Electrical Grid Impact of Ground Source Heat Pump Technologies

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ACRONYMS

°F	degrees Fahrenheit
AC	air conditioning
ACH	air change per hour
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AHU	air-handling units
ASHP	air source heat pump
BAS	building automation system
BMS	building management system
CAMA	computer Assisted Mass Appraisal
CBECS	commercial Buildings Energy Consumption Survey
CDD	cooling degree day
CGSHP	Community Ground Source Heat Pump
CHW	chilled water
CHWS	chilled Water System
CSNA	Climate Solutions Now Act
CV	constant volume
DDC	direct digital control
ECM	energy conservation measures
EIA	Energy Information Administration of the U.S.
GHG	greenhouse gas
GSHP	ground source heat pump
HDD	heating degree day
HHW	heating hot water
HVAC	heating, ventilation, and air conditioning
HWS	hot Water System
kW	kilowatt
MMCF	million cubic feet
MMTCO2e	million metric tons of carbon dioxide equivalent
OA	outside air
psi	pounds per square inch
SAT	supply air temperature
SF	square foot
VAV	variable air volume
VFD	variable frequency drive

1. EXECUTIVE SUMMARY

The state of Maryland's Climate Solutions Now Act (CSNA) of 2022 set greenhouse gas emissions targets of 60% reduction based on 2006 levels by 2031 and net-zero emissions by 2045. Under the CSNA, Maryland's mission is to transition workers in fossil fuel industries to employment opportunities in clean energy economy, in addition to focusing on energy infrastructure improvements, transmission efficiency and battery backups. The State has been working to meet CSNA targets by enacting several policies in their building and energy sectors. Under the Building Energy Transition Plan, Maryland found that decarbonization goals can be met through adoption of heat pumps, all-electric new construction to start in 2025, and replacement of fossil fuels with low-carbon renewable fuels by 2045.

Assessing current heating technologies is a crucial step towards understanding their impacts on energy efficiency, cost-effectiveness, and environmental sustainability, particularly within the context of a carbon-free future. Electrification of the heating energy sector is one of the critical challenges that will need to be overcome for Maryland to be successful in meeting their short and long-term goals.

Ground Source Heat Pump (GSHP) HVAC systems stand out as a potential technology in the ongoing process of electrifying the heating sector. These systems leverage the Earth's consistent surface temperature to provide both heating and cooling, achieving a high Coefficient of Performance (COP) through the stable temperature of the ground or water bodies as a heat transfer medium.

The primary objective of this analysis is to assess the impact of widespread GSHP adoption on statewide electrical demand. The goal is to determine whether the costs avoided in electric grid infrastructure upgrades could be redirected to invest in GSHP networks, resulting in a net savings for the end consumer. This report thoroughly examines the grid impact of implementing GSHP systems at scale and compares it to alternative fully electrified scenarios, such as those involving utility Air Source Heat Pumps, which, despite their utility, fall short of the efficiency achieved by GSHP systems.

In a similar vein, Community Ground Source Heat Pump (CGSHP) HVAC systems have been identified as a potential technology to be utilized to expand access to GSHP technology. These systems utilize a shared ground source heat pump infrastructure to cater to multiple structures or units within a community. What sets CGSHP systems apart is the shared infrastructure serving multiple community units, enabling economies of scale and heightened efficiency. Notably, CGSHPs would contribute to improved access to thermal energy by enabling a local utility company to handle a substantial portion of the system cost.

Data was collected from a variety of sources to model the impact of GSHPs, including statewide energy use statistics from the Energy Information Administration (EIA), hourly consumption data for all utilities serving the state (PJM System Operator Data), and the Maryland Department of Planning (MDP) building stock database (CAMA). This data was used to construct a “top-down” analysis of electricity use profiles for all hours of the year. Additionally, combustible fuel data for heating systems was collected monthly to benchmark building use data with various systems retrofits.

In conjunction with the top-down analysis, a “bottom-up” analysis was performed by using modeling tools for residential and commercial data developed by the National Renewable Energy Laboratory (NREL). The modeling tools use housing stock data, weather data, and energy modeling software to simulate the energy use of all buildings in the state and provide hourly energy use profiles for all heating energy sources in the residential and commercial sector. The final analysis combined both the top-down and bottom-up analyses and used published energy use benchmarks for the State of Maryland to validate the results.

The analysis of the current grid peak demand shows that the winter heating peak is 12.6 GW. Comparing the peak demand conditions or the various electrified heating scenarios, the air source heat pump scenario creates the largest peak demand, at just over 18GW. The best-case scenario for peak demand reduction, which is the maximum grid impact for GSHP systems, yields a winter heating peak demand of just over 10GW, or 20% reduction compared to the current grid demand and a 45% reduction compared to the ASHP scenario. The maximum grid impact for GSHP systems occurs at approximately at 75% adoption rate. Any additional use of GSHP systems above this level no longer results in reduced peak heating demand over the current levels.

Analyzing the peak heating loads experienced by all commercial and residential buildings, it is calculated that the total statewide heating system consumes heat at a rate of approximately 105 million MBH, or 8.7 million tons (1 ton = 12,000 BTUs). Comparing this heating rate to the peak demand reduction, this analysis shows that approximately **1kW of electricity grid demand reduction can be achieved for each ton of GSHP technology installed. This amounts to roughly 1MW of demand reduction for every 250 homes connected to GSHP systems. For commercial buildings, 1MW of demand reduction can be achieved for approximately every 400,000 sqft of conditioned space.**

Reduction in statewide carbon emissions from full electrification of the heating sector is significant, even ignoring electrical grid decarbonization scenarios. Section 3 demonstrates that heat pump systems with high COP can use 70%-90% less energy than combustible fuel burning systems operating at 85% efficiency. Even with current electric grid carbon composition it can be estimated that overall carbon emissions will fall by 20%-40% as electric heating technologies are adopted at greater rates. As the electric grid continues to shift to zero-carbon generation sources, these numbers can reach 80%-99% depending on electrification of other fuel consuming sectors.

It is recognized that the best- and worst-case scenarios presented in Section 7 have several barriers to implementation that will prevent large scale adoption of the technology. Barriers to implementation include:

1. Technical issues such as geological conditions, environmental barriers, and physical limitations for end users to install and connect to GSHP networks.
2. Logistical concerns such as lack of equipment, limited workforce to implement at scale, and gaining access to public and private land to drill wells and install distribution infrastructure.
3. Financial limitations such as high cost to implement GSHP infrastructure compared to alternative heating technologies.
4. Technology advances such as low-cost distributed energy storage that provide comparable benefits to grid demand reduction.

Despite the challenges in implementation, adept policy design, such as The Inflation Reduction Act (IRA) of 2022, which provides a 30% tax credit for ENERGY STAR-rated Ground Source Heat Pumps (GSHPs) through 2032, has the potential to overcome non-physical limitations. Commercial GHP systems are also eligible for the Investment Tax Credit.[1] By instituting effective incentives like these that yield a positive return on investment for consumers, stimulate investment from utility providers in GSHP system development, and foster the training of a proficient workforce for installing high-efficiency heating systems, adoption rates can be substantially increased. This, in turn, facilitates a smoother transition to a carbon-free economy. Additional incentives, such as redirecting avoided costs for upgrading electrical grid infrastructure into implementation of GSHP systems, can further improve the economic viability of the technology. This financial analysis was not included in this report but can be completed using the results of the grid analysis presented in Section 8.

In addition to analyzing the avoided grid infrastructure costs, analysis of the impact of CGSHP systems should also considered as a pathway to increase adoption rates of the technology. The coincident load analysis in Section 4.4 indicates that the most efficient strategy would be to identify the geographical regions where coincident load between heating and cooling is greatest and incentivize adoption in those areas. This targeted approach would maximize efficiency and impact of these technologies. Identifying the ideal locations for CGSHP systems in the State should be included in selection of a pilot project for the technology to maximize system efficiency and effectiveness.

[1] Geothermal Heat Pump Information for Consumers | Department of Energy

This study concludes that GSHP and CGSHP technologies—while statewide viability is currently unclear at large scale due to high upfront costs to implement—can play an important role in the overall electrification of the heating sector and should be incentivized through public policy in such a way that barriers to implementation are reduced. Thoughtful design and implementation of incentives to facilitate GSPH adoption can aid the State of Maryland in achieving its 2045 goal of zero carbon emissions.

2. MOTIVATION AND GOALS OF STUDY

2.1 Motivation and MEA Partnership for the Study

The state of Maryland's Climate Solutions Now Act (CSNA) of 2022 set greenhouse gas emissions targets of 60% reduction based on 2006 levels by 2031 and net-zero emissions by 2045. Under the CSNA, Maryland's mission is to transition workers in fossil fuel industries to employment opportunities in clean energy economy, in addition to focusing on energy infrastructure improvements, transmission efficiency and battery backups. The State has been working to meet CSNA targets by enacting several policies in their building and energy sectors. Under the Building Energy Transition Plan, Maryland found that decarbonization goals can be met through adoption of heat pumps, all-electric new construction to start in 2025, and replacement of fossil fuels with low-carbon renewable fuels by 2045.

The objective of this report is to provide the Maryland Energy Administration (MEA) an analysis that evaluates the potential of community ground-source heat pump systems as a solution to help electrify heating systems across the state of Maryland. By analyzing if the capability exists within the state to expand the use of geothermal system at an acceptable cost, this could provide both cost and environmental benefits over the useful lifespan of such systems.

This study is legislatively mandated in HB 400 to be completed by the Maryland Energy Administration in conjunction with an appropriate third party and submitted to the Geothermal Energy Workgroup.

2.2 Goals of the Study

The goals of this study centered around four main tasks:

1) Define Technologies – As seen in Sections 3.4 and 3.5, ground source heat pumps (GSHP) and community ground source heat pumps (CGSHP) take on a variety of forms that would affect their performance throughout the year. Various electric heating technologies are discussed, and heating efficiencies defined in Sections 3 and 4.

2) Establish Baseline Energy Data – Using real time electricity consumption, grid load, and building data establishes a reference point that electrified heating solutions can be measured against. This information is critical to understanding the grid impact of decarbonization measures and helps ground the scenarios. Validating real data with energy modeling results will establish greater accuracy and dependability on the conclusions made. This is detailed in Section 5.

3) Create Scenarios – The initial scenario established assumes statewide decarbonization of all fossil fuel-based heating sources to air source heat pumps (ASHP), which are historically the most common replacement option.

Once a baseline of full ASHP adoption was established, this was compared to various adoption rates of GSHPs, specifically 10%, 25%, 50%, 75%, and 100% adoption rates. This is discussed in Sections 6 and 7.

4) Determine Avoided Demand Capacity – with much higher efficiency capabilities from GSHPs, impact to the grid from electrification can be mitigated by higher utilization rates. Understanding grid impact will help planning for future infrastructure needs and targeting GSHPs could contribute to limiting additional needs. This is discussed in Section 7.

Note that certain elements are not in the scope of this report, such as: Feasibility of specific technologies, design of systems, geological analysis, system cost estimates, ground-level scalability of technology.

3. HEATING SYSTEM TECHNOLOGY REVIEW

Assessing current heating technologies is a crucial step towards understanding their impacts on energy efficiency, cost-effectiveness, and environmental sustainability, particularly within the context of a carbon-free future. Examining various available heating technologies enables us to gain insights into the potential advantages, obstacles, and trade-offs associated with each option. The aim of this analysis is to subject each technology to an equitable evaluation, ensuring that they are individually scrutinized. This approach is essential to avoid any assumptions regarding the efficacy of each technology in addressing the challenge of global warming, emphasizing the need to consider their respective merits and drawbacks.

3.1 Electric Resistance

Electric resistance heating operates on a straightforward principle where electric current passes through a resistive element (typically coil or wire) which then generates heat through electrical resistance.

This heat is then distributed to the surrounding air using a fan or blower.[2]

This system is 100% efficient, as all the electrical energy is converted into heat. However, this high efficiency is relative to the conversion of electrical energy into heat and not the overall efficiency of the heating system which can be less efficient in terms of energy consumption and cost when compared to other heating methods.

Electric resistance heating is often used as a supplementary or backup heating source, or in smaller spaces where efficiency is less of a concern. It is often found in baseboard heaters, radiant heating systems, and some forced-air furnaces.

The environmental impact depends on the cleanliness of the fuels used to generate electricity in the area. Therefore, in regions where electricity is generated from non-renewable sources, this technology may result in greater emissions compared to more energy-efficient HVAC systems, such as heat pumps.

[2] The Science of Heating: Types of Electric Resistance Heating Elements – Newair

3.2 Natural Gas

Natural gas technology in HVAC relies on the combustion of natural gas to generate heat. This heat is used to warm air or water, which is then distributed throughout the building to provide heating. Modern gas furnaces can convert a significant portion of the energy in the natural gas into heat, often exceeding 85%.[3]

Natural gas is often cheaper than electricity in many regions, making gas heating cost-effective for space heating. However, the cost advantage may vary depending on local utility rates and the availability of natural gas infrastructure.

This technology can be a cost-effective choice for larger spaces or in regions where natural gas is readily available.

Gas furnaces are often used in forced air heating systems, while gas boilers are used for radiant heating and hydronic systems.

Even though natural gas is a fossil fuel and produces carbon emissions when burned, modern natural gas HVAC systems are designed to be more efficient and emit fewer pollutants than older models. Nevertheless, their environmental impact is still a concern in the context of climate change. This has led to increasing interest in alternative heating technologies with lower emissions, such as heat pumps.

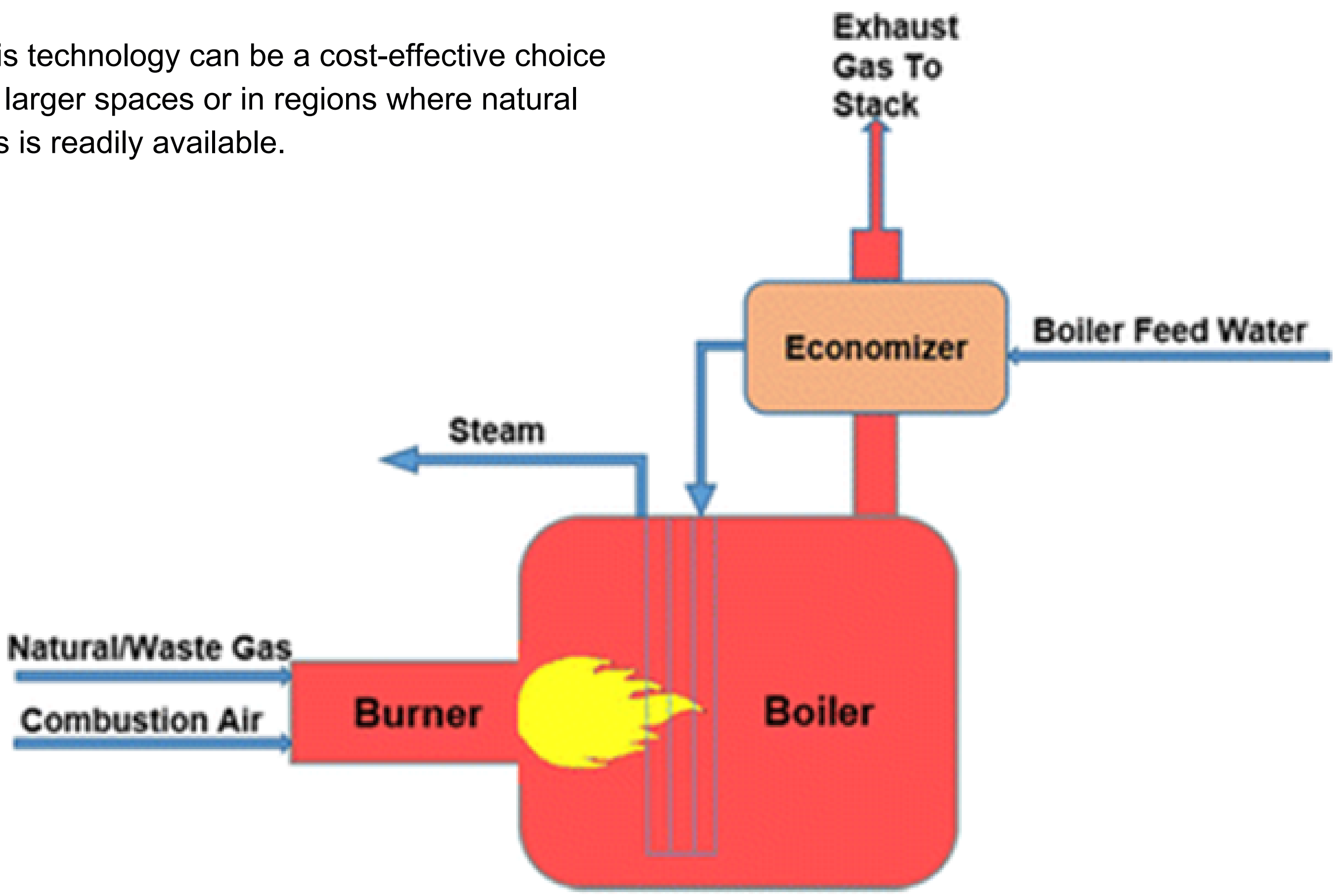

Figure 1: Natural Gas Boiler Diagram [4]

[3] Furnaces and Boilers | Department of Energy

[4] A simplified diagram of a gas-fired boiler system | Download Scientific Diagram

3.3 Air Source Heat Pump

Air Source Heat Pumps (ASHPs) are HVAC systems that work by extracting heat from the outdoor air and transferring it indoors to heat a space. On the other hand, they can also be used for cooling by reversing the process to remove heat from indoor spaces. These systems are considered versatile for year-round use because they can provide both heating and cooling.

