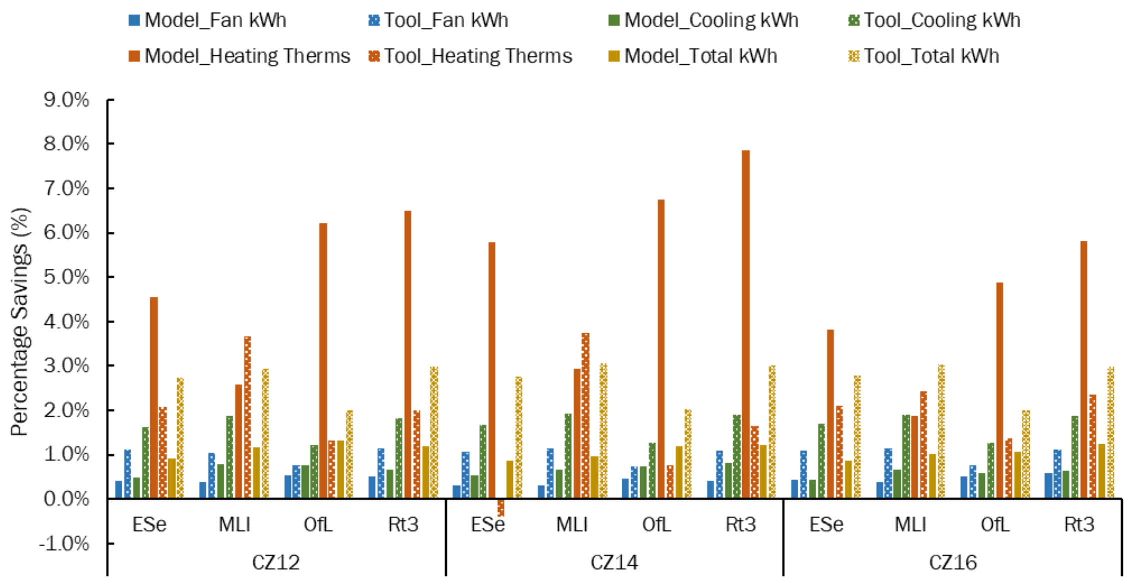

Figure 3: Scheduling Optimization Measure Energy Savings Comparison for All Cases

ECONOMIZER OPTIMIZATION

There are mainly cooling savings for this measure. Table 11 shows the calculated range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool seems to overestimate the cooling savings for this measure, compared with modeling results. Figure 4 lists the savings percentages from both modeling and Tool results for each prototype and each CZ. CZ12 has the largest savings, since milder CZs are more favorable for free cooling. The heating savings from modeling came from the controls set up in E+, which could be negligible.

Table 11: Economizer Optimization Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_Range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	0% - 0%	0% - 0%	0.0%	0.0%
Cooling (kWh)	5.7% - 17.7%	12.7% - 18.2%	10.8%	14.8%
Total (kWh)	5.6% - 17.7%	12.7% - 18.2%	10.8%	14.8%
Heating (Therms)	0.1% - 0.5%	0% - 0%	0.2%	0.0%

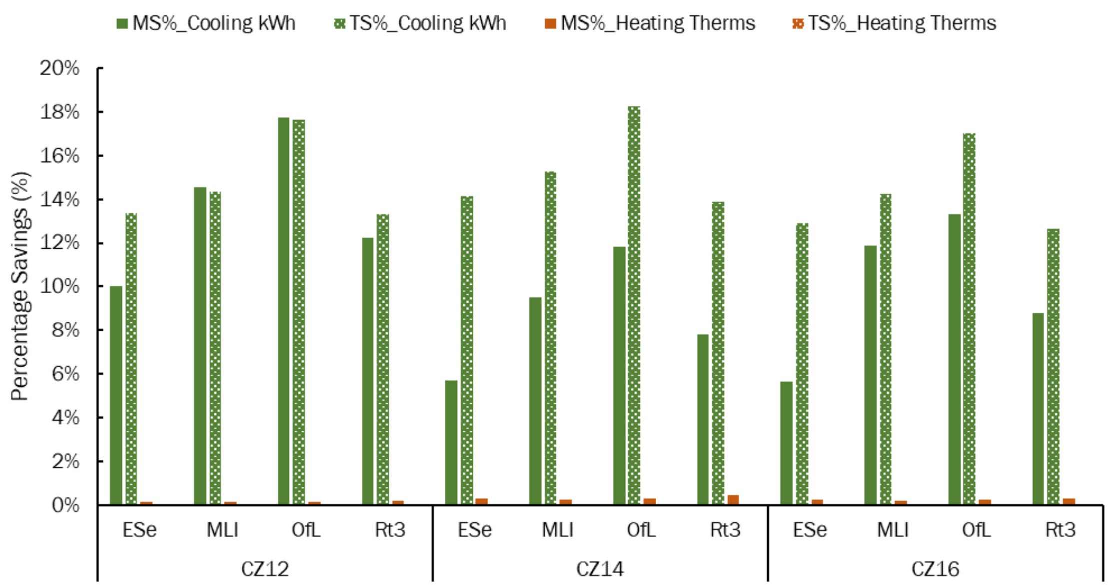

Figure 4: Economizer Optimization Measure Energy Savings Comparison for all Cases

SP RESET

There are mainly fan savings for this measure. Table 12 indicates the calculated range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool seems to overestimate the fan savings for this measure, compared with modeling results. Figure 5 represents the savings percentages from both modeling and Tool results for each prototype and each CZ. The cooling savings and heating savings from modeling came from the interactive effect between the fan and cooling and heating due to the fan heat entering the air stream in the model. The Tool does not consider these interactive effects.

Table 12: SP Reset Measure Savings Statistical Summary.

