ComStock Measure Scenario Documentation: Chiller Replacement

Janghyun Kim and Chris CaraDonna

National Renewable Energy Laboratory

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List of Acronyms

CBECS	Commercial Buildings Energy Consumption Survey
COP	coefficient of performance
DOAS	dedicated outdoor air system
EER	energy efficiency ratio
EIA	U.S. Energy Information Administration
EIR	energy input ratio
EUI	energy use intensity
HVAC	heating, ventilating, and air conditioning
IPLV	Integrated Part-Load Value
LRMER High RE	long-run marginal emissions rate high renewable energy
MMT	million metric tons
TBtu	trillion British thermal units
URDB	Utility Rate Database
VAV	variable air volume

Executive Summary

Building on a 3-year effort to calibrate and validate the U.S. Department of Energy's ResStock™ and ComStock™ models, this work produces national datasets that empower analysts working for federal, state, utility, city, and manufacturer stakeholders to answer a broad range of questions regarding their commercial building stock.

ComStock is a highly granular, bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual energy consumption (at a subhourly resolution) of the commercial building stock across the United States. The baseline model intends to represent the U.S. commercial building stock as it existed in 2018. The methodology and results of the baseline model are discussed in the final technical report of the End-Use Load Profiles project.

The goal of this work is to develop energy efficiency and demand flexibility end-use load shapes that cover high-impact, market-ready (or nearly market-ready) measures. "Measures" refers to various "what-if" scenarios that can be applied to buildings.

An *end-use savings shape* is the difference in energy consumption between a baseline building (or collection of buildings) and a building with an energy efficiency or demand flexibility measure applied. It results in a time-series profile broken down by end use and fuel (electricity or on-site gas, propane, or fuel oil use) at each time step, as well as annual aggregations.

This report describes the modeling methodology for a single end-use savings shape measure—chiller replacement—and briefly introduces key results. The full public dataset can be accessed on the ComStock™ data lake or via the Data Viewer at comstock.nrel.gov. The public dataset enables users to create custom aggregations of results for their use case (e.g., filter to a specific county).

Key modeling assumptions and technology details are summarized in Table ES-1.

Table ES-1. Key Modeling Specifications

Technology Description	• This study investigates replacing existing chillers (air-cooled and water-cooled) with new chillers that reflect the latest performance (i.e., average of medium- to high-performance chillers) in the current market. Also, variable speed pumps and chilled/condenser water temperature resets are applied if not available.
Performance Assumptions	• Manufacturer data are gathered from public resources (e.g., manufacturer websites), processed to derive average full-load performances (e.g., full-load energy efficiency ratio [EER]) between configurations (e.g., air-cooled versus water-cooled), and applied to building models with chillers. • Part-load performances (e.g., Integrated Part-Load Value [IPLV] EER) of chillers are also derived from manufacturer data and used in a software tool (i.e., Copper) to create EnergyPlus®-compatible performance maps. • Data collected for air-cooled chillers cover (1) cooling tonnage between 11 and 547, (2) full-load EER between 9 and 15, and (3) IPLV EER between 13 and 23. • Data collected for water-cooled chillers cover (1) cooling tonnage between 30 and 4,000, (2) full-load EER between 15 and 25, and (3) IPLV EER between 20 and 25. • These data are collected from public resources (e.g., webpages) from six different manufacturers: Aermec, Carrier, Daikin, LG Electronics, Trane, and York.
Applicability	• Heating, ventilating, and air-conditioning systems including either air-cooled or water-cooled chillers. • 21% of the stock floor area.
Release	2025 Release 1: 2025/comstock_amy2018_release_1/

National annual results for site energy, energy bills, and carbon emissions equivalent are summarized in Table ES-2 to Table ES-3.

Table ES-2. Key Results for Annual Site Energy Savings

Fuel Type	Absolute Savings (TBtu)	Baseline Total (All Buildings, TBtu)	Percent Savings (All Buildings)	Baseline Total (Applicable Buildings Only, TBtu)	Percent Savings (Applicable Buildings Only)
Natural Gas	15.5	1524.1	1.0	380.3	4.1
Electricity	44.8	3173.4	1.4	595.5	7.5

Table ES-3. Key Results for Annual Utility Cost Savings

Fuel Type	Absolute Savings (Billion USD, 2022)	Baseline Total (All Buildings, Billion USD, 2022)	Percent Savings (All Buildings)	Baseline Total (Applicable Buildings Only, Billion USD, 2022)	Percent Savings (Applicable Buildings Only)
Natural Gas	0.2	17.4	1.2	4.5	4.5
Electricity	1.7	107.7	1.6	20.1	8.4
Fuel Oil	0.0	0.7	0.3	0.1	2.7
Propane	0.0	1.0	0.0	0.0	0.0
Total	1.9	126.8	1.5	24.6	7.7

Electricity cost savings in this table are calculated using the mean available electricity rate available for each building. Other electricity rate structures are available in this report and in the public dataset.

Table ES-4. Key Results for Annual Carbon Emissions Equivalent Savings

Fuel Type	Absolute Savings (MMT CO_2e)	Baseline Total (All Buildings, MMT CO_2e)	Percent Savings (All Buildings)	Baseline Total (Applicable Buildings Only, MMT CO_2e)	Percent Savings (Applicable Buildings Only)
Natural Gas	1.0	101.8	1.0	25.4	4.1
Electricity	3.1	239.6	1.3	42.1	7.4
Fuel Oil	0.0	1.7	0.3	0.2	2.7
Propane	0.0	2.7	0.0	0.0	0.0
Total	4.2	345.9	1.2	67.7	6.1

Electricity emissions avoided in this table are calculated using Cambium Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year grid scenario. Other grid scenarios are presented in this report and in the public dataset.

While this report presents the impacts of various upgrade options (based on reduced stock models) for the overall chilled water system, the final results and dataset—representing the full

stock models—include four specific upgrades: chiller replacement, chilled water temperature reset, condenser water temperature reset, and pump upgrades.

Upgrading to more efficient chillers—whether air-cooled or water-cooled—results in electricity savings, primarily through reduced chiller energy consumption. The bulk of these savings come from replacing older, less efficient units with newer models. Additionally, as chillers operate more efficiently, they reject less heat through the condenser, leading to reduced operation of cooling tower fans and, consequently, lower fan energy use. Improved pump motor efficiency and better control strategies, such as differential pressure reset, also contribute to overall energy reductions by optimizing pump power usage.

Another important benefit comes from strategies like chilled water supply temperature setpoint reset based on outdoor air temperature. By raising the chilled water supply temperature earlier in the day, chillers operate in more favorable part-load conditions, enhancing energy efficiency. However, this temperature increase reduces the temperature difference (ΔT) between supply and return water, which in turn requires a higher flow rate to maintain the same cooling output. Despite this, systems with reheat capabilities—especially in multi-zone central air systems—see heating energy savings due to less reheat being required when the air temperature at the evaporator outlet is higher.

These efficiency measures not only benefit traditional variable air volume systems but also affect systems like fan coil units with dedicated outdoor air systems and water-source heat pumps, all of which rely on chillers. Because chillers typically serve large heating, ventilating, and air-conditioning systems, the energy and operational improvements from this upgrade have a pronounced impact on large buildings such as hospitals, schools, and office buildings. Enhanced control settings that adapt to weather conditions further optimize heat rejection, contributing to additional cooling tower energy savings not always visible in standard performance figures.

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1 Technology Summary

Chillers are a fundamental component of many heating, ventilating, and air-conditioning (HVAC) systems, providing chilled water for a wide range of applications, including commercial and residential buildings as well as industrial processes. They work by removing heat from an incoming fluid stream and rejecting it either directly to the ambient air (air-cooled chillers) or to a separate water loop with its own heat rejection equipment (water-cooled chillers). Air-cooled chillers are typically used in lower tonnages, where simpler installation and maintenance are priorities, or locations where water resources are limited. In contrast, water-cooled chillers offer higher efficiency and are preferred for larger buildings and applications requiring significant cooling capacity.

Chillers are widely used in building cooling systems, with prevalence in large-scale commercial and industrial settings. According to the U.S. Energy Information Administration's (EIA) 2018 Commercial Buildings Energy Consumption Survey (CBECS), chillers served approximately 19% of the total commercial building floor area in the United States [1]. Given that commercial buildings consumed 6.8 quadrillion British thermal units (quads) of energy in 2018, improving chiller efficiency can have substantial energy and cost-saving implications.

Over time, advancements in chiller technology have focused on increasing energy efficiency, reducing environmental impact, and enhancing system reliability. Some key innovations include:

- Variable-Speed Drives: Modulating compressor speeds to improve part-load efficiency and lower energy consumption.
- Heat Recovery Systems: Capturing waste heat for use in domestic hot water or space heating, enhancing overall system efficiency.
- Advanced Controls and Internet of Things Integration: Enabling real-time monitoring and optimization through smart controls and Internet of Things connectivity.
- Improved Heat Exchangers: Utilizing microchannel condensers and high-efficiency evaporators to enhance heat transfer and reduce energy losses.

Several studies have examined the impact of replacing outdated chillers with modern, high-efficiency models. Research has shown that upgrading to the latest generation of chillers can lead to energy savings ranging from 20% to 50%, depending on system configuration and operational factors [2], [3]. Retrofitting projects have also demonstrated improved operational reliability, particularly when combined with optimized building automation controls. Additionally, organizations pursuing building certifications, such as Leadership in Energy and Environmental Design (LEED), often prioritize chiller upgrades as part of broader energy efficiency strategies.

To assess the potential benefits of chiller replacements, this study explores a hypothetical scenario in which existing chillers are replaced with efficient models currently available on the market. The analysis considers energy consumption, cost savings, and environmental impact to highlight the role of advanced chiller technologies in achieving cost-effective cooling solutions.

2 ComStock Baseline Approach

The characteristics of existing chiller-equipped HVAC systems in ComStock™ are based on a combination of when the buildings were built and how the HVAC equipment has been assumed to have been updated over time. This is described in detail in the ComStock Reference Documentation [4]. HVAC equipment performance is assumed to meet the energy code requirements in force at the time and place of installation. The in-force energy code for the ComStock baseline is shown as total applicable floor area (and percentage) in Figure 1. Applicable floor area for this analysis includes ComStock buildings with HVAC system types that have either air-cooled or water-cooled chillers. Most ComStock baseline chillers follow energy code requirements from the early 2000s.

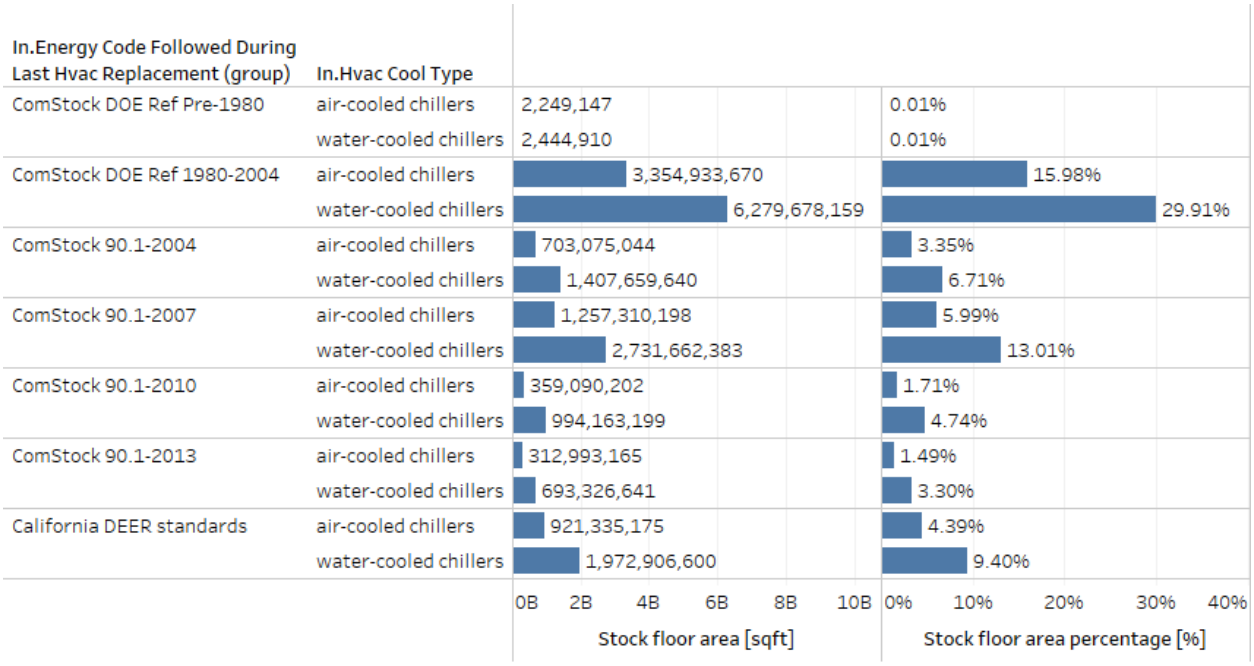

Figure 1. ComStock baseline in-force energy code followed as a percentage of applicable floor area.

Applicable floor area includes ComStock buildings with chillers. DEER stands for Database for Energy Efficiency Resources, which represents building characteristics for California models following Title 24.

Air-cooled chillers provide chilled water for building cooling systems by using an air-cooled condenser for heat rejection, eliminating the need for a separate condenser water loop. The air-cooled chiller efficiencies, both full-load and part load, are assigned based on the building code and capacity, aligning with ASHRAE-90.1 standards. ComStock models air-cooled chiller performance using three curve types: capacity as a function of leaving chilled water temperature and the entering condenser fluid temperature, energy input ratio (EIR) as a function of leaving chilled water temperature and the entering condenser fluid temperature, and EIR as a function of part-load ratio. These modifiers adjust the chiller's rated EIR and capacity for each time step to determine modified efficiency and capacity based on operating conditions. Below is a list of HVAC system types in ComStock that include air-cooled chillers:

- Dedicated outdoor air system (DOAS) with fan coil air-cooled chiller with baseboard electric

- DOAS with fan coil air-cooled chiller with boiler
- DOAS with fan coil air-cooled chiller with district hot water
- DOAS with fan coil chiller with baseboard electric
- Variable air volume (VAV) air-cooled chiller with parallel fan power (PFP) boxes
- VAV air-cooled chiller with district hot water reheat
- VAV air-cooled chiller with gas boiler reheat.

Water-cooled chillers provide chilled water for building cooling systems using a water-cooled condenser. These systems require condenser water to dissipate heat to the ambient air through cooling towers or fluid coolers. They are used in various HVAC configurations, such as DOAS and VAV systems, and can incorporate different heating options, including electric baseboards, boilers, and district hot water. Similar to air-cooled chillers, the efficiency of water-cooled chillers, both at full load and part load, is determined based on HVAC code templates and capacity, in accordance with ASHRAE 90.1 standards. ComStock models water-cooled chiller performance using the same three curve types as air-cooled chillers. Cooling towers, essential components of water-cooled chiller systems, reject heat from condenser water loops and are integrated into multiple ComStock HVAC configurations. The HVAC system types in ComStock that include water-cooled chillers are identical to those that incorporate air-cooled chillers, as previously listed.

More details on modeling HVAC systems including chillers can be found from the ComStock Reference Documentation [4].

3 Modeling Approach

3.1 Applicability

The chiller replacement measure applies to ComStock models where a building's HVAC system includes either air-cooled chillers or water-cooled chillers. This accounts for approximately 21% of the ComStock gross floor area, as shown in Figure 2. Figure 2 also highlights the major HVAC categories across the entire building stock and indicates where chillers (either air-cooled or water-cooled) are used as the cooling type for these categories. ComStock HVAC distributions are informed by the CBECS (2012 and 2018 data combined). The methodology for interpreting CBECS data to create HVAC probability distributions for ComStock is discussed in the ComStock Reference Documentation [4].

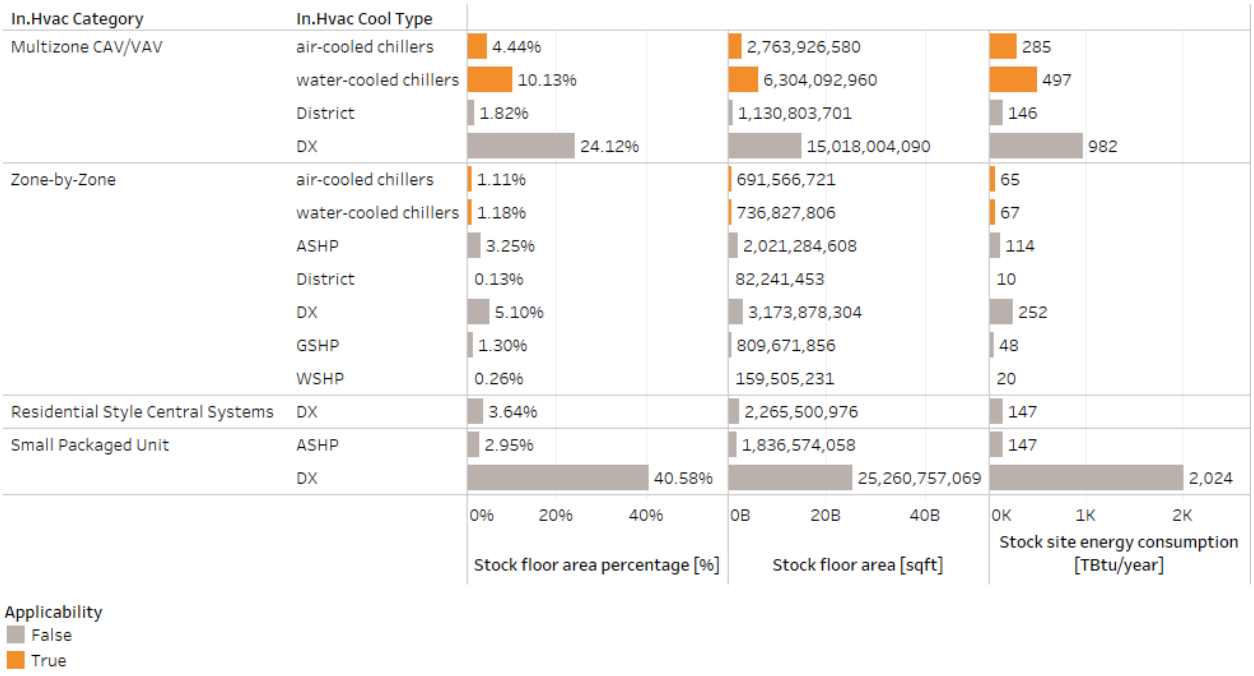

Figure 2. ComStock HVAC system type prevalence by stock floor area

3.2 Technology Specifics

This section includes how information/data reflecting the performance of chillers in the current market are gathered and processed for modeling in ComStock.

3.2.1 Gathering Chiller Performance From Public Resources

To understand the performance of market-available chillers as of January 2025, performance specification datasheets are gathered from public resources (e.g., manufacturer webpages). Table A-1 includes the raw data collected and summarized from the manufacturer product specification datasheets prior to data processing, reflecting data sources and specifications of chillers in different configurations (e.g., cooling type, compressor type, cooling tonnage, and performance metrics). As shown in Table A-1, specifications of air-cooled chillers cover 136 different products in different sizes, cooling tonnage between 11 and 547, full-load energy efficiency ratio (EER in Btu/Wh) between 9 and 15, and EER of Integrated Part-Load Value (IPLV) between 13

and 23. Specifications of water-cooled chillers cover 28 different products in different sizes, cooling tonnage between 30 and 4,000, full-load EER between 15 and 25, and EER of IPLV between 20 and 25. These data are collected from public resources (e.g., webpages) from six different manufacturers: Aermec, Carrier, Daikin, LG Electronics, Trane, and York [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19].

