Pacific Northwest NATIONAL LABORATORY

PNNL- 36570

Analysis of Ground Source Heat Pump ECMs

Implemented Under DOE ESPC IDIQ Contract

September 2024

1 John Shonder, Oak Ridge National Laboratory
2 Christine Walker, Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Abstract

Several federal performance and decarbonization objectives are driving the U.S. government to transition to net-zero emissions across the federal building portfolio. The overarching purpose of this Federal Energy Management Program (FEMP)-Geothermal Technologies Office (GTO) work is to support federal facilities in accomplishing the administration's federal building decarbonization goals. Creating awareness of existing geothermal (or ground-source) heat pump (GHP) systems deployed on federal property, implemented using performance contracts and evaluating the energy and environmental impacts of these systems, this work will assist federal facilities in considering inclusion of GHP technology energy conservation measures (ECMs) in future performance contracting project awards.

Department of Energy's (DOE's) FEMP supports implementation of ECMs through its Energy Service Performance Contract (ESPC) and Utility Energy Service Contract (UESC) programs for Federal Agencies. FEMP maintains a database of projects awarded under the DOE ESPC Indefinite Delivery, Indefinite Quantity (IDIQ) contract, which lends itself to an analysis of past awarded projects that included GHP technology deployment as an ECM. In total, 32 ESPC projects were identified that included GHP technology as an ECM; UESCs have also been used to implement GHP ECMs, but they are not included in this analysis. In 1999 DOE competitively awarded the geothermal technology-specific ESPC IDIQ contract with a $500 million ceiling, focused on GHP deployment at federal facilities, to 5 Energy Service Companies (ESCOs). The maximum contract term for an ESPC is 25-years; projects awarded in the early years of the DOE ESPC IDIQ program are nearing completion of their performance term and could represent the most comprehensive GHP performance dataset in the United States.

This report summarizes analyses of data from GHP ECMs installed under the DOE ESPC IDIQ contract across various climate areas and geographic locations, agencies, and building use types. While recognizing limitations in the data, the authors found that installed cost of GHP ECMs correlates well (R^2 = 0.90) with installed capacity, with installed costs averaging about $13,084 per ton in 2024 dollars. The analysis indicated that energy savings are well correlated (R^2 = 0.97) with installed capacity, with savings averaging about 17.36 MTBU/year per ton of installed capacity. Greenhouse gas reduction was less well-correlated with installed capacity (R^2 = 0.78), with the slope of the regression line indicating that greenhouse gas reductions from this set of GHP ECMs averages 1.07 MT CO_2e per ton of cooling capacity. Finally, there was greater variation in energy cost savings and total cost savings with respect to installed capacity (R^2 =0.71 and 0.61, respectively), with annual energy cost savings averaging 318 dollars per ton, and total annual cost savings averaging 413 dollars per ton, both in 2024 dollars.

Through the analysis of proposed GHP ECMs and understanding key metrics on implemented GHP systems in a variety of applications, FEMP and GTO can further support federal agencies in meeting decarbonization and net-zero building goals by evaluating and incorporating GHP systems into performance contracts and communicate the benefits of this technology.

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy (DOE), Office of Federal Energy Management Program (FEMP) and Office of Energy Efficiency and Renewable Energy (EERE), specifically the Geothermal Technologies Office (GTO). The authors would like to acknowledge the valuable guidance and input provided by GTO and FEMP in the development of this report. The authors are grateful to Miranda Heiland and Brian Boyd from PNNL for their review and contributions to this report. This report was prepared by Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL).

Acronyms and Abbreviations

CO_2e	carbon dioxide equivalent (accounts for all greenhouse gas emissions)
CPI	consumer price index
DOD	Department of Defense
DOE	Department of Energy
ECM	energy conservation measure
EERE	(Office of) Energy Efficiency and Renewable Energy
ESCO	energy services company
ESPC	energy savings performance contract
FEMP	Federal Energy Management Program
GHP	Geothermal (ground-source) heat pump
GTO	Geothermal Technologies Office
HVAC	heating, ventilation and air-conditioning
IDIQ	indefinite delivery, indefinite quantity
M&V	measurement and verification
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
TO	task order
UESC	utility energy services contract

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1.0 Introduction

The objective of this study was to evaluate GHP ECM characteristics as implemented through ESPCs. This included examining statistics on cost, cost savings, energy savings and greenhouse gas emission reductions resulting from GHP ECMs installed under DOE's ESPC IDIQ contracts, as well as building types and sizes.

1.1 Background

An ESPC allows federal agencies to implement ECMs including GHP ECMs for little to no upfront capital costs. The agency partners with an energy services company (ESCO) that shoulders the upfront capital costs of the project. Energy savings generated by the measures installed as part of the project are used to pay for the costs over the contract term. The ESCO is responsible for the design, construction, and ongoing performance, as well as the operation and maintenance of the project, over the duration of the contract, which has a maximum term of 25 years.

GHPs take advantage of the more constant temperatures found underground to provide facilities with heating and cooling while reducing facility energy use by using the ground as a heat (energy) source or sink, depending on the season. Ground temperatures are warmer than outdoor air temperatures in the winter, therefore they can act as a heating source when a facility requires heating. Conversely, ground temperatures will be cooler than outdoor air in the summer, allowing the ground to act as a heat sink when a facility requires cooling. There are a variety of GHP systems that can be applied at residential, commercial, or community scales. The best system for a facility is determined by factors such as climate, soil conditions, and land available.

1.2 Methodology

Data for the study were drawn from the documentation of individual ESPC projects. DOE's first ESPC IDIQ contract was awarded in 1998, with the technology specific geothermal ESPC IDIQ contract awarded in 1999, and the current fourth-generation contract was awarded in August of 2023. The DOE ESPC IDIQ contracts are umbrella-type contracts awarded for a specific period (usually 3 to 5 years) to a group of qualified ESCOs. Individual ESPC projects – which consist of a set of ECMs installed at one or more sites belonging to a single federal agency – are then awarded as Task Orders under the umbrella contract. As of July 2024, approximately $8 billion in project investment has been installed under 445 project awards.[1]

Each Task Order (TO) award requires the submission of a set of TO schedules, which contain basic information about the project, including a list of the ECMs to be installed, their general size (for example, the total capacity of chillers to be replaced, the number of plumbing fixtures to be retrofitted, etc.), their cost, and the energy, water and cost savings they generate. The Federal Energy Management Program (FEMP) maintains a database of award TO schedules and other project documentation for every TO awarded under the DOE ESPC IDIQ contract.