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	8.4% - 13.5%	14.4% - 17.7%	10.6%	15.8%
Cooling (kWh)	2.4% - 3.1%	0% - 0%	2.7%	0.0%
Total (kWh)	10.8% - 16.5%	14.4% - 17.7%	13.3%	15.8%
Heating (Therms)	-0.1% - 0%	0% - 0%	-0.1%	0.0%

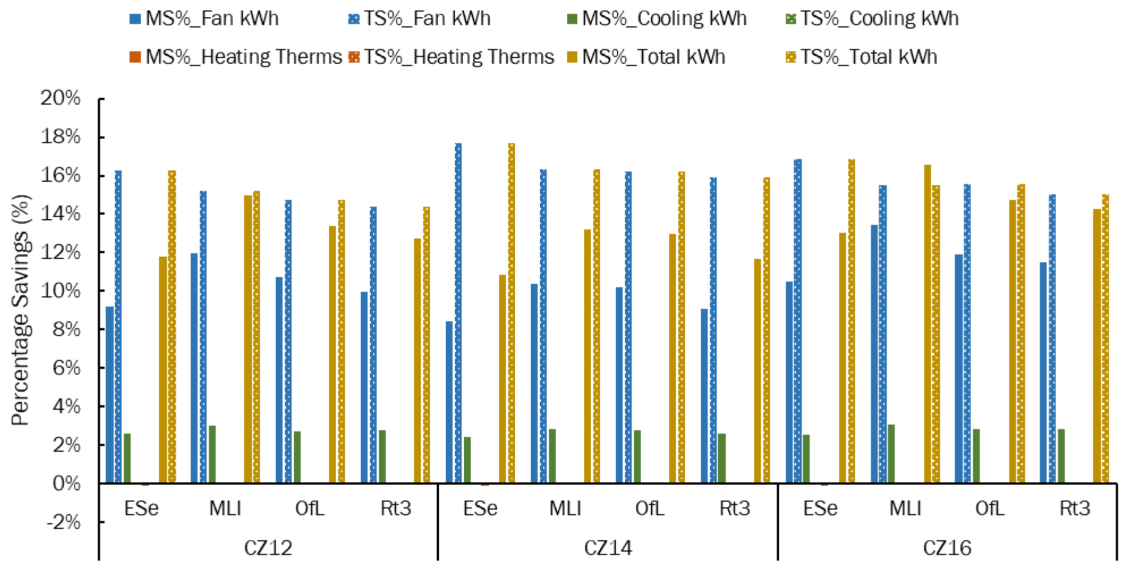

Figure 5: SP Reset Measure Energy Savings Comparison for All Cases

SAT RESET

There are mainly cooling and heating savings for this measure. Table 13 summarizes the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool overestimates the cooling and heating savings, compared with modeling results. Figure 6 indicates the savings percentages from both modeling and Tool results for each prototype and each CZ. There are fan penalties from the modeling results, since the increase of SAT may cause an increase in the fan air flow. However, the Tool does not consider the fan impact from this measure.

Table 13: SAT Reset Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	-2% - 0%	0% - 0%	-0.9%	0.0%
Cooling (kWh)	1.8% - 5.6%	6.4% - 8.1%	3.7%	7.2%
Total (kWh)	0.8% - 5.4%	6.4% - 8.1%	2.9%	7.2%
Heating (Therms)	28.2% - 42.6%	36.4% - 67.1%	34.5%	47.8%

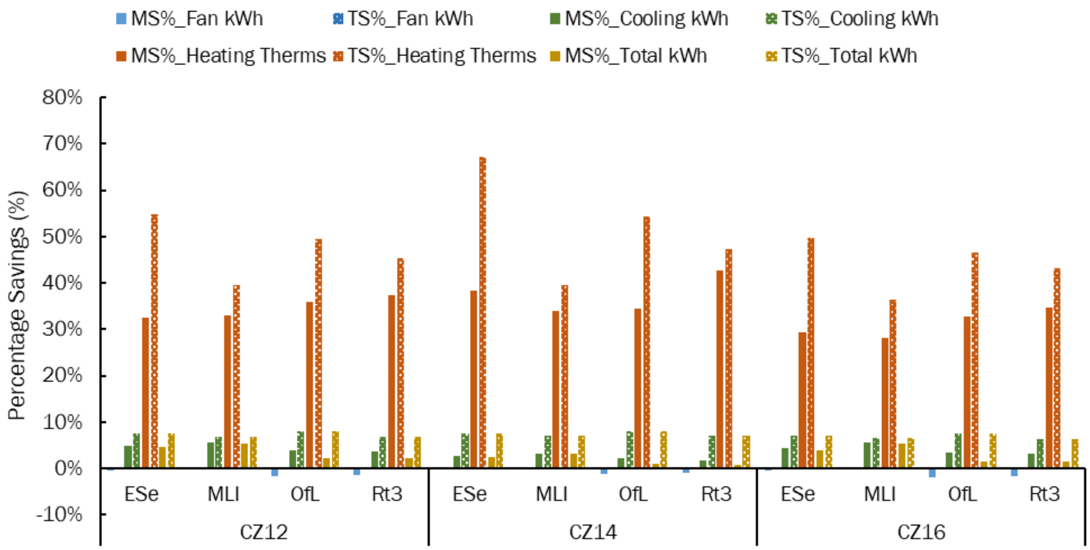

Figure 6: SAT Reset Measure Energy Savings Comparison for All Cases

FAN SETBACK

There are fan, cooling, and heating savings for this measure. Table 14 presents the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool does not overestimate this measure of savings, and the savings from modeling and the Tool seem to align. Figure 7 shows the savings percentages from both modeling and Tool results for each prototype and each CZ. For larger buildings with core zones, the modeling savings might be a little underestimated since the VAV min cannot go down to the expected value of the measure case (0.2) for core zones due to ventilation rate requirements. Even with this underestimation of the modeling results, the savings from the Tool estimate seem lower for most cases.