Some highlights can be extracted from the gathered data:

- As shown in Figure 3 (*x*-axis is in log scale), compared to air-cooled chillers, water-cooled chillers are more suitable for applications serving larger loads. Also, air-cooled chillers are ready to use off the shelf, as their condenser is integrated into the unit. In contrast, water-cooled chillers require connection to a separate condenser.

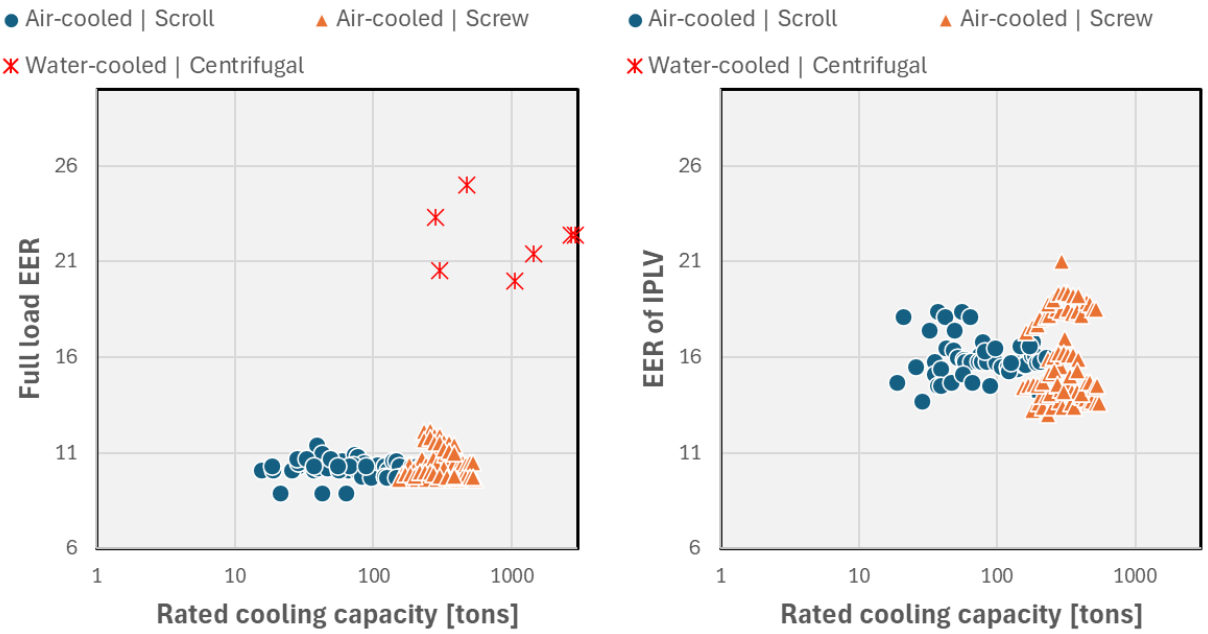

Figure 3. Chiller performance comparison: compressor types

- Scroll compressors are used in smaller applications (and are more common for air-cooled chillers) compared to screw and centrifugal compressors. Centrifugal compressors are used in the larger end of the applications and are more common for water-cooled chillers. This is reflected in Figure 3. To note, IPLV values were not available for water-cooled chillers using centrifugal compressors as shown in Figure 3.
- Water-cooled chillers have relatively higher EER values (for both full-load and part-load conditions) compared to air-cooled chillers, as they are leveraging a cooling tower. This is reflected in Figure 4. It is also important to note that when comparing the rated efficiencies of different types of chillers, the rating conditions vary due to differences in condenser fluids and temperatures.

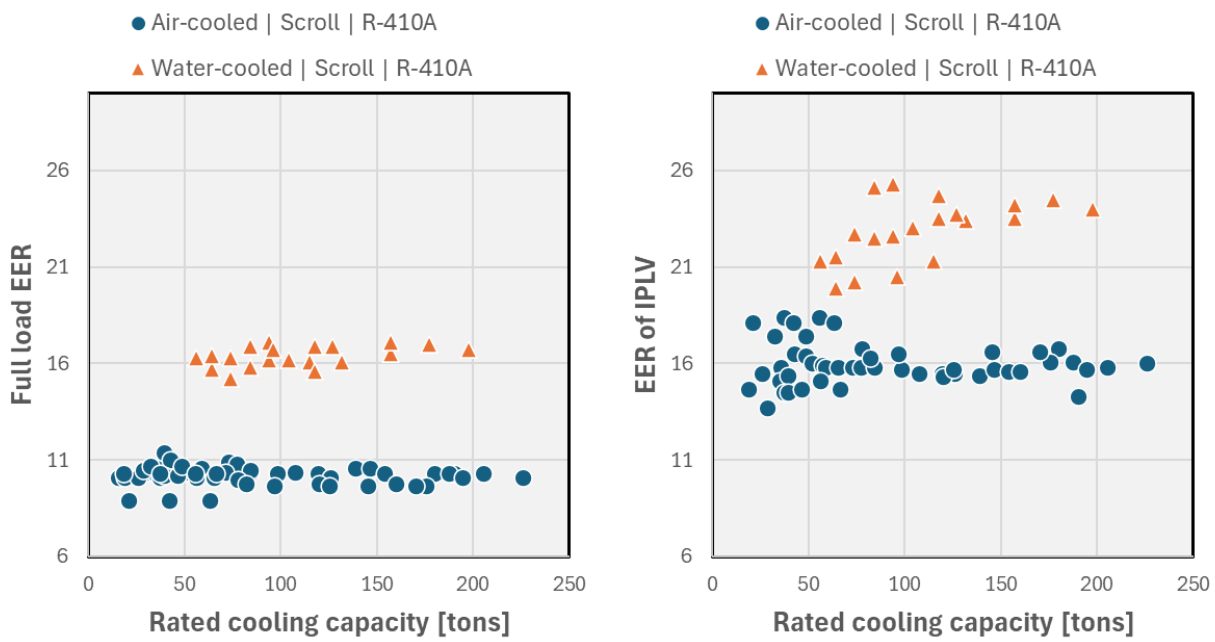

Figure 4. Chiller performance comparison: air-cooled versus water-cooled

- Chiller efficiencies at rated conditions are lower than those of part-load conditions, as IPLVs reflecting more weights on part-load conditions are higher than full-load EER values. This is reflected in Figure 4. Also, in real building applications, chillers are operated more often under part-load conditions.
- There are some products with either standard-efficiency or high-efficiency nameplate. High-efficiency products show better performance on part-load conditions (reflected with IPLV) rather than on rated/full-load conditions (reflected with full-load EER). This is reflected in Figure 5. These high-efficiency products commonly include variable-speed compressors that often operate more efficiently under part-load conditions.

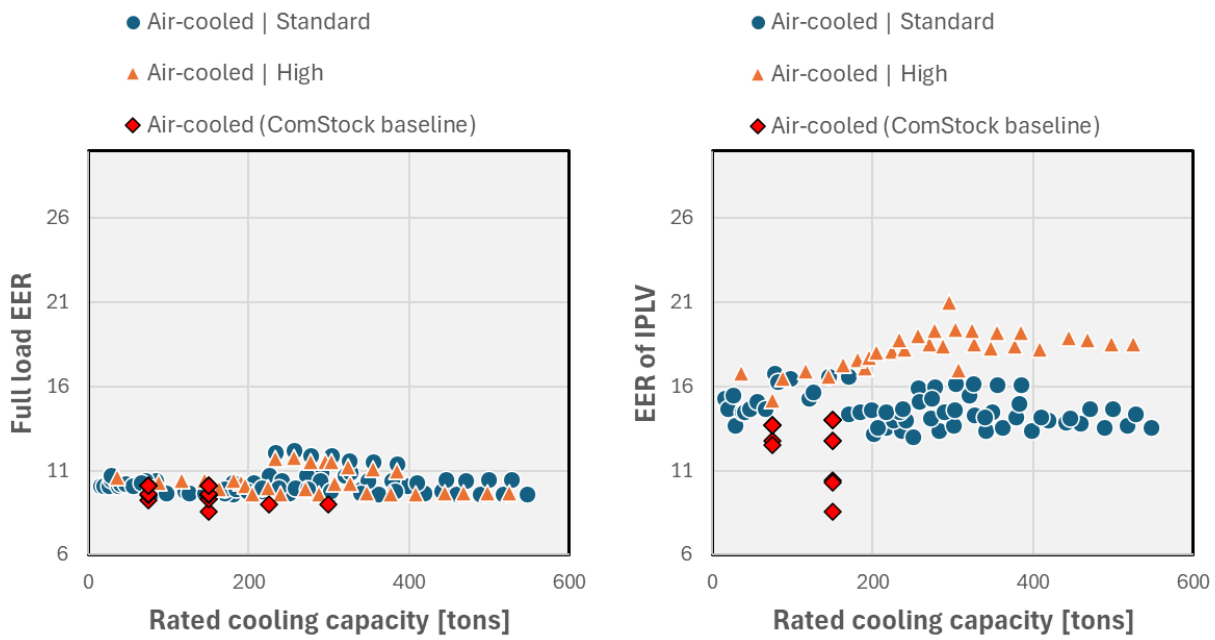

Figure 5. Chiller performance comparison: manufacturer specs (standard/high efficiency) versus ComStock baseline for air-cooled chillers

- Full-load EER and IPLV EER values applied in ComStock baseline models are slightly less efficient than performances gathered from the latest manufacturer specification datasheets. This is reflected in Figure 5 (for air-cooled chillers) and Figure 6 (for water-cooled chillers). Some water-cooled chillers only included full-load EER and not IPLV EER, thus only providing half of the information, as reflected in Figure 6. ComStock baseline values in these figures are extracted and slightly simplified (i.e., using averaged capacity instead of min/max range values) from the ComStock Reference Documentation [4]. And as shown in Figure 6, full-load EER of the upgrade chiller (e.g., 24) can be twice as efficient as some low-end baseline full-load EER values (e.g., 12).

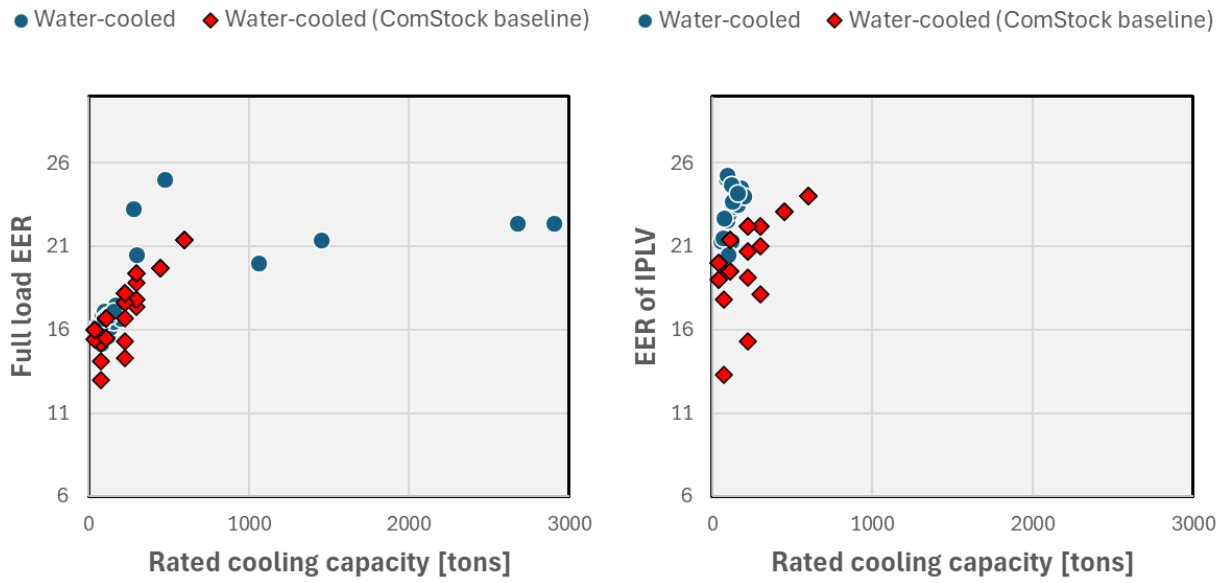

Figure 6. Chiller performance comparison: manufacturer specs versus ComStock baseline for water-cooled chillers

- Besides Daikin products, data are extracted from manufacturer webpages in January 2025. Daikin products are extracted from older (2014–2016) materials that were still publicly available because the performance metrics (i.e., EER) were not available in the latest specification datasheet documents. Although these products are from 10 years ago, their performance, as indicated in the spec sheets, remains comparable to the latest models. Therefore, they were included to expand the data pool for later averaging.
- While full-load EER and IPLV EER were relatively easy (but not "always" available) from manufacturer specification datasheets, only one manufacturer provided EER values under varying operating conditions (i.e., performance maps), which makes it difficult to generalize part-load operating characteristics between products across different manufacturers.

3.2.2 Processing Data Collected From Public Resources

Based on the distinct differences in chiller performances shown in Table A-1 (with key highlights in Section 3.2.1), we have translated the real-world data into EnergyPlus®/OpenStudio®-compatible inputs using the following criteria:

- **Exclude chillers** in Table A-1 where performance metrics (i.e., full-load EER and IPLV EER) fall below the ASHRAE 90.1-2019 standard, which is the latest benchmark used in our models. This ensures that the remaining data points represent the most efficient and market-available options.
- **Calculate the arithmetic average full-load EER** separately for air-cooled and water-cooled chillers.
- **Calculate the arithmetic average IPLV EER** separately for air-cooled and water-cooled chillers.
- For creating performance curves, we found two options:

Use **Pacific Northwest National Laboratory's Copper** tool [20], [21] to generate part-load performance curves from IPLV EER values for air-cooled and water-cooled chillers independently. This option was chosen for creating new performance curves.

Use **manufacturers' published performance maps** to generate a new set of curves. Based on the data collected during this exercise, not all manufacturers provide relevant performance maps (e.g., capacity and EER variations under different operating conditions). Therefore, while we are not endorsing any specific manufacturer, this approach will ultimately reflect the performance of only one manufacturer's chiller. Refer to the "Include performance map?" column in Table A-1 to see which chillers include performance maps. This option was not chosen in this study for creating new performance curves.

3.2.3 Creating EnergyPlus/OpenStudio Compatible Data

Based on the first three criteria outlined in the previous section, Table 1 presents the average full-load and IPLV EER values for the upgraded chillers considered in this study. The selected values are 10.8 for full-load EER and 16.4 for IPLV EER in air-cooled chillers, and 23.3 for full-load EER and 24.8 for IPLV EER in water-cooled chillers. Although these metrics were expected to vary with unit size, the data collected in this study (as highlighted in Section 3.2.1) did not show a significant size-based trend. Consequently, the average full-load EER was applied across all chiller sizes. Additionally, we gathered 164 product specifications covering both air- and water-cooled chillers (shown in Table A- 1), each containing at least one relevant data point (e.g., full-load EER available but not IPLV EER) for our modeling. However, filtering these data points for specific use cases resulted in too few data points. For example, extracting (1) average EERs separately for different size categories and (2) average EERs exceeding ASHRAE 90.1-2019 minimum requirements for water-cooled chillers significantly reduced the dataset. As a result, EER values for water-cooled chillers were not further differentiated by size category.

Table 1. Average Full-Load and IPLV EERs of Chiller Upgrade

From Data Points Exceeding the Standards Set by ASHRAE 90.1-2019			
Air-Cooled Chiller		**Water-Cooled Chiller**	
Average Full-Load EER	**Average IPLV EER**	**Average Full-Load EER**	**Average IPLV EER**
10.8 Btu/Wh	16.4 Btu/Wh	23.3 Btu/Wh	24.8 Btu/Wh
Coefficient of Performance (COP)	**COP**	**COP**	**COP**
3.17	4.81	6.83	7.27

However, there is a slight difference in how the average IPLV EER values from Table 1 are utilized. The Copper tool, which is used to generate performance curves, requires three inputs: the chiller's reference capacity, full-load efficiency, and part-load efficiency. Since the capacity range for water-cooled chillers is broader than that for air-cooled chillers, we created two sets of performance curves—one for smaller units and one for larger units—using 150 tons as the threshold. Based on the IPLV EER values in Table 1, Table 2 presents the details of all new performance curves. The curve names indicate: (1) the type of curve (e.g., CAPFT = capacity

function of temperatures), (2) the condenser type (e.g., water- or air-cooled), and (3) the size category only for water-cooled chillers (e.g., LT150 = less than 150 tons).

Table 2. Details of New Chiller Performance Curves

Curve name	AirCooledCAPFT	AirCooledEIRFT	AirCooledEIRFPLR	WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR
Curve type	Biquadratic	Biquadratic	Quadratic	Biquadratic	Biquadratic	Quadratic	Biquadratic	Biquadratic	Quadratic
Reference chiller water supply temperature [°C]	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Reference entering condenser temperature [°C]	35	35	35	29.4	29.4	29.4	29.4	29.4	29.4
Coefficient 1	1.087888	0.504314	0.184512	1.283519	0.567948	0.356683	0.981858	0.367708	0.344264
Coefficient 2	0.031718	-0.00121	0.246955	-0.0159	0.013215	-0.136572	0.009268	-0.00752	0.072927
Coefficient 3	0.000947	1.0245E-05	0.568558	0.002942	-0.00184	0.778651	-0.00068	-0.0006	0.586879
Coefficient 4	-0.00405	0.004643	-	-0.0178	0.025972	-	-0.00131	0.039086	-
Coefficient 5	-9.10E-05	0.000391	-	0.000195	-0.00037	-	-0.0002	-0.00047	-
Coefficient 6	-0.00038	-0.00059	-	0.000238	-8.66E-05	-	0.000993	-0.00019	-

As shown in Figure 1, our building models adhere to specific energy code years. Depending on the code year, the efficiency metrics (full-load EER and IPLV EER) and/or the performance curves are applied differently. To provide a comprehensive overview of the chiller upgrade in this context, Table B-1 presents a complete mapping of where the new performance curves replace the old ones. The full-load EERs and IPLV EERs in Table B-1 represent the baseline model's performance before the upgrade, while the upgraded performance is already shown in Table 1. Additionally, Table B-1 includes both the old and new curve names to clarify how the new curves are mapped to the previous ones and the chiller specifications. Table B-1 also includes a final column that references corresponding figures comparing the new and old curves. Figure 7 to Figure 9 highlight the comparison between the new curves and the old curves that represent the most up-to-date building standards (i.e., ASHRAE 90.1 2013 and later). Additional comparison figures can be found in Appendix C.