For the analysis, we extracted the following information from all TO schedules that listed GHP as one of the project ECMs:

- Project award date

[1] https://www.energy.gov/femp/articles/doe-idiq-energy-savings-performance-contract-awarded-projects

- Cost of the GHP ECM
- ECM simple payback
- Size of the GHP ECM, in tons of cooling capacity
- Energy, water, and O&M cost savings of the GHP ECM
- Total energy savings in MBTU of the GHP ECM
- Energy savings by energy type (gas, electric, fuel oil, etc.) for the GHP ECM

Not all of this information was available on the TO schedules of every project. Where possible, we extracted additional details on the application and preliminary design of the GHP ECM, including:

- Number of buildings affected/included in GHP ECM
- Building use type of buildings included in GHP ECM
- M&V option

It is important to note the limitations of the data available for this analysis. Project TO schedules (at award) are produced prior to a final design (typically about the 35%-65% design stage). Costs at this stage are firm-fixed prices only; final ECM design does not occur until after TO award. In addition, ESCOs have a great deal of leeway in what they include in the ECM price, as ECMs are organized under broad technology categories. A GHP ECM, for example, may include other associated HVAC equipment such as dedicated outdoor air units, air handlers, ductwork, etc. ECM costs also include demolition of existing equipment, which varies by project. Detailed cost breakdowns may be available once final designs are complete, but this information is not usually provided to DOE.

2.0 Analysis of Data

A total of 32 ESPC projects awarded under the DOE ESPC IDIQ program were identified as installing GHP ECMs. The project investment for those ECMs is estimated at $125 million in as-spent dollars (approximately $200 million in 2024 dollars). The estimated installed capacity of GHP systems implemented as part of a DOE ESPC IDIQ awarded project is estimated as at least 13,000 tons of cooling capacity.

2.1 Overview of GHP ECMS

Altogether, we identified 27 GHP ECMs in 24 separate projects awarded between 2001 and 2014. While all of the ECMs included price information, due to the limited documentation available for some older projects, we were able to determine the ECM size (in tons of cooling capacity) for only 20 of the 27 ECMs.

Of the 20 ECMs with cooling capacity data, 17 were commercial and 3 were residential, serving single-family homes. Due to the small number of residential projects, we decided to focus our analysis on projects with commercial applications only. The residential ECMs were all at Department of Defense (DOD) sites, and since the majority of DOD family housing has now been privatized, it is unlikely that such ECMs will be included in future projects.

The remaining DOE ESPC IDIQ projects awarded between 2001 and 2014 were located throughout the continental U.S., as shown in Figure 1 below. The majority of projects were located on the eastern part of the U.S., with a few in the Midwest and western region.

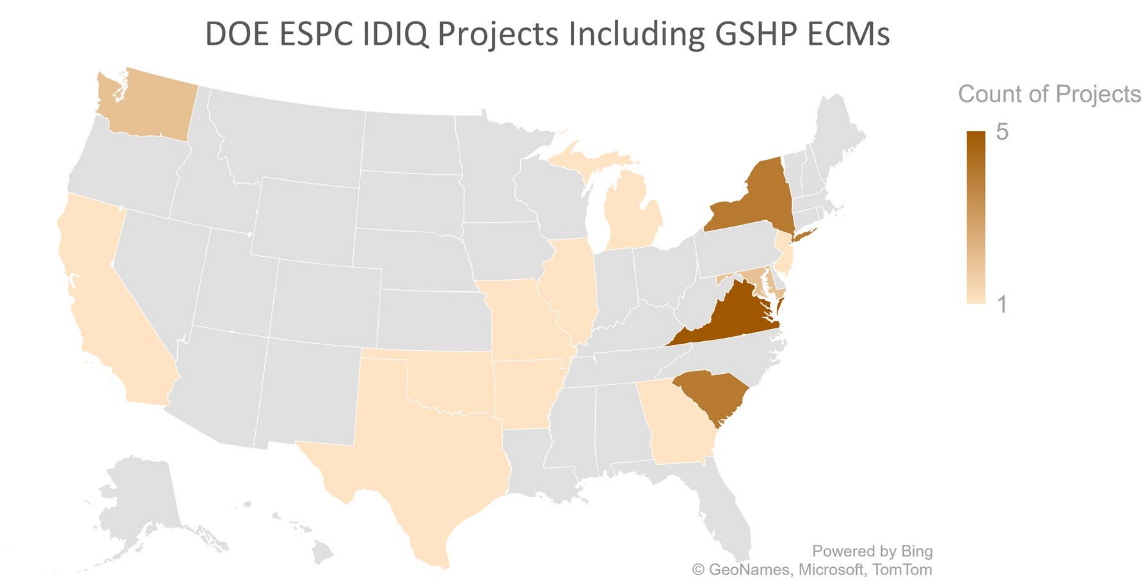

Figure 1. Projects awarded under DOE ESPC IDIQ contract by location.

2.2 Building Characteristics

Nearly 4.0 million square feet of buildings were impacted by an installed GHP ECM, with nearly two-thirds falling in the commercial category (i.e., excluding residential, homes, apartments), with projects ranging in size from 8,000 square feet at a single location to nearly 300,000 square feet across 10 buildings at a campus location. Similarly, there was a large range of building types where GHP ECMs were installed, including:

- Office
- Lodging
- Food Service
- Recreational
- Service/Shop
- Laboratory
- Warehouse
- Educational/Training
- Data Centers

The disaggregation of building use types where GHP ECMs were installed is shown by floor area in Figure 2 and by number of buildings impacted in Figure 3 when this information was available. In some instances, the floor area or building type had multiple use types assigned; in those cases, the combined use type is shown. Office-type buildings had the majority of GHP systems installed as part of an ESPC, followed by residential applications. Lodging building types differ from residential in that they are barracks or hotel-type spaces, rather than individual residential units.