Table 14: Fan Setback Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	0.6% - 4.3%	0.2% - 2.2%	2.1%	1.3%
Cooling (kWh)	1% - 4.8%	1.3% - 3.6%	3.2%	2.4%
Total (kWh)	2% - 8.5%	1.7% - 5.7%	5.3%	3.8%
Heating (Therms)	27.2% - 45.1%	27% - 44.3%	35.9%	35.6%

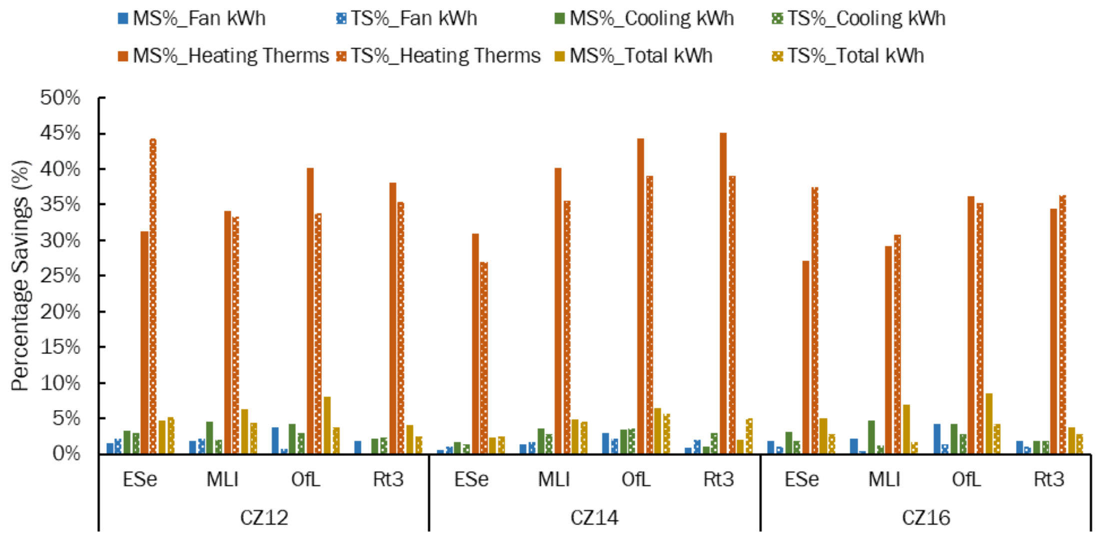

Figure 7: Fan Setback Measure Energy Savings Comparison for all Cases

SPACE TEMPERATURE SETBACK

There are fan, cooling, and heating savings for this measure. Table 15 shows the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool seems to underestimate this measure of savings compared to the modeling results. Figure 8 indicates the savings percentages from both modeling and Tool results for each prototype and each CZ. The Tool does not have fan savings due to the Tool setup. Except for the MLI prototype, the heating savings from the modeling results are higher than the Tool results, which might be due to the reheat effects in larger buildings with core zones that are not captured in the Tool.

Table 15: Space Temperature Setback Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Fan (kWh)	1.4% - 4.7%	0% - 0%	3.0%	0.0%
Cooling (kWh)	2.6% - 9.2%	1.7% - 2.9%	5.1%	2.3%
Total (kWh)	4% - 13.9%	1.7% - 2.9%	8.2%	2.3%
Heating (Therms)	8.9% - 49.9%	16.2% - 52.7%	31.9%	28.0%

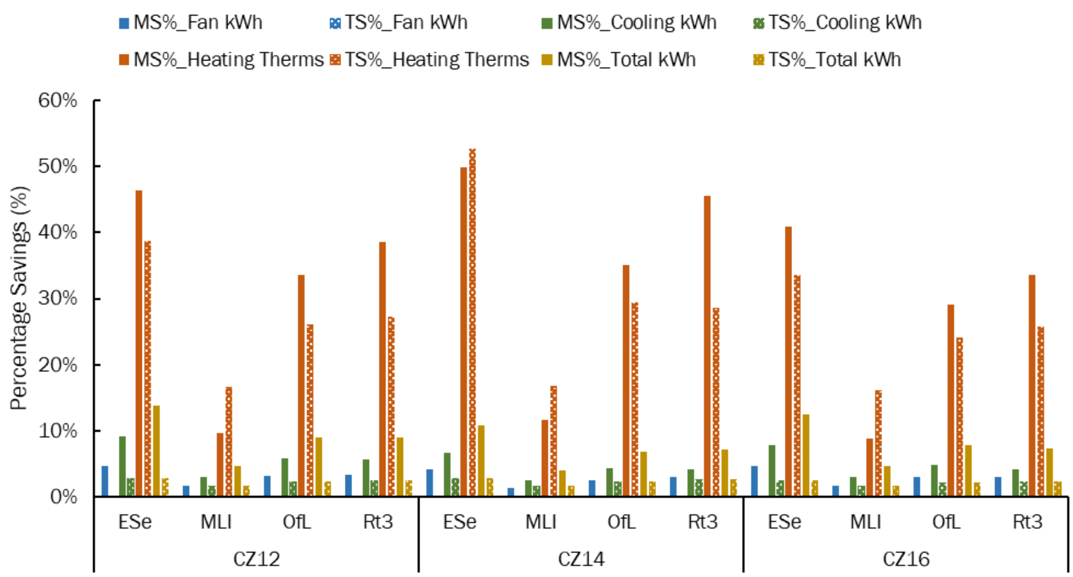

Figure 8: Space Temperature Setback Measure Energy Savings Comparison for all Cases

Hot Water System Measures Inputs

Boilers & Pumps Specifications

This measure is for boiler efficiency upgrades, either by increasing the nameplate efficiency or adding more boilers. The inputs under this measure include hot water plant equipment type and sizing. For these inputs, the project team used the auto-sized capacities extracted from E+ output tables. The Tool assumes to share the same inputs for the building heating load, HW operation schedule, pump configurations, and associated pump inputs, which are not allowed to change between base case and measure case.