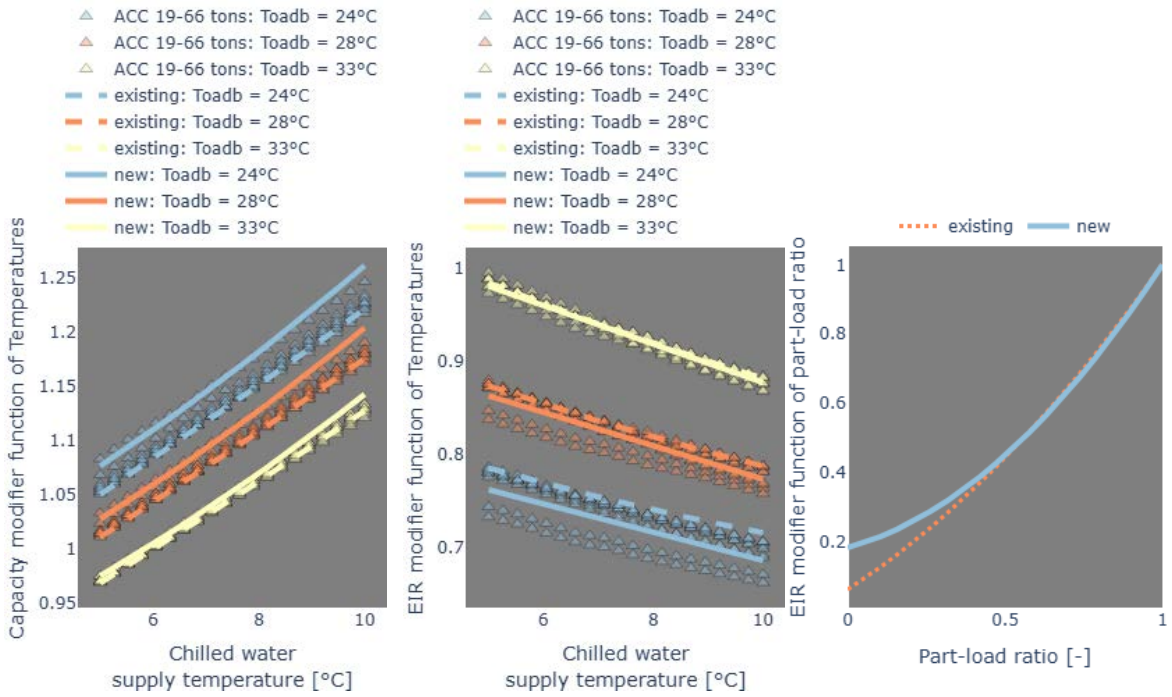

Figure 7. Air-cooled chiller performance curves comparisons against post 90.1-2010

As shown in Figure 7 (where Toadb is outdoor air dry-bulb temperature), the new air-cooled chiller performance curves exhibit improved capacity and EIR modifiers compared to the existing curves under varying temperature conditions. However, the part-load EIR of the new curve performs worse in the lower part-load ratio region. For quality assurance, we also overlaid data points from a single manufacturer (York), which only provided detailed performance data under varying operating conditions, as indicated in Table A-1. These data points covered eight different air-cooled chillers ranging from 19 to 66 tons. As shown in Figure 7, the new curves extend their performance—both in capacity and EIR modifier—closer to the best performance range observed in actual product data.

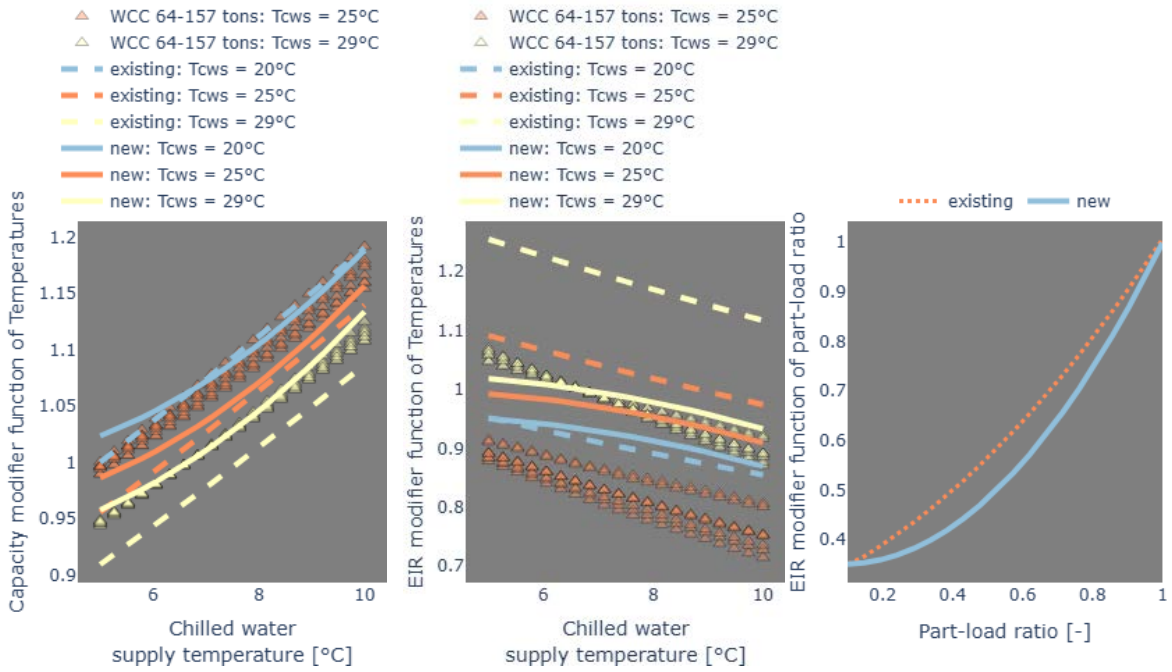

Figure 8. Water-cooled chiller (less than 150 ton) performance curves comparisons against post 90.1-2010

In Figure 8, which compares water-cooled chillers under 150 tons, the new capacity modifier curve exhibits a narrower variation range than the existing curve while still performing better under warmer conditions (e.g., entering condenser water temperature [Tcws] of 29°C). The EIR modifiers with the new curves generally show improved performance across higher condenser water temperatures and part-load ratios. Similar to Figure 7, actual data points from the same manufacturer are overlaid in Figure 8, covering eight different water-cooled chillers ranging from 64 to 157 tons. As shown in the capacity modifier graph, the new curves align more closely with actual product data at the warmest condenser water temperature conditions. In other words, they capture less capacity degradation in hotter outdoor conditions compared to the existing curve. The EIR modifiers with the new curve also exhibit a narrower range than both the existing curve and manufacturer data points. However, the new curve aligns relatively closely with the manufacturer's data, resulting in lower EIR (i.e., better coefficient of performance [COP] and improved efficiency) under warmer condenser water temperature conditions.

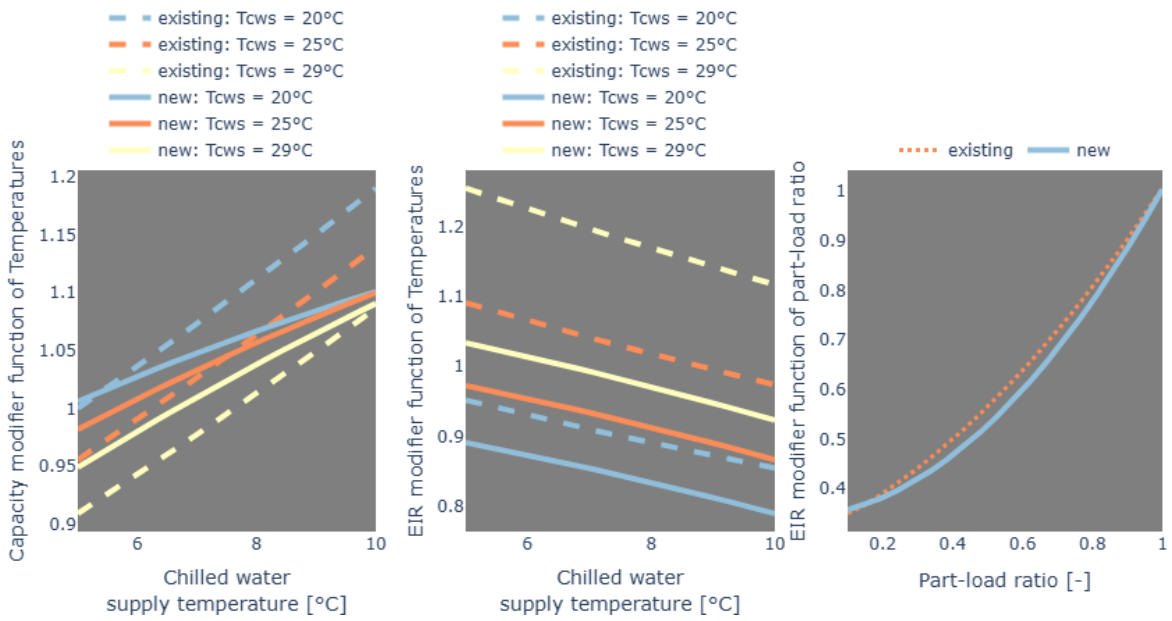

Figure 9. Water-cooled chiller (over 150 ton) performance curves comparisons against post 90.1-2010

Figure 9 presents similar plots to Figure 8, but for chillers larger than 150 tons. No manufacturer data were available for these larger chillers. As with smaller chillers, the new curve exhibits less capacity degradation and better efficiency in warmer condenser water conditions, along with slightly improved efficiency under part-load conditions. While the convergence of the three condenser temperature lines in the capacity modifier graph for the new curve appears less ideal—and may be a result of overfitting with the biquadratic equation—there was no opportunity to revise this curve due to the lack of manufacturer data for these larger chillers.

3.2.4 Upgrades in Other Parts of the Chilled Water System

While full-load and IPLV EERs reflect chiller performance, other components of the chilled/condenser water system can also be optimized through various upgrades. These improvements include replacing constant-speed pumps with variable-speed pumps, implementing advanced chilled water setpoint controls (such as outdoor air temperature reset), enhancing condenser water setpoint control, and incorporating variable-speed fans in cooling towers. Since most of these upgrades are already mandated by ASHRAE 90.1-2019, this study will update the building's chilled/condenser water system to align with ASHRAE 90.1-2019 if the current model follows an older standard. Additionally, a sensitivity analysis will be performed using a reduced sample size (10,000 models) in ComStock to evaluate the impact of different upgrade options within the chiller system—such as chiller replacement alone versus a combination of pump and control system upgrades.

Below is the list of all the other adjustments, *if not already implemented*, besides specifically on chillers:

Pump upgrade:

- Apply ASHRAE 90.1-2019 minimum motor efficiencies for pumps
- Replace variable-speed pumps with variable-speed pumps with differential pressure reset control.

Chilled water setpoint control upgrade:

- Replace chiller water setpoint control with outdoor air temperature reset, which relaxes chilled water temperature setpoint when outdoor temperature gets colder
- Outdoor air temperature range for reset: 60°F–80°F (15.6°C–26.7°C)
- Chilled water supply temperature range for reset: chilled water loop design temperature to 10°F (5.6°C) higher
- For example, if the outdoor air temperature is 80°F (26.7°C) or above, the chilled water supply temperature will be set to the building's chilled water loop design temperature for that location. As the outdoor air temperature decreases toward 60°F (15.6°C), the chilled water supply temperature will be adjusted, increasing linearly up to 10°F above the setpoint. If the outdoor air temperature falls below 60°F, the chilled water supply temperature setpoint will remain 10°F above the original setpoint.

Condenser water setpoint control update:

- Change condenser water system (including cooling tower) specifications based on ASHRAE 90.1-2019 section G3.1.3.11
- Calculating and applying condenser water design supply temperature based on section G3.1.3.11, which reflects local weather and wet-bulb temperature limits within 55°F (12.8°C) and 90°F (32.2°C)
- Also updating condenser water setpoint temperatures accordingly based on the calculated condenser water design supply temperature: maximum setpoint temperature, minimum setpoint temperature, and the offset temperature compared to the outdoor wet-bulb temperature.

3.3 Utility Bills

ComStock provides utility cost estimates for several fuel types in buildings: electricity, natural gas, propane, and fuel oil. The current implementation represents utility bills circa 2022, which is the most current year of utility data available from the EIA. This section provides a high-level overview of the methodology behind utility rates in ComStock, but more detailed information is available in the ComStock Reference Documentation [26]. Summary statistics from this implementation are shown in Table 3. ComStock does not currently estimate utility costs for district heating and cooling.

Table 3. Summary Statistics of Utility Bill Implementation in ComStock by Fuel Type

Fuel Type	Minimum Price ($)	Average Price ($)	Maximum Price ($)
Natural gas	$0.007/kBtu ($0.70/therm)	$0.012/kBtu ($1.20/therm)	$0.048/kBtu ($4.80/therm)
Propane	$0.022/kBtu ($2.20/therm)	$0.032/kBtu ($3.20/therm)	$0.052/kBtu ($5.20/therm)
Fuel oil	$0.027/kBtu ($2.70/therm)	$0.033/kBtu ($3.30/therm)	$0.036/kBtu ($3.60/therm)
Electricity	$0.003/kBtu ($0.01/kWh)	$0.035/kBtu ($0.12/kWh)	$3.530/kBtu ($12.04/kWh)

Natural gas bills are estimated using 2022 EIA averages by state. 2022 U.S. EIA Natural Gas Prices (Commercial Price) and U.S. EIA Heat Content of Natural Gas Delivered to Consumers are used to create an energy price in dollars per kBtu [27]. Propane and fuel oil bills are estimated using 2022 EIA averages by state. Residential No. 2 Distillate Prices by Sales Type and U.S. EIA residential Weekly Heating Oil and Propane Prices (October–March) and EIA assumed heat content for these fuels are used to create an energy price in dollars per kBtu [28]. Residential prices are used because commercial prices are only available at the national resolution. Additionally, most commercial buildings using these fuels are assumed to be smaller buildings where a residential rate is likely realistic. For states where state-level pricing was available, these prices are used directly. For other states, Petroleum Administration for Defense District (PADD)-average pricing is used. For states where PADD-level pricing is not available, national average pricing is used.

The primary resource for ComStock electric utility rates is the Utility Rate Database (URDB), which includes rate structures for about 85% of the buildings and 85% of the floor area in ComStock [29]. The URDB rates include detailed cost features such as time-of-use pricing, demand charges, ratchets, etc. ComStock only uses URDB rates that were entered starting in 2013, and a cost adjustment factor is applied such that the rates reflect 2022 U.S. dollars. URDB rates are assigned to ComStock models at the census tract level. The URDB can include several rate structures for a census tract. Instead of attempting to presume any single rate, multiple rates from the model's census tract are simulated; the ComStock dataset includes the minimum, median, mean, and maximum simulated rates for each model.

Many precautions are implemented to prevent less reasonable rates from being applied. This includes removing non-commercial rates, rates with non-building-load keywords (e.g. Security Light, Irrigation, Snow, Cotton Gin), rates where the load profile does not follow any potential min/max demand or energy consumption qualifiers, and rates that cause unrealistically low (<$0.01/kWh) or high (>$0.45/kWh) blended averages. Additionally, any bill that is lower than 25% of the median or higher than 200% of the median is eliminated to avoid unrealistic bills.

For buildings with no URDB electric utility assigned, or for buildings where none of the stored rates are applicable, the annual bill is estimated using the 2022 EIA Form-861 average prices based on the state each model is located in [30]. While this method does not reflect the detailed rate structures and demand charges, it is a fallback for the 15% of buildings in ComStock with no utility assigned. The utility bill implementation described in this section does not include possible future rate changes, specifically those designed for electric heating.

3.4 Carbon Emissions Equivalent

Three electricity grid scenarios are presented to compare the emissions of the ComStock baseline and the chiller replacement scenario. More are available in the full public dataset. The choice of grid scenario will impact the grid emissions factors used in the simulation, which determines the corresponding emissions produced per kilowatt-hour. Two scenarios—Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year and LRMER Low RE Cost 15-Year—use the Cambium dataset, and the third scenario uses the eGrid dataset [22], [23]. All three scenarios vary the emissions factors geospatially to reflect the variation in grid resources used to produce electricity across the United States. The Cambium datasets also vary emissions factors seasonally and by time of day. This study does not imply a preference for any

particular grid emissions scenario, but other analysis suggests that the choice of grid emissions scenario can impact results [24]. Emissions due to on-site combustion of fossil fuels use the emissions factors shown in Table 4, which are from Table 7.1.2(1) of draft American National Standards Institute/Residential Energy Services Network/International Code Council 301 [25]. To compare total emissions due to both on-site fossil fuel consumption and grid electricity generation, the emissions from a single electricity grid scenario should be combined with all three on-site fossil fuel emissions factors.

Table 4. On-Site Fossil Fuel Emissions Factors

Natural gas	147.3 lb/MMBtu (228.0 kg/MWh)[a]
Propane	177.8 lb/MMBtu (182.3 kg/MWh)
Fuel oil	195.9 lb/MMBtu (303.2 kg/MWh)

[a] lb = pound; MMBtu = million British thermal units; kg = kilogram; MWh = megawatt-hour

3.5 Limitations and Concerns

Comprehensive chiller performance maps across many different chiller products, which are required for detailed energy modeling, are not publicly available as a whole. Consequently, we have to make engineering judgements to closely reflect products in the current market. The work presented here attempts to use the most informative data available and makes documented assumptions about chiller operation and performance. These will notably impact results. Please consider these assumptions.

- This study relies on data gathered from public sources, such as manufacturer websites. While we made an effort to collect as much data as possible in an unbiased manner, some relevant information may not have been included. We welcome input from others, including readers of this report, regarding any additional data that can enhance this work. Since the process of deriving chiller performance and applying measures to ComStock can be repeated, we are open to incorporating new data as they become available.
- Air-cooled chillers under 150 tons and chillers following the energy code of DOE reference 1980–2004 are incorrectly modeled with higher rated COPs (i.e., 5.2). The upgrade measure in this study skips these chillers with higher efficiency. Details of the issue are also described in this pull request: https://github.com/NREL/openstudio-standards/pull/1905.

4 Output Variables

Table 5 includes a list of output variables that are calculated in ComStock. These variables are important in terms of understanding the differences between buildings with and without the chiller replacement measure applied. These output variables can also be used to help understand the economics of the upgrade (e.g., return on investment) if cost information (i.e., material, labor, and maintenance costs for technology implementation) is available.

Table 5. Output Variables Calculated From the Measure Application

Variable Name	Description
out.params.chiller_average_cop	Load weighted annual average operating COP of all chillers
out.params.chiller_capacity	Total chiller capacity in tons
out.params.hvac_count_chillers_0_to_75_tons	Count of chillers in 0–75 tons category
out.params.hvac_count_chillers_75_to_150_tons	Count of chillers in 75–150 tons category
out.params.hvac_count_chillers_150_to_300_tons	Count of chillers in 150–300 tons category
out.params.hvac_count_chillers_300_to_600_tons	Count of chillers in 300–600 tons category
out.params.hvac_count_chillers_600_plus_tons	Count of chillers above 600 tons
out.params.design_chiller_cop	Load weighted average COP of all chillers
out.params.hvac_chiller_acc_capacity_fraction	Fraction of air-cooled chillers by capacity
out.params.hvac_chiller_wcc_capacity_fraction	Fraction of water-cooled chillers by capacity
out.params.hvac_chiller_ecc_capacity_fraction	Fraction of evaporatively-cooled chillers by capacity
out.params.hvac_chiller_iplv_eer	Load weighted annual average operating IPLV EER of all chillers

5 Results

In this section, results are presented both at the stock level and for individual buildings through savings distributions. Stock-level results include the combined impact of all the analyzed buildings in ComStock, including buildings that are not applicable to this measure. Therefore, they do not necessarily represent the energy savings of a particular or average building. Stock-level results should not be interpreted as the savings that a building might realize by implementing the measure.