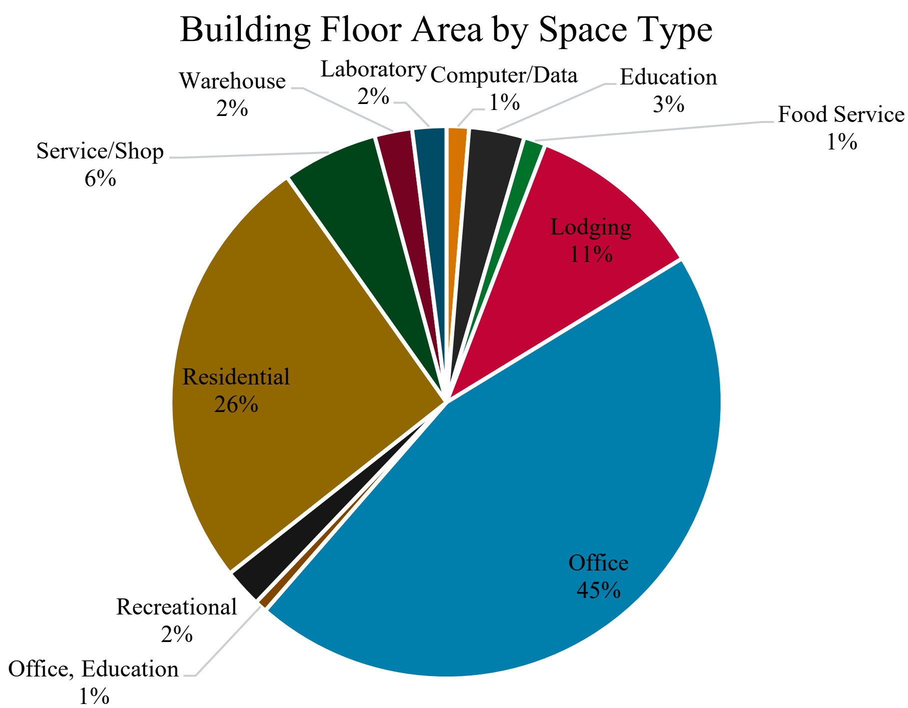

Figure 2. Breakout of Building Floor Area by Space Type (where known)

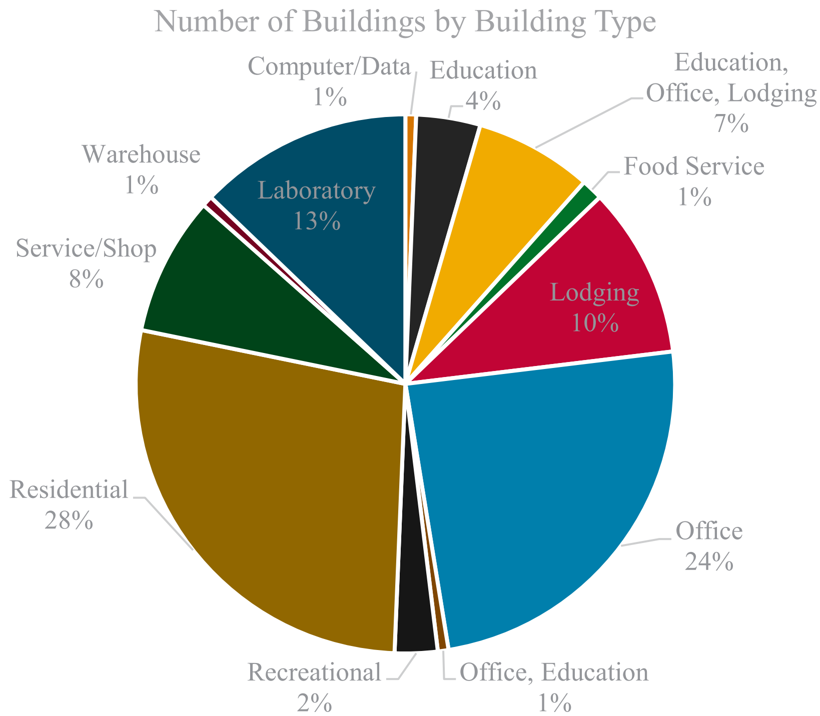

Figure 3. Number of Buildings by Primary Space Type (where known)

2.3 Cost of GHP ECMS

Figure 4 plots the price of GHP ECMs (adjusted to 2024 dollars via the Bureau of Labor Statistics' CPI calculator) vs. total cooling capacity for the 17 commercial projects. Installed price is well correlated with installed capacity, with $R^2 = 0.90$. The slope of the regression line is $13,084/ton, with a 95% confidence interval of [10,746, 15,424].

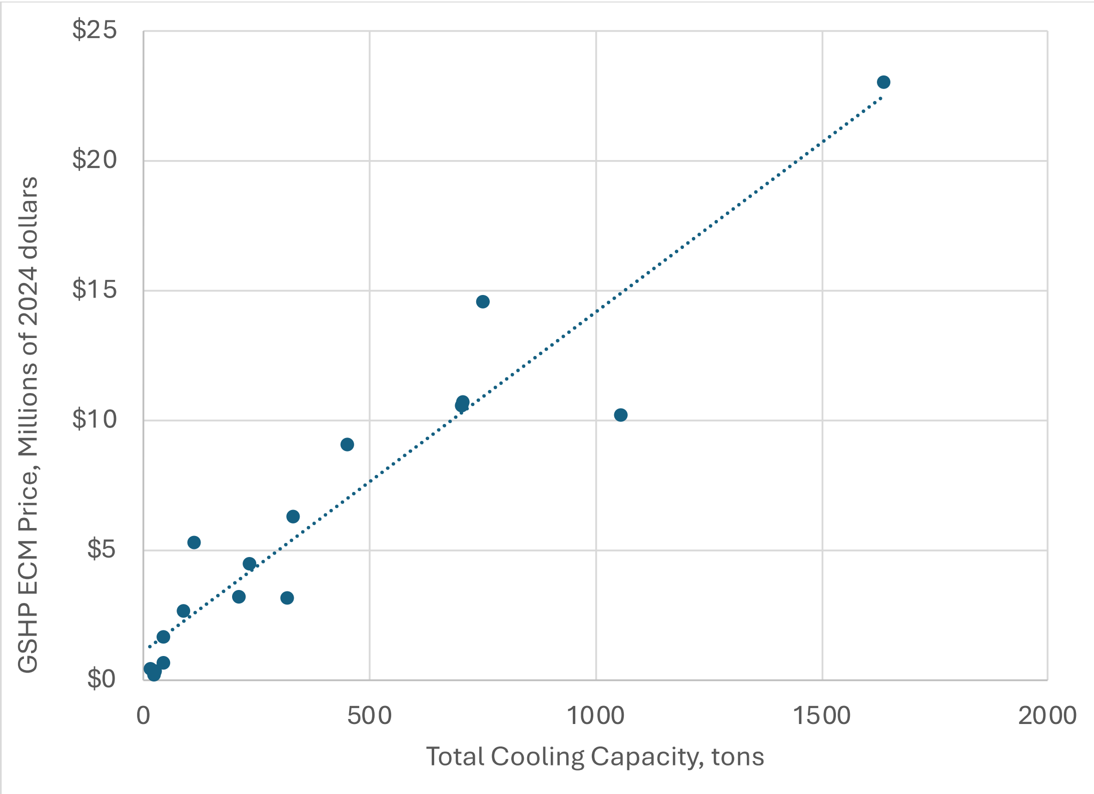

Figure 4. Adjusted price vs. cooling capacity for commercial GHP ECMs installed under the DOE ESPC IDIQ.