The efficiency of these systems is typically measured by the Coefficient of Performance (COP), which fluctuates in response to the ambient air temperature, impacting the heat transfer between the condenser and the external environment.

Modern ASHPs have COPs that range between 1.0 at the coldest temperatures, and 4.8 at optimal temperatures.[5] This means that they produce between one and four times more heating or cooling energy than the electricity they consume.

ASHPs are well-suited for residential and commercial HVAC applications in regions with moderate climates. They are highly effective in areas with temperature ranges that do not require extreme heating or cooling. ASHPs can also be used in combination with other heating and cooling systems, such as electric resistance heating, as backup during extreme weather conditions.

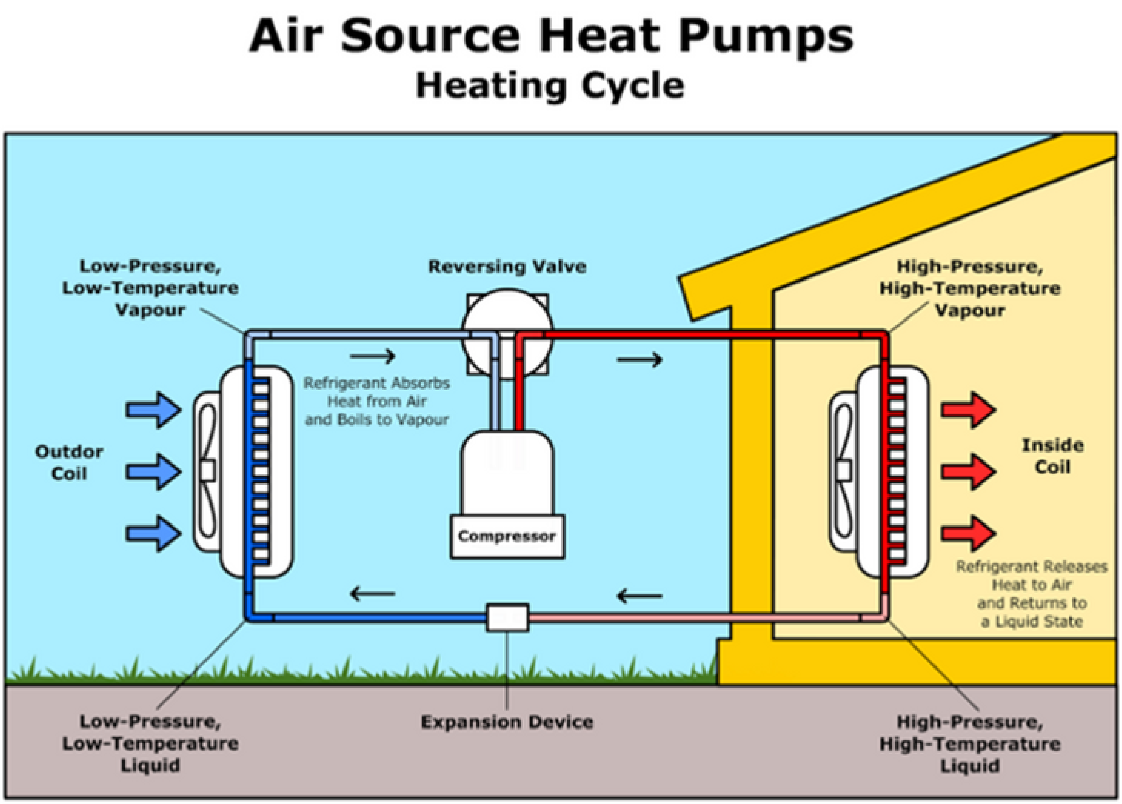

Figure 2: ASHP Diagram [6]

[5] [Measured Performance of a Low Temperature Air Source Heat Pump (nrel.gov)]

[6] [Air Source Heat Pump Installation | TEK (total-environmental.co.uk)]

The environmental impact of ASHPs is lower when compared to systems that rely on fossil fuels or are less energy efficient. They produce fewer carbon emissions when compared to fossil fuel alternatives because they use electricity to move heat rather than burning fuel. Moreover, their efficiency in heat transfer surpasses that of other electric alternatives like resistance heaters, making them one of the most environmentally friendly options in the market.

3.4 Ground Source Heat Pump

Ground Source Heat Pumps (GSHPs) work by utilizing the relatively constant temperature of the Earth's subsurface to provide heating and cooling. GSHPs come in several different configurations, each designed for specific applications and geological conditions. The main types are:

1) Closed-Loop GSHP: In this type of configuration, the flow of the heat transfer fluid is contained within a closed and continuous pathway. This means that the substance circulates through the system, exchanging thermal energy with the surrounding environment, without introducing or releasing the fluid outside of the loop.

- **Horizontal Ground Loop:** This system involves burying a network of pipes horizontally in the ground, typically at a depth of 4 to 6 feet. It is suitable for properties with sufficient available land area.
- **Vertical Ground Loop:** In this design, pipes are installed vertically in boreholes that can extend hundreds of feet deep into the ground. Vertical loops are used when land space is limited or where the soil is not suitable for horizontal loops.
- **Pond/Lake Loop:** If a property has a nearby pond or lake with sufficient water depth, a closed-loop system can be installed in the water to extract or dissipate heat.

2) Open-Loop GSHP: In this type of configuration, water is used as the heat transfer fluid, and it is drawn from an external source without recirculation or recycling. This means that water is extracted from a natural water source, circulated in a linear fashion to extract heat, and then it is released back into the environment.

- **Well Water System:** This type of GSHP uses groundwater as a direct heat exchange medium, with a supply well to extract water and a discharge well to return it to the ground or to a body of water.
- **Surface Water System:** Similar to well water systems, surface water systems use a nearby river, stream, or lake as a heat source or sink.

3) Direct Exchange (DX) GSHP: DX systems circulate refrigerant through copper tubes buried in the ground, eliminating the need for a heat transfer fluid. These systems can be more efficient but may require specific geological conditions to be effective.

4) Hybrid GSHP: Hybrid systems combine a ground source heat pump with another heating or cooling source, such as a gas furnace or solar panels. This setup provides additional flexibility and energy savings, especially in extreme weather conditions.

GSHPs are very efficient HVAC systems, their increased efficiency comes from utilizing the ground or water bodies (Which have a relatively constant temperature) as a heat transfer medium. Modern GSHPs have COPs that surpass 4.0 in the most extreme temperature conditions.[7] Meaning that they produce four times more heating or cooling energy than the electricity they consume.

GSHPs are well-suited for residential, commercial, and industrial HVAC applications. They are especially effective in areas with relatively stable underground temperatures. GSHPs can provide both heating and cooling and are particularly useful for large buildings and areas with a consistent need for temperature control.

GSHPs are considered environmentally friendly. They are more efficient than ASHPs, and when they don't depend on fossil fuels for supplemental heating, they represent a sustainable HVAC solution.

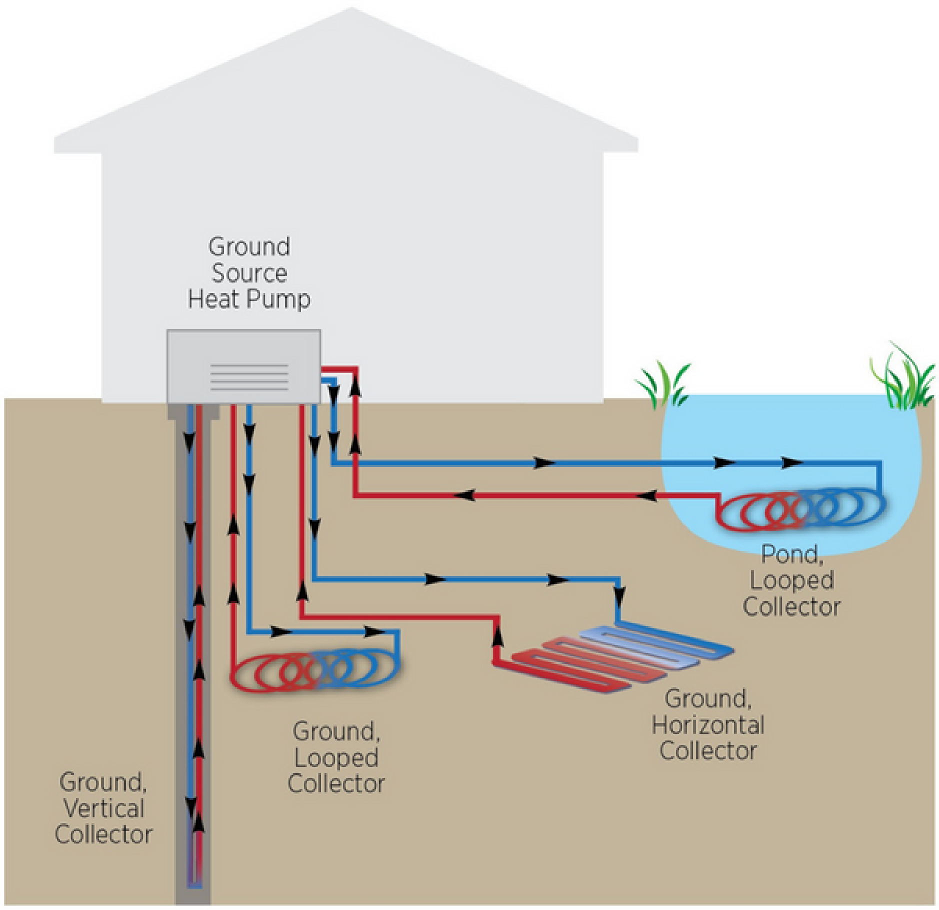

Figure 3: GSHP Diagram [8]

[7] AHRI Certification Directory (ahridirectory.org)

[8] Ground-source heat pump diagram | Building America Solution Center (pnnl.gov)

3.5 Community Ground Source Heat Pump

Community Ground Source Heat Pumps (CGSHPs) employ a communal ground source heat pump system to serve multiple structures or units within a community. These systems harness the Earth's consistent surface temperature to offer heating and cooling to a network of interconnected buildings. Like traditional GSHPs, they achieve high Coefficient of Performance (COP) by using the stable temperature of the ground or water bodies as a heat transfer medium. However, what sets them apart is the shared infrastructure serving multiple community units, enabling economies of scale and heightened efficiency.

The shared infrastructure model ensures that the costs associated with drilling boreholes, installing piping, and implementing the central heat pump system are distributed among multiple buildings or units within the community. This collective approach significantly reduces the upfront capital expenditure for individual structures compared to standalone ground source heat pump installations. CGSHP systems can also incorporate energy sharing mechanisms, allowing surplus energy from one building to be distributed to others within the community, increasing overall system efficiency.

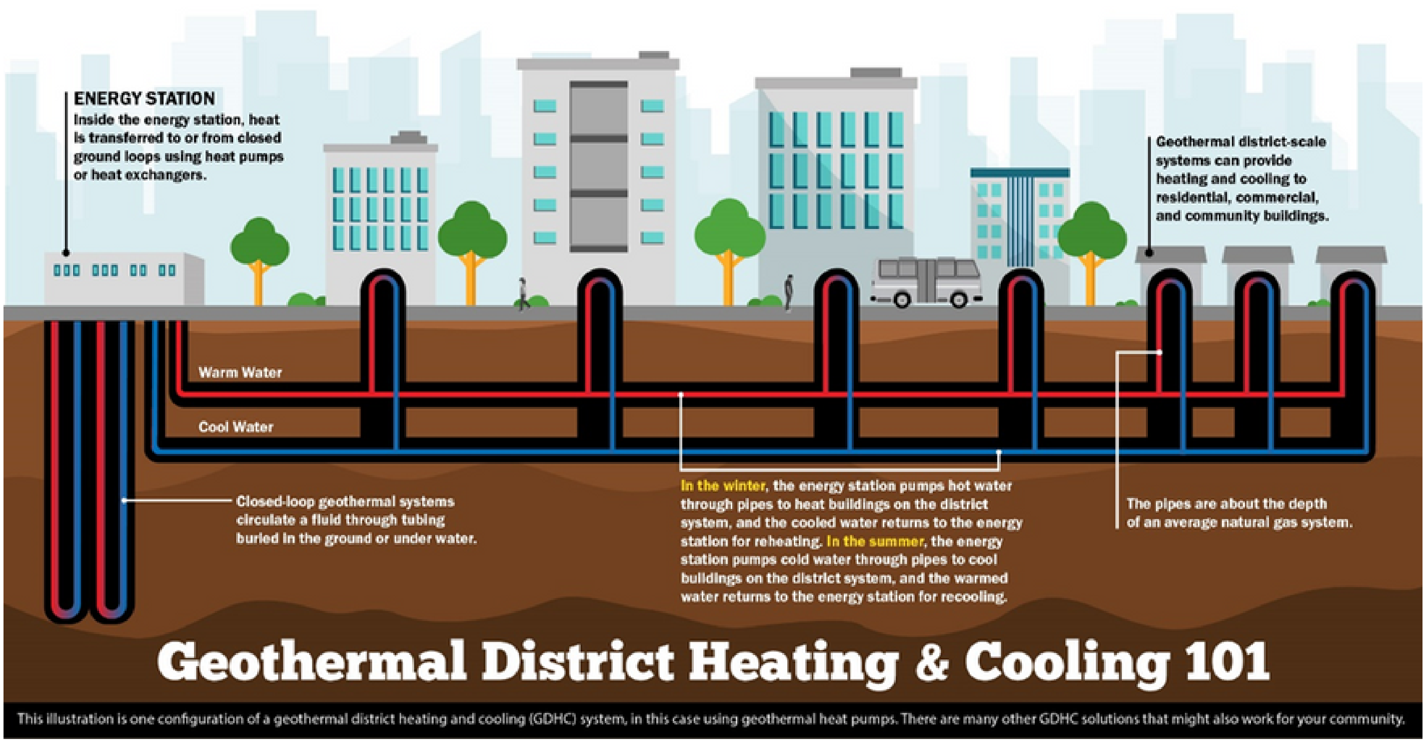

Figure 4: CGSHP Diagram [9]

[9] Geothermal Heat Pumps | Department of Energy

CGSHP technology is well-suited for multi-unit residential developments, housing communities, commercial complexes, and district heating applications. It is especially effective in areas with stable ground temperatures and a concentration of buildings with HVAC needs.

CGSHPs are considered environmentally friendly. They can be more efficient than GSHPs, and when they don't depend on fossil fuels for supplemental heating, they represent a sustainable HVAC solution.

3.6 Other

Within the diverse landscape of heating technologies, it is also important to examine the systems that constitute a smaller share of the energy breakdown. In the state of Maryland, these heating technologies contribute to around 12% of the total heating energy consumption based on the building modeling analysis shown in Sections 4.3 and 4.4. Exploring their characteristics, challenges, and advantages will help have a better understanding of the heating energy breakdown.