Total site energy savings are also presented in this section. Total site energy savings can be a useful metric, especially for quality assurance/quality control, but this metric on its own can have limitations for drawing conclusions. Further context should be considered, as site energy savings alone do not necessarily translate proportionally to savings for a particular fuel type (e.g., gas or electricity), source energy savings, cost savings, or reduction in emissions. This is especially important when a measure impacts multiple fuel types or causes decreased consumption of one fuel type and increased consumption of another. Many factors should be considered when analyzing the impact of an energy efficiency strategy, depending on the use case.

5.1 Single-Building Measure Tests

An office model was selected to demonstrate the impact of water-cooled chiller system upgrades on a single building model. The baseline building model features a VAV system, where chilled water for cooling is provided by an electric chiller and hot water for heating is provided by a natural gas-fired boiler. The chiller is water cooled, meaning the chiller's condenser rejects heat via an evaporative cooling tower. The following sections analyze the effects of chiller replacement alone as well as the impact of combining chiller replacement with additional system upgrades. To clarify once more and as described in Sections 3.2.3 and 3.2.4, the final chiller upgrade in this study—and which is reflected in the final published dataset—includes all upgrade options described in those two sections as well as in this section.

5.1.1 Chiller Replacement

Figure 10 illustrates the impact of chiller replacement alone compared to the baseline model. It presents daily profiles (averaged over 365 days) for various chiller system aspects, including chiller power consumption, operating COP, cooling tower fan power, chilled water supply temperature, pump power, cooling tower heat transfer rate, gas boiler usage, and chilled water system COP (including electricity usage for chiller, chilled/condenser water pumps, and cooling tower fan). In the baseline model, the chiller had a rated COP of 5.5 (representing an older unit), whereas the new chiller features a rated COP of 6.8 (as shown in Table 1). Due to this noticeable improvement in COP, along with enhanced part-load performance (discussed in Section 3.2.3), Figure 10 shows noticeable improvements in chiller operating COP and reduced chiller power consumption. Additionally, because the upgraded chiller operates more efficiently, it rejects less heat through the condenser for the same cooling load. As a result, the cooling tower fan operates less, leading to lower cooling tower heat transfer rates and reduced fan power consumption.

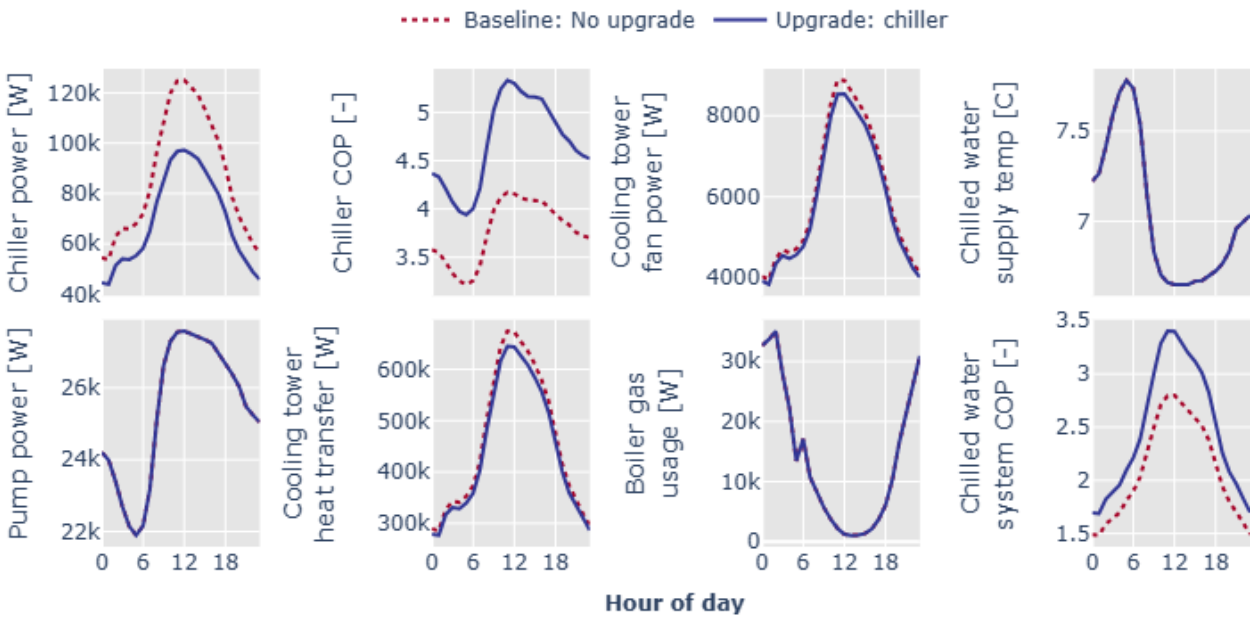

Figure 10. Single-building model test results: chiller upgrade only

5.1.2 Chiller and Pump Upgrade

Figure 11 presents similar results but includes the additional upgrade of pumps in both the chilled water loop and condenser water loop, alongside the chiller replacement. In addition to the improvements observed in Figure 10, Figure 11 also highlights a reduction in pump power consumption (compared to chiller replacement only). This improvement in pump power is attributed to enhanced pump motor efficiency and optimized pump control using differential pressure reset, as described in Section 3.2.4. Because the pump power is reduced with more efficient pump, the chilled water system COP with upgraded pump also shows a slight increase.

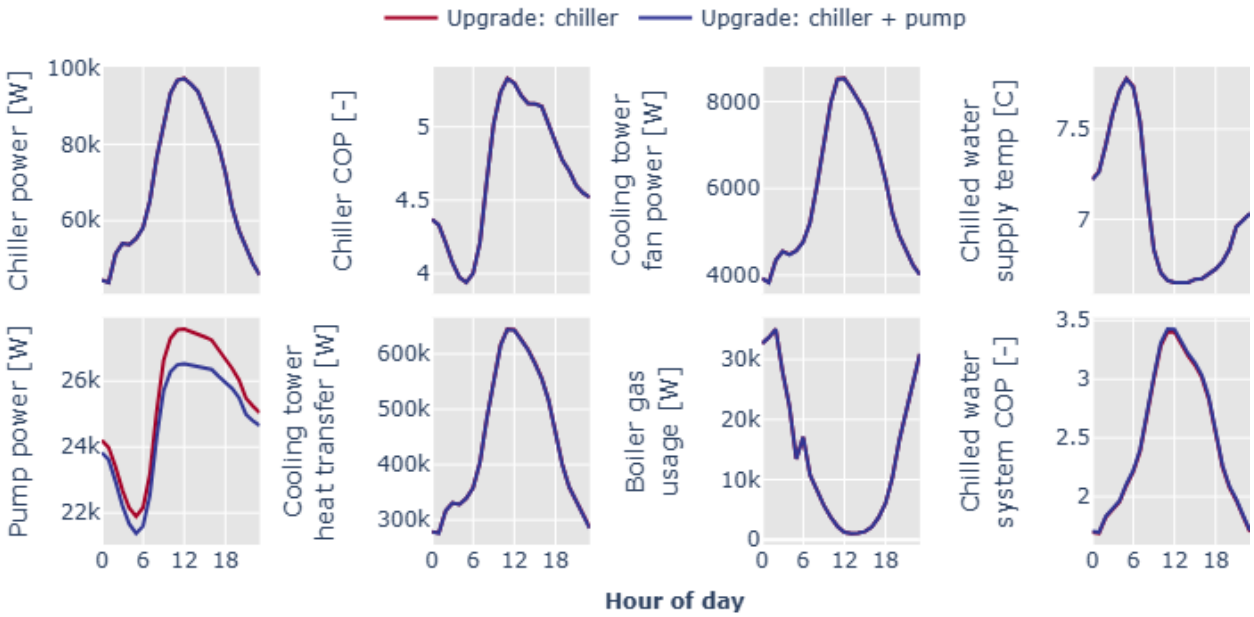

Figure 11. Single-building model test results: chiller upgrade + pump upgrade

5.1.3 Chiller Upgrade and Chilled Water Set Point Control Upgrade

Figure 12 presents similar results to earlier figures but includes an additional upgrade: the implementation of chilled water supply temperature reset in the chilled water loop, along with the chiller replacement. In addition to the improvements shown in Figure 10, Figure 12 illustrates that the chilled water supply temperature is increased during the upgrade scenario, when outdoor temperatures are relatively low. This enables the chiller to operate under more favorable part-load conditions, resulting in additional energy savings. Furthermore, as the chilled water supply temperature is raised through the reset strategy, the temperature difference (ΔT) between supply and return water decreases. To meet the same cooling load, this reduced temperature difference necessitates an increase in flow rate, which is reflected in the pump power increase shown in Figure 12. However, the slight increase in pump power is expected to be outweighed by the energy savings from more efficient chiller operation. Also, the chilled water supply temperature relaxation (or increase) with reset also resulted in slight reheat energy savings (i.e., slightly reduced gas boiler usage).

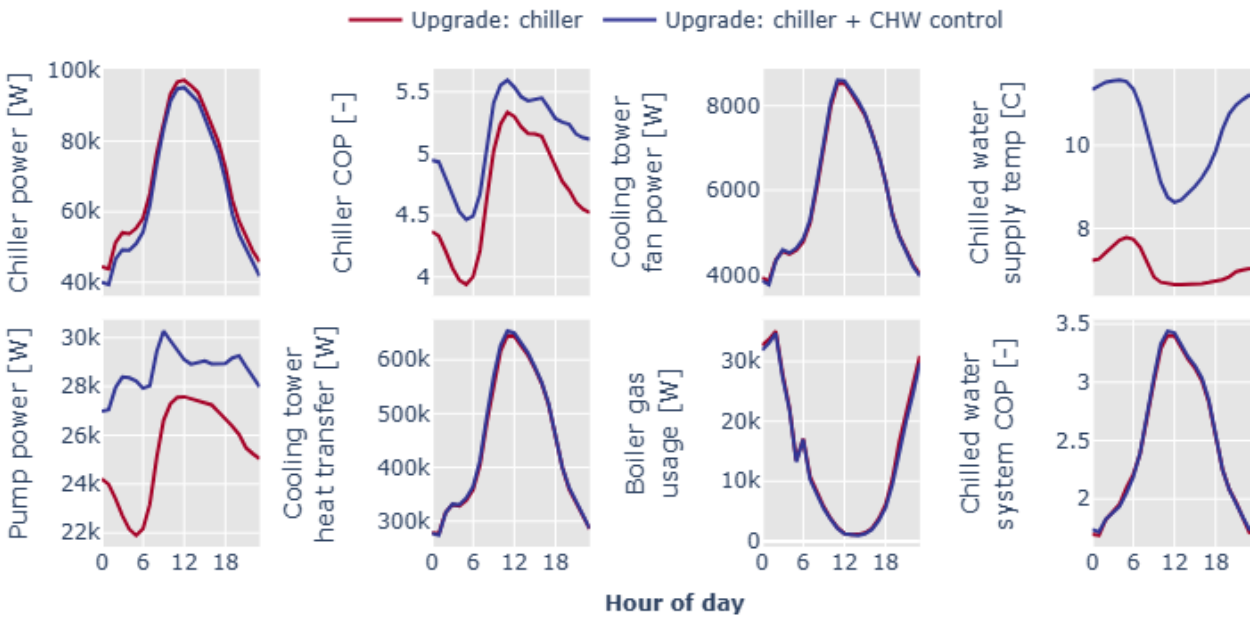

Figure 12. Single-building model test results: chiller upgrade + chilled water setpoint reset

5.1.4 Chiller Upgrade and Condenser Water Set Point Control Update

Figure 13 presents similar results but includes an additional upgrade to condenser water supply temperature control in the condenser water loop, alongside the chiller replacement. In addition to the improvements from chiller replacement alone, Figure 13 shows an increase in cooling tower fan energy usage and slightly better chiller COP compared to the chiller only replacement scenario. This improvement results from updated control settings, which allow the system to reject heat more efficiently by adjusting condenser water system specifications based on weather conditions. Based on the chilled water system COP, the improvement with this condenser water setpoint control scenario did not seem noticeable for this example model.

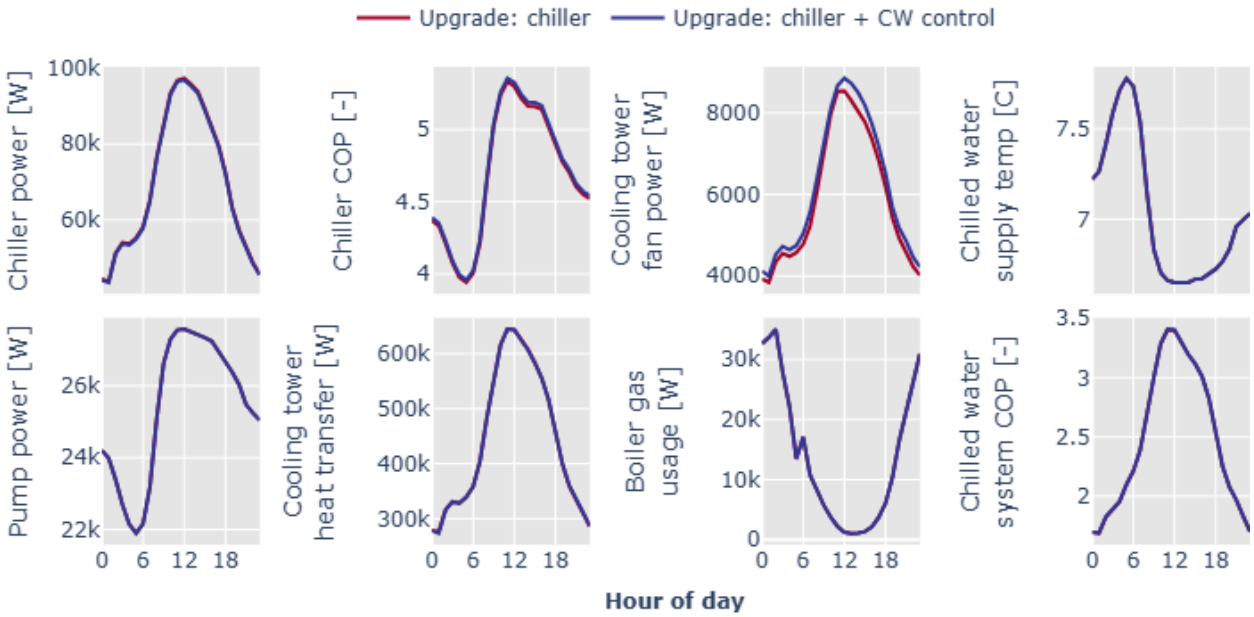

Figure 13. Single building model test results: chiller upgrade and condenser water setpoint update

5.2 Sensitivity Results With Reduced Stock Models

We conducted a sensitivity analysis by (1) varying the chilled water system upgrades and (2) applying these different upgrades to ComStock with reduced stock models (i.e., ~14,000 instead of ~150,000 models that reasonably represent variations of the commercial building stock). This section includes the results of this sensitivity analysis to provide partial snapshots of how these different upsizing allowances propagate to the stock of building models. Note that because the sensitivity analysis in this section uses far fewer models to represent the building stock than a full ComStock run, results should be used for understanding generalized and conceptual trends only. Results with the full ComStock run shown in Section 6.3 and after might show slightly different trends because of including the remaining ~140,000 models. More detailed analyses should always utilize the available scenarios in the full published ComStock datasets.

Figure 14 shows the aggregated site energy consumption across different chilled water system upgrade scenarios: baseline, chiller replacement only (shown as Chlr), chiller and pump replacement (shown as Chlr Pmp), chiller/pump replacement and chilled water temperature reset (shown as Chlr Pmp CHW), and chiller/pump replacement and chilled/condenser water temperature reset (shown as Chlr Pmp CHW CW). As expected, the chiller replacement had the greatest impact on site energy savings, while the other upgrade options—such as pump improvements and chilled water/condenser water setpoint controls—contributed to a lesser extent. Also, as mentioned earlier in Section 5.1, chilled water supply temperature reset strategy resulted in reheat energy savings (i.e., heating energy savings shown in Figure 14).

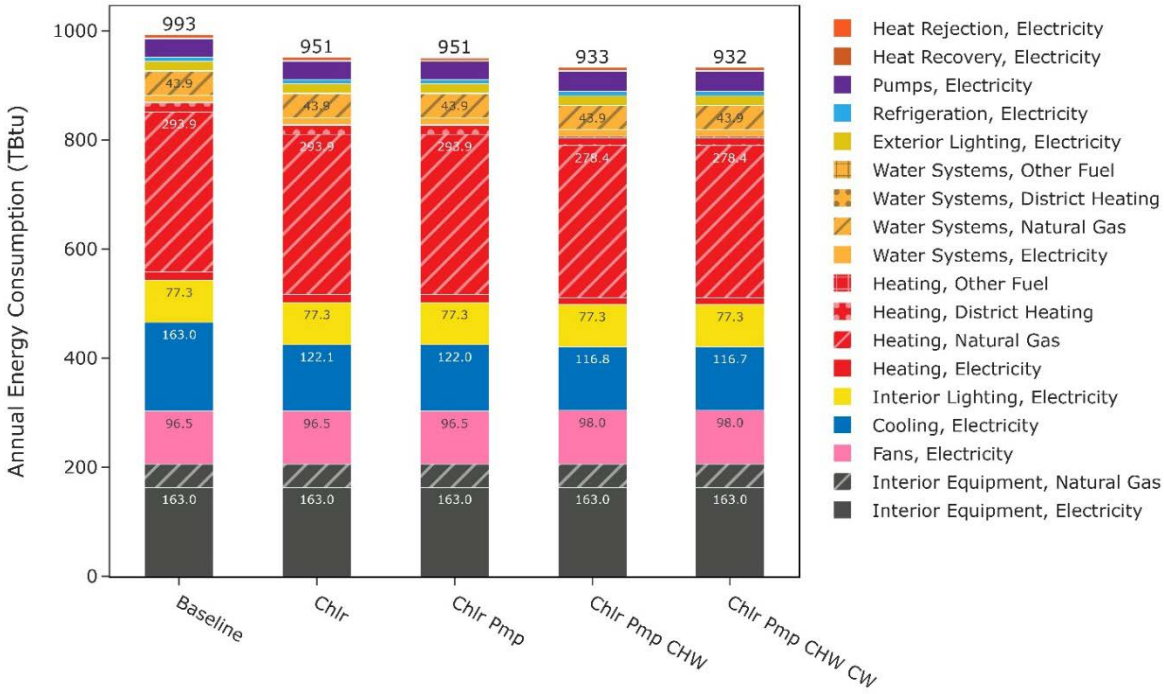

Figure 14. Sensitivity analysis: aggregated site energy consumption with applicable models only

To break this down further, Figure 15 isolates electricity consumption for cooling, pumps, and heat rejection (i.e., cooling tower fans). An increase in pump power is noticeable when the chilled water supply temperature reset is implemented, as discussed in Section 5.1. Changes in cooling tower fan energy use are minimal and nearly negligible.