For comparison, in 2007 the Department of Defense found the average cost of commercial GHP installations to be $6,951.5/ton, equivalent to $10,340/ton in 2024 dollars. This is just outside the lower limit of the confidence interval on dollars per ton from the FEMP data. While the DOD report included some of the same projects analyzed here, the authors of the DOD report may have had access to more detailed cost information. Separating the cost of the GHP systems from the cost of any additional HVAC equipment installed under the same project would result in a lower cost per ton.

Annual Energy Savings

Depending on the equipment that was replaced, GHP ECMs saved energy of various forms, including electricity, steam, district hot water, and fuel oil. These projects saved over 300,000 MMBtu of annual energy savings across these energy types, as shown in Figure 5. The majority of the savings are from direct or indirect reductions in fossil fuel consumption. In several cases, implementing GHP ECMs removed buildings from or eliminated aging centralized steam systems with extensive distribution systems, while other projects replaced end of useful life equipment with a GHP solution. Figure 6 plots the total annual energy savings in MBTU/year vs. total cooling capacity. Aside from a single outlier, there appears to be a linear relationship between energy savings and cooling capacity.

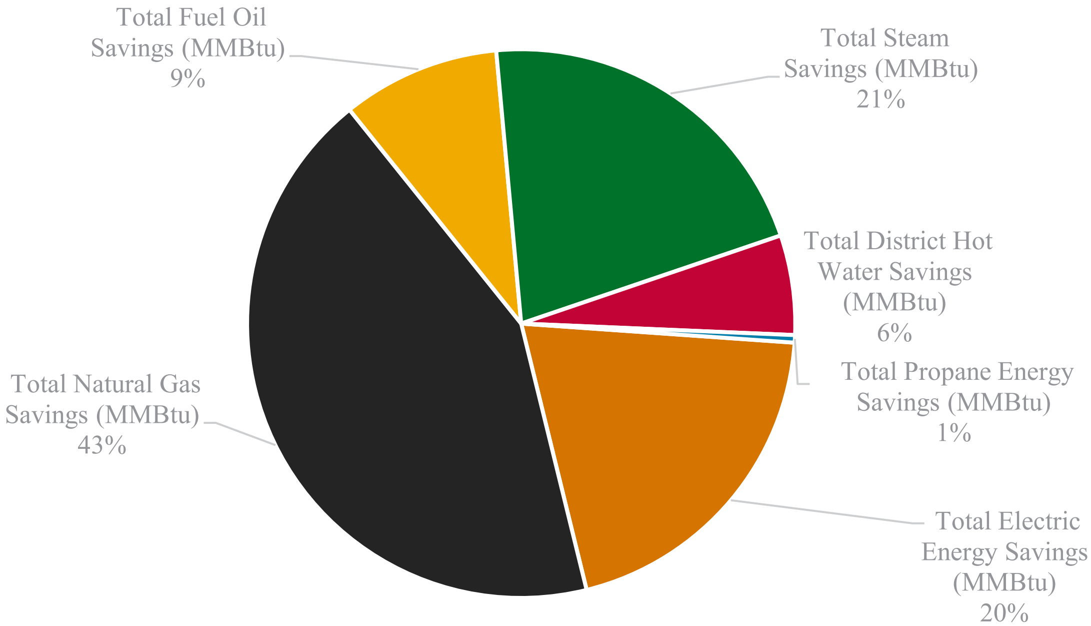

Figure 5. Energy Savings Across all 27 Projects by Energy Type

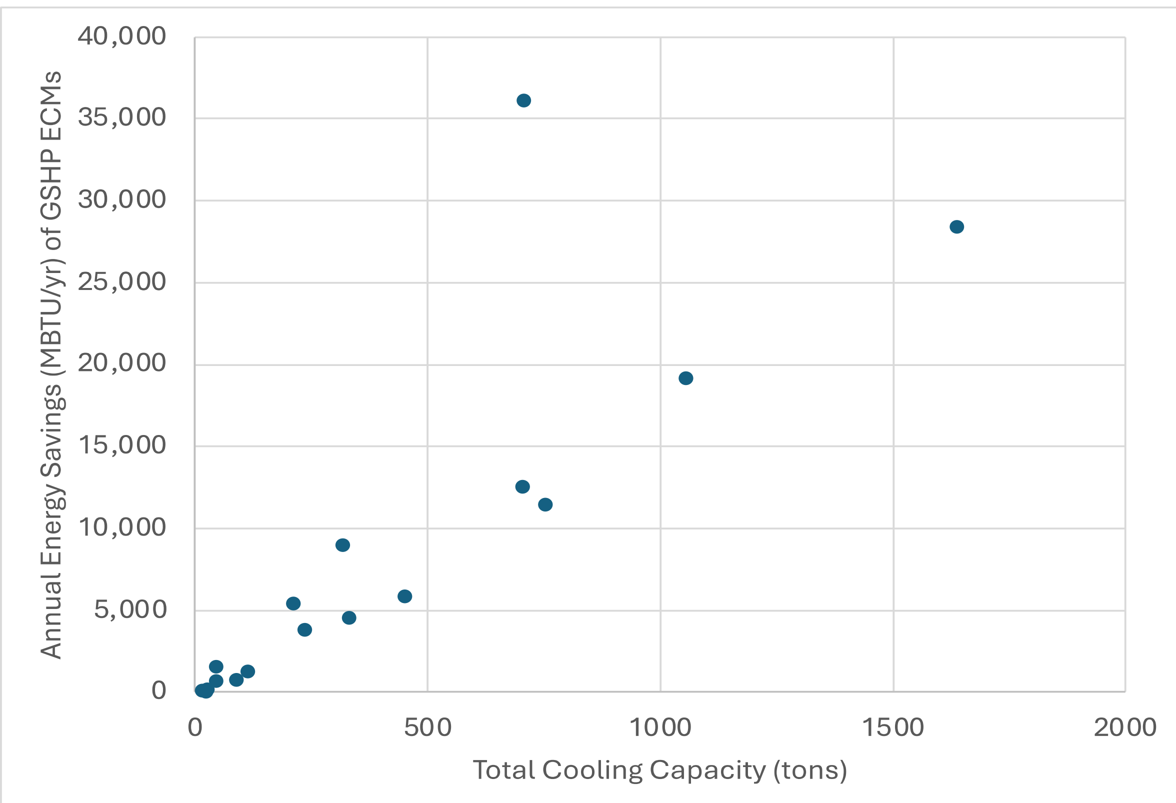

Figure 6. Annual energy savings vs. total cooling capacity in tons.

Reviewing the documentation for the project corresponding to the outlier in Figure 6 indicates that in addition to the GHPs, the ECM also included 140 tons of water source heat pumps tied to a boiler-cooling tower system. The actual cooling capacity was thus larger than the capacity of the ground source heat pumps installed, which resulted in larger energy savings than one would expect from the GHPs alone.