The base case assumes two boilers, each with a sizing factor of 0.5; while the measure case assumes three boilers, each with a sizing factor of 0.33.

Table 16 summarizes the inputs under this measure.

Table 16: Tool Inputs under Hot Water System: Boilers & Pumps Specifications

Parameters	Base Case	Measure Case	Source
Number of Boilers	2	3	Rule of thumb
Input Capacity (kBtu/h)	Varies for each prototype and each CZ	Varies for each prototype and each CZ	E+ output tables
Efficiency (%)	80	Same as base case	DEER prototype default
Output Capacity (kbtu/h)	Input Capacity * Efficiency	Same as base case	Tool auto-calculate
Max Building Heating Load (kBtu/h)	Varies for each prototype and each CZ	Same as base case	E+ hourly variable output: HW: Plant Supply Side Heating Demand Rate
Min Building Heating Load (kBtu/h)	Varies for each prototype and each CZ	Same as base case	E+ hourly variable output: HW: Plant Supply Side Heating Demand Rate
@OAT (°F)	60 to Design heating OAT Varies for each CZ	Same as base case	Rule of thumb
Load Profile	Baseload*	Same as base case	Rule of thumb
Main Location Of Boilers	Indoor	Same as base case	Tool default
Air Temperature If Indoor (°F)	60	Same as base case	Tool default
Weekday Schedule	0-24	Same as base case	DEER prototype default
Saturday Schedule	0-24	Same as base case	DEER prototype default
Sunday Schedule	0-24	Same as base case	DEER prototype default
Hot Water Pumps System Configuration	Primary Only	Same as base case	DEER prototype default

Parameters	Base Case	Measure Case	Source
Select Inputs for Power Calc	Design Flow and Head	Same as base case	DEER prototype default
Flow (gpm)	Varies for each prototype and each CZ	Same as base case	E+ output tables
Head (ft) per pump	Varies for each prototype and each CZ	Same as base case	DEER prototype default
Motor Efficiency (%)	90%	Same as base case	DEER prototype default
Pump Eff (%) per pump	66.67%	Same as base case	DEER prototype default
Maximum Pump Qty Operating	1	Same as base case	DEER prototype default

***Baseload means the heating load will remain at a minimum load above the high limit OAT. Between the low limit and high limit OAT, the heating load will decrease linearly to zero as OAT increases.**

Hot Water (HW) Plant Lockout Control

HW plant lockout control allows the HW plant to stop running when OAT is above the heating lockout temperature. The project team assumed that the hot water plant operates whenever it is needed for the base case. For the measure case, the project team selected 75°F recommended by ASHRAE Guideline 36 (ASHRAE 2021). Table 17 shows the inputs under this measure.

Table 17: Tool Inputs under Hot Water System: HW Plant Lockout Control

Parameters	Base Case	Measure Case
Heating Lockout Temperature (°F)	N/A	75

Boiler Staging Sequence

Close coordination between boiler staging and actual load minimizes energy use. For example, it is beneficial to use a smaller boiler with good turn-down efficiency to meet low loads and to enable a larger boiler only when the load surpasses the heating capacity of the smaller boiler. The boiler staging sequence measure tends to optimize the load distribution schemes to maximize the boiler efficiency. E+ uses boiler efficiency performance curves, where boiler efficiency is a function of boiler loading (part-load-ratio (PLR)), and/or boiler inlet water temperature. At lower PLR or lower hot water return temperature (HWRT), the boiler efficiency will usually be lower than the nominal thermal efficiency, thus higher energy usage. Therefore, the energy savings for this measure are closely related to the boiler efficiency performance curves. However, the Tool uses a uniform boiler efficiency, which does not justify energy savings unless the boiler plant includes a combination of high- and low-efficiency boilers.

Additionally, the load distribution scheme listed in the Tool does not align with E+. There are two basic load distribution schemes in E+, including uniform load and sequential load. However, it seems the Tool only allows uniform load. Whenever two boilers are chosen for a higher load, the algorithm in the Tool distributes the load uniformly between the boilers. The Tool cannot mimic a sequential load distribution scheme used by E+ where the first boiler will be loaded up to the full load, and then the remaining load will be met by the other boilers.

Given the above two considerations and the current assumptions and setup in the Tool, the project team excluded this measure from further study in E+.

Hot Water (HW) Temperature Reset

This measure uses the OA reset method to reset the supply hot water temperature (SHWT) based on the OAT to allow for lower SHWT at higher OAT to reduce distribution loss. The project team used the DEER Prototype default SHWT and OAT range, also aligning with ASHRAE Standard 90.1 (ASHRAE 2022). Table 18 lists the inputs under this measure.

Table 18: Tool Inputs under Hot Water System: HW Temperature Reset

Parameters	Base Case	Measure Case
SHWT (°F)	180	180 to 150
@OAT (°F)	20 to 50	Same as base case

Primary-Only Hot Water Pump (PHWP) VFD and Speed Control

This measure is to upgrade the pump control method to optimize the pump speed and flow control. It uses different pump performance curves to represent changing the pump VFD and speed control. For the base case, the project team assumed the pump control is VFD without differential pressure (DP) reset, and the measure case has DP reset. The pump flow percentage is the percentage of the design pump flow, and the range came from the E+ hourly output variables.

Table 19 shows the inputs under this measure.