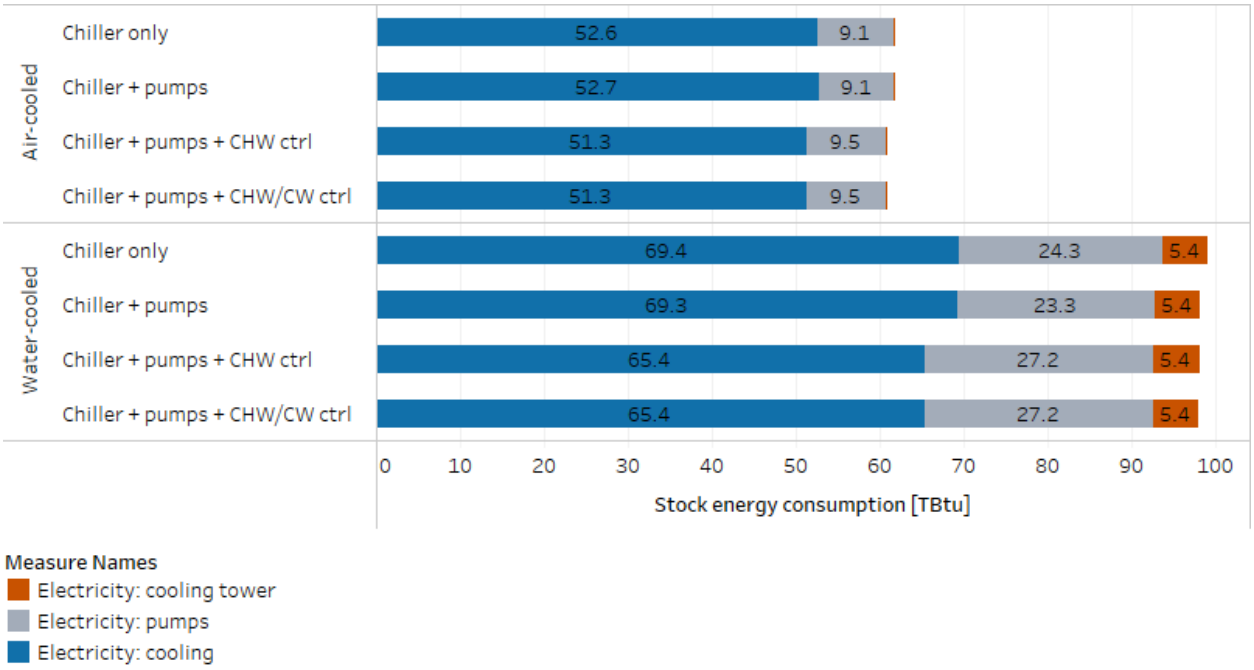

Figure 15. Sensitivity analysis: aggregated electricity consumption related to chilled water systems

To better understand the chiller operation characteristics across upgrade scenarios, Figure 16 presents chiller performance metrics and capacities using box plots. Compared to the baseline scenario, the rated COPs of chillers in all upgrade cases are higher, with the rated COP for upgraded water-cooled chillers nearly doubling. To provide a more industry-recognized performance metric, the IPLV expressed in EER is also included in Figure 16. A similar trend is observed in the annual average operating COPs across the different scenarios.

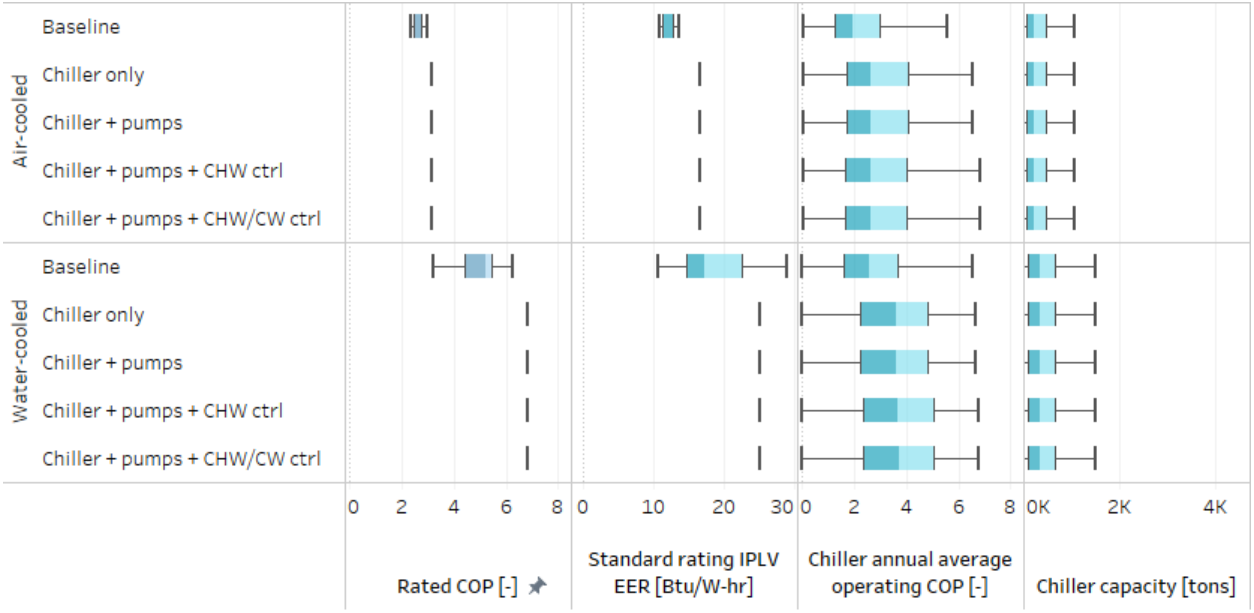

Figure 16. Sensitivity analysis: chiller capacities and performance metrics

5.3 Stock Energy Impacts

Figure 17 and Figure 18 show the comparison of annual site energy consumption between the baseline and upgrade scenarios for the entire building stock and buildings that are only applicable to the upgrade, respectively. The complete package of chiller upgrade measure demonstrates 1.3% total site energy savings (62 trillion British thermal units [TBtu]) for the U.S. commercial building stock modeled in ComStock including both applicable and inapplicable buildings for this upgrade. The savings of the complete chiller upgrade package are primarily attributed to:

- 6.5% stock cooling electricity savings (47.1 TBtu)
- 1.6% stock heating natural gas savings (15.6 TBtu)
- 0.7% stock heating electricity savings (1.9 TBtu)
- 2.7% stock district heating savings (1.1 TBtu)
- -0.2% stock fan electricity savings (-1.4 TBtu)
- -8.2% stock pump electricity savings (-3.2 TBtu).

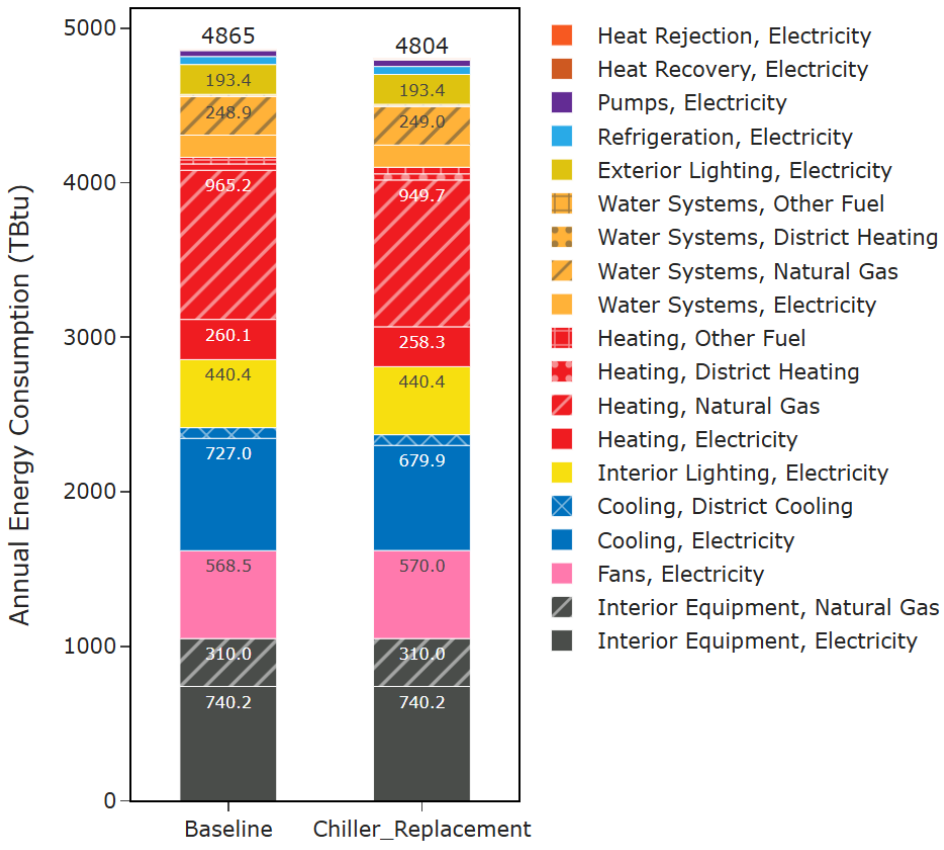

Figure 17. Comparison of annual site energy consumption between the ComStock baseline and the chiller replacement measure scenarios for the entire building stock, including buildings not applicable to the chiller upgrade.

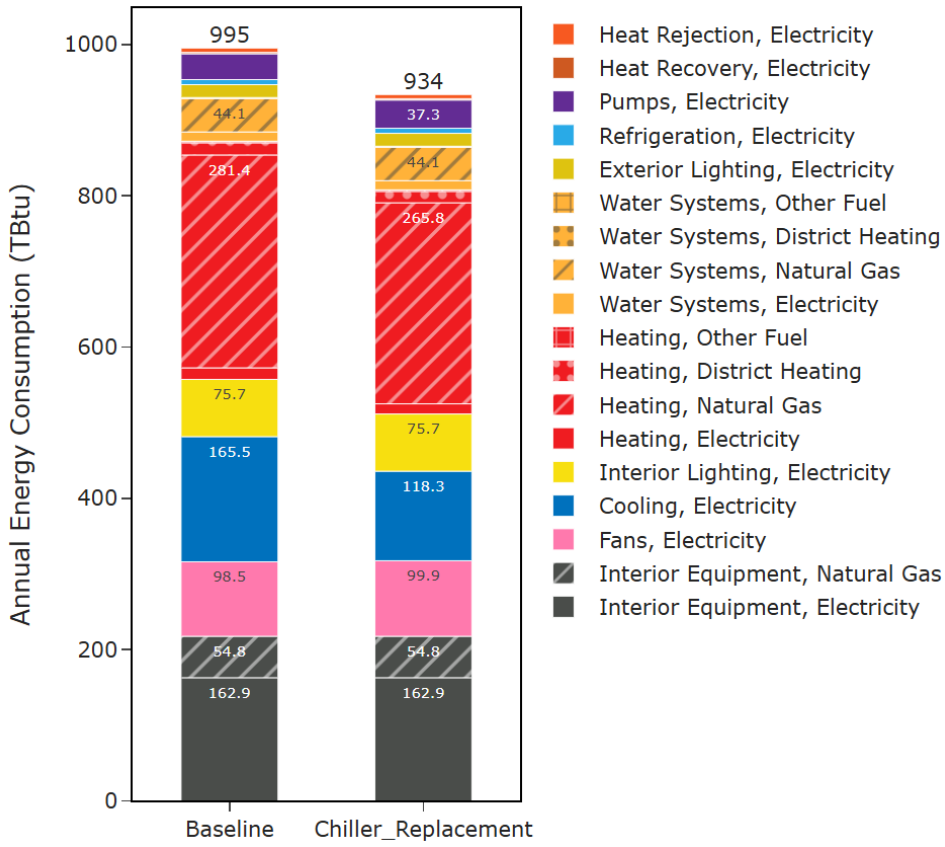

Figure 18. Comparison of annual site energy consumption between the ComStock baseline and the chiller replacement measure scenarios only for buildings that are applicable to the upgrade

As discussed in Sections 5.1 and 5.2, Figure 17 and Figure 18 illustrate similar trends: reduced electricity consumption for cooling, lower site energy use for heating (i.e., less reheat), and increased pump energy use due to the chilled water supply temperature reset strategy. Although the energy savings from the chiller upgrade package may appear modest at the stock level, a closer look at Figure 18—which focuses only on buildings eligible for the upgrade—reveals a noticeable impact: 29% (47 TBtu) of the electricity used for cooling is saved with this package.

5.4 Stock Utility Bill Impacts

This section includes a comparison of annual utility bills for buildings using different energy sources (i.e., electricity, natural gas, propane, fuel oil) and for the entire building stock. Because we apply many electricity utility rate structures that are available for a building located in a certain geographical location, our data include many annual utility bills per building model. Figure 20 shows a comparison among two scenarios (i.e., baseline and entire chilled water system upgrade), including three different electricity utility bill statistics. The comparison highlights three statistics (maximum, mean, and minimum) across all electric utility bill costs. For detailed information regarding utility rate implementation, refer to the ComStock Reference Documentation [26].

Site energy savings and utility bills savings do not necessarily align due to cost differences between fuel types as well as primary energy conversion factor differences. Figure 17 shows

aggregated “site” energy consumption, which does not reflect the “primary” energy perspectives. Thus, the annual aggregated cost comparisons, shown in Figure 19, can also tell us the primary energy consumption comparisons between different scenarios.

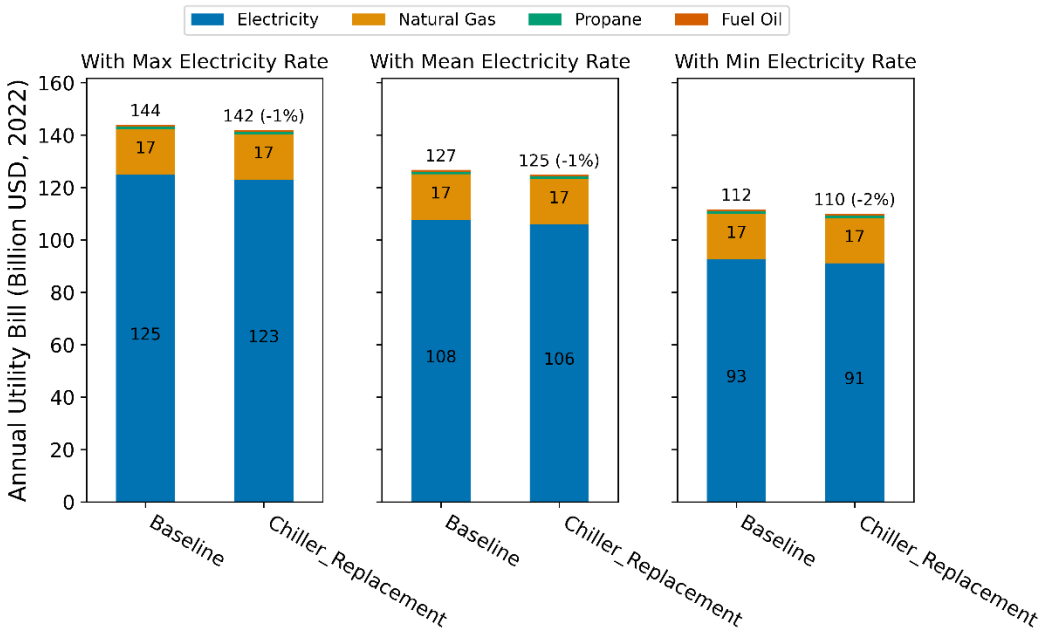

Figure 19. Utility bill comparison of the ComStock baseline and the chiller replacement scenario

Figure 20 shows the distribution of utility bill saving percentage across all climate zones. As expected, leveraging a more efficient chilled water system can save more energy and cost in hotter climate zones. And as the weather gets colder (e.g., climate zone 8), savings percentage decreases since cooling contributes a lesser amount to a building’s total energy usage.

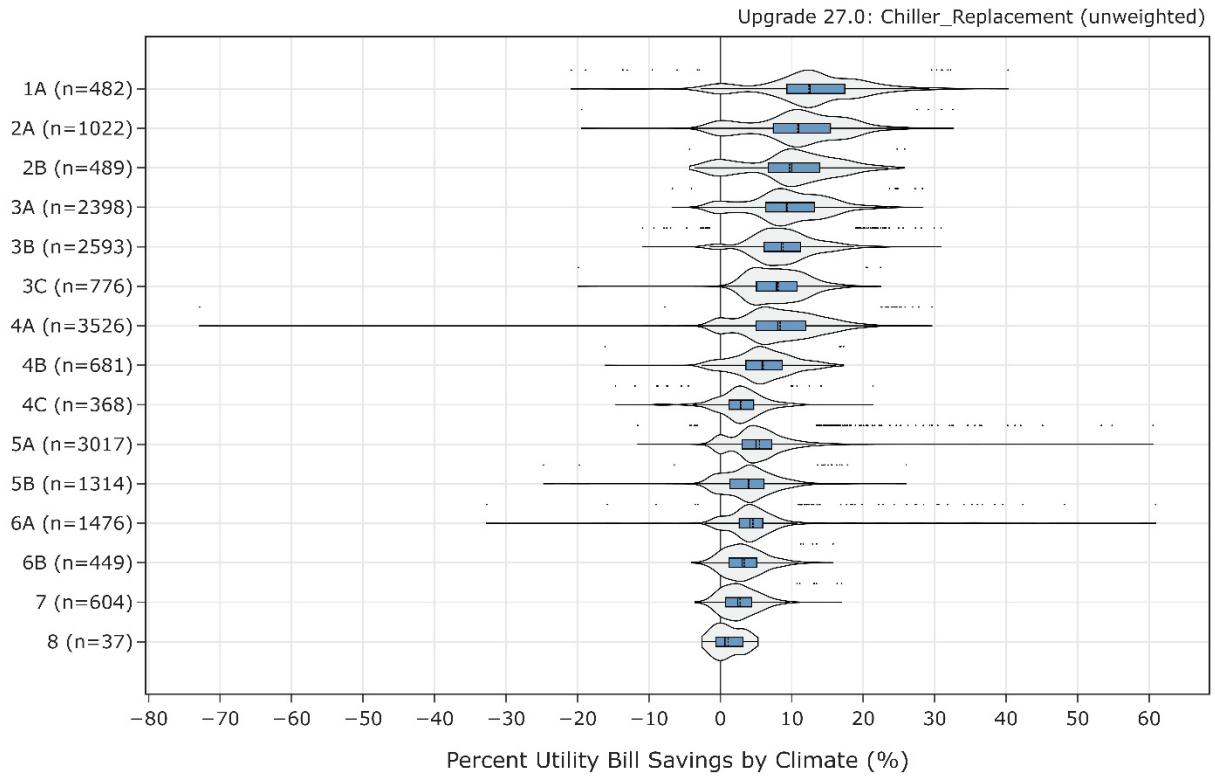

Figure 20. Utility bill savings (compared to baseline) distribution for ComStock models with the chiller replacement measure applied by climate zone

5.5 Stock Carbon Emissions Equivalent Impacts

Figure 21 shows ComStock simulation results for carbon emissions avoided across all electricity grid scenarios and on-site combustion fuel types against the total ComStock baseline building stock. Additionally, Table ES-3 (in the Executive Summary) also tabulates avoided emissions between different end-use types and against the entire building stock and applicable building stock. Overall, the chilled water system upgrade demonstrates between 2 and 6 million metric tons (MMT) of carbon emissions avoided (for all fuel types) across the three electricity scenarios presented. The 2 MMT number corresponds to a 0.8% reduction for the LRMER Low RE Cost 15-Year scenario, while the 6 MMT number corresponds to a 1.3% reduction for the eGRID 2021 scenario. These results are mostly attributed to higher-efficiency chiller operations. The 1% emissions avoided from on-site combustion are attributable to reheat energy savings.