Figure 7 removes the outlier. There is very good agreement between energy savings and installed capacity, with R^2 = 0.97. The slope of the regression line indicates that GHP ECMs save on average 17.36 MBTU per ton of cooling capacity installed.

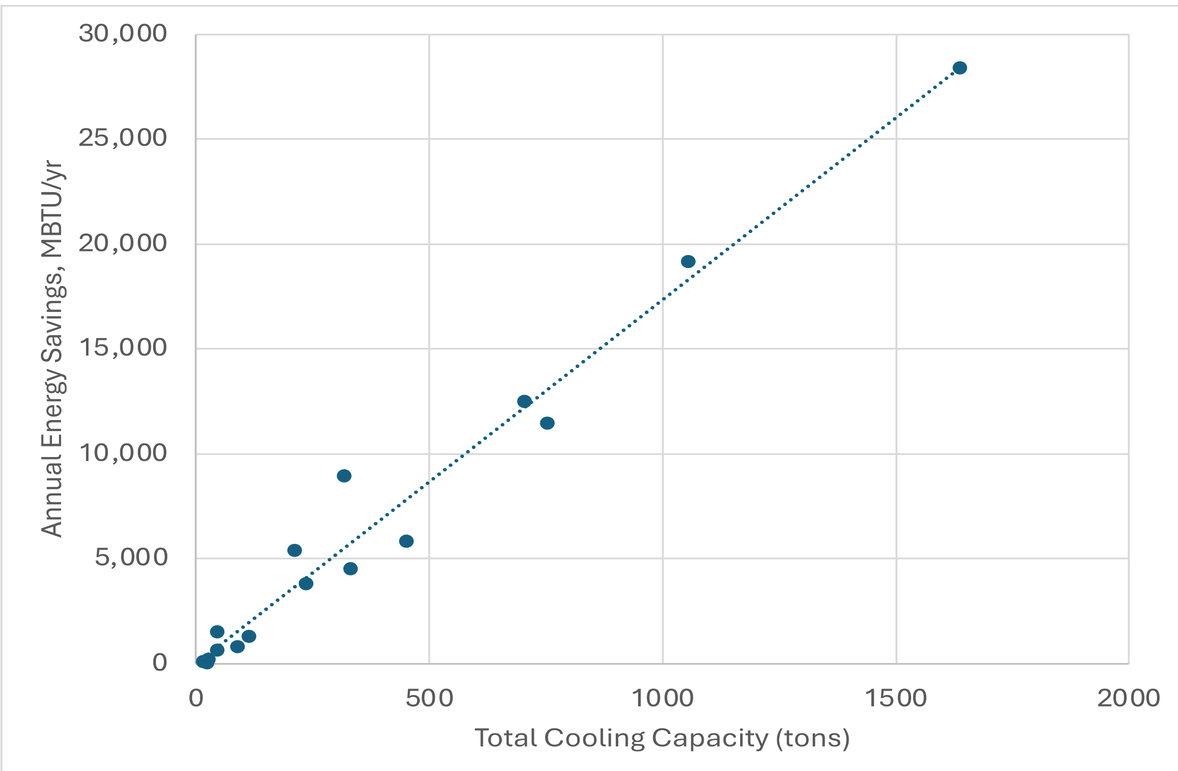

Figure 7. Annual energy savings vs. total cooling capacity, with the outlier of Figure 6 removed.

2.4 Greenhouse Gas Reduction

To calculate greenhouse reductions, current (U.S. EPA, eGRID 2019) U.S. average electric emission factors were used, so as not to bias the figures based on the date the equipment was installed and the location of the ECM. Figure 8 plots annual greenhouse gas reductions vs. installed cooling capacity. Again, the outlier corresponds to the project that includes 140 tons of water source heat pumps tied to a boiler-cooling tower system, in addition to the GHPs. With this data point eliminated, Figure 9 shows that while not as well correlated as energy savings (R^2 = 0.78 in this case), there is a linear relationship between greenhouse gas reduction and total cooling capacity. The slope of the regression line indicates that greenhouse gas reductions from this set of GHP ECMs average 1.07 MT CO_2e/ton of cooling capacity.

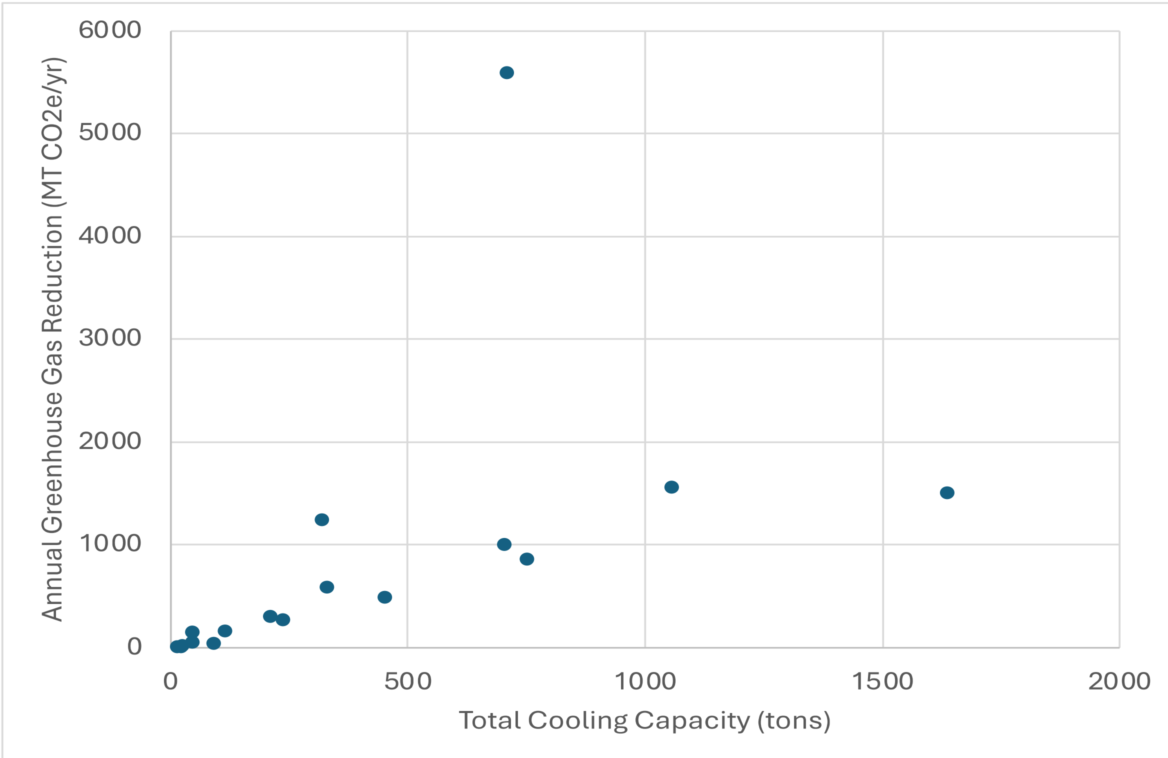

Figure 8. Annual greenhouse gas reduction, metric tons CO2e/year vs. cooling capacity in tons.