Table 19: Tool Inputs under Hot Water System: PHWP VFD and Speed Control

Parameters	Base Case	Measure Case
Data Type	Simple Data	Same as base case
Max Pump Flow (%)	Varies for each prototype and each CZ	Same as base case
Min Pump Flow (%)	Varies for each prototype and each CZ	Same as base case
@OAT (°F)	Design heating OAT to 60	Same as base case
Pump Control	VFD - no DP reset	VFD - with DP reset

Hot Water System Measures Results

Base Case Energy Consumption Comparison

First, the project team compared the base case energy consumption between the Tool and modeling (Figure 9 and Figure 10). Taking the modeling results as the denominator, the percentage difference ranges from minus 35 percent to 12 percent, and minus 39 percent to 18 percent between modeling and the Tool for the pump electricity and heating energy consumption, respectively, across all prototypes and CZs (

Table 20). The average percentage differences are minus 10 percent and minus 17 percent for pump electricity and heating energy consumption.

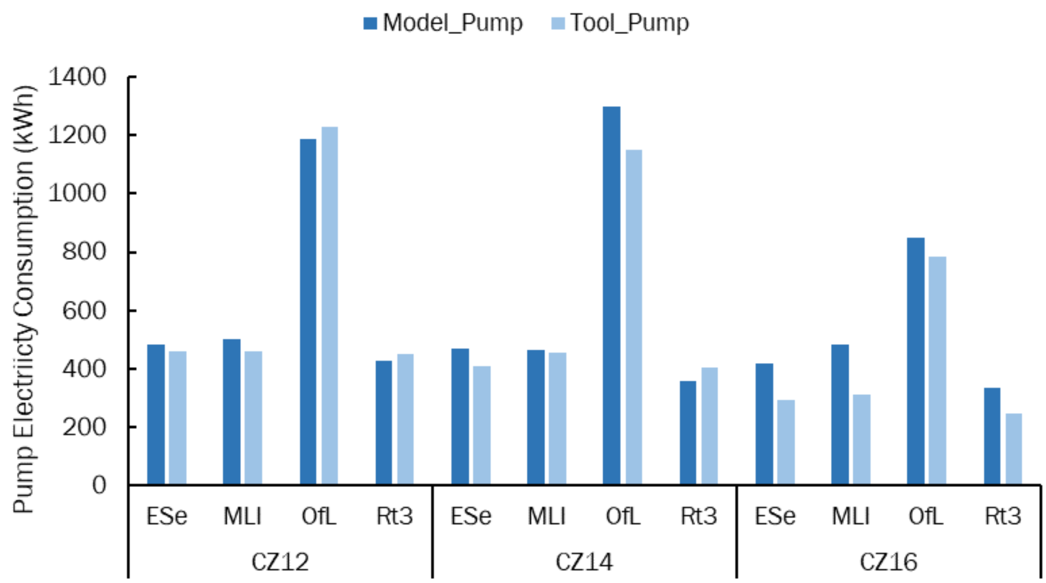

Figure 9: Base Case Pump Electricity Energy Consumptions Comparison for Hot Water System Measures

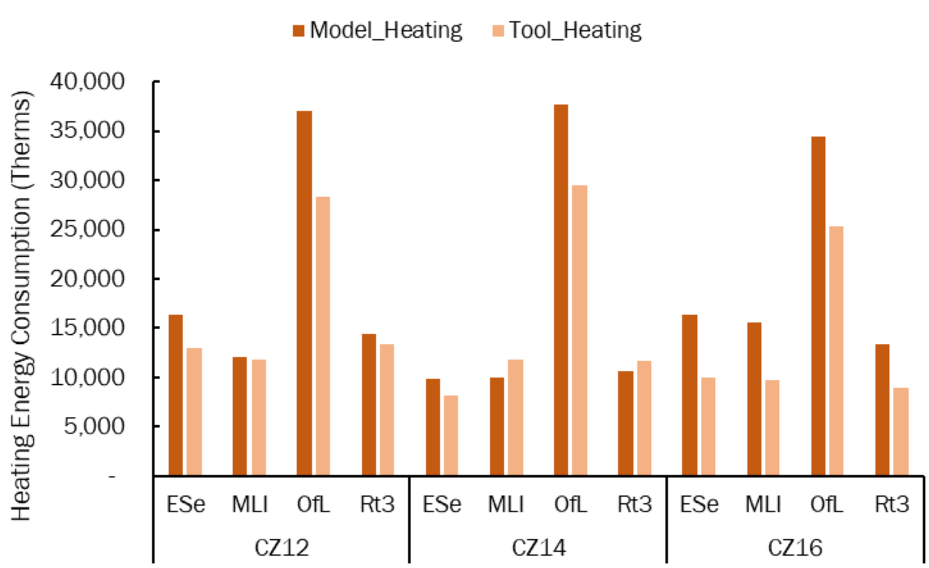

Figure 10: Base Case Heating Energy Consumptions Comparison for Hot Water System Measures

Table 20: Percentage Differences for Pump Electricity and Heating Summary for Hot Water System Measures

CZ	Prototype	Pump Electricity_% difference	Heating_% difference
CZ12	ESe	-5%	-21%
CZ12	MLI	-9%	-2%
CZ12	OfL	4%	-24%
CZ12	Rt3	5%	-8%
CZ14	ESe	-13%	-18%
CZ14	MLI	-1%	18%
CZ14	OfL	-12%	-22%
CZ14	Rt3	12%	10%
CZ16	ESe	-29%	-39%
CZ16	MLI	-35%	-37%
CZ16	OfL	-8%	-26%
CZ16	Rt3	-27%	-33%
Mean	-	-10%	-17%

Measure Cases Energy Savings Comparison and Sensitivity Analysis

Then, the project team calculated the energy savings and energy savings percentages for each measure and compared the results to the output from the Tool and modeling.