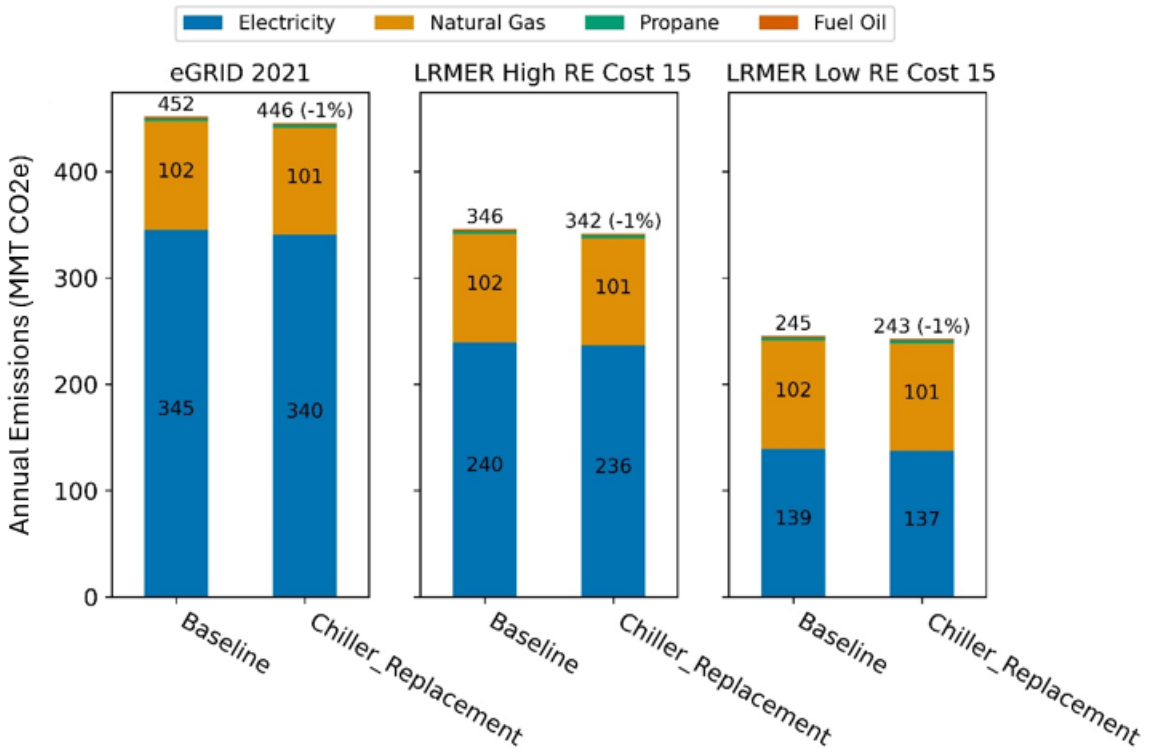

Figure 21. Carbon emissions equivalent comparison of the ComStock baseline and the chiller replacement scenario

5.6 Site Energy Savings Distributions

This section discusses site energy consumption for quality assurance/quality control purposes. Site energy savings can be useful for these (and possibly other) purposes, but additional factors should be considered when drawing conclusions, as site energy savings do not necessarily translate proportionally to source energy savings, carbon emissions avoided, or energy costs, which vary widely across the United States. Savings shown in this section are based on comparisons between the baseline and the entire upgrades on the chilled water system.

Figure 22 through Figure 24 show distributions of the applicable baseline ComStock models versus the upgrade scenario for percent site energy or site energy use intensity (EUI) savings with different HVAC types, fuel types, or end uses. Percent savings provide relative impact of the measure at the individual building level, while site EUI savings provide absolute (or aggregated) scale of impact. The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of ComStock models that were applicable for energy savings for the fuel type category. It should also be noted that these pairwise comparisons represented with distributions only calculate percent savings for buildings where the baseline included some prevalence of end-use/fuel type. Thus, the electric heating savings only shows buildings that originally used some amount of electric heating and does not represent buildings where natural gas was the only heating fuel.

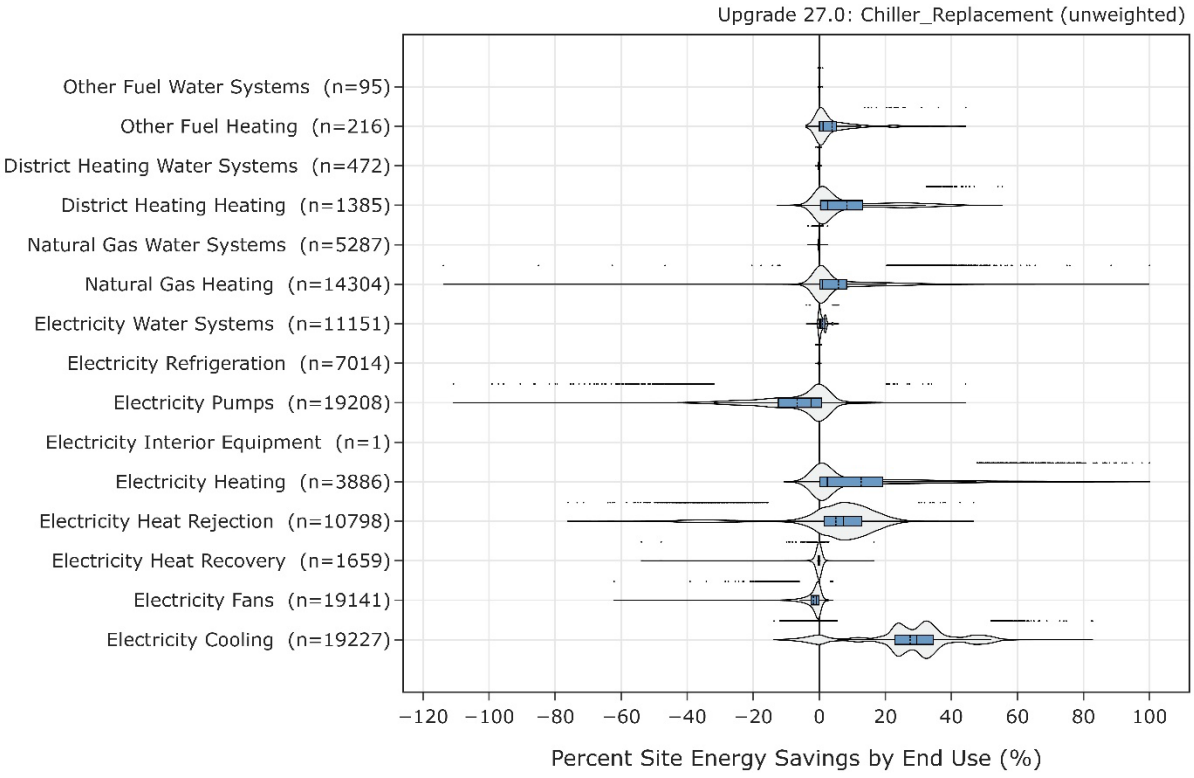

Figure 22. Percent savings (compared to baseline) distribution for ComStock models with the chiller upgrade measure by end use and fuel type

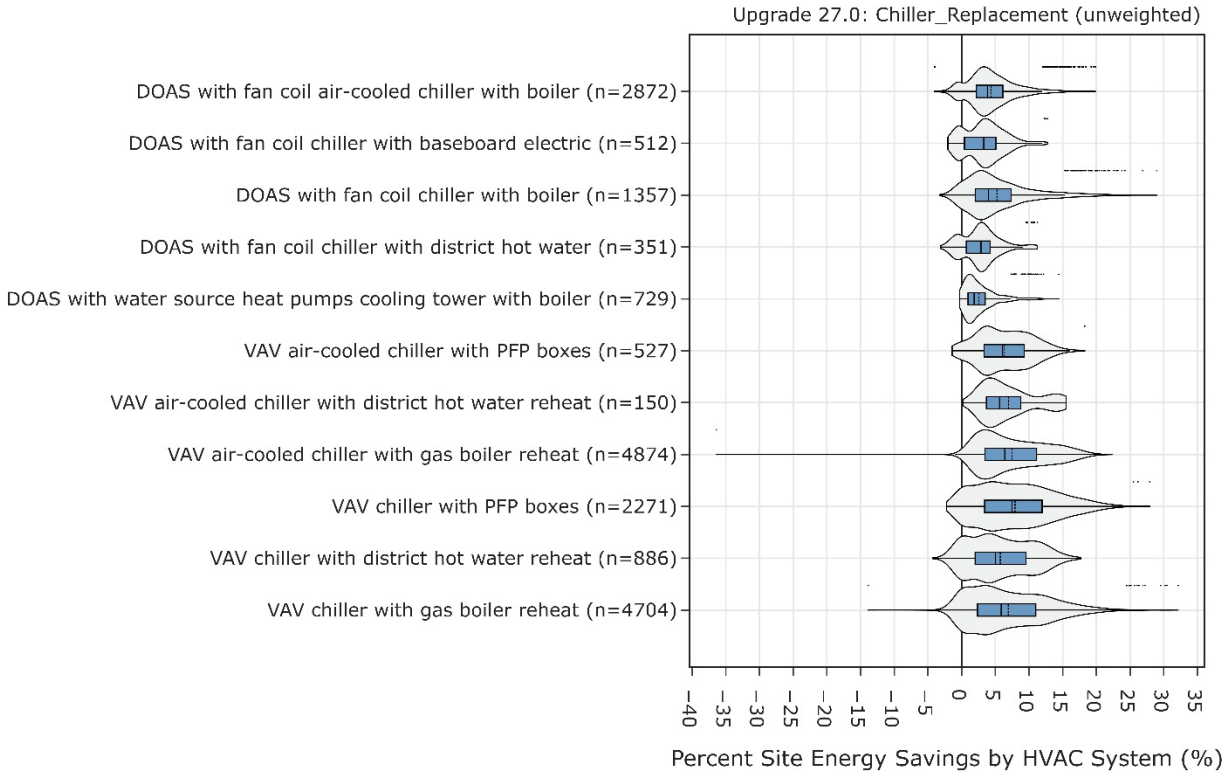

Figure 23. Percent savings (compared to baseline) distribution for ComStock models with the chiller upgrade measure by HVAC type

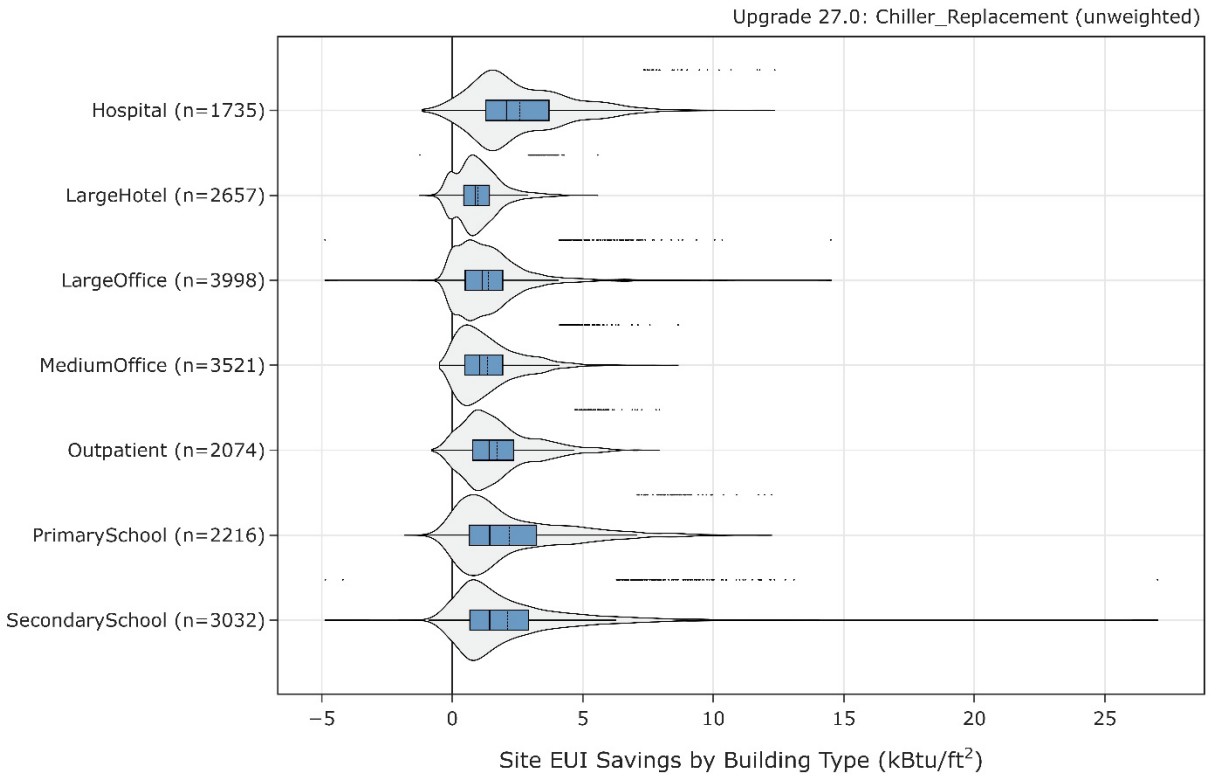

Figure 24. Site EUI savings (compared to baseline) distribution for ComStock models with the chiller upgrade measure by building type

Highlights of conclusions drawn from Figure 22 through Figure 24 include:

- Positive electricity cooling savings (Figure 22):
    - The main savings are realized by replacing old chillers with newer chillers.
    - This is the majority of all site energy savings from this upgrade.
- Positive heating savings (Figure 22):
    - Savings from electricity, natural gas, district heating, and other fuels used for heating.
    - For multi-zone central air systems with reheat mechanisms, chilled water supply temperature setpoint reset based on outdoor air temperature increases the air temperature at the evaporator outlet and resulting in less reheat (i.e., heating savings).
- Negative pump savings (Figure 22):
    - When chilled water supply temperature setpoint is reset based on outdoor air temperature, the temperature difference across the evaporator decreases due to the relaxed supply temperature control.
    - To meet the same cooling demand, the pump has to operate at a higher flow rate and this consume more electricity.
    - However, the increase in pump power is outweighed by the energy savings from more efficient chiller operation.

- Various HVAC system types using chillers (Figure 23):
    - VAV multi-zone air systems use air-cooled/water-cooled chillers, as do fan coil units coupled with DOAS and water-source heat pumps.
    - Due to the bigger efficiency improvements realized in water-cooled chillers compared to air-cooled chillers (reflected in Figure 16), the percentage savings are slightly higher for water-cooled systems across most comparable HVAC system types.
- Impacts on bigger buildings (Figure 24):
    - Because chillers are used in relatively bigger HVAC systems serving larger loads, this upgrade also impacts relatively bigger buildings such as larger offices, hospitals, and schools.

References

[1] "Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS)." Accessed: Jan. 14, 2025. [Online]. Available: https://www.eia.gov/consumption/commercial/

[2] P. Evans, "Chiller Replacement Savings Calculations," The Engineering Mindset. Accessed: Jan. 30, 2025. [Online]. Available: https://theengineeringmindset.com/energy-savings-from-replacing-a-chiller/

[3] D. Alias *et al.*, "Feasibility Analysis on Energy Retrofitting of Chiller Plant and Air-Distribution System of an Existing Building for Energy Efficiency Improvement," Jan. 17, 2025, *Social Science Research Network, Rochester, NY*: 5093825. doi: 10.2139/ssrn.5093825.

[4] A. Parker *et al.*, "ComStock Reference Documentation: Version 1," Golden, CO, 2023.

[5] "AQUASNAP® AND AQUAFORCE® AIR-COOLED CHILLERS," Carrier, 2020. [Online]. Available: https://www.shareddocs.com/hvac/docs/1001/Public/0F/04-811-90019.pdf

[6] "Ascend® Air-Cooled Chillers," Trane, 2023. [Online]. Available: https://elibrary.tranetechnologies.com/public/commercial-hvac/Literature/Sales/AC-SLB002-EN_08252023.pdf

[7] "Air-Cooled Chillers," Trane, 2024. [Online]. Available: https://elibrary.tranetechnologies.com/public/commercial-hvac/Literature/Sales/PROD-SLB049-EN_04222024.pdf

[8] "Agility® Centrifugal Water-Cooled Chillers." Accessed: Jan. 09, 2025. [Online]. Available: https://www.trane.com/commercial/north-america/us/en/products-systems/chillers/water-cooled-chillers/agility.html

[9] "Water-cooled Scroll Chiller," Daikin Applied. Accessed: Jan. 09, 2025. [Online]. Available: https://www.daikinapplied.com/products/chiller-products/water-cooled-scroll

[10] "MAGNITUDE® WMT MAGNETIC BEARING OIL-FREE CENTRIFUGAL CHILLERS," Daikin, CAT-637, 2024. [Online]. Available: https://tahoeweb.daikinapplied.com/api/general/DownloadDocumentByName/media/Magnitude%20WMT%20-%20CAT%20637%20(published%206-5-24).pdf/

[11] "Trailblazer® air cooled scroll chillers," Daikin, 2016. [Online]. Available: https://daikinlatam.com/wp-content/uploads/2018/05/Daikin_trailblazer_agz-e_scroll_chiller_microchannel.pdf

[12] "Pathfinder® Air-cooled Screw Chiller," Daikin, 623–2, 2014. [Online]. Available: https://www.directindustry.com/prod/daikin-applied/product-17916-2573968.html

[13] "YLAA Air-Cooled Scroll Chillers Style B," York, 150.72-EG6. [Online]. Available: https://docs.johnsoncontrols.com/chillers/v/u/YORK/en-US/YLAA0070SE-0080SE-0089SE-0100SE-0120SE-0136SE-0155SE-0170SE-Standard-Efficiency-0041HE-0048HE-0058HE-0065HE-0082HE-0092HE-0101HE-0125HE-0139HE-0156HE-0175HE-0200HE-0230HE-Style-B-60-Hz-with-Brazed-Plate-Heat-Exchangers/1023

[14] "YCIV Variable Speed Drive Screw Chiller," York, 201.23-EG3, 2018. [Online]. Available: https://docs.johnsoncontrols.com/chillers/v/u/YORK/en-US/YCIV0157-YCIV0177-YCIV0187-YCIV0207-YCIV0227-YCIV0247-YCIV0267-YCIV0287-YCIV0307-YCIV0357-YCIV0397-Style-A-60-Hz-Variable-Speed-Drive/818