- **Oil & derived products:** These heating systems utilize oil-fired furnaces or boilers to produce heat, generating hot water or warm air for distribution by igniting oil. The efficiency of these systems can vary, with their effectiveness contingent upon the age and maintenance of the equipment.
- **Coal:** These systems use coal-fired furnaces or boilers to generate heat, generating hot water or warm air for distribution by igniting coal. The efficiency of these systems can vary, but they are less common due to environmental concerns and availability of cleaner alternatives.
- **Wood:** These heating systems commonly entail the combustion of wood logs or pellets in a wood stove, fireplace, or wood-burning furnace to produce heat. The efficiency of these systems can show significant variations depending on combustion practices. Modern, well-maintained wood stoves and boilers can achieve good efficiency, while older models may not perform as effectively.
- **Solar Heating:** These systems harness solar energy to generate heat for space heating or hot water. They are usually used in conjunction with other systems because their efficiency depends on available sunlight. A well-designed and properly sized system can meet most of the building's heating or hot water loads, significantly reducing energy costs.

4. METHODOLOGIES AND DATA COLLECTION

4.1 General Approach

To model the statewide energy use with various heating technologies, two methodologies of analysis were completed and compared to provide validation of results. The two approaches are defined below:

Top-Down Electricity Demand and Consumption Analysis:

The top-down approach considered statewide and regional data sources to benchmark the current electricity usage in the state and develop seasonal usage patterns based on weather conditions. Statewide data was taken from EIA.gov and metered electricity data from PJM's Data Miner tool were used. Using these two data sources, the following was completed:

- From EIA: Monthly Electricity[10], Natural gas[11], and other fuel consumption for the state of Maryland was collected and used to determine the total seasonal consumption of various energy sources.
- Additionally, energy use per building sector was collected to understand the overall energy use breakdown between residential, commercial, industrial, and other energy end-users. Additionally, electricity consumption for additional utility territories was collected, including Washington DC and the State of Delaware, which was used to adjust the grid electricity usage received from the system operator.
- From PJM: Hourly electricity consumption was collected for years 2018-2022 for all utility providers for the State of Maryland.
- Weather Data: Hourly weather data was collected from WeatherUnderground.com from weather stations in all climate regions of the state.

[10] EIA Electricity Data Browser
[11] EIA Natural Gas Summary Data

Bottom-Up Building Energy Use Modeling:

The bottom-up approach was performed by using modeling tools for residential and commercial data developed by the National Renewable Energy Laboratory (NREL). The modeling tools use housing stock data, weather data, and energy modeling software to simulate the energy use of all buildings in the state and provide hourly energy use profiles for all heating energy sources in the residential and commercial sector. Building stock data used in the analysis was validated using building stock data provided by the Maryland Department of Planning (MDP). The tools used in the analysis include:

- From NREL: ResStock residential energy use modeling tool, ComStock commercial building energy use modeling tool
- From MDP: CAMA database of buildings in State of Maryland

Combined Results:

The top-down and bottom-up analysis were used to validate each other results, and scenarios for various electrification technologies were developed using modeling data for specific energy use electrification strategies. This process is described in Sections 6 and 7.

4.2 Summary of Statewide Grid Modeling Data

Maryland power transmission is served by four utilities operating within state lines:

- Baltimore Gas and Electric (BGE)
- Potomac Electric Power Company (PEPCO)
- Delmarva Power (DP&L)
- Alleghany Power (AP)

Data from the Energy Information Administration (EIA) provided total electricity consumption trends for Maryland. Figures for 2018 showed total consumption of 62,086,455 MWh.[12]

Hourly grid load data is available through the Regional Transmission Organization (RTO) PJM Interconnection. PJM Data Miner catalogues years of hourly demand data for all its associated transmission zones, including all operating throughout Maryland.[13] Notably BGE operates entirely in Maryland, PEPCO including District of Columbia, DP&L including all of Delaware, and only a small portion of AP being contained within state lines.

[12] EIA Electricity Data Browser
[13] PJM Operating Zones Map

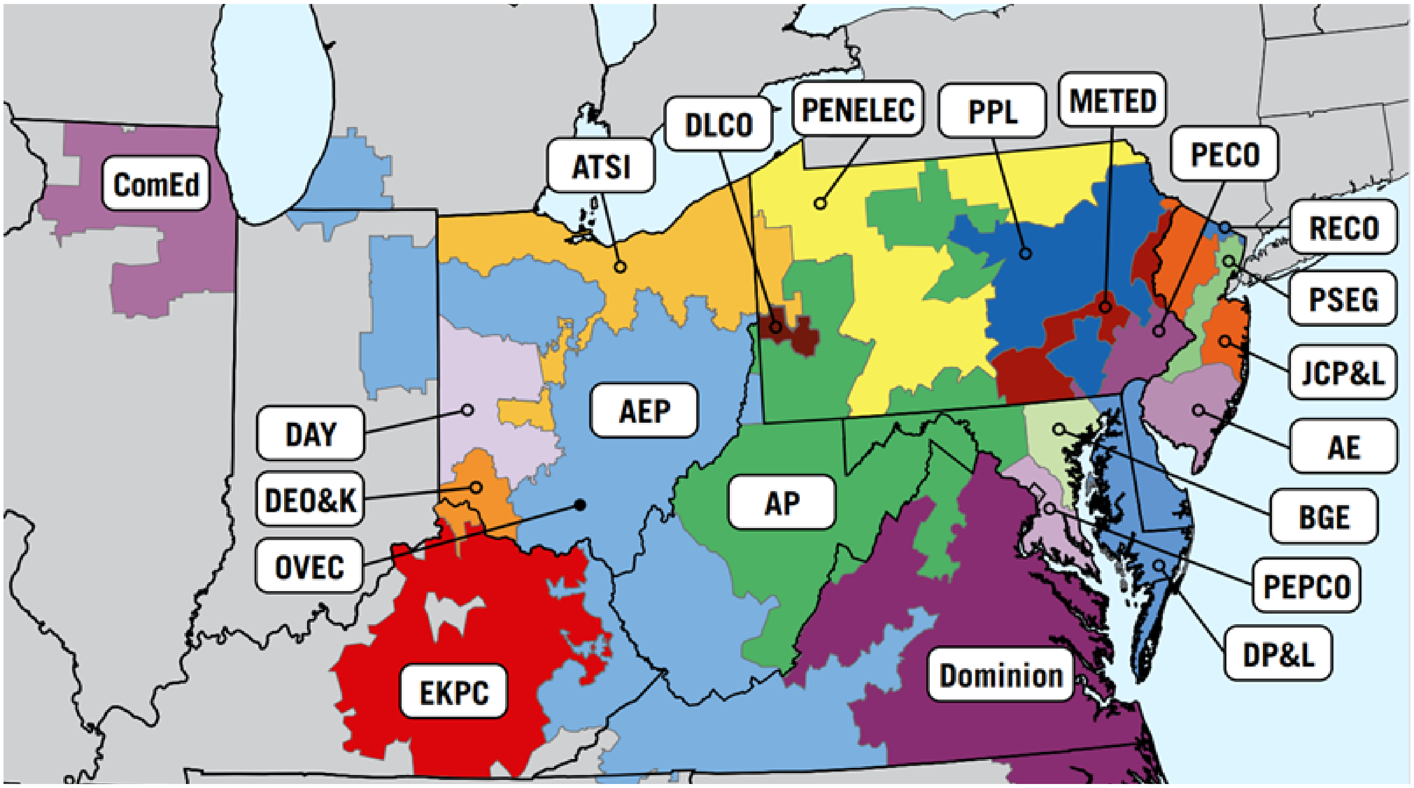

Figure 5: PJM Territory Map

These delineations allowed for granular grid analysis based on the available PJM Instantaneous Load Database.[14] Using 2018 as the benchmark year for analysis, 8760-hour megawatt load profiles for BGE, PEPCO, DP&L, and AP were cross-referenced with EIA totals for Maryland. Since PJM data does not adhere to state lines exclusively, several issues had to be considered.

Normalization was necessary to consider the ratio of electricity consumption that applies to the state of Maryland only. This normalization was accomplished by multiplying each PJM hourly entry by the associated percentage correlating to the ratio of usage by month.

The percentage applied to Maryland only are shown below for DP&L and PEPCO in Table 1, with the percentages calculated as the summed PJM monthly totals compared to EIA monthly totals for Delaware and D.C.

As BGE is entirely within Maryland's borders, no normalization was required. The PJM time series for BGE is unaltered from the database. For PEPCO and DP&L, normalization was required due to the presence of D.C. in PEPCO territory and Delaware in DP&L territory. DP&L does contain a sparsely populated portion of Virginia within its territory, but this is assumed to have minimal contribution to the load profile.

EIA monthly totals were available for D.C. and Delaware[15], allowing for normalization to strictly Maryland-based usage. The results of this approach can be seen in Table 1.

Table 1.

Comparison of PJM and EIA Totals for Utility-Based Consumption

2018	PJM Total	EIA Total	Delaware Total	DP&L minus DE		D.C. Total	PEPCO minus D.C.		PJM minus DE/D.C.	Diff from EIA
Mo.	**MWh**	**MWh**	**MWh**	**MWh**	**%**	**MWh**	**MWh**	**%**	**MWh**	**MWh**
Jan	8,085,345	6,216,546	1,088,000	853,720	44%	969,000	1,988,201	67%	6,028,345	188,201
Feb	6,158,051	4,738,650	910,000	520,581	36%	890,000	1,388,447	61%	4,358,051	380,599
Mar	6,748,058	5,231,411	957,000	648,262	40%	861,000	1,634,781	66%	4,930,058	301,353
Apr	5,609,261	4,334,218	896,000	410,692	31%	835,000	1,261,385	60%	3,878,261	455,957
May	6,328,110	4,684,430	875,000	544,003	38%	907,000	1,537,523	63%	4,546,110	138,320
Jun	6,843,694	5,087,627	957,000	617,536	39%	1,148,000	1,458,425	56%	4,738,694	348,933
Jul	7,970,269	5,963,825	1,153,000	724,204	39%	1,198,000	1,779,973	60%	5,619,269	344,557
Aug	8,168,347	6,024,584	1,167,000	790,671	40%	1,075,000	1,949,914	64%	5,926,347	98,237
Sep	6,906,377	5,161,606	1,024,000	579,450	36%	989,000	1,613,800	62%	4,893,377	268,229
Oct	6,099,855	4,586,008	920,000	468,481	34%	892,000	1,417,608	61%	4,287,855	298,153
Nov	6,228,492	4,757,125	878,000	568,026	39%	885,000	1,434,750	62%	4,465,492	291,633
Dec	6,853,750	5,300,425	948,000	669,249	41%	966,000	1,536,727	61%	4,939,750	360,675
Total	**81,999,607**	**62,086,455**	**11,773,000**	**7,394,876**	**40%**	**11,615,000**	**19,001,532**	**62%**	**58,611,607**	**3,474,848**

[14] PJM Data Miner
[15] EIA Electricity Data Browser

The results in Table 1 show that, with Delaware and D.C. subtracted from the PJM time series, the PJM and EIA data are closely aligned with each other. Following that, removing D.C. and Delaware's usage from PEPCO and DP&L, respectively, the normalization percentages in Table 1 could be applied for each region and corresponding to the relevant month to create new PJM series outputs for PEPCO and DP&L as they relate to Maryland only.

There is a small remainder when comparing the normalized PJM data with the EIA data, and AP was assumed to be the remaining unaccounted EIA usage. An hourly profile was developed for AP as the normalized average of the other profiles multiplied by the remainder usage between PJM and EIA data. Monthly totals are available in Table 2, and total share of consumption can be seen in Figure 6 below.

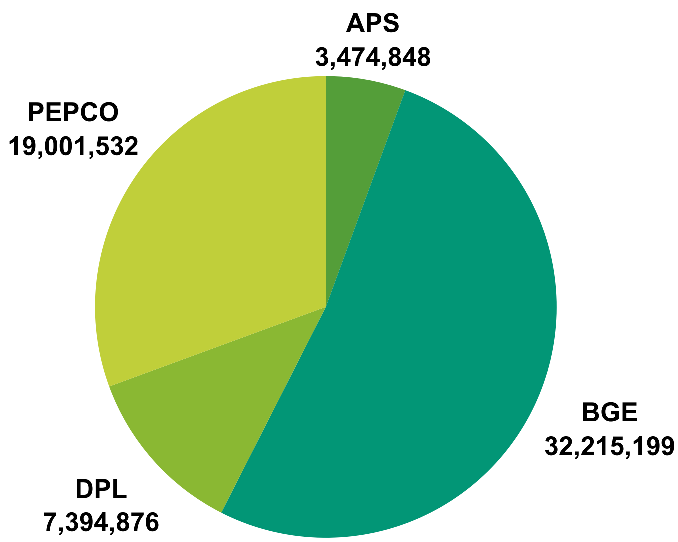

Figure 6: Approximate Electricity Consumption by Utility in Maryland (MWh)

Table 2.

Normalized monthly usage by transmission zone (MWh)

Month (2018)	AP	DP&L	PEPCO	BGE
January	188,201	853,720	1,988,201	3,186,424
February	380,599	520,581	1,388,447	2,449,023
March	301,353	648,262	1,634,781	2,647,015
April	455,957	410,692	1,261,385	2,206,184
May	138,320	544,003	1,537,523	2,464,584
June	348,933	617,536	1,458,425	2,662,733
July	344,557	724,204	1,779,973	3,115,091
August	98,237	790,671	1,949,914	3,185,762
September	268,229	579,450	1,613,800	2,700,127
October	298,153	468,481	1,417,608	2,401,766
November	291,633	568,026	1,434,750	2,462,716
December	360,675	669,249	1,536,727	2,733,774
Total (MWh)	**3,474,848**	**7,394,876**	**19,001,532**	**32,215,199**

4.3 Building Stock Modeling

4.3.1 MDP CAMA Database

MDP CAMA[16] data is an acronym for Maryland Department of Planning Computer Assisted Mass Appraisal Database, downloaded from the website maryland.gov. Data for the CAMA Land point theme are obtained from the State Department of Assessments and Taxation for all jurisdictions on a yearly basis and is divided based on detailed building characteristics.

The data consisted of 2,110,982 records for different type of building enclosures throughout the state. To consolidate the huge data set Building Style Description was considered i.e., BL_DSCSTYL. This datatype had 161 subcategories which were further categorized under three major categories as shown in Table 3 and Figure 7.

Table 3.
MDP CAMA Building Summary

Sector	# of Buildings	Total Sq. Feet
Residential	1,869,773	3,601,018,425
Commercial	237,218	1,565,262,501
Industrial	3,990	131,224,758
Total	**2,110,982**	**5,297,505,684**

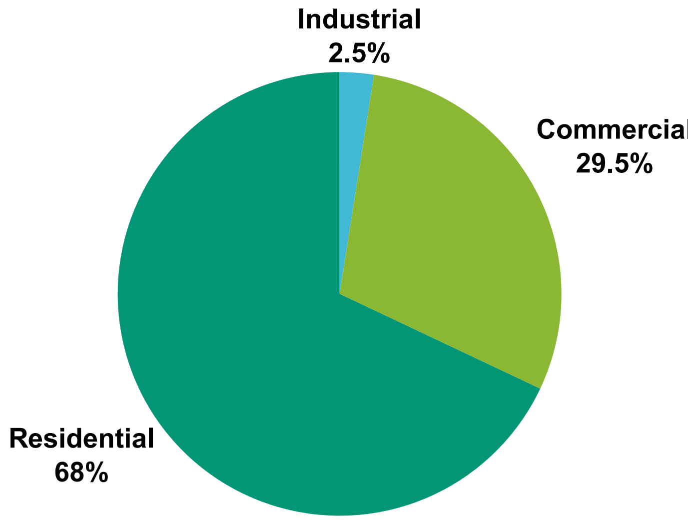

Figure 7: MDP CAMA Distribution of Square Footage by Sector

4.3.2 ResStock

The National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy created ResStock,[17] a database for evaluating the financial, environmental, and energy effectiveness of household energy-saving initiatives. The acronym "ResStock" stands for "Residential Energy Stock." It is primarily used to evaluate the potential benefits of implementing energy-efficient technologies and measures in residential buildings.