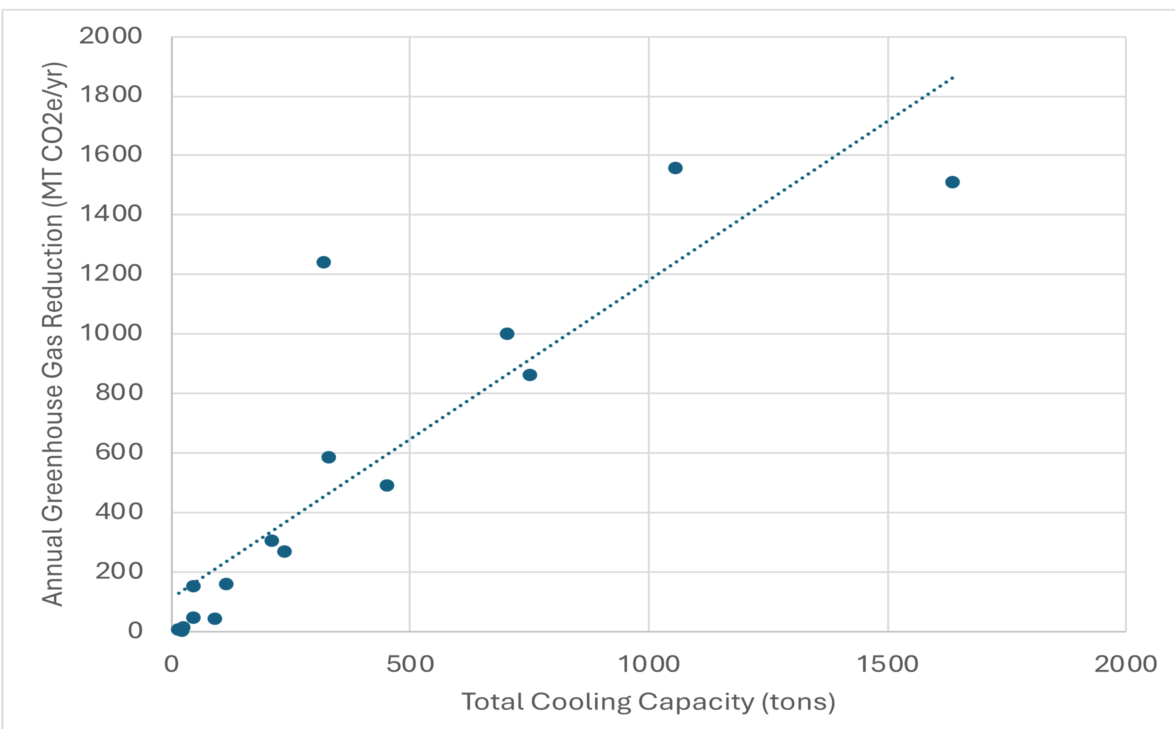

Figure 9. Annual greenhouse gas reduction, metric tons CO2e/year vs. cooling capacity in tons, with outlier removed.

Though electricity comprised 20 percent of the energy savings as shown in Figure 5, it accounted for just over 40 percent of emission reductions resulting from energy savings associated with GHP ECMs, as shown in Figure 10 below. Note that steam hot water savings were assumed to be from purchased or distributed systems.

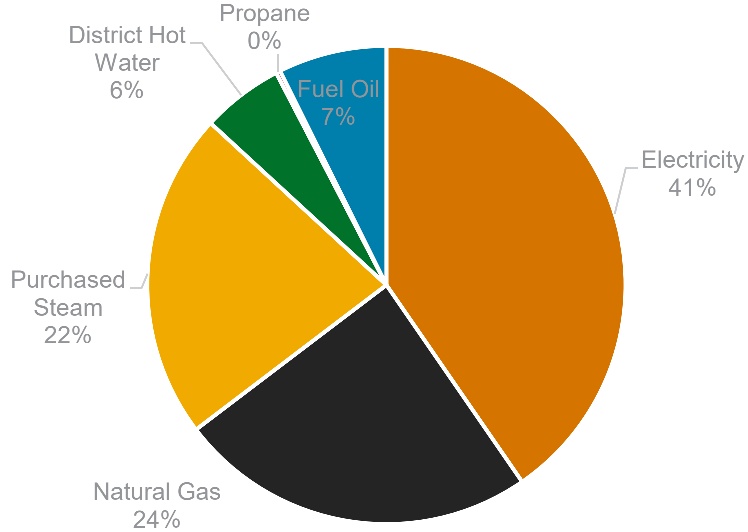

Figure 10. Emission reductions resulting from the implementation of GHP ECMs by energy type

2.5 Annual Cost Savings

Cost savings from GHP ECMs resulted from reductions in energy use, water use, and O&M costs. Not all projects included water or O&M savings[1]. In the aggregate, energy cost savings were responsible for 71% of savings, O&M savings were responsible for 26% of savings, and water savings were responsible for 3% of savings, as shown in Figure 11 below.

[1] O&M savings are energy-/water-related cost savings and may be one-time or recurring in an ESPC. O&M savings presented here were annual cost savings resulting from reduced maintenance associated with the GHP ECMs, often due to existing aging infrastructure and equipment replaced as a result of the GHP ECM.