BOILERS & PUMPS SPECIFICATIONS

There are mainly heating savings for this measure. Table 21 summarizes the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Figure 11 shows the savings percentages from both modeling and Tool results for each prototype and each CZ. In most cases, the Tool has fewer heating savings, compared with modeling results. Measure savings from the Tool came from the jacket loss reduction since the Tool assumes a flat boiler efficiency curve. However, the modeling savings came from the boiler efficiency according to the part load ratio. The jacket loss is considered in the boiler efficiency curve in the model. The modeling results also reflect the pump savings interaction which is not captured in the Tool.

Table 21: Boilers & Pumps Specifications Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Pump (kWh)	-5.3% - 0.9%	0% - 0%	-1.1%	0.0%
Heating (Therms)	3.1% - 6.3%	1.8% - 10.1%	4.9%	4.6%

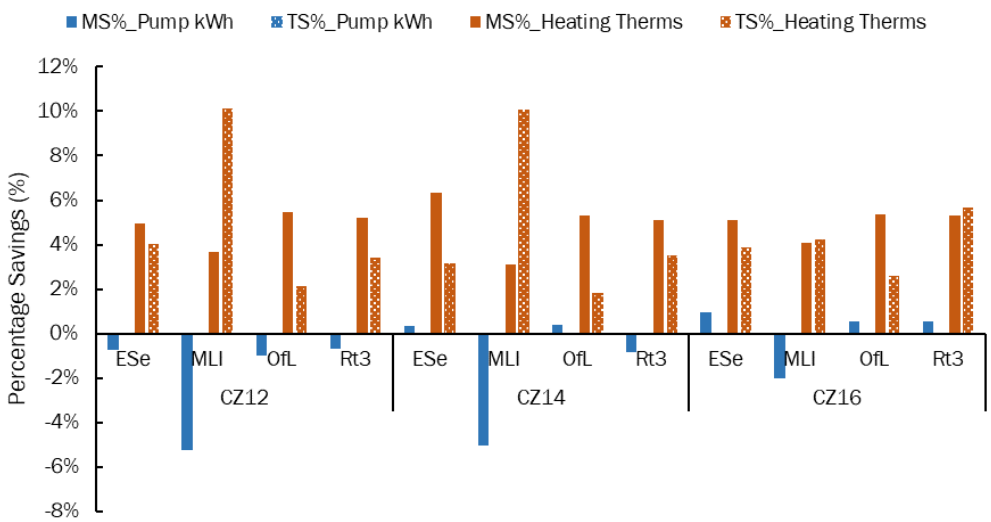

Figure 11: Boilers & Pumps Specifications Measure Energy Savings Comparison for all Cases

HW PLANT LOCKOUT CONTROL

There are pump and heating savings for this measure. Table 22 lists the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool doesn't seem to overestimate the heating savings for this measure, compared with modeling results. Figure 12 shows the savings percentages from both modeling and Tool results for each prototype and each CZ. The results seem to align better for larger buildings (OfL and Rt3). The modeling savings for MLI are minimal since MLI is a relatively small building without a core zone like other prototypes. The hourly heating load profile shows that there is no heating load (reheat) when OAT is above a certain OAT. However, for other larger prototypes with core zones, there is still reheat required as OAT increases to cooling design OAT.

Table 22: HW Plant Lockout Control Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Pump (kWh)	0.3% - 22.3%	3% - 13.5%	6.9%	7.5%
Heating (Therms)	0% - 19.9%	2.6% - 12.4%	5.6%	6.7%

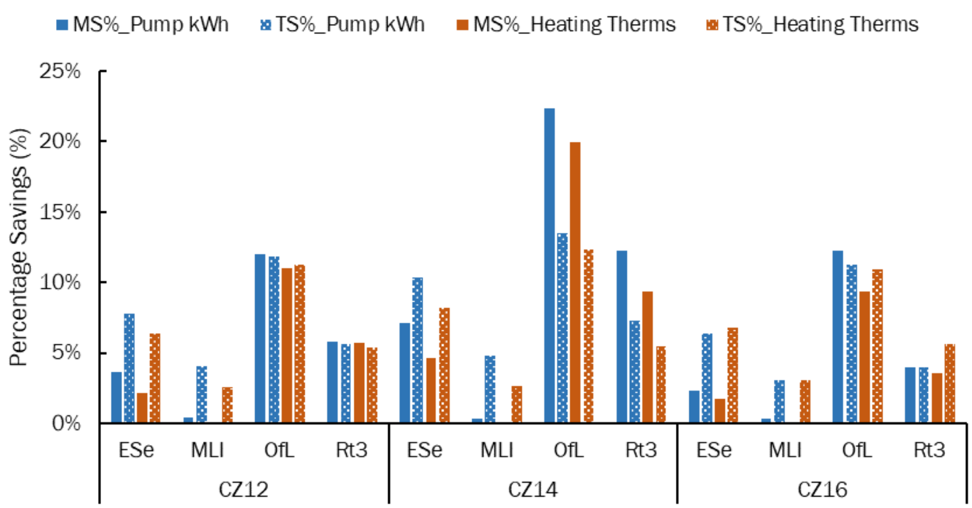

Figure 12: HW Plant Lockout Control Measure Energy Savings Comparison for all Cases

HW TEMPERATURE RESET

There are pump and heating savings for this measure. Table 23 indicates the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Figure 13 shows the savings percentages from both modeling and Tool results for each prototype and each CZ. The heating savings from the Tool seem to be overestimated for almost all cases except for ESe in CZ14. It is also difficult to compare this measure, since the Tool savings came from the jacket loss reduction, however, the modeling savings came from the boiler efficiency change due to the part load ratio, where the jacket loss might be considered in the boiler efficiency curve. The Tool doesn't consider the pump penalty for this measure because of the reduced supply hot water temperature, either.