[15] "YCAL Scroll Chiller," York, 150.67-EG1, 2021. [Online]. Available: https://docs.johnsoncontrols.com/chillers/v/u/YORK/en-US/YCAL0019-0022-0028-0033-0043-0046-0052-0056-0066-Style-E-50-and-60-Hz-Single-and-Dual-Circuit/321
[16] "YCWL Water-Cooled Scroll Chiller," York, 150.26-EG1, 2016. [Online]. Available: https://www.latam.johnsoncontrols.com/en/-/media/jci/be/united-states/hvac-equipment/chillers/be_engguide_ycwl-watercooled-scroll-liquid-chiller-style-a-60-hz.pdf?la=en&hash=39CCBF44A41757FE3EF6AA9089B995483275086A
[17] "Air-water chiller NYG 0500," AERMEC, NYG-0500-CO_Y_NA60_04. [Online]. Available: https://www.aermec.com/download/?id=21248
[18] "Air-water chiller NYG 1000-1800," AERMEC, NYG-1000-1800-CO_Y_NA60_08. [Online]. Available: https://www.aermec.com/download/?id=20344
[19] "LG HVAC Solution Air Cooled Inverter Scroll Chiller," 2022. [Online]. Available: https://www.lg.com/global/business/download/airsolution/2022_LG_Air_Cooled_Scroll_Chiller[20221202_110528853].pdf
[20] J. Lerond, A. Rahman, J. Zhang, and M. Rosenberg, "Copper: a performance curve generator for building energy simulation," *Journal of Open Source Software*, vol. 8, no. 82, p. 4876, Feb. 2023, doi: 10.21105/joss.04876.
[21] J. Lerond, A. Rahman, Y. Zhang, J. Zhang, and M. Rosenberg, "Copper: A Performance Curve Generator for Building Energy Simulation," presented at the SimBuild Conference 2024, in IBPSA-USA Building Simulation Conference, vol. 11. IBPSA-USA, 2024, pp. 185–196. Accessed: Feb. 04, 2025. [Online]. Available: https://publications.ibpsa.org/conference/paper/?id=simbuild2024_2102
[22] "Cambium | Energy Analysis | NREL." Accessed: Sep. 02, 2022. [Online]. Available: https://www.nrel.gov/analysis/cambium.html
[23] "Emissions & Generation Resource Integrated Database (eGRID) | US EPA." Accessed: Sep. 02, 2022. [Online]. Available: https://www.epa.gov/egrid
[24] E. Present, Pieter Gagnon, Eric J.H. Wilson, Noel Merket, Philip R. White, and Scott Horowitz, "Choosing the Best Carbon Factor for the Job: Exploring Available Carbon Emissions Factors and the Impact of Factor Selection," 2022.
[25] G. Vijayakumar *et al.*, "ANSI/RESNET/ICC 301-2022 - Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index," Oceanside, CA, 2022.
[26] A. Parker *et al.*, "ComStock Reference Documentation: Version 1," National Renewable Energy Laboratory, Golden, CO, NREL/TP-5500-83819. [Online]. Available: https://www.nrel.gov/docs/fy23osti/83819.pdf
[27] "Use of natural gas - U.S. Energy Information Administration (EIA)." Accessed: Jul. 02, 2024. [Online]. Available: https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php
[28] "No. 2 Distillate Prices - Residential." Accessed: Jul. 02, 2024. [Online]. Available: https://www.eia.gov/dnav/pet/pet_pri_dist_a_epd2_prt_dpgal_a.htm
[29] S. Ong and R. McKeel, "National Utility Rate Database: Preprint," National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/CP-6A20-54633, Aug. 2012. doi: 10.2172/1050105.
[30] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Accessed: Jul. 02, 2024. [Online]. Available: https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T07.06#/?f=A

Appendix A. Raw Data From Manufacturer Specification Datasheets

Table A-1. Chiller Performances Gathered From Public Resources as of January of 2025 [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]

Manufacturer	Model	Cooling type	Compressor type	Cooling ton range - min	Cooling ton range - max	Refrigerant	Full-load EER	IPLV (EER)	Full-load kW/ton	Stated efficiency level	Include performance map?	Latest public resource as of 2025 JAN?
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	18	150	R-410A	10.4	15.79		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	11	60	R-410A	10.6	16.77		High	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	60	300	R-410A	10.3	14.3		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	80	300	R-410A	10.3	17.1		High	No	Yes
Carrier	AquaForce® Air-Cooled Screw Chiller 30XA	Air-cooled	Screw	80	500	R-134a	10.9	15.5		Standard	No	Yes
Carrier	AquaForce® Variable-speed Air-Cooled Screw Chiller 30XV	Air-cooled	Screw (variable-speed)	140	500	R-513a	10.7	19.42		Standard	No	Yes
Carrier	AquaForce® Variable-speed Air-Cooled Screw Chiller 30XV	Air-cooled	Screw (variable-speed)	140	450	R-513a	11.54	21		High	No	Yes
Trane	Ascend™ Air-Cooled Chiller	Air-cooled	Scroll	140	160	R-454B	9.7	15.8		N/A	No	Yes
Trane	Ascend™ Air-Cooled Chiller	Air-cooled	Scroll	180	230	R-454B	9.7	16.1		N/A	No	Yes
Trane	CGAM Air-Cooled Scroll Chiller	Air-cooled	Scroll (variable volume ratio)	20	130	R-454B	10.1	15.2		High	No	Yes
Trane	Sintesis® Air-Cooled Chillers	Air-cooled	Screw (helical rotary)	115	500	R-513A	10.2	17		High	No	Yes
Trane	Air-Cooled Magnetic Bearing Chiller	Air-cooled	Centrifugal (oil free magnetic bearing)	60	440	R-513A	15.26	23		N/A	No	Yes
Trane	Series R® Helical Rotary Screw Chillers	Water-cooled	Screw (duplex helical)	80	250	R-134a, R-513A			0.685	N/A	No	Yes
Trane	CenTraVac® Water-Cooled Chiller	Water-cooled	Centrifugal	180	380	R-514A			0.515	N/A	No	Yes
Trane	CenTraVac® Water-Cooled Chiller	Water-cooled	Centrifugal	125	2000	R-514A			0.6	N/A	No	Yes
Trane	CenTraVac® Water-Cooled Chiller	Water-cooled	Centrifugal	1400	3950	R-514A			0.535	N/A	No	Yes
Trane	CenTraVac® Water-Cooled Chiller	Water-cooled	Centrifugal	900	2000	R-1233zd			0.56	N/A	No	Yes
Trane	CenTraVac® Water-Cooled Chiller	Water-cooled	Centrifugal	1800	4000	R-1233zd			0.535	N/A	No	Yes
Trane	Agility® Centrifugal Water-Cooled Chiller	Water-cooled	Centrifugal (magnetic bearing)	150	450	R-134a, R-513A			0.585	N/A	No	Yes
Daikin	Scroll Compressor Water-Cooled (WGZ)	Water-cooled	Scroll	30	200	R-410A	16.1	21.3		N/A	No	Yes
Daikin	Magnetic Bearing Magnitude® (WMT)	Water-cooled	Centrifugal	350	600	R-134a, R-513A			0.48	N/A	No	Yes
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	28.3	28.3	R-410A	10.3	15.1		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	35.1	35.1	R-410A	10.3	15.4		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	39.2	39.2	R-410A	11.4	16.5		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	42.6	42.6	R-410A	11	16.4		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	48.3	48.3	R-410A	10.6	16		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	51.8	51.8	R-410A	10.4	15.9		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	57	57	R-410A	10.5	15.8		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	58.7	58.7	R-410A	10.6	15.8		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	65.1	65.1	R-410A	10.1	15.8		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	72.9	72.9	R-410A	10.9	15.8		N/A	No	No (2016)

Manufacturer	Model	Cooling type	Compressor type	Cooling ton range - min	Cooling ton range - max	Refrigerant	Full-load EER	IPLV (EER)	Full-load kW/ton	Stated efficiency level	Include performance map?	Latest public resource as of 2025 JAN?
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	18	150	R-410A	10.4	15.79		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	11	60	R-410A	10.6	16.77		High	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	60	300	R-410A	10.3	14.3		Standard	No	Yes
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	77.2	77.2	R-410A	10.8	15.8		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	84.4	84.4	R-410A	10.5	15.7		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	98.4	98.4	R-410A	10.3	15.5		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	107.3	107.3	R-410A	10.4	15.5		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	119.4	119.4	R-410A	10.3	15.5		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	125.7	125.7	R-410A	10.1	15.4		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	138.9	138.9	R-410A	10.6	15.7		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	146.2	146.2	R-410A	10.6	15.6		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	153.7	153.7	R-410A	10.3	15.6		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	160	160	R-410A	9.8	16.1		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	175.8	175.8	R-410A	9.7	16.1		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	187.3	187.3	R-410A	10.3	15.7		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	194.5	194.5	R-410A	10.1	15.8		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	205.3	205.3	R-410A	10.3	16		N/A	No	No (2016)
Daikin	Scroll Compressor Trailblazer®	Air-cooled	Scroll	225.9	225.9	R-410A	10.1	16		N/A	No	No (2016)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	180.1	180.1	R-134a	9.6	13.2		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	201.3	201.3	R-134a	10.1	13.6		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	216.3	216.3	R-134a	9.8	13.4		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	235.8	235.8	R-134a	10	13		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	250.5	250.5	R-134a	9.7	13.4		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	282.9	282.9	R-134a	9.8	13.7		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	300.4	300.4	R-134a	9.6	13.4		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	340.6	340.6	R-134a	9.9	13.6		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	361.4	361.4	R-134a	9.6	13.4		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	398.3	398.3	R-134a	10.1	14		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	418.7	418.7	R-134a	9.7	13.9		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	441.4	441.4	R-134a	9.8	13.8		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	459.2	459.2	R-134a	9.6	13.6		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	488.3	488.3	R-134a	9.6	13.7		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	517.7	517.7	R-134a	9.6	13.6		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	547.3	547.3	R-134a	9.6	13.6		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	205.7	205.7	R-134a	10.3	14		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	225.2	225.2	R-134a	10.7	14		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	240.6	240.6	R-134a	10.4	14.1		Standard	No	No (2014)

Manufacturer	Model	Cooling type	Compressor type	Cooling ton range - min	Cooling ton range - max	Refrigerant	Full-load EER	IPLV (EER)	Full-load kW/ton	Stated efficiency level	Include performance map?	Latest public resource as of 2025 JAN?
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	18	150	R-410A	10.4	15.79		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	11	60	R-410A	10.6	16.77		High	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	60	300	R-410A	10.3	14.3		Standard	No	Yes
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	271.9	271.9	R-134a	10.7	14.5		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	288.7	288.7	R-134a	10.4	14.3		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	327.3	327.3	R-134a	10.9	14.5		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	348.1	348.1	R-134a	10.4	14.2		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	378.7	378.7	R-134a	10.4	14.2		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	409.8	409.8	R-134a	10.3	14.1		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	446.3	446.3	R-134a	10.5	14.7		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	470.3	470.3	R-134a	10.4	14.7		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	499.4	499.4	R-134a	10.5	14.4		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	528.3	528.3	R-134a	10.5	14.5		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	232.8	232.8	R-134a	12.1	15.9		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	256.4	256.4	R-134a	12.2	16		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	277.5	277.5	R-134a	11.9	16.2		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	303.9	303.9	R-134a	11.9	16.2		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	324.9	324.9	R-134a	11.6	16.1		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	355	355	R-134a	11.5	16.1		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	385.4	385.4	R-134a	11.4	15.9		Standard	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	162.6	162.6	R-134a	9.9	17.3		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	181.3	181.3	R-134a	10.4	17.6		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	195.1	195.1	R-134a	10.1	17.7		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	205.2	205.2	R-134a	9.6	18		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	224.8	224.8	R-134a	10	18.1		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	240	240	R-134a	9.6	18.2		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	270.6	270.6	R-134a	9.9	18.5		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	287.7	287.7	R-134a	9.6	18.4		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	326.3	326.3	R-134a	10.2	18.5		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	347.1	347.1	R-134a	9.7	18.3		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	377.8	377.8	R-134a	9.6	18.4		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	408.7	408.7	R-134a	9.6	18.2		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	445.2	445.2	R-134a	9.7	18.9		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	467.7	467.7	R-134a	9.7	18.8		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	497.8	497.8	R-134a	9.7	18.5		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	524.8	524.8	R-134a	9.7	18.5		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	232.7	232.7	R-134a	11.7	18.8		High	No	No (2014)

Manufacturer	Model	Cooling type	Compressor type	Cooling ton range - min	Cooling ton range - max	Refrigerant	Full-load EER	IPLV (EER)	Full-load kW/ton	Stated efficiency level	Include performance map?	Latest public resource as of 2025 JAN?
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	18	150	R-410A	10.4	15.79		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	11	60	R-410A	10.6	16.77		High	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	60	300	R-410A	10.3	14.3		Standard	No	Yes
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	256.3	256.3	R-134a	11.8	19		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	277.6	277.6	R-134a	11.5	19.3		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	303.8	303.8	R-134a	11.5	19.4		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	324.7	324.7	R-134a	11.2	19.3		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	354.8	354.8	R-134a	11.1	19.2		High	No	No (2014)
Daikin	Screw Compressor Pathfinder®	Air-cooled	Screw	385.4	385.4	R-134a	11	19.2		High	No	No (2014)
York	YLAA Scroll Chiller	Air-cooled	Scroll	71	71	R-410A	10.4	16.8		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	77.8	77.8	R-410A	10	16.3		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	81.8	81.8	R-410A	9.8	16.5		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	96.5	96.5	R-410A	9.7	15.3		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	120	120	R-410A	9.8	15.7		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	125.3	125.3	R-410A	9.7	16.6		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	145.3	145.3	R-410A	9.7	16.6		Standard	No	Yes
York	YLAA Scroll Chiller	Air-cooled	Scroll	170.1	170.1	R-410A	9.7	16.2		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	153	153	R-134a	9.6	14.4		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	169.3	169.3	R-134a	9.9	14.5		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	184.6	184.6	R-134a	9.9	14.6		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	197.7	197.7	R-134a	9.8	14.5		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	216	216	R-134a	10	14.7		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	237.6	237.6	R-134a	10	15.1		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	257.9	257.9	R-134a	10	15.3		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	272.9	272.9	R-134a	9.9	14.6		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	301.5	301.5	R-134a	9.8	14.2		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	339.8	339.8	R-134a	9.7	15		Standard	No	Yes
York	YCIV Variable-speed Drive Screw Chiller	Air-cooled	Screw	382.7	382.7	R-134a	9.8	15.3		Standard	No	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	15.5	15.5	R-410A	10.1	14.7		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	18.7	18.7	R-410A	10.1	15.5		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	25.6	25.6	R-410A	10.1	13.7		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	28.6	28.6	R-410A	10.5	14.5		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	37.2	37.2	R-410A	10.1	14.5		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	39.4	39.4	R-410A	10.2	14.7		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	46.2	46.2	R-410A	10.2	15.1		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	56.2	56.2	R-410A	10.1	14.7		Standard	Yes	Yes
York	YCAL Scroll Chiller	Air-cooled	Scroll	66.2	66.2	R-410A	10.3	15.5		Standard	Yes	Yes

Manufacturer	Model	Cooling type	Compressor type	Cooling ton range - min	Cooling ton range - max	Refrigerant	Full-load EER	IPLV (EER)	Full-load kW/ton	Stated efficiency level	Include performance map?	Latest public resource as of 2025 JAN?
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	18	150	R-410A	10.4	15.79		Standard	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RAP	Air-cooled	Scroll (digital)	11	60	R-410A	10.6	16.77		High	No	Yes
Carrier	AquaSnap® Air-Cooled Liquid Chiller 30RB	Air-cooled	Scroll	60	300	R-410A	10.3	14.3		Standard	No	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	56	56	R-410A	16.3	21.3		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	64	64	R-410A	15.7	19.9		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	74	74	R-410A	15.2	20.2		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	84	84	R-410A	15.8	22.5		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	94	94	R-410A	16.2	22.6		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	104	104	R-410A	16.2	23		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	118	118	R-410A	15.6	23.5		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	132	132	R-410A	16.1	23.4		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	157	157	R-410A	16.5	23.5		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	177	177	R-410A	17	24.5		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	198	198	R-410A	16.7	24		Standard	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	64	64	R-410A	16.4	21.5		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	74	74	R-410A	16.3	22.7		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	84	84	R-410A	16.9	25.1		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	94	94	R-410A	17.1	25.3		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	96	96	R-410A	16.7	20.5		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	118	118	R-410A	16.9	24.7		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	127	127	R-410A	16.9	23.7		High	Yes	Yes
York	YCWL Water-Cooled Scroll Chiller	Water-cooled	Scroll	157	157	R-410A	17.1	24.2		High	Yes	Yes
Aermec	Air-water chiller NYG	Air-cooled	Scroll	27.8	27.8	R-454B	10.69	14.47		Standard	No	Yes
Aermec	Air-water chiller NYG	Air-cooled	Scroll	88.46	88.46	R-454B	10.29	16.45		High	No	Yes
Aermec	Air-water chiller NYG	Air-cooled	Scroll	116.7	116.7	R-454B	10.36	16.86		High	No	Yes
Aermec	Air-water chiller NYG	Air-cooled	Scroll	144.9	144.9	R-454B	10.4	16.58		High	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	18.5	18.5	R-410A	10.30424	18.0836		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	21	21	R-410A	8.8712	17.4012		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	32.4	32.4	R-410A	10.7478	18.4248		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	37	37	R-410A	10.30424	18.0836		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	42.1	42.1	R-410A	8.8712	17.4012		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	48.6	48.6	R-410A	10.7478	18.4248		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	55.4	55.4	R-410A	10.30424	18.0836		N/A	No	Yes
LG	Air Cooled Inverter Scroll Chiller	Air-cooled	Scroll	63.1	63.1	R-410A	8.8712	17.4012		N/A	No	Yes

Appendix B. Mapping of New Performance Curves to Old Curves

Table B-1. Replacement of Old Chiller Curves to New Chiller Curves

Condenser Type	Template	Minimum Capacity (Tons)	Maximum Capacity (Tons)	Minimum Full Load EER	Minimum IPLV EER	Existing Curves			New Curves			Curve Comparison Figure
						CAPFT	EIRFT	EIRFPLR	CAPFT	EIRFT	EIRFPLR	
Air-cooled	DOE Ref Pre-1980	0	149.99	9.2	-	ChlrAirRecipQRatio_fTchwsToadbSI	ChlrAirRecipEIRRatio_fTchwsToadbSI	ChlrAirRecipEIRRatio_fQRatio	AirCooledCAPFT	AirCooledEIRFT	AirCooledEIRFPLR	Figure A-1
	DOE Ref Pre-1980	150	299.99	9.0	-							
	DOE Ref Pre-1980	300	9999	9.0	-							
	DOE Ref 1980-2004	150	9999	8.5	8.5							
	90.1-2004	0	9999	9.6	10.4	AirCooled_Chiller_2010_PathA_CAPFT	AirCooled_Chiller_2010_PathA_EIRFT	AirCooled_Chiller_AllCapacities_2004_2010_EIRFPLR				Figure A-2
	90.1-2007	0	9999	9.3	10.3							
	90.1-2010	0	149.99	9.6	12.8							
	90.1-2010	150	9999	9.6	12.8							
	90.1-2013	0	149.99	9.6	12.5	ChlrAirScrollQRatio_fTchwsToadbSI	ChlrAirScrollEIRRatio_fTchwsToadbSI	ChlrAirScrollEIRRatio_fQRatio				Figure 7
	90.1-2013	150	9999	9.6	12.8							
	90.1-2013	0	149.99	10.1	13.7							
	90.1-2013	150	9999	10.1	14							
	90.1-2016	0	149.99	10.1	13.7							
	90.1-2016	150	9999	10.1	14							
	90.1-2019	0	149.99	10.1	13.7							
	90.1-2019	150	9999	10.1	14							
Water-cooled	DOE Ref Pre-1980	0	149.99	14.1	-	ChlrWtrPosDispPathAAllQRatio_fTchwsTcwsSI	ChlrWtrPosDispPathAAllEIRRatio_fTchwsTcwsSI	ChlrWtrPosDispPathAAllEIRRatio_fQRatio	WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure A-3
	DOE Ref Pre-1980	150	299.99	15.3	-				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure A-5
	DOE Ref Pre-1980	300	9999	17.4	-							
	DOE Ref 1980-2004	0	149.99	13	13.3				WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure A-3
	DOE Ref 1980-2004	150	299.99	14.3	15.3				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure A-5
	DOE Ref 1980-2004	300	9999	17.8	18.1							
	90.1-2004	0	149.99	15.2	17.8				WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure A-3
	90.1-2004	150	299.99	16.7	19.1				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure A-5
	90.1-2004	300	9999	18.8	21							