[16] Maryland Department of Planning CAMA Data
[17] ResStock

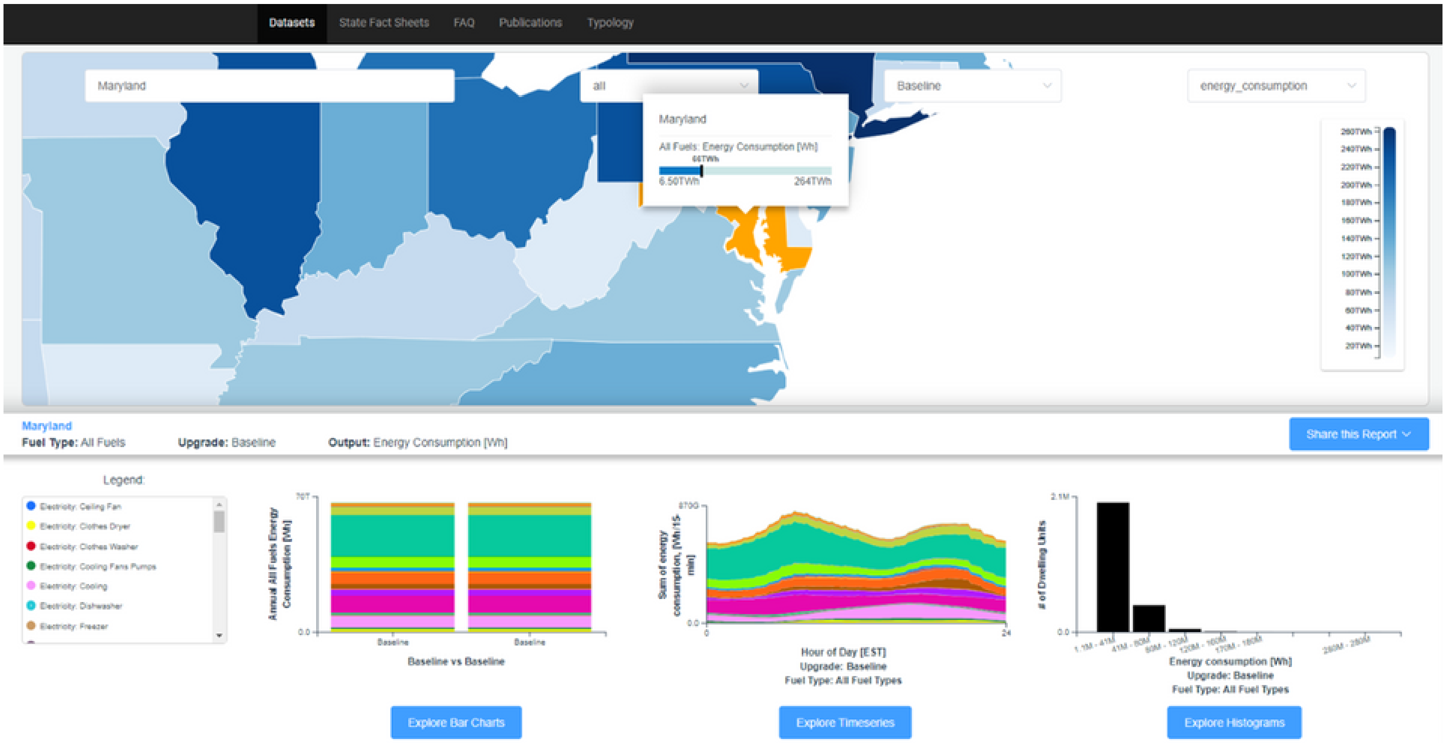

Figure 8: ResStock Overview of Maryland

To determine Maryland's baseline energy estimate, information was retrieved via the metadata which had data at 15 minute intervals. 8,760 hours of hourly data were generated into a CSV file as part of an annual profile. Peaks for electricity, heating, and cooling were generated, along with summer and winter profiles. In order to realize modeled data with real utility data and produce results that are realistic, this information was normalized using utility PJM data.

Figure 9 shows all the heating and cooling energy used in Maryland's residential sector during the year 2018. The data includes electricity and other fuels including natural gas, propane, fuel oil etc. All these fuel sources usage was converted to equivalent electricity (kWh).

The heating peak occurs in winter 1/7/2018 and is 12,297 MW whereas cooling peak occurs in the summer month on 7/3/2018 of 5,093 MW.

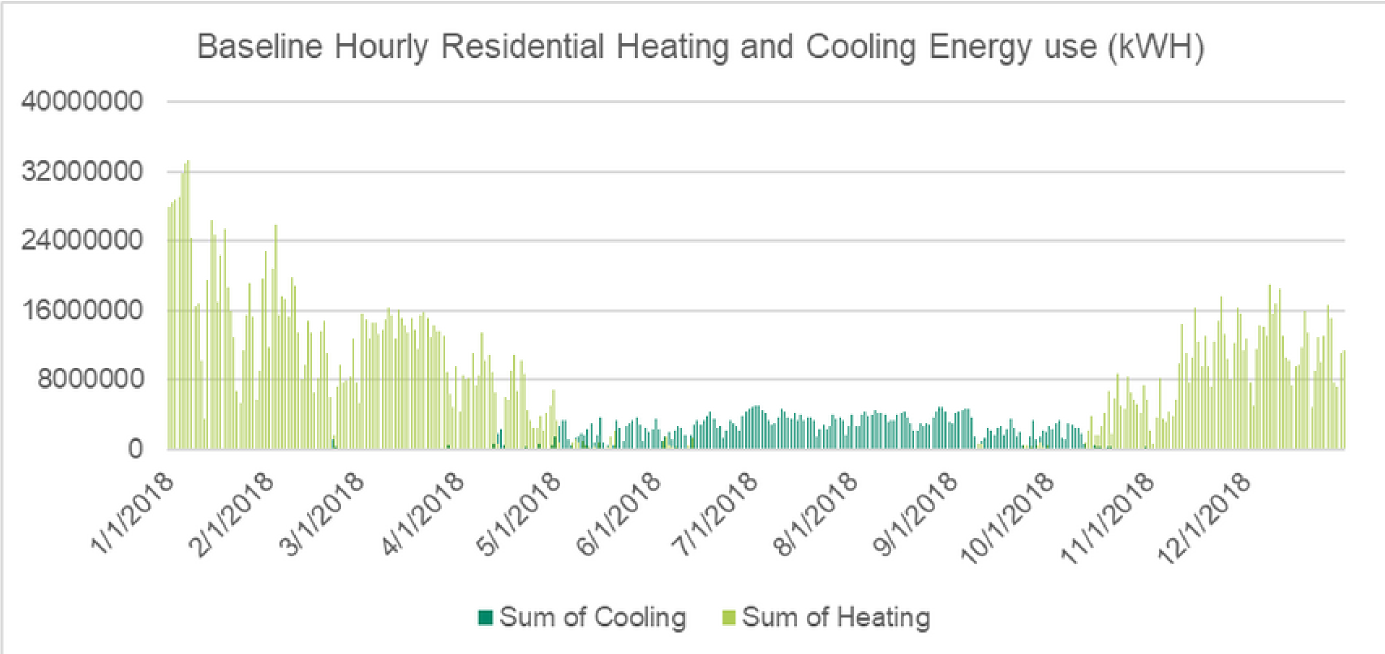

Figure 9: Baseline Hourly Residential Heating and Cooling Energy Use (kWh)

Figure 10, following, is the electricity profile with all heating and cooling sources being upgraded to ASHPs. This data has been generated in the ResStock tool. By ASHP upgrade, all heating sources that use other combustible fuels such as natural gas, propane, fuel oil have been upgraded with electricity which has a lower carbon emissions factor thus reducing the carbon emissions for the state. The previous electric heat with lower COP is replaced by electric heat with higher COP of the ASHP reducing the electric energy use considerably. By switching to ASHP the total energy used is slashed in half with the added benefit of reduced carbon emissions. However, due to higher electric demand the electric peak increased to 16,973 MW.

Each year, the MDP CAMA database is made available to all jurisdictions by the State Department of Assessments and Taxation (Last updated March 19, 2022).

Whereas ResStock SqFt data is modeled to match the state's SqFt, it is not a true number. Rather, it represents the sample for the entire state of Maryland by of distinct data types (Last updated 2018). Both data sources have data gaps for quantity and time frame and the discrepancies are mentioned in Table 4.

Due to high discrepancies above it was critical to normalize data with actual PJM data to build realistic results.

Table 4.

CAMA, ResStock and EIA Data Discrepancies

	Total Area (SqFt)
MDP CAMA	3,601,018,425
ResStock	4,543,373,925
Difference	**26%**

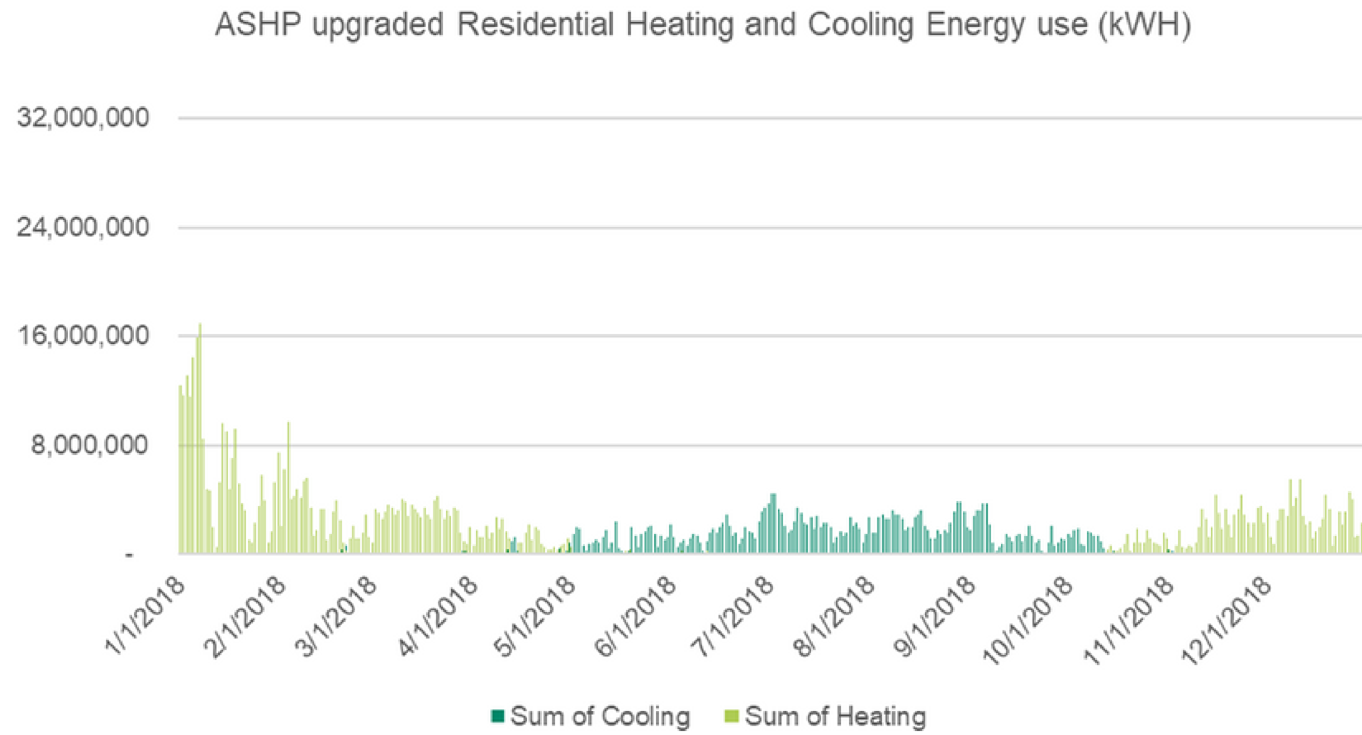

Figure 10: ASHP Upgraded Residential Heating and Cooling Energy Use (kWh)

4.3.3 ComStock

Comstock is a tool created by the National Renewable Energy Lab (NREL) which uses a commercial stock characteristics database combined with physics-based computer modeling and high-performance computing[18] to estimate the energy usage of the United States, with the ability to drill down to specific states.

Data was accessed through the metadata data set to find both the baseline energy estimate for the state of Maryland and a statewide energy estimate based on a 100% heat pump scenario. This data is downloaded as a CSV with 8,760 hours of data in 15 minute intervals, which was processed to display a yearly profile for the state of Maryland; summer and winter profiles; and peaks for heating, cooling, and electricity.

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[18] Comstock.nrel.gov

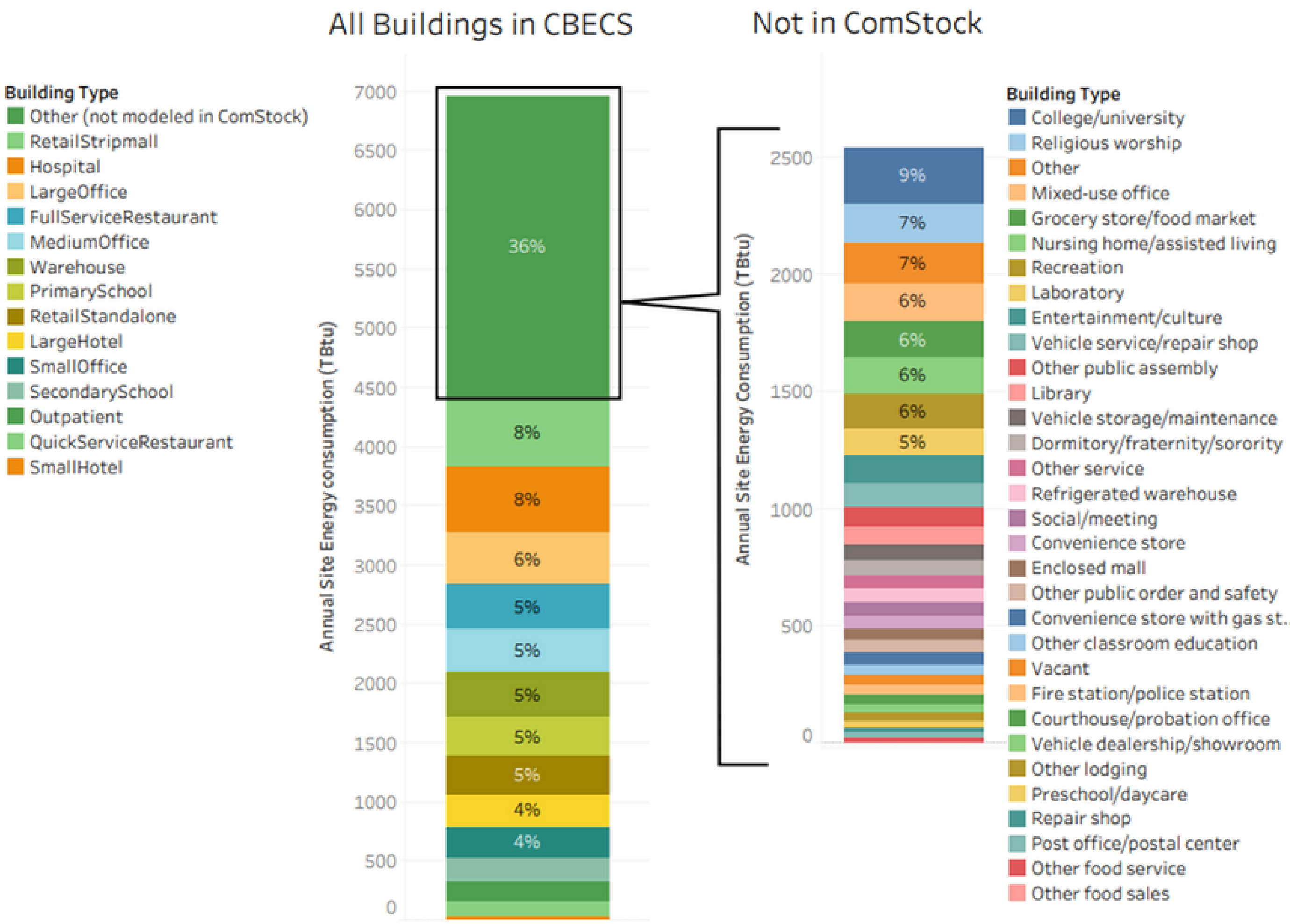


Figure 11: Buildings Modeled in ComStock[19]

As illustrated by Figure 11, ComStock does not model all building types. Due to the modeling deficiency for these building types, the commercial data used from ComStock accounts for 64% of the total commercial energy use for the state. To account for the remaining 36% in the analysis, data from PJM was used to normalize the data.