Table 23: HW Temperature Reset Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Pump (kWh)	-51.1% - -11.6%	0% - 0%	-35.8%	0.0%
Heating (Therms)	0% - 9.5%	2.3% - 7%	1.3%	3.7%

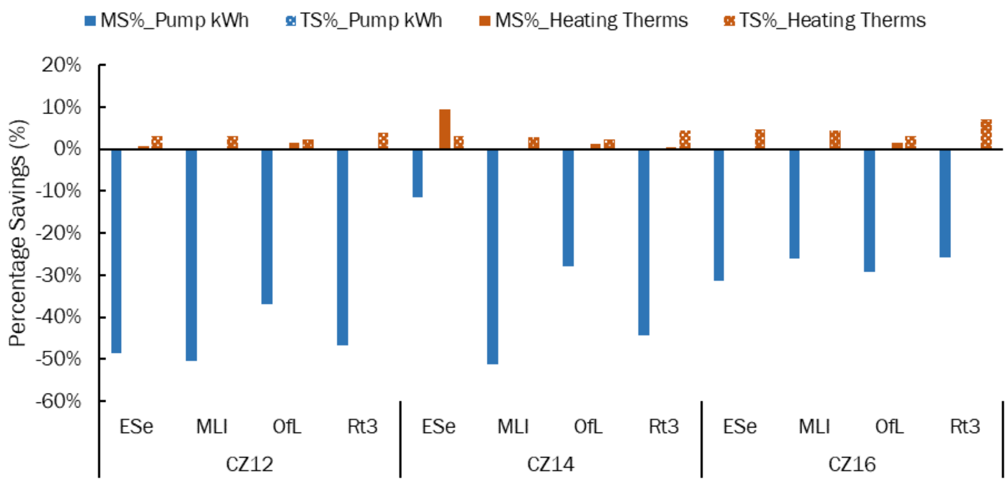

Figure 13: HW Temperature Reset Measure Energy Savings Comparison for all Cases

PHWP VFD AND SPEED CONTROL

There are mainly pump savings for this measure. Table 24 indicates the range and mean of the measure savings for both the modeling results and the Tool results across all prototypes and CZs. Overall, the Tool seems to overestimate the savings compared to modeling results for this measure compared to modeling results. Figure 14 shows the savings percentages from both modeling and Tool results for each prototype and each CZ. The Tool savings are larger compared to modeling results for all cases. The heating penalty from modeling results might be due to the interactive effects, but the savings are minimal and can be neglected.

Table 24: PHWP VFD and Speed Control Measure Savings Statistical Summary

End Use	Model Savings_Range (%)	Tool Savings_range (%)	Model Savings _mean (%)	Tool Savings _mean (%)
Pump kWh	65.3% - 85.1%	81.8% - 92.8%	76.7%	87.7%
Heating Therms	-0.1% - -0.1%	0% - 0%	-0.1%	0.0%

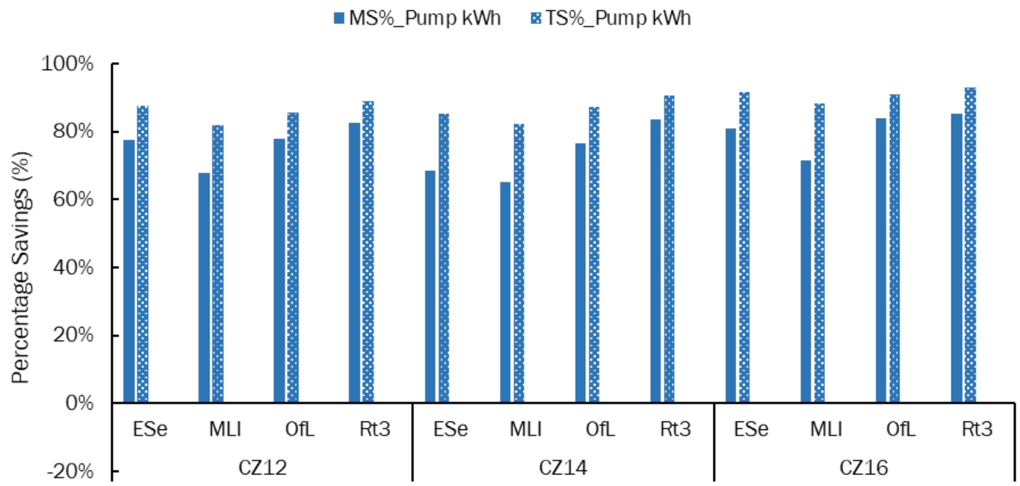

Figure 14: PHWP VFD and Speed Control Measure Energy Savings Comparison for all Cases

Sources of Modeling Uncertainty

Full building energy modeling is generally considered to be the most detailed and accurate methodology to predict building energy consumption, which requires users to provide a detailed description of the building's geometry and construction, a variety of internal loads, various schedules, and mechanical systems. However, there are still significant simplifications, due to the complexity of the building systems and the unavailability of detailed information on building materials, components, and systems specifications in the real world in the simulation model. All of these add to the modeling uncertainties.

For this study, the project team used prototype building models. Prototype modeling usually simplifies the zoning of buildings, which does not reflect the exact zoning in a real building. On the other hand, the Tool does not consider zoning. The fan, boiler, and pump performance curves used in modeling might be different from the real product specifications, which can also add uncertainty. In addition, modeling uses a boiler curve that considers the jacket loss into the boiler efficiency as a function of the part load ratio, while the Tool assumes a flat boiler curve with respect to the part load ratio and calculates the jacket loss separately based on temperature. Furthermore, the controls used in modeling might not reflect the exact controls in real buildings, while the tool relies on correlations between outdoor temperature and HVAC loads found in BAS data instead of explicitly modeling controls.

Conclusions

Overall, the team found that the hot water system measures base case energy consumptions and measure savings align better and easier with the modeling results, compared with the air side system measures, given the more complicated relationships in the air side.