	90.1-2007	0	74.99	15.4	19	WaterCooled_PositiveDisplacement_Chiller_LT150_2010_PathA_CAPFT	WaterCooled_PositiveDisplacement_Chiller_LT150_2010_PathA_EIRFT		WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure A-4
	90.1-2007	75	149.99	15.5	19.5							
	90.1-2007	150	299.99	17.6	20.7				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure A-6
	90.1-2007	300	9999	19.4	22.2							
	90.1-2010	0	74.99	15.4	19				WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure A-4
	90.1-2010	75	149.99	15.5	19.5							
	90.1-2010	150	299.99	17.6	20.7				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure A-6
	90.1-2010	300	9999	19.4	22.2							
	90.1-2013	0	74.99	16	20	ChlrWtrPosDispPathAAllQRatio_fTchwsTcwsSI	ChlrWtrPosDispPathAAllEIRRatio_fTchwsTcwsSI		WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure 8
	90.1-2013	75	149.99	16.7	21.4							
	90.1-2013	150	299.99	18.2	22.2				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure 9
	90.1-2013	300	599.99	19.7	23.1							
	90.1-2013	600	9999	21.4	24							
	90.1-2016	0	74.99	16	20				WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure 8
	90.1-2016	75	149.99	16.7	21.4							
	90.1-2016	150	299.99	18.2	22.2				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure 9
	90.1-2016	300	599.99	19.7	23.1							
	90.1-2016	600	9999	21.4	24							
	90.1-2019	0	74.99	16	20				WaterCooled_LT150_CAPFT	WaterCooled_LT150_EIRFT	WaterCooled_LT150_EIRFPLR	Figure 8
	90.1-2019	75	149.99	16.7	21.4							
	90.1-2019	150	299.99	18.2	22.2				WaterCooled_GT150_CAPFT	WaterCooled_GT150_EIRFT	WaterCooled_GT150_EIRFPLR	Figure 9
	90.1-2019	300	599.99	19.7	23.1							
	90.1-2019	600	9999	21.4	24							

Appendix C. Comparison of New Performance Curves to Old Curves

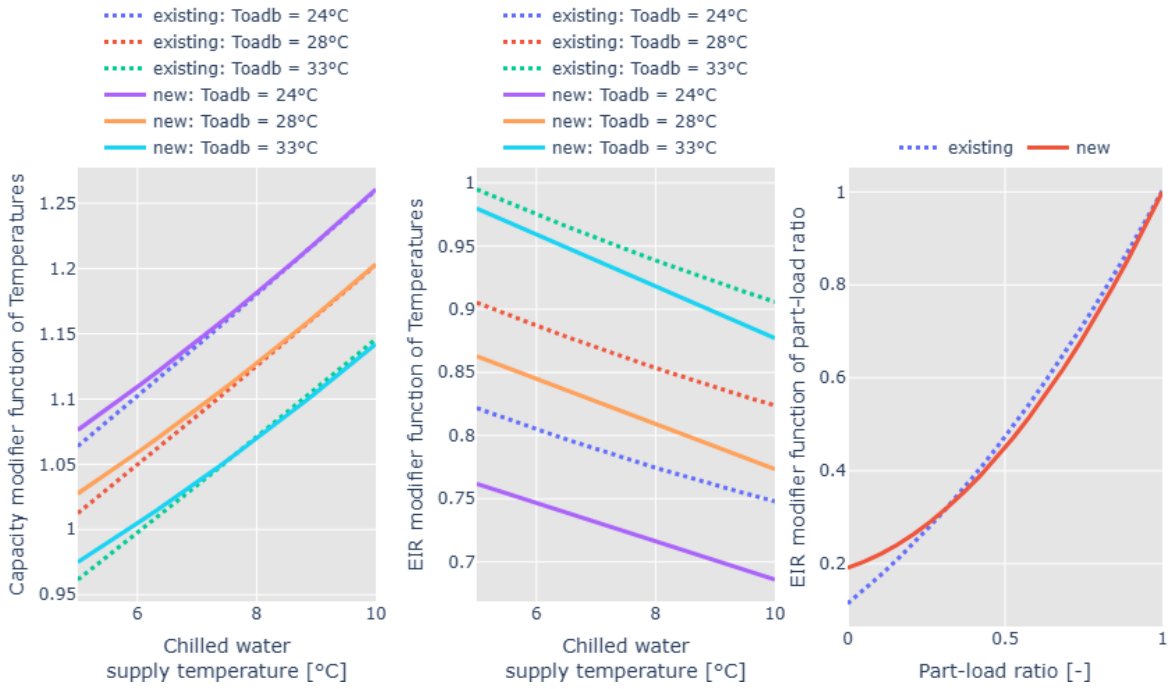

Figure C-1. Air-cooled chiller performance curves comparisons against pre 90.1-2004

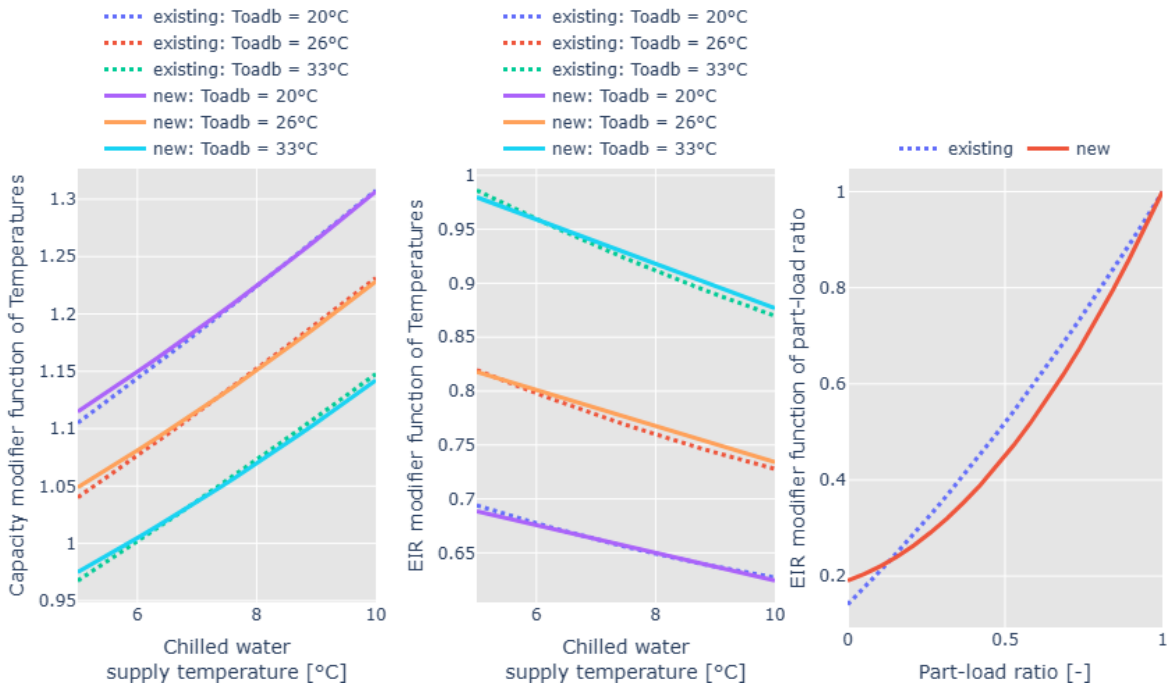

Figure C-2. Air-cooled chiller performance curves comparisons against 90.1 2004-2010

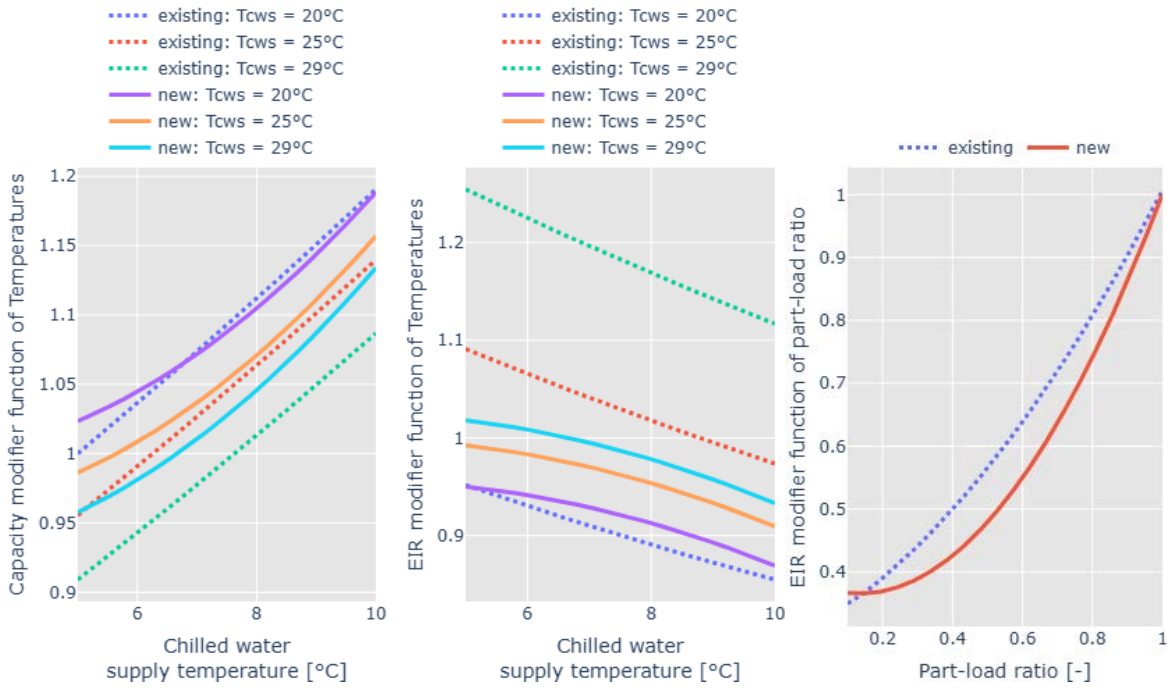

Figure C-3. Water-cooled chiller (less than 150 ton) performance curves comparisons against pre 90.1-2007

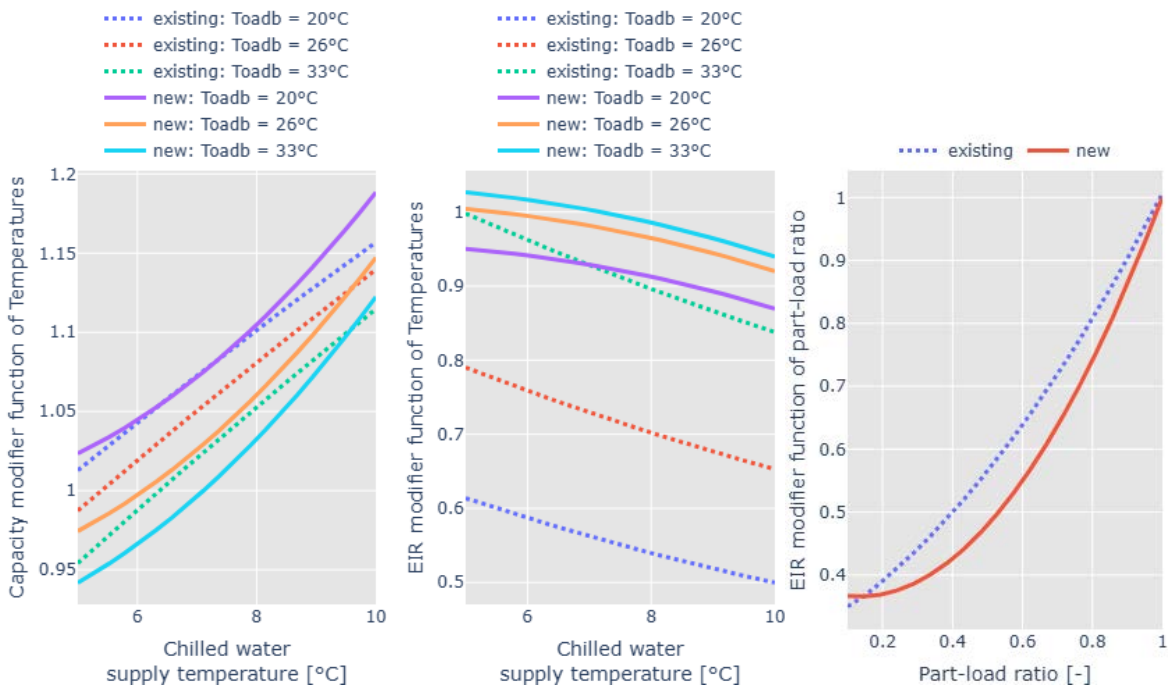

Figure C-4. Water-cooled chiller (less than 150 ton) performance curves comparisons against 90.1 2007-2010

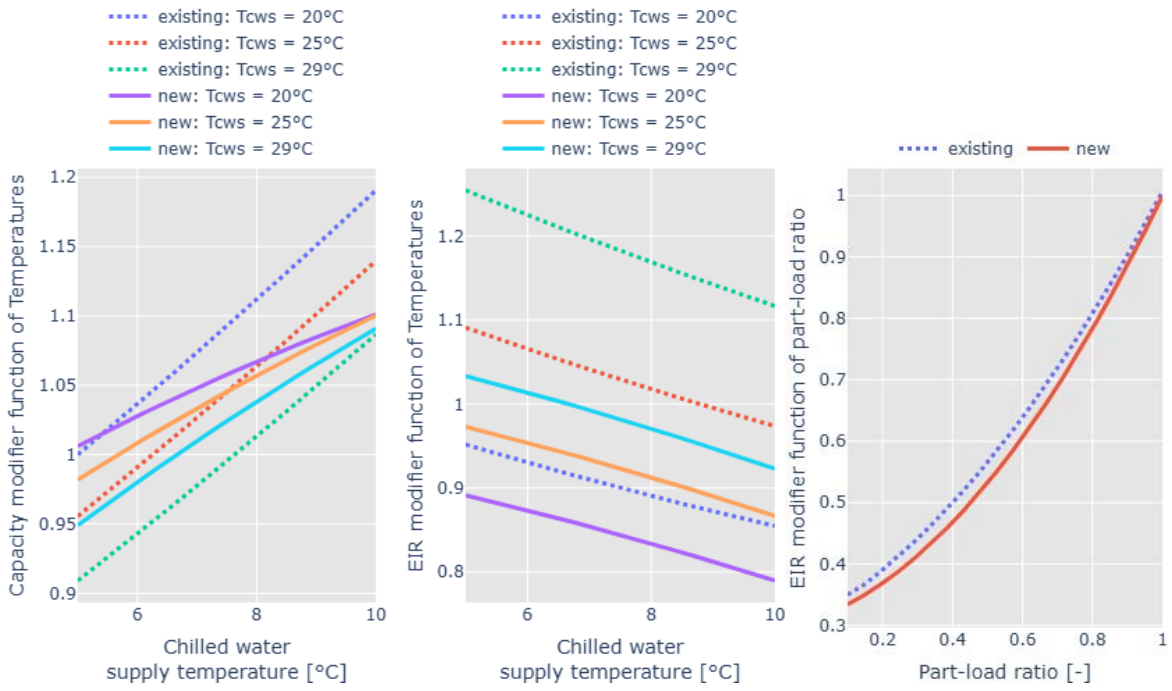

Figure C-5. Water-cooled chiller (over 150 ton) performance curves comparisons against pre 90.1-2007

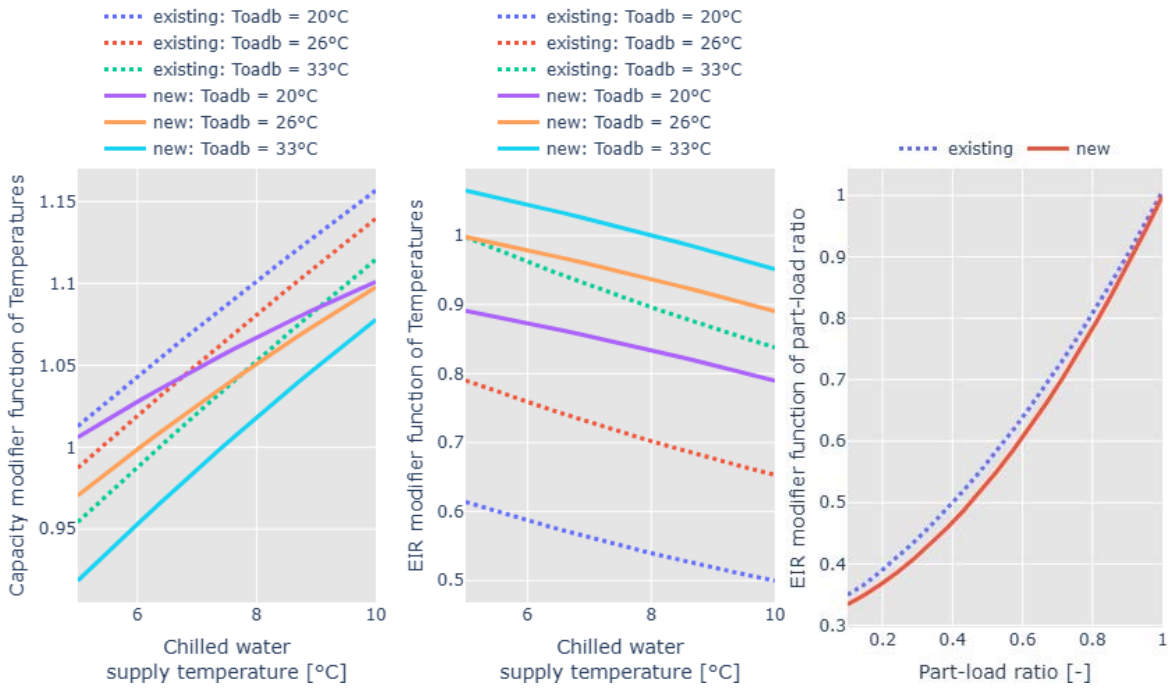

Figure C-6. Water-cooled chiller (over 150 ton) performance curves comparisons against 90.1 2007-2010