Figure 12 illustrates a peak heating electricity demand of 2,870 MW and overall energy use reduction of 9% compared to the baseline in and a heating consumption reduction of 21%. This is primarily due to the increased efficiency of ASHPs vs the baseline conditions.

Table 5.
CAMA and ComStock Comparison

Tool	Area (SqFt)
CAMA	1,565,260,000
ComStock	1,140,430,000
Difference	**27%**

[19] Comstock Reference Documentation

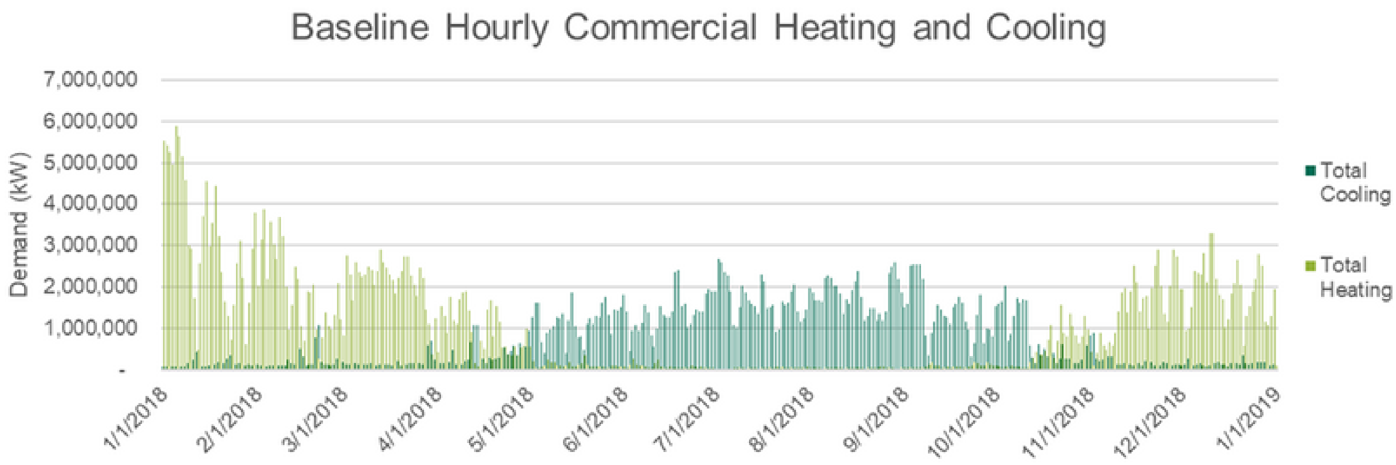


Figure 12: Baseline Hourly Commercial Heating and Cooling

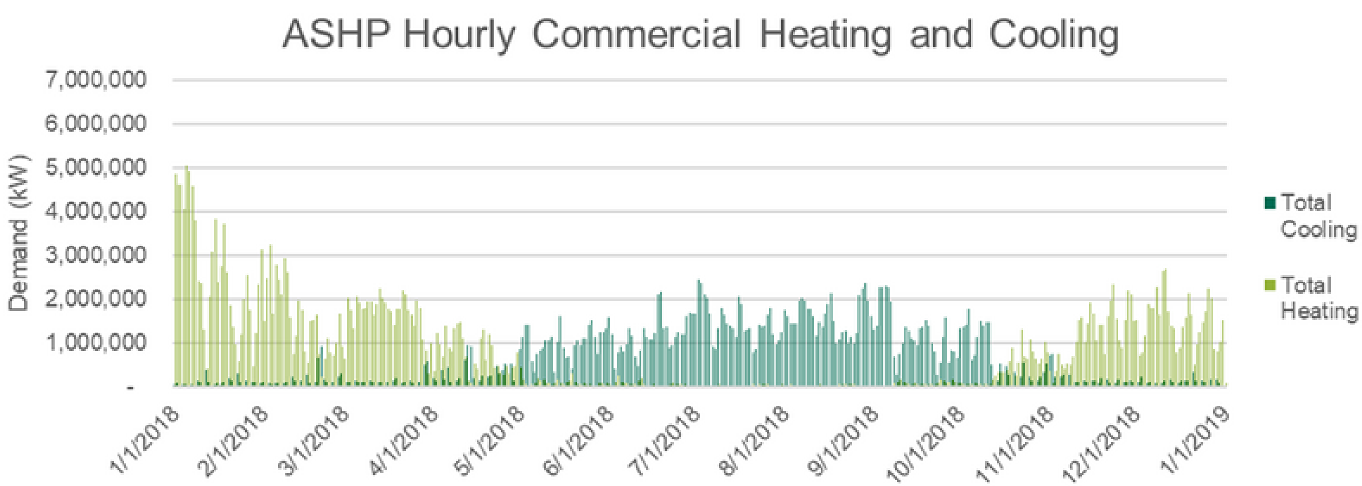


Figure 13: Air Source Heat Pump Commercial Heating and Cooling

Due to the exclusion of quite a few typology types, the ComStock data is not comprehensive. Table 5 indicates that the area missing from ComStock is around 30%. Thus, there is a need to normalize the data using PJM data to have a more realistic expectation of the true peak after application of ASHP or GSHP technologies.

4.4 Heating Technologies Efficiency Analysis

One of the key factors in assessing the efficiency of ASHPs and GSHPs is their Coefficient of Performance (COP), which measures how effectively they convert electrical energy into heat. The COP value is highly sensitive to environmental conditions, making it a critical parameter to evaluate their performance. This efficiency analysis is essential for understanding the real-world efficacy of these heating technologies in various climates and weather conditions.

Due to the exclusion of quite a few typology types, the ComStock data is not comprehensive. Table 5 indicates that the area missing from ComStock is around 30%. Thus, there is a need to normalize the data using PJM data to have a more realistic expectation of the true peak after application of ASHP or GSHP technologies.

The foundation for comparing their distinct performances was based on the following premise:

"Throughout the analysis, the internal heat energy would remain constant, and any improvements in efficiency would be derived from examining the heat transfer process between the condenser and the surrounding environment."

A schematic to this premise can be seen in Figure 14. In the diagram, it is observed that **Qin** and **Qout** will remain consistent throughout the analysis. However, the overall efficiency (comprising both **ηevap** and **ηcond**) will be influenced by the enhanced heat transfer efficiency between the two distinct environmental media, namely air and ground.

Moreover, to maintain the simplicity of the analysis, this analysis doe not incorporate supplementary electrical resistance within the evaporator. This choice was made to facilitate a direct one-to-one comparison of equipment efficiencies between ASHPs and GSHPs. Incorporating electrical resistance as supplementary heating within the ASHP evaporator would introduce an inherent disparity in the comparison of evaporator efficiencies.

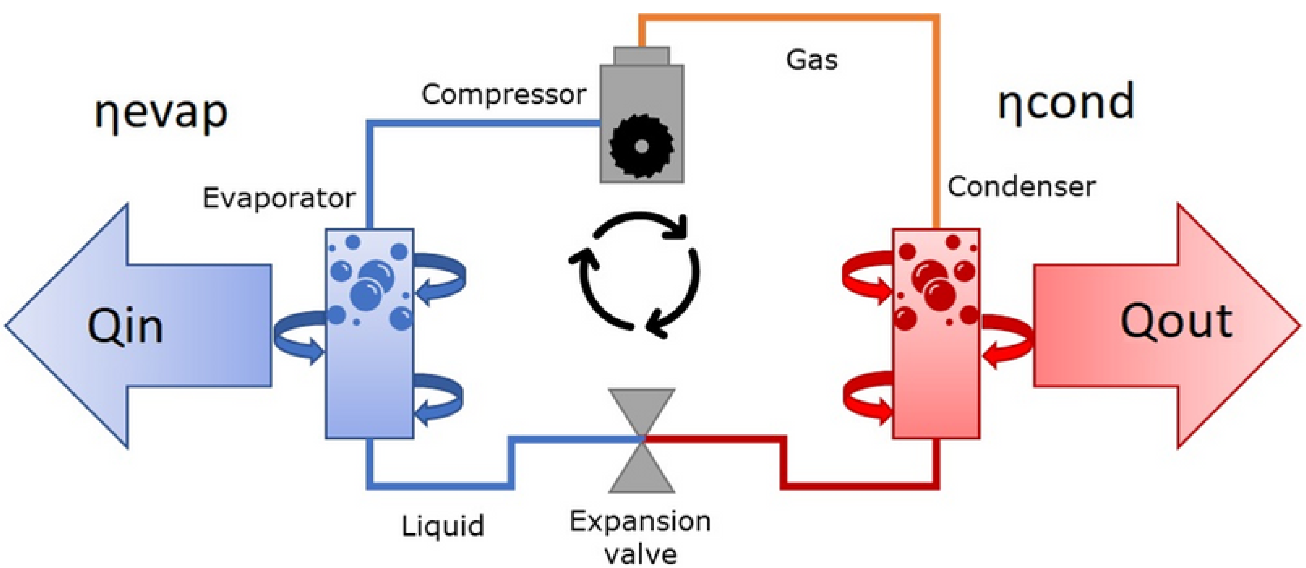


Figure 14: Heat Pump Diagram

This is because the ASHP would simultaneously draw electricity for running the compressor, fan, and electric resistance for supplemental heating. Conversely, in the GSHP configuration, this added electrical load is unnecessary due to the inherently superior efficiency of heat transfer from the ground to the interior space. Furthermore, as ASHP technology advances, the expectation is that improved models will eliminate the need for supplemental electric resistance, which is seen with cold-weather heat pump technologies already available in the market. However, it is crucial for building codes to be revised to acknowledge the capability of ASHPs to achieve indoor comfort temperatures without relying on electric resistance.

Having laid down the foundation with our baseline case, the next step in determining the system efficiencies required obtaining the design conditions specific to the state of Maryland. This was accomplished this by accessing the design data for all cities in Maryland as provided in ASHRAE Standard 169: *Climatic Data for Building Design Standards*.[20] Heating and Cooling conditions were taken from the Standard, along with the associated degree days at an inside temperature of 65°F (HDD65 & CDD65).

This information was used to establish the annual heating and cooling loads that need to be met by the HVAC systems.

The data was organized by outside air temperature (OAT) to align with the COP of the ASHP. The COP values were sourced from the most reputable models available in the market, obtained from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) catalog.[21] In the case of GSHPs, analysis of various efficiencies was derived from different configurations, all of which were also sourced from the AHRI catalog. After a comprehensive analysis of various configurations, the Ground Loop Heat Pump (GLHP) configuration was selected as the focus of the assessment. This choice was informed by its ease of implementation and its relatively conservative efficiency.

To determine the efficiency of the GLHP system, HDD65 and CDD65 data was used to calculate the annual heating and cooling loads. Table 6 displays the average state-level results derived from this calculation.

Table 6.

Maryland Average HDD65 and CDD65 Information

Location	HDD65	CDD65
State Average	4,260	1,382

[20] ASHRAE 169-2021 | ASHRAE Store (techstreet.com)
[21] Quick Search (ahridirectory.org)

The system's energy balance was calculated using the equation below. Because the system energy balance is over 50% (i.e., the difference between annual heating and cooling loads met by a GSHP systems), it is expected that both ground temperature and system efficiency will be impacted. Ideally system energy balance should remain less than 10 to 15 percent[22] to avoid the need for supplemental heating or cooling systems.

$$\textit{Energy Balance} = \frac{|CDD65 - HDD65|}{(CDD65 + HDD65)}$$

$$\textit{Energy Balance} = \frac{|1382 - 4260|}{(1382 + 4260)}$$

$$\textit{Energy Balance} = 51.01\%$$

To validate the findings, the percentage of coincident loads was assessed.

Leveraging the grid data acquired in earlier stages, which had computed heating and cooling data in kWh, the the total monthly heating energy usage was determined. This involved assigning 100% efficiency to electrical heating and 80% efficiency to combustion heating. For electrical cooling electricity, a COP of 4 was applied to calculate the total monthly cooling electricity consumption. Subsequently, the percent coincident loads was computed by comparing load discrepancies with the overall monthly load.

As indicated in Table 7, it is evident that the percent coincident loads are consistently low in most months, indicating sub-optimal performance of any GSHP set up.

Table 7.

Coincident Loads Percentage Based on Monthly Heating and Cooling Loads in the State of Maryland

Month (2018)	Heating Energy (kWh)	Cooling Energy (kWh)	Difference	% Diff	% Coincident Loads
January	13,194,029	547,176	12,646,853	92%	8%
February	8,203,549	749,252	7,454,296	83%	17%
March	8,277,845	650,771	7,627,075	85%	15%
April	3,443,521	1,232,826	2,210,696	47%	53%
May	166,319	5,738,352	5,572,033	94%	6%
June	82,678	8,259,272	8,176,594	98%	2%

[22] GeoMicroDistrict Feasibility Study

July	24,396	11,361,758	11,337,362	100%	0%
August	23,428	11,718,005	11,694,577	100%	0%
September	104,908	8,001,203	7,896,295	97%	3%
October	1,487,517	3,441,174	1,953,658	40%	60%
November	6,491,383	776,928	5,714,455	79%	21%
December	8,206,664	580,459	7,626,205	87%	13%

To thoroughly assess the variation in efficiency of the GLHP system, it was imperative to derive HDD65 data from the publicly available weather data around the state and the modeled heating energy use described in Section 4.2 and 4.3. With the the annual HDD65 data, COP values were assigned based on the ground temperature. Examining the Department of Energy's statement, which notes that *"GSHPs leverage the consistent temperature of the shallow earth (40–70°F/4.5–21°C) to facilitate efficient temperature exchange for heating homes in the winter and cooling homes in the summer"*[23] a reference point of 70°F was set for the first of October. This specific date was chosen because it aligns with the onset of the fiscal year and marks the conclusion of the summer season. The analysis proceeded by establishing the ground temperature of 40°F for the first of May, as this date signifies the end of the heating season for the GLHP system.

Afterwards, the relevant heating and cooling COPs were assigned based on ground temperature.

After setting up these reference points, the alterations in ground temperature and COP were computed relying on HDD65 data from October 1st to May 1st. This method enabled efficiency values to be assigned for each first day of the month, spanning from the beginning of the fiscal year through May. During the months of June, July, and August, it was assumed that the system would have access to a heat sink that could be utilized to increase the ground temperature before the onset of winter. This would allow the heating efficiency of the system to return to the level initially examined when the reference points were defined.

Based on the calculations and assumptions listed above, the following comparison of efficiency of ASHPs and GSHPs was generated (Table 8, following).

[23] Geothermal Heat Pump Information for Consumers

Table 8.

ASHP & GSHP COPs Compared to OAT

OAT (°F)	ASHP COP	GSHP COP
95	3.66	8.79
90	3.97	8.64
85	4.29	8.79
80	4.60	8.64
75	4.92	8.53
70	5.23	8.95
65	5.54	4.30
60	5.86	4.38
55	5.86	4.45
50	5.86	4.45
45	5.86	4.44
40	4.59	4.45
35	4.18	4.44
30	3.77	4.50
25	3.37	4.52
20	2.96	4.52
15	2.55	4.57
10	2.14	4.56
5	1.80	4.55

These results were later employed to allocate efficiency ratings to the hourly grid data, which was utilized to evaluate the change in energy demand resulting from the widespread adoption of GSHPs across the state.

By examining the heating and cooling energies on days with the highest demand for each energy type, it is noted that the percent coincident loads stands at 3% (Table 9 below). This percentage indicates the adoption rate at which GSHP systems would achieve optimal efficiency. The strategy revolves around identifying the specific geographic locations within the state where these coincident loads occur and strategically implementing networked GSHP systems in those areas. This targeted approach aims to maximize the adoption and utilization of GSHP systems, capitalizing on their efficiency in locations where heating and cooling demands align most favorably.