The modeling savings estimates and Tool savings estimates generally aligned well for the following air side system measures (average error[7] is less than five percent for both total electricity and heating):

- Air Side System Measures: Equipment Specifications & Replacement, Scheduling Optimization, Economizer Optimization, SP Reset, Fan Setback

The modeling savings estimates and Tool savings estimates did not align well for the following measures with possible reasons for the air side system measures:

- Air Side System Measures:
    - SAT Reset: The Tool overestimates the cooling and heating savings, which might be due to the detailed controls used in E+ which the Tool doesn't consider.
    - Space Temperature Setback: The Tool underestimates the savings; one possible reason is that the Tool doesn't present fan savings due to the Tool setup.

For hot water system measures, since the Tool assumes a flat boiler efficiency and this impacts all measures, the project team recommends updating the boiler efficiency in the Tool for all the measures. Before this update, the modeling savings estimates, and Tool savings estimates generally aligned well for the following hot water system measures:

- Hot Water System Measures: Boilers & Pumps Specifications, HW Plant Lockout Control, Pump VFD and Speed Control

The modeling savings estimates and Tool savings estimates did not align well for the following measures with possible reasons for the hot water system measures:

- HW Temperature Reset: The Tool seems to overestimate the savings since the heating savings from the Tool came from the separate jacket loss reduction based on temperature. However, modeling considers the jacket loss into the boiler efficiency curve as a function of the part load ratio.

The project team provided recommendations to improve the measures whose savings estimates didn't align well with the modeling results where a path to improve the Tool was identified. For those measures that already align well with modeling estimates, the project team also provided recommendations to improve the Tool further. The project team summarized all the recommendations for air side and hot water system measures in the following section. It is not guaranteed that these improvements would bring the Tool estimates and modeling estimates much

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[7] Average error here means the absolute value of the percentages difference between the Modeling Savings_mean (%) and the Tool Savings_mean (%) that we summarized for each measure in Findings section.

closer to the results before improvements are made due to the methodology applied. However, these improvements would enhance the validity of the assumptions and calculations in the Tool. Industry professionals consider the whole building modeling approach to be the most accurate methodology to estimate building usage and savings, however, it is usually time-consuming and costly, which may make it not cost-effective in some cases. For such cases, the Tool could be suitable as an alternative savings estimate Tool.

Recommendations

The project team developed recommendations for the PG&E HVAC Tool that will improve tool usability and accuracy. This Tool has the potential to be a valuable asset for IOU programs implementing RCx HVAC projects. CalTF has established itself as the IOU platform for overseeing its peer-reviewed deemed/custom measure. It is also their goal to build consensus between all program stakeholders, one example being getting custom estimation tools approved by the CPUC. The list of air side and hot water system measure improvements are:

Air Side System Measures

- For the equipment specifications and replacement measure, there is an input specifying the fan control method. There are six selectable fan control methods in the tool, including Damper, IGV, VFD, Air-Foil or Backward-Inclined – Dampers Control Flow, Air-Foil or Backward-Inclined – Inlet Vanes, and Vane-Axial – Variable Pitch Blades. For different fan control types, associated fan curves are used and listed under the "Process" – "Fan Curves" section. The Tool mentions "ASHRAE 90.1 Fan Curves" as the source for the different fan curves, however, the fan type and fan curves don't match what was found in the ASHRAE 90.1-2016 Performance Rating Method Reference Manual (PNNL 2017). The reason might be the fan curves in the Tool were from an older version of ASHRAE 90.1. Some fan types might have been abandoned, or the fan curves might have been updated. The project team recommends re-checking these fan types and fan curves and making necessary updates in the Tool.
- For the equipment specifications and replacement measure, there is an input called "System Type (CAV/VAV)", which seems to be a potential measure where the base case is CAV, and the measure case is VAV. However, the Tool provides no energy consumption differences in selecting CAV versus VAV. The project team recommends re-checking the formulas related to this input or clarifying this is not supposed to be a potential measure.
- For the scheduling optimization measure, the Tool assumes the same schedule across the year, however, for certain prototypes, such as school, there will be multiple holidays when the school is closed which cannot be reflected in the Tool. The project team recommends considering these situations or mentioning the limitations of these building types.
- For the space temperature setback sub-measure, the Tool doesn't have fan savings due to the Tool setup where the fan inputs remain unchanged. The project team recommends updating the setup for this measure to capture fan savings and possibly improve cooling/heating savings.
- The project team recommend providing guidance on how to use the data from building Energy Management Systems (EMS) or other resources to come up with the various curves used in the Tool for air side system measures, including outdoor air flow percentage curve, supply fan flow

percentage curve, and average discharged air temperature (DAT) curve, etc. Consistency could be improved if users have guidance on how to determine maximums, minimums, and intercept points from large datasets which do not always show clean linear relationships.

How Water System Measures

- In the calculation engine section of the hot water system measures, the “Therms” column gives a value of zero consumption if the user chooses less than three boilers, which needs to be corrected.
- For the boiler staging sequence measure, the project team recommends updating the boiler efficiency performance calculations to reflect a sequential load distribution scheme and including boiler performance curves as a function of part load ratio and/or hot water temperature.
- For the hot water temperature reset measure, the Tool does not account for the impact of SHWT reduction on the boiler thermal efficiency and pump energy consumption. The project team recommends updating the calculations in the Tool to reflect these impacts.
- For the PHWP VFD and speed control measure, the Tool lists three options for pump control, including "Constant-Variable Flow", “VFD - no DP reset”, and “VFD - with DP reset”, and provides associated pump performance curves. The project team checked the ASHRAE 90.1-2016 Performance Rating Method Reference Manual and found the curves for the two VFD control methods. However, a pump performance curve for the “Constant-Variable Flow” could not be identified. The project team recommends adding references for each of the pump performance curves.
- The project team recommends providing guidance on how to use the data from building Energy Management Systems (EMS) or other resources to come up with the various curves used in the Tool for hot water system measures, including the heating load curve, and pump flow percentage curve.

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