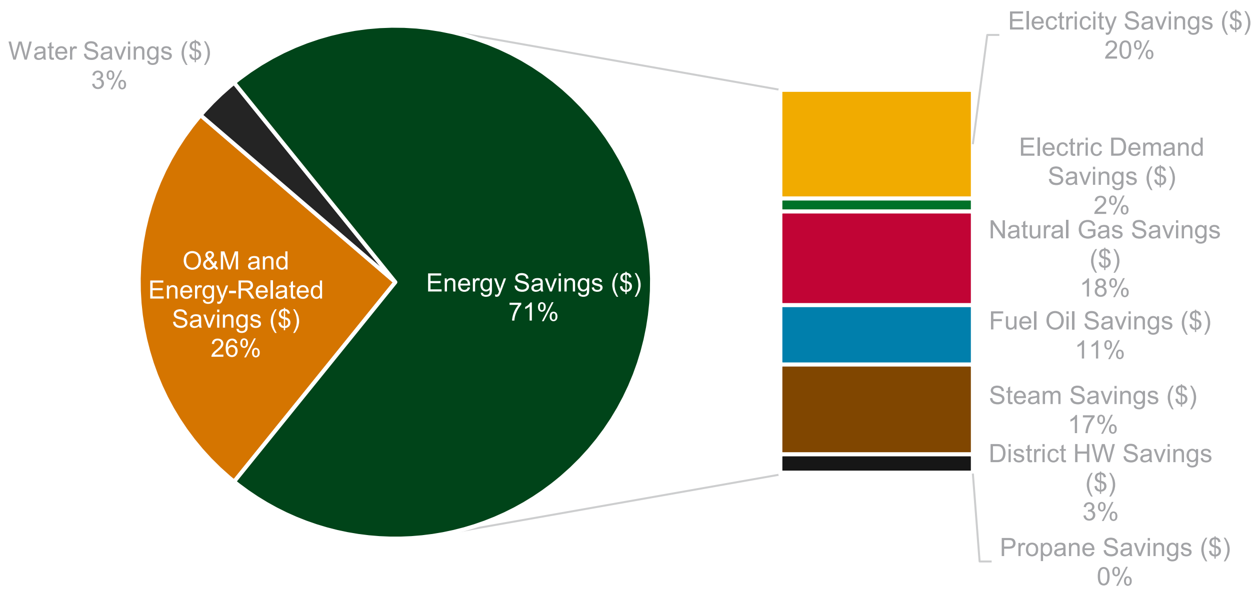

Figure 11. Breakout of Cost Savings by Type across GHP measures.

Figure 12 plots annual energy cost savings in 2024 dollars vs. cooling capacity in tons. While this plot does not include the outlier identified in Figure 6 and Figure 8, energy cost savings show wide variation with respect to cooling capacity, with R^2 =0.7068. This is as one might expect, given variations in energy prices across the U.S. The slope of the regression line in Figure 12 indicates that this set of GHP ECMs resulted in annual energy cost savings of about $318/ton on installed capacity.

Figure 13 plots total annual cost savings (including energy, water and O&M savings) vs. installed cooling capacity in tons. The figure shows greater variation than for energy cost savings alone (R^2 = 0.6137), likely due to the fact that not all projects included O&M and water savings. The slope of the regression line is 413, indicating that for this set of GHP ECMs, total annual cost savings was about $413/ton of installed capacity. Then given that energy cost savings were $318/ton, and the fact that water savings were negligible, we can estimate that O&M savings from this set of ECMs was approximately $95/ton, on average.

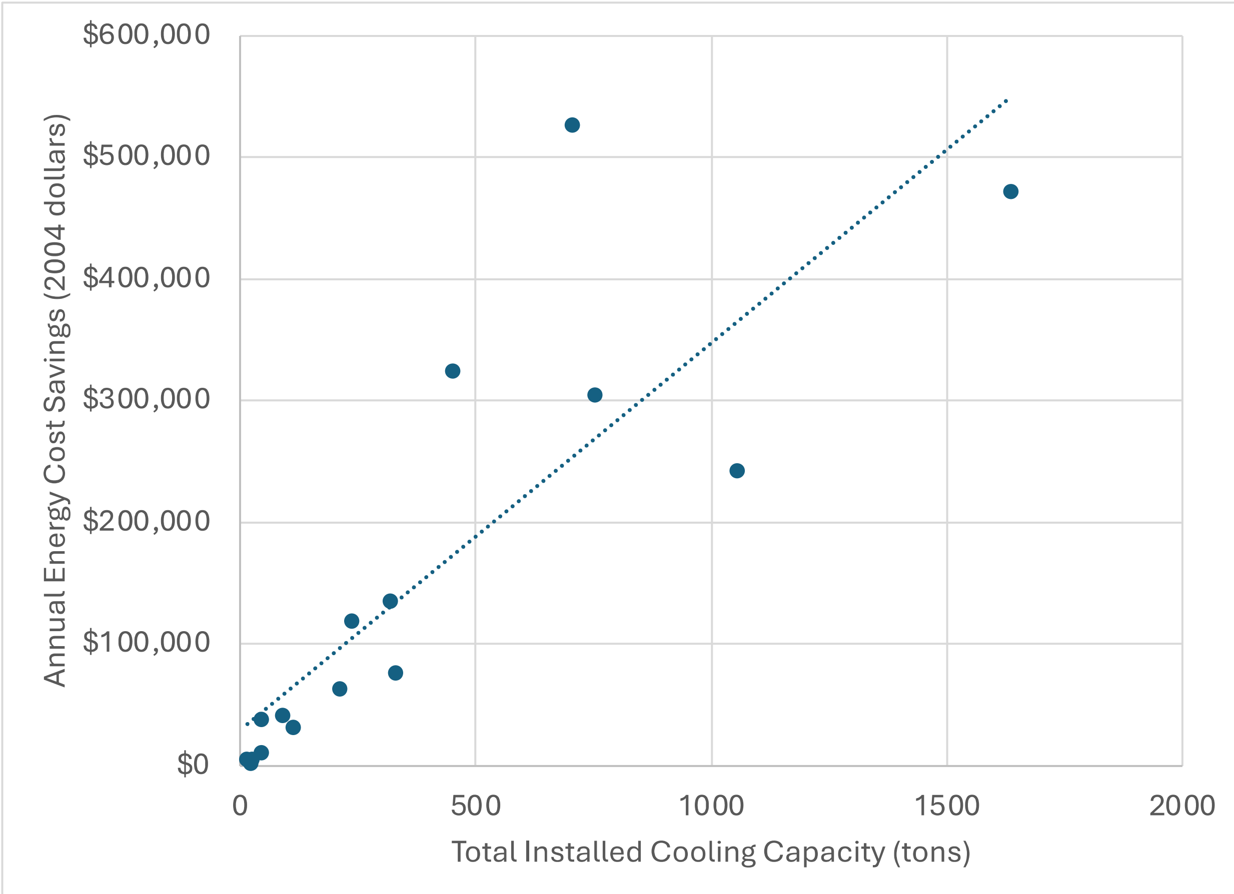

Figure 12. Annual energy cost savings (2024 dollars) vs. installed cooling capacity.

Given the average cost of $13,984/ton and the average savings of $413/ton as calculated by the regression equations, the average simple payback for the set of GHP ECMs can be calculated as 33.6 years. Simple paybacks for individual ECMs varied widely, from a low of 14.1 years to a high of 169 years. The average for the dataset, weighted by installed cost, was 41.6 years.