Table 9.

Percent Coincident Loads Based on Highest Heating and Cooling Loads in the State of Maryland

Day	Heating Energy (kWh)	Cooling Energy (kWh)	Difference	% Diff	% Coincident Loads
1/5/2018	635,951,409	10,133,214	625,818,195	97%	3%
7/2/2018	375,632	425,956,462	425,580,829	100%	0%

4.5 Industrial Energy Assumptions

4.5.1 Energy Information Administration (EIA) Data

Due to the large variety of industrial uses and building types, hourly data for industrial usage is difficult to model and therefore, it is difficult to find. While hourly data was not gathered, monthly electricity consumption was acquired through the EIA Electricity Data Browser,[24] while the monthly natural gas consumption is available in the form of a downloadable CSV from EIA data.

4.5.2 Methodology

Monthly and annual data alone are incapable of determining a peak. Without hourly data, the peak electricity for the industrial sector could not be determined. Ideally, hourly data and typology system types would allow for analysis on the impact of switching to air source heat pumps (ASHPs) or ground source heat pumps (GSHPs).

Therefore, since that data is unavailable and the impact is indeterminate, **conversions of industrial energy systems to ground source or air source heating technologies were not included in this analysis.** Industrial energy was considered when analyzing overall energy use and calculation of various electrification scenarios, which is discussed in Section 6.

[24] Electricity Data Browser

5. DEFINE CURRENT BASELINE

5.1 Statewide Electricity Load

EIA data for Maryland shows electricity consumption trends as illustrated in Table 10. Of note, residential and commercial usage are comparable on an annual basis but have very different baselines of consumption throughout the year. The commercial sector has more rigidity to its baseline whereas the residential consumption shows very clear seasonality trends.

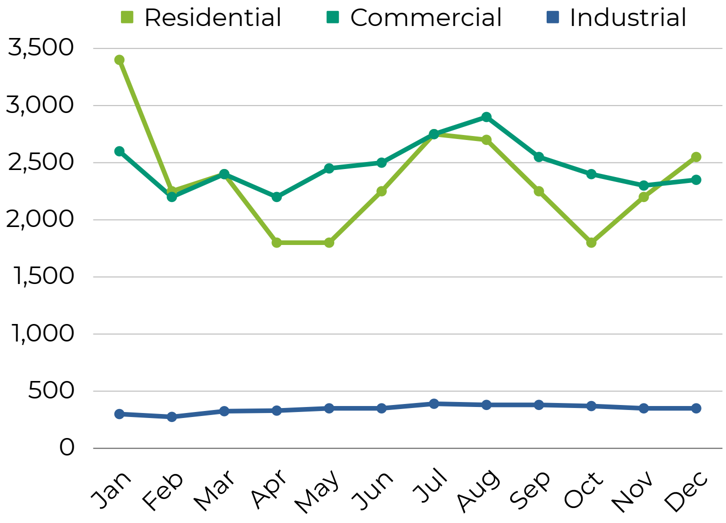


Figure 15: EIA Electricity Consumption Totals by Sector for Maryland (million kWh)[25]

Table 10.

EIA Electricity Consumption Totals by Sector for Maryland (millions kWh)

	Residential (million kWh)	Commercial (million kWh)	Industrial (million kWh)
Total	28,138	29,548	3,871

5.2 Estimate of Current Statewide Gas and Other Combustible Heating Loads

5.2.1 EIA Data

EIA data referencing useful thermal output is shown below in Table 11. EIA defines useful thermal output as "the thermal energy made available in a combined-heat-and-power system for use in any industrial or commercial process, heating or cooling application, or delivered to other end users, i.e., total thermal energy made available for processes and applications other than electrical generation."[26]

[25] Electricity Data Browser
[26] EIA Glossary

Table 11.
Fossil Fuel Based Electricity Generation[27]

Month	Natural Gas (MMCF)	Residential Electricity (Million kWh)	Commercial Electricity (Million kWh)
Jan-18	17,760	3,230	2,640
Feb-18	11,360	2,290	2,150
Mar-18	13,70	2,440	2,430
Apr-18	7,350	1,870	2,120
May-18	3,410	1,870	2,430
Jun-18	1,860	2,200	2,530
Jul-18	1,560	2,770	2,780
Aug-18	1,470	2,740	2,890
Sep-18	1,520	2,250	2,520
Oct-18	3,590	1,810	2,410
Nov-18	10,100	2,110	2,280
Dec-18	12,720	2,560	2,370
Total	**86,400**	**28,140**	**29,550**

Table 12.
Maryland Useful Thermal Output of Combustible Heating Sources (MWh)[28]

Month	Coal	Petroleum Liquids	Natural Gas
Units	MWh	MWh	MWh
Jan-18	17,760	3,230	2,640
Feb-18	11,360	2,290	2,150
Mar-18	13,70	2,440	2,430
Apr-18	7,350	1,870	2,120
May-18	160	2	173

[27] Electricity Data Browser
[28] Electricity Data Browser

Month	Coal	Petroleum Liquids	Natural Gas
Units	MWh	MWh	MWh
Jun-18	127	3	200
Jul-18	132	3	204
Aug-18	143	3	195
Sep-18	83	3	205
Oct-18	66	7	176
Nov-18	165	-	134
Dec-18	149	2	124
Annual Total	**1,588**	**55**	**2,051**

5.2.2 ResStock Gas and Other Combustible Heating Loads

ResStock provides energy use metadata for sources other than electricity including natural gas, propane, and fuel oil. These combustible fuel sources are widely used in residential buildings' heating furnaces, direct-fired infrared heaters, or other related heating technologies. In ResStock, this data is converted to equivalent usage of electricity and displayed in a time series graph below. The data characteristics indicate that the winter months of mid-October to April are when alternative fuels are primarily utilized for heating, with a few shoulder days in September to mid-October and May to mid-June. In January, electric heating drives the electric grid peak, which aligns with the heating peak.

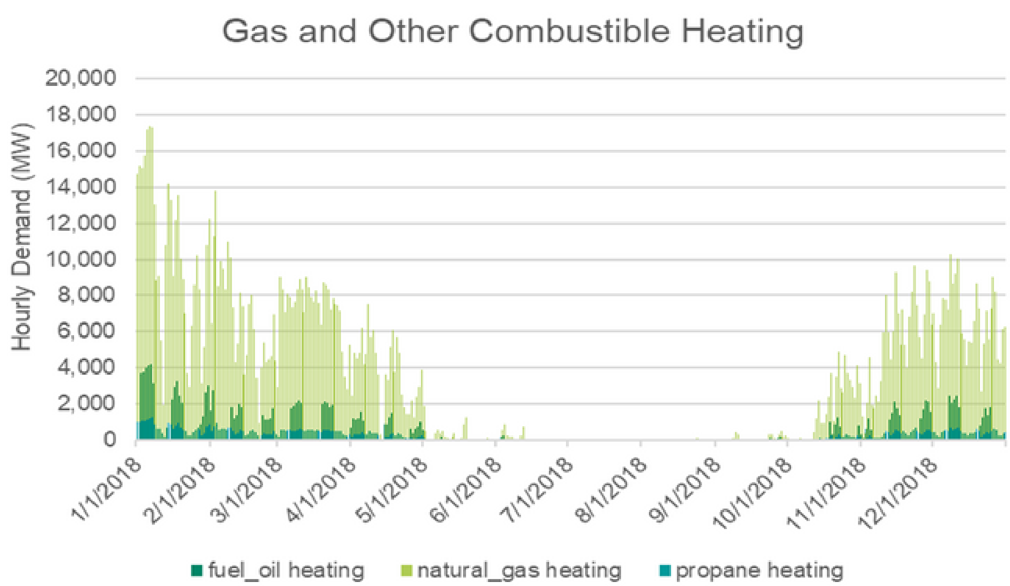


Figure 16: ResStock Baseline Energy Consumption

5.2.3 ComStock Gas and Other Combustible Heating Loads

ComStock metadata includes energy usage for non-electric sources such as natural gas and propane. The metadata separates these as natural gas heating and 'other' fuel heating, which includes fuel sources such as propane and fuel oil. These various fuel sources are often used in commercial heating equipment such as gas-fired furnaces for rooftop units (RTUs) and in gas boilers. In ComStock, this is converted to a kilowatt-hour equivalent in the time series graph below.

As illustrated by Figure 17, the non-electric fuels are mainly used for heating in the winter, falling to nearly zero during the summer months.

The electricity peak and the heating peak do not coincide for commercial buildings and electricity instead appears to be driven by cooling in baseline conditions. This study does not consider the projected heating-degree-days or cooling-degree-days and how that would affect the seasonal heating and cooling demands.

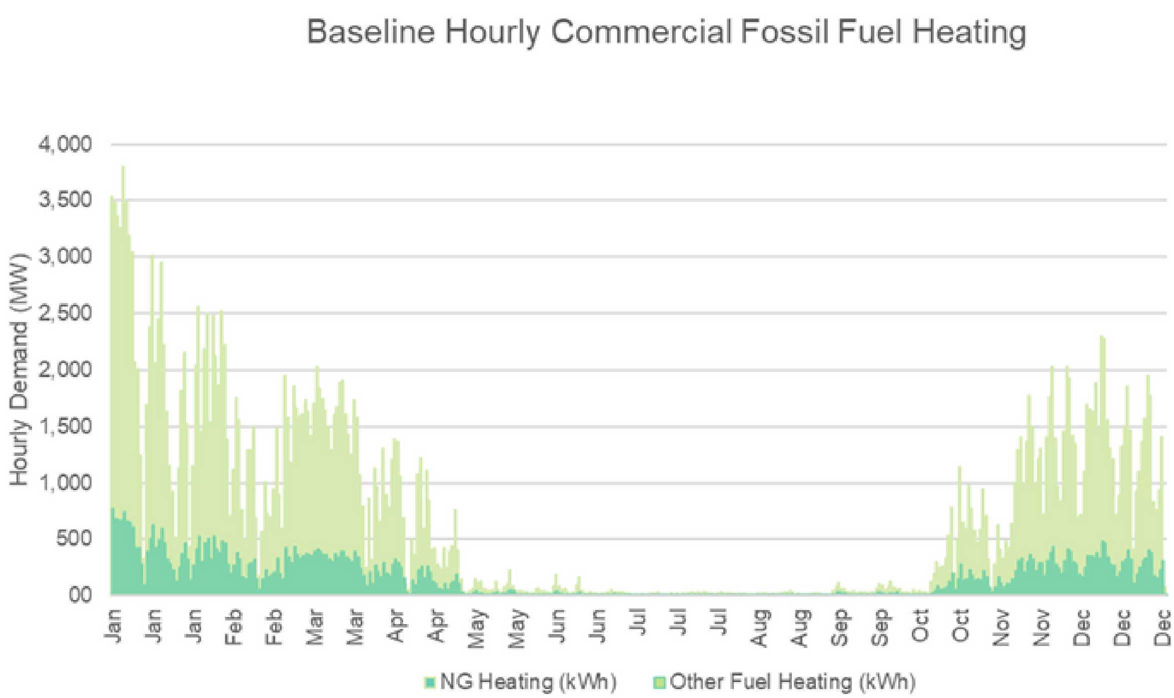


Figure 17: ComStock Modeled Baseline Fossil Fuel Heating Consumption

5.3 Estimate Current Distribution of Electric Heating Sources in Current Heating Load

5.3.1 ResStock Electric Heating Sources

The ResStock data has three sources of electric heating, which are as follows:

- **Electricity Heating:** Used similar to resistive heating and electric baseboard heaters. This is the major source of electricity heating sources. It is 88.11% of the total electric heat.
- **Heating Heat-pump Backup:** These are ASHP using heat pump technology to provide additional heat to an existing system. 5.89% of total heating energy is provided by this heating source.
- **Heating Fans & Pumps:** These are ASHP systems to provide primary heat to the building enclosure. They attribute to 6% of total heating electricity.

5.3.2 ComStock Electric Heating Sources

ComStock Data uses four different sources of electric heating, which are as follows:

- **Electric Resistance Heating:** Uses heat generated by electrical resistance. This is the most common source of electrical heating, accounting for 76% of the heating electricity in the baseline scenario.
- **Air Source Heat Pump:** Extracts heat from ambient outside air. 24% of the heating electricity comes from ASHPs.
- **Water Source Heat Pump:** Extracts heat from water at a stable temperature below ground. This source makes up <1% of the total heating electricity.
- **Ground Source Heat Pump:** Extracts heat from the ground at depths that provide a stable temperature. This source makes up <1% of the total heating electricity.

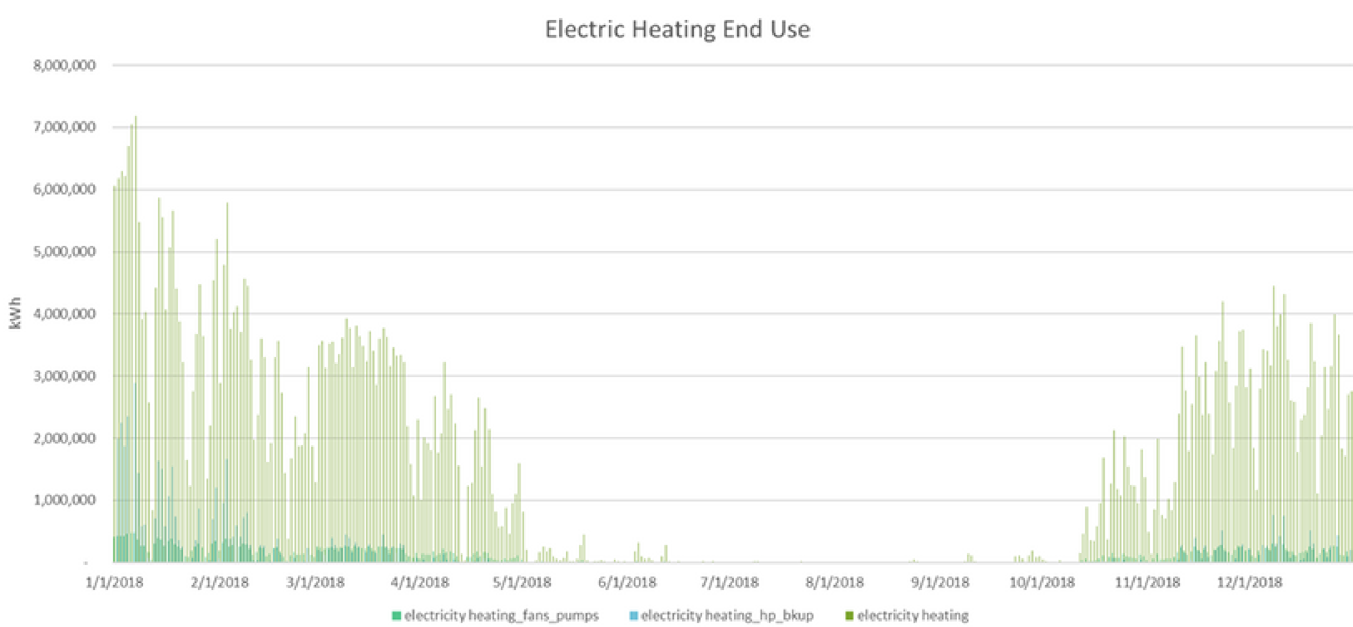


Figure 18: Electric Heating Time series Data

5.3.3 Comparison of Annual Heating Energy Sources

The heating energy sources data for ResStock and ComStock includes multiple heating fuels. For the ease of these statistics the data is combined under three main categories:

- **Electricity**
- **Natural Gas**
- **Other Fuels (Propane, Fuel Oil, etc.)**

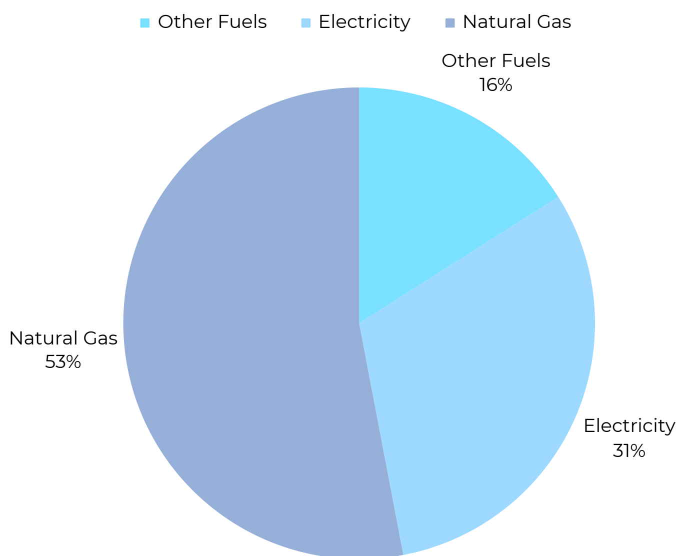


Figure 19: Total Heating Energy Consumption Sources Contribution to Annual Heating

As shown in Figure 19, natural gas is the primary fuel used for space heating, contributing 53% of the total. The peak for natural gas is 20,817 MW which is equivalent to 215,281 therms and comparing with total natural gas annual consumption for the state 94% is used for space heating.

Electricity peak for space heating is 9,712 MW which also coincides with the annual electricity peak. 31% of space heating is provided with electricity.

The remaining 16% of the heating comes from the other fuels group, which includes fuel oil, propane, and other combustible fuels.

Table 13.

Total Consumption and Peak Demand for Various Heating Energy Sources

	Electricity (kWh)	Natural Gas (kWh)	Other Fuels (kWh)
Peak Demand	9,712,455	20,817,736	5,604,033
Consumption	14,450,455,00	24,550,242,856	7,112,299,256

5.4 Analyze Statewide Electric Grid Demand for Peak Heating and Cooling

Analyzing peak demand is critical to understanding the full context of grid infrastructure needs by giving insight to the upper thresholds that the infrastructure must be designed to handle. Reviewing the PJM hourly load data shows that there are trends between the various transmission zones, with the strongest trend that cooling peak loads currently exceed heating peak loads, although just slightly. This is expected in a grid profile that has not experienced intensive decarbonization, which often centers around finding electricity-based heating alternatives.

However, as decarbonization efforts accelerate, this will change the peak loads over time, with the potential for heating loads to exceed grid peak limits. Efficiency and technology selection will be crucial to balancing decarbonization with increased strain on electrical infrastructure. The current grid demand is provided in Figure 20.

5.4 Analyze Statewide Electric Grid Demand for Peak Heating and Cooling

Analyzing peak demand is critical to understanding the full context of grid infrastructure needs by giving insight to the upper thresholds that the infrastructure must be designed to handle. Reviewing the PJM hourly load data shows that there are trends between the various transmission zones, with the strongest trend that cooling peak loads currently exceed heating peak loads, although just slightly. This is expected in a grid profile that has not experienced intensive decarbonization, which often centers around finding electricity-based heating alternatives.

However, as decarbonization efforts accelerate, this will change the peak loads over time, with the potential for heating loads to exceed grid peak limits. Efficiency and technology selection will be crucial to balancing decarbonization with increased strain on electrical infrastructure. The current grid demand is provided in Figure 20.

The figure shows that the peak demand in winter and summer correlate with the coldest and warmest temperatures, respectively. The peak demand for both summer and winter are slightly above 12 GW.

Looking at individual utilities, DP&L and BG&E both saw their cooling peaks on August 2nd and 3rd, respectively.

This correlates well with the strongest heat wave that occurred in Maryland during that time according to 2018 historical temperature data. Both successive cooling peak days saw the specific grid load hit its maximum at 5:00P.M. This is commonly around the time for peak cooling loads as air conditioners are working near the hottest part of the day and other evening and home appliances begin their usage as well. Using this grid profile as a base, the various scenarios for electrified heating could be developed.

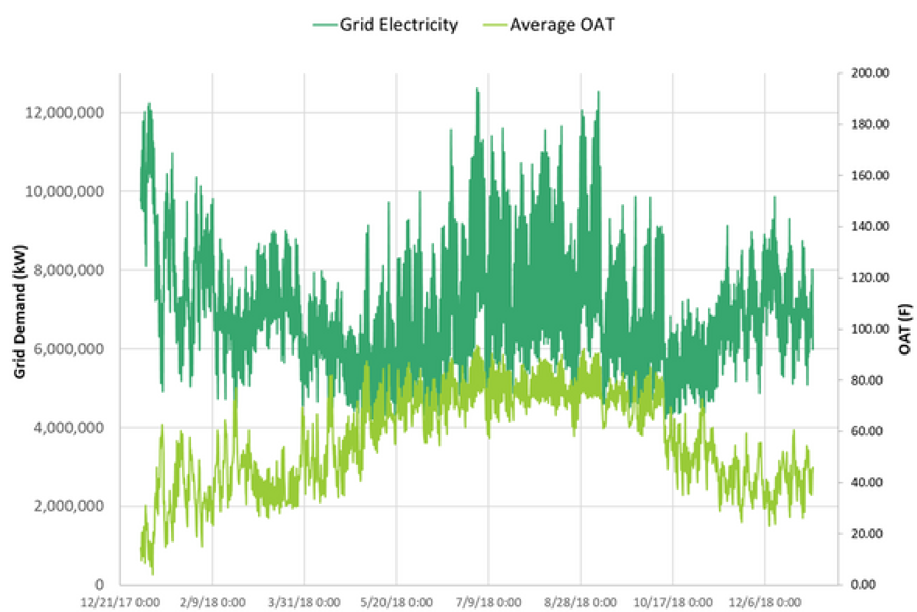
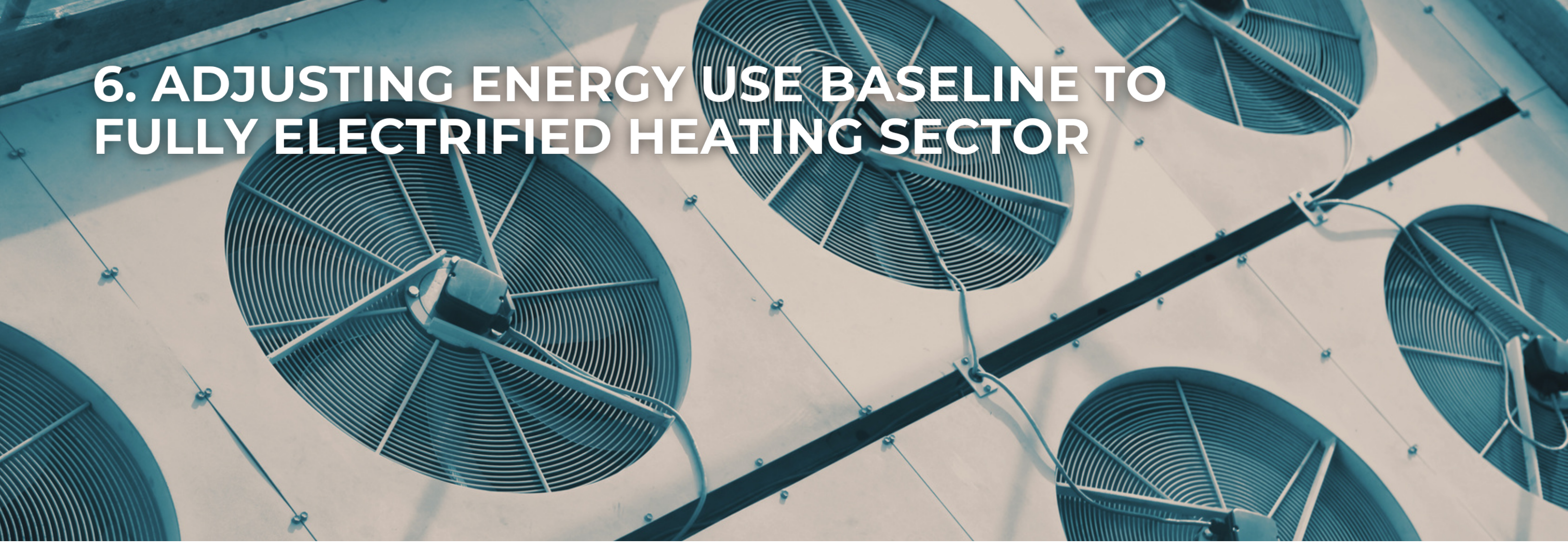


Figure 20: Hourly Grid Demand from PJM for 2018



6. ADJUSTING ENERGY USE BASELINE TO FULLY ELECTRIFIED HEATING SECTOR

6.1 Define Purpose of Adjusted Baseline

The stated purpose of this analysis is to evaluate the impact on the electric grid of various heating technologies in a 100% electrified scenario. Looking at current technologies, the most logical technology to dominate the electrified transition is air-source heat pumps. Referencing the analysis provided in Section 3, ASPHs have several advantages:

1. High efficiency compared to electric or combustion systems.
2. Well established commercially, including installation and service professional networks.
3. Do not typically require additional electrical service if application is already using air conditioning systems.
4. Can be installed in almost any existing building without significant cost.

As the current trend of reduction in use of combustion fuel heating sources continues,[29] electrification of a large percentage of the heating sector is a likely future scenario.

The purpose of this analysis is to compare the ground-source heat pump technology to an alternative electrified heating scenario. To do this, we will create an 'adjusted baseline' which calculates the energy use of all fuel types if they were converted to electricity. Adjusting the baseline energy use will allow us to compare between various adoption rates of heat-pump technology and determine how electrical grid infrastructure is impacted by various heating sector efficiencies.

6.2 Adjusted Baseline Process

This study assumes that ASHP technology is used universally in the 100% electrified baseline scenario. This assumption likely reduces the overall peak heating electricity demand in the adjusted baseline but is reasonable for the purpose of comparing the two heat pump technologies. The likely application of electric heating technologies will occur gradually and incorporate new heat pump systems, existing electric resistance heating, and other forms of heat such as solar hot water, district heating from waste heat, and other potential technologies that become commercially available.

[29] EIA Today In Energy

The decision to use 100% ASHP adoption as the baseline scenario is helpful in that it produces a “low-limit” for future electric heating demand using current technology. This means that results from this analysis are likely conservative compared to real-world applications of ground source heat pump technology.

The process for adjusting the heating energy baseline involves combining the efficiency analysis provided in Section 4.5 with the analysis of the baseline data provided in Section 5. This process was conducted on an hourly basis using calendar year 2018 as the baseline year. Section 5 of this report provides the current electricity and combustible fuel baselines and highlights the heating energy split between energy sources.

Calculations to convert energy use to electricity used the following assumptions:

- Natural gas, Fuel Oil, Propane, and other fuel heating sources were assumed to operate at 80% combustion efficiency.
- Resistance electric heating sources have an efficiency of 100%, or COP of 1.
- ASHP efficiency correlates directly with outside air temperatures. Efficiencies were calculated hourly based on the historical weather data for calendar year 2018.
- Heating energy use for commercial and residential buildings were modeled using ComStock and ResStock tools published by NREL.
- PJM Electricity data was used for the base load condition. Energy modeling of residential and commercial buildings resulted in greater than expected energy use compared to documented statewide electricity usage.
- Modeled energy usage for residential and commercial energy use were only used to calculate the additional energy use from converting electric heating and combustion fuel heating to ASHP heating. The change in heating energy was then applied to the PJM data for base load usage. This methodology was applied to limit the total impact of the energy modeling software on the analysis.
- Supplemental electric heating for air source heat pump systems was not included in this analysis. The current technology being produced for ASHP units is capable of maintaining COP greater than 1.5 in < 0°F conditions.[30]

Calculating overall heating energy followed the following formulas:

- (Electric heating kW) * (Electric Heating Eff.) / (ASHP Eff.) = ASHP kW_{elec}
- (Combustion heating kW) * (Combustion Heating Eff.) / (ASHP Eff.) = ASHP $kW_{combustion}$
- ASHP kW_{elec} + ASHP $kW_{combustion}$ = Heating ad_{justed}
- Total kW_{base} = Heating kW_{base} + Non-Heating kW
- Total $kW_{adjusted}$ = Non-Heating kW + Heating $kW_{adjusted}$
- Grid $kW_{adjusted}$ = Grid kW_{base} + (Total $kW_{adjusted}$ - Total kW_{base})

[30] EIA Today In Energy

Using this calculation methodology, the adjusted baseline was calculated for all 8760 hours of the 2018 calendar year and used in the grid analysis.

6.3 Impact of ASHP Scenario on Statewide Electricity Grid

Comparing the ASHP scenario and methodology from 6.1 and 6.2 with the baseline data from the electric grid in Section 5 yield expected results. During peak heating conditions, electrical grid demand increases considerably.

During peak cooling conditions, grid demand is reduced. Figure 21 provides the annual trend of adjusted baseline energy compared to the baseline grid energy from PJM.

Comparing heating and cooling trends in Figure 22, following, there is a predictable pattern. The electrified ASHP scenario has a considerably higher peak heating demand and little to no change for cooling energy. This is expected because cooling technology for ASHP systems is identical to typical vapor compression cooling systems used in most buildings. A focus on the peak heating demand is shown in Figure 22, following.

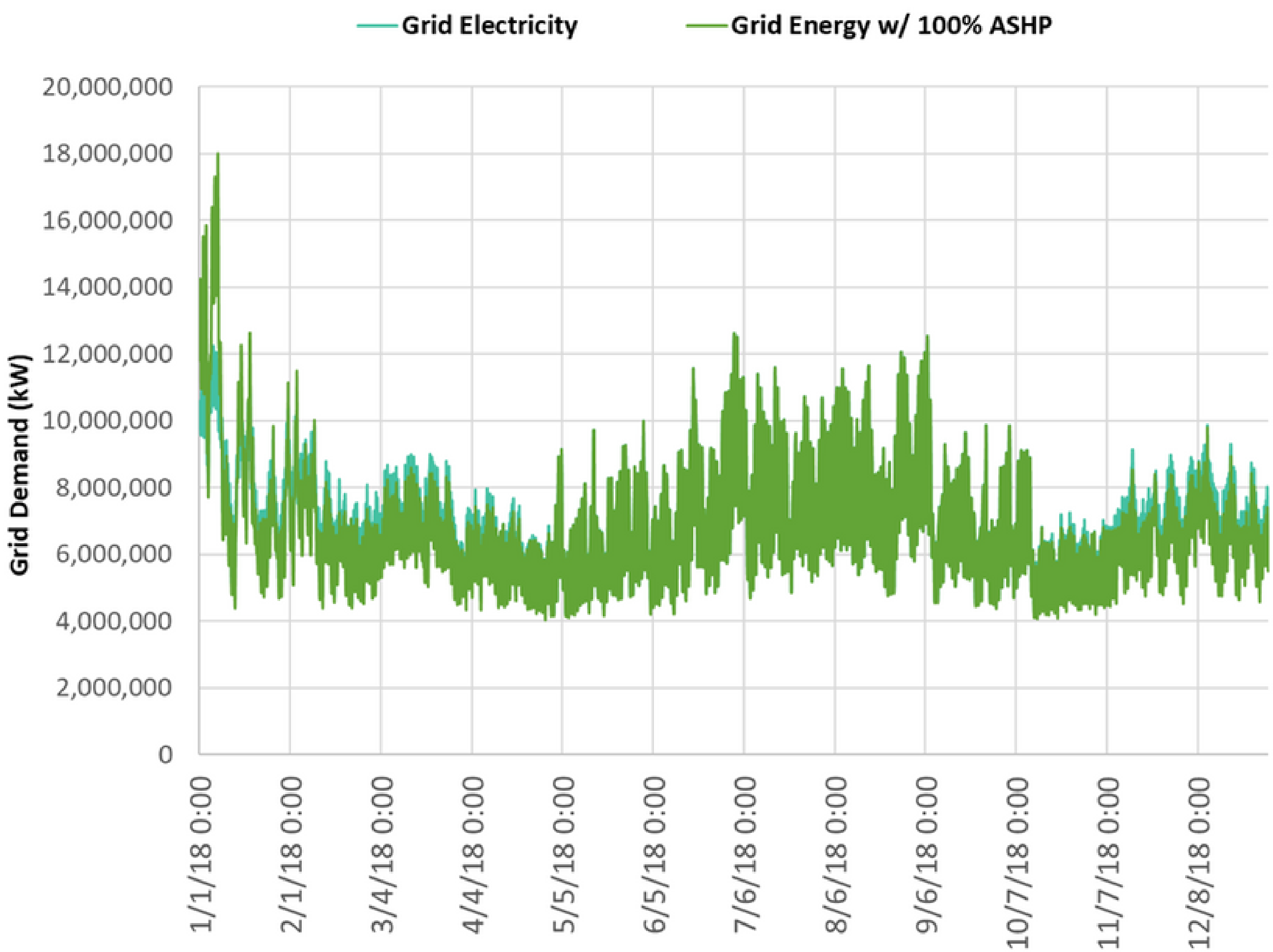


Figure 21: 2018 Annual Electricity Usage for Actual Metered Grid Demand and Adjusted ASHP Scenario