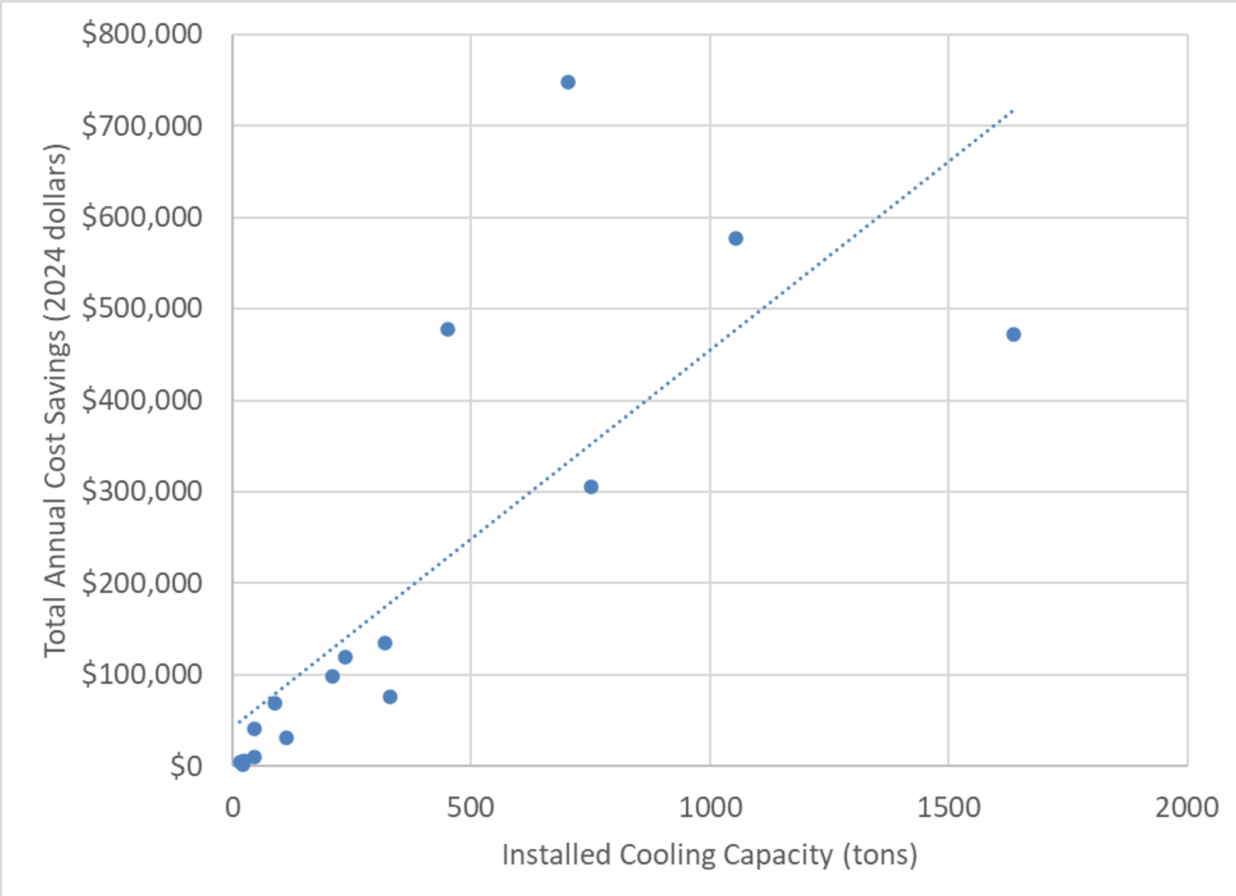

Figure 13. Total annual cost savings (energy and O&M) vs. installed cooling capacity

The inclusion of O&M savings within the total savings for the GHP ECM impacted the simple payback for the measure. Removing outliers, the average simple payback is 41.6 years, and the median is 24.4 years. Figure 14 illustrates the shift in simple payback for GHP measures as reported (with and without O&M savings) and removing any O&M savings attributed to the GHP ECM. Those projects that included O&M savings resulted in a simple payback for the GHP ECM of 20.6 years on average.

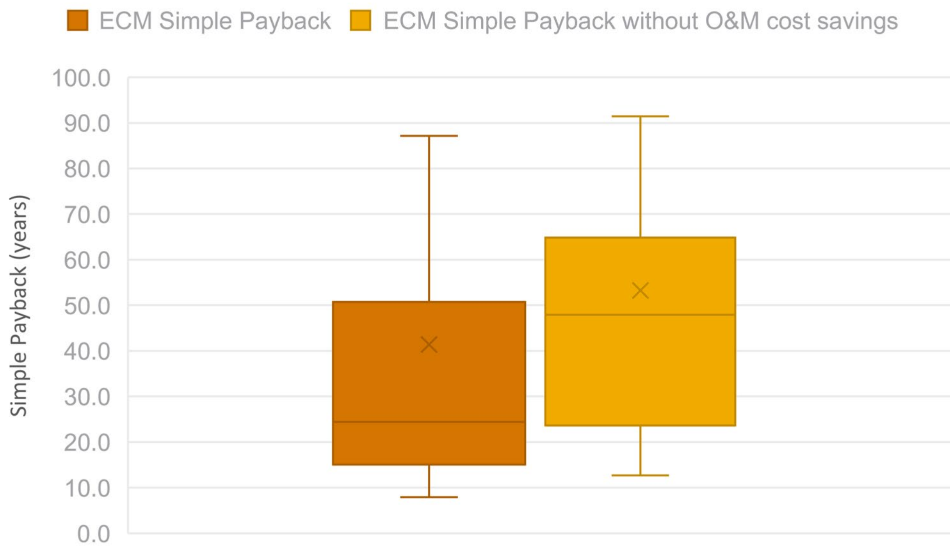

Figure 14. Distribution of GHP ECM Simple Payback as Reported and with O&M Cost Savings Removed.

The average term of ESPC task order awards that included GHP ECMs was 18.5 years, with the longest term of 24 years, and the shortest term of 13 years.

For monitoring the performance of GHP ECMs over the term of the contract, M&V Option D[1] (whole building calibrated simulation model) was the most common, often with annual measurements or control points trends for a sample set of installed units to confirm continued efficiency and performance.

[1] M&V Option D is a whole-facility calibrated computer building model. See FEMP M&V Guidelines for additional details. https://www.energy.gov/femp/articles/mv-guidelines-measurement-and-verification-performance-based-contracts-version-40

3.0 Conclusions

This analysis of energy, cost, and savings data from GHP ECMs implemented as part of ESPCs demonstrated that installed cost and estimated energy savings of GHP ECMs correlated well with installed capacity, while greenhouse gas reduction was less well correlated with installed capacity. The inclusion of O&M cost savings impacted the simple payback of GHP ECMs, which in turn can impact the economic viability of the measure. This will further inform federal agencies that GHP systems are readily available, proven technologies that can support their effort to in meet decarbonization and net-zero building goals, across a spectrum of climate areas and building use types.

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