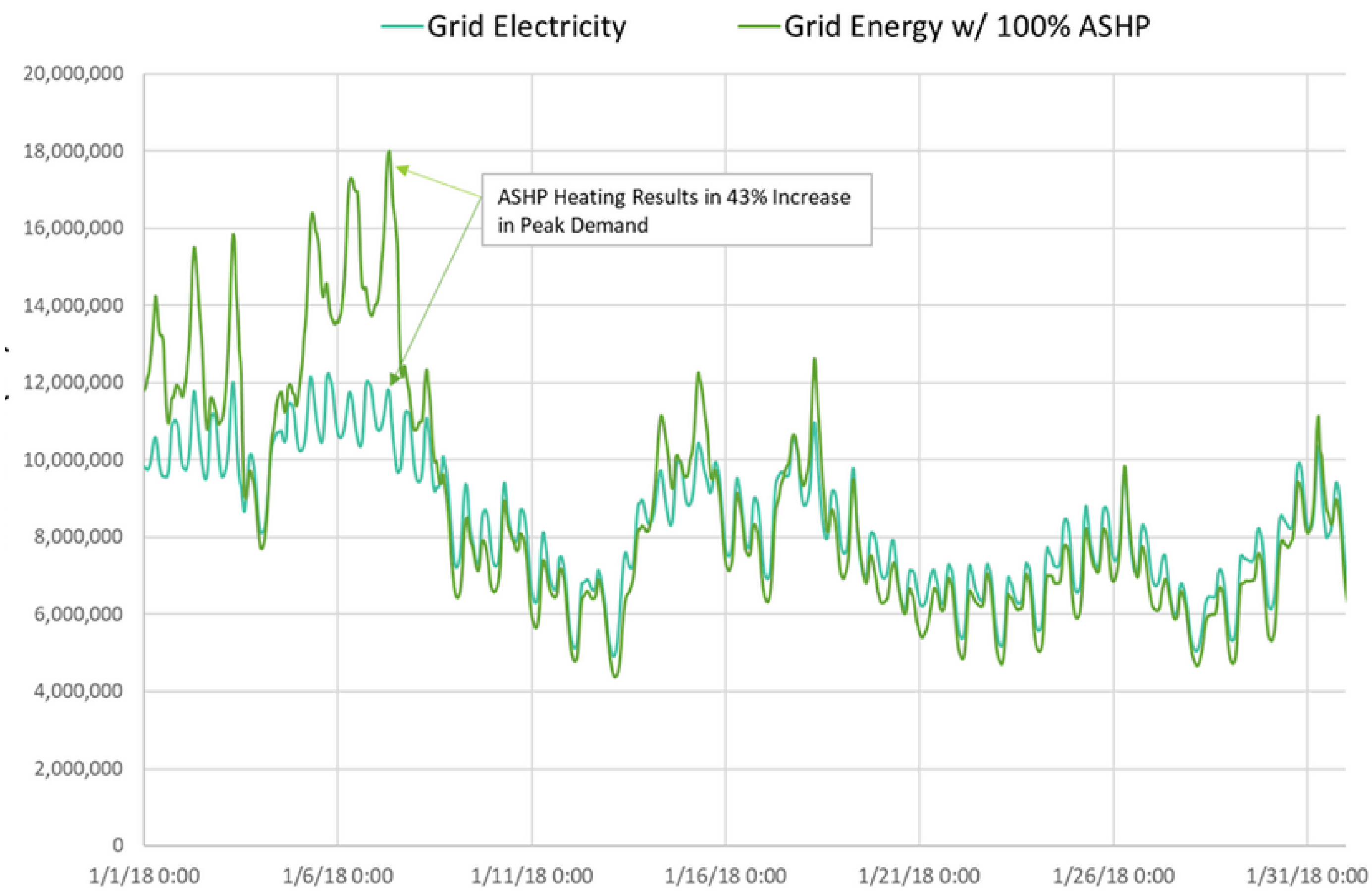


Figure 22: 2018 Peak Heating Electricity for Actual Metered Grid Demand and Adjusted ASHP Scenario

Following the 2018 weather patterns shown in the modeling review of Section 5, the peak heating demand occurs at 3am on January 7th. This corresponds with the coldest temperature of the year and equates to the lowest overall efficiency for the ASHP systems. Comparing the peak demand for the baseline and the ASHP scenario, there is an increase from 12.6GW to 18GW, or 43% greater in the electrified scenario. Note that this correlates to a COP of approximately 1.8 for cold weather ASHP efficiency and full adoption of the technology. This likely represents a low limit for the peak heating demand in a fully electrified scenario without GSHP adoption.

6.4 Comparison of Modeled Results vs. Statewide Grid

Comparing the statewide utility grid to the modeled energy use for the residential and commercial sectors resulted in unexpected inconsistencies.

While energy use closely followed grid energy trends during non-peak conditions, the peak heating demand in the modeled approach was significantly greater than the actual metered grid energy recorded by PJM. Figure 23 provides the trend of the peak heating demand for modeled vs. grid data.

During the peak demand condition, the modeling approach overestimates the total demand by nearly 25% compared to the real energy data trends.

Additional uncertainty is introduced when industrial energy use is considered, which accounts for 10% of the state's energy use, but is omitted from the modeled demand.

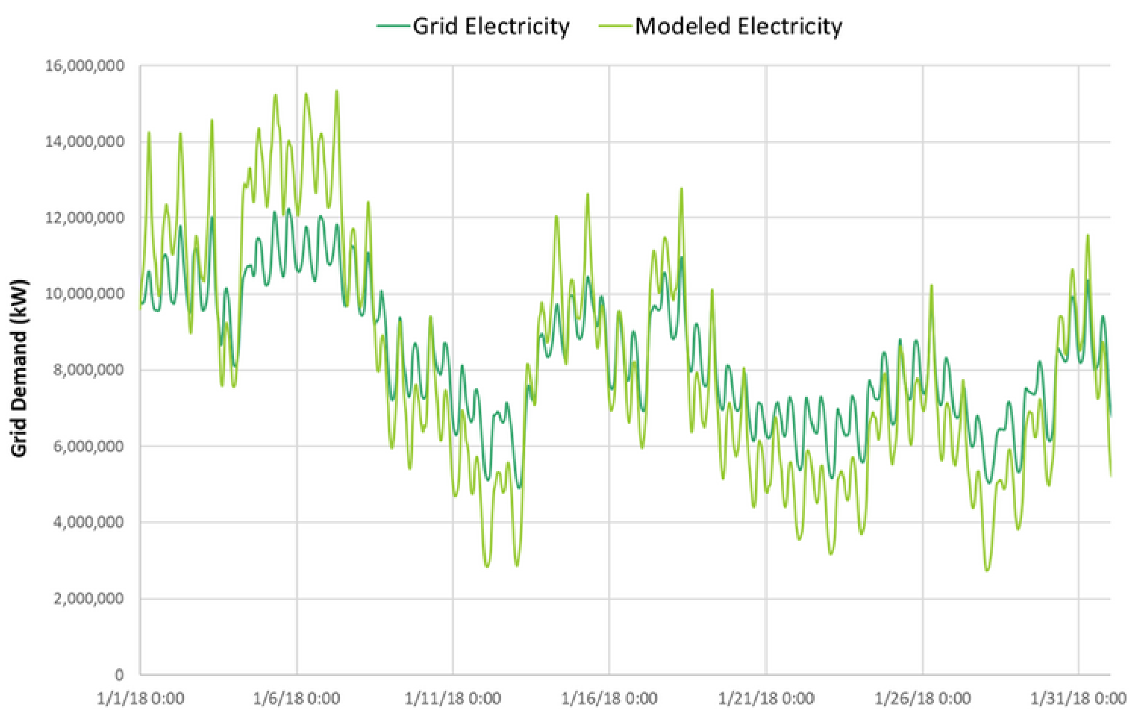


Figure 23: Comparison of Grid Energy Peak Demand vs. Modeled Energy Peak Demand

Several factors likely contribute to this phenomenon, including but not limited to:

- **Predictability of Modeled Performance:** The ResStock and ComStock tools run modeling software across thousands of building types statewide to summarize the data. It is possible that the models predict similar equipment usage patterns in response to the weather data of the system, which would result in greater peak than expected in real-world conditions when equipment cycling patterns would never line up across all buildings.

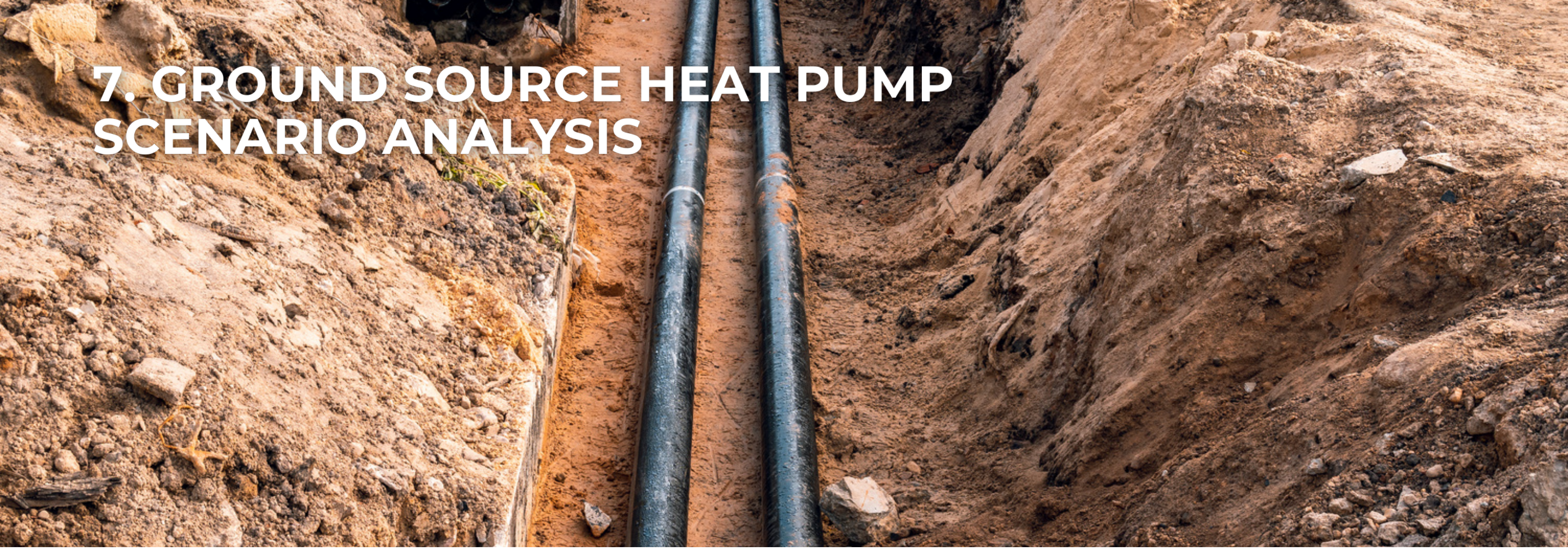
- **Behavioral Considerations to Heating Use:** Consumers of energy are unpredictable and may be reducing their energy consumption in peak conditions for economic reasons. Such conditions may include lowering thermostat temperatures at night, closing heating vents to unoccupied areas of buildings, and using supplemental heating devices such as fireplaces or combustion unit heaters. These variables would not be accurately represented in the modeling results.

- **Overestimates of systems sizing:** The modeling software assumes heating system sizes that are correctly designed for each type of building. Older buildings, or buildings in areas without strict building codes, may not be designed properly for peak heating conditions or have undersized equipment that was installed to reduce first-cost of construction. These systems may protect buildings from freezing but use considerably less energy than a properly designed system.

- **Aging Equipment and Maintenance concerns:** Equipment that has not been maintained properly or that is nearing its end of useful life may not be cycling correctly for some homes. Systems in this condition may be consuming less energy at the cost of creating harmful indoor environmental conditions. Modeling software would not address buildings in this condition.

- **Vacation homes and seasonal living patterns:** Many homes that appear in the housing stock data may not be occupied during winter due to undesirable weather conditions and/or retirees and other MD residents moving south for the winter. This data would not be captured in the housing stock data and may be over-represented in the modeling assumptions.

While any and/or all of these issues may exist, the primary takeaway is that the modeled results are only used to determine the energy use breakdown of the state and should not be used without benchmarking and rating results against the known electricity use.



7. GROUND SOURCE HEAT PUMP SCENARIO ANALYSIS

7.1 Define GSHP Scenarios

Modeling of geothermal heating energy use was performed for multiple scenarios of adoption rates, ranging from 10-100%. For each scenario, hourly analysis was performed based on the expected geothermal system efficiency compared to the baseline condition. Seven heating energy scenarios were modeled, including baseline and ASHP scenarios, with 2018 data being used as the baseline year.

7.2 GSHP Scenario Analysis Process

The calculation process for the various GSHP scenarios follows a similar process to the ASHP calculation provided in Section 6.2. First, the heating energy for 100% adoption of GSHP was calculated based on the formulas below.

Calculating overall heating energy followed the following formulas:

Table 14.

Definitions for Grid Energy Scenarios

Scenario	Definition	Data Source
Baseline	This is the current metered electricity consumption as provided by publicly available grid operator data. Does not include the heating energy provided by combustible fuel sources.	PJM
100% ASHP	This scenario represents the electric grid energy after all combustible fuel energy and resistance electric heat has been converted to air source heat pump equipment.	Baseline, Modeling Results, Efficiency Analysis
10% GSHP	This scenario is a fully electrified heating sector that is 10% GSPH and 90% ASHP	Baseline, Modeling Results, Efficiency Analysis
25% GSHP	This scenario is a fully electrified heating sector that is 25% GSPH and 75% ASHP	Baseline, Modeling Results, Efficiency Analysis
50% GSHP	This scenario is a fully electrified heating sector that is 50% GSPH and 50% ASHP	Baseline, Modeling Results, Efficiency Analysis
75% GSHP	This scenario is a fully electrified heating sector that is 75% GSPH and 25% ASHP	Baseline, Modeling Results, Efficiency Analysis
100% GSHP	This scenario is a fully electrified heating sector that is 100% GSPH	Baseline, Modeling Results, Efficiency Analysis

- (Electric heating kW) * (Electric Heating Eff.) / (GSHP Eff.) = GSHP kW_{elec}
- (Combustion heating kW) * (Combustion Heating Eff.) / (GSHP Eff.) = GSHP $kW_{combustion}$
- GSHP kW_{elec} + GSHP $kW_{combustion}$ = Heating $GW_{100\%\ GSHP}$
- Total kW_{base} = Heating kW_{base} + Non-Heating kW
- Total $kW_{100\%\ GSHP}$ = Non-Heating kW + Heating $kW_{100\%\ GSHP}$
- Grid $kW_{100\%\ GSHP}$ = Grid kW_{base} + (Total $kW_{100\%\ GSHP}$ - Total kW_{base})

With the 100% GSHP adoption rate defined as the high limit for demand reduction, and the 100% ASHP adoption defined as the peak demand scenario, various adoption rates of GSHP technology can be interpolated between the two. A sample interpolation for the 10% GSHP adoption rate is provided below.

- 10% GSHP kW = 0.1 * Grid $kW_{100\%\ GSHP}$ + 0.9 * Grid $kW_{adjusted}$

This process was applied to all scenarios at each hourly interval. The results of this analysis form the basis for the statewide grid analysis.

7.3 Impact on Statewide Electrical Demand of GSHP Scenarios

Expanding the comparison between the baseline data from the electric grid in Section 5 and the ASHP scenario and methodology from 6.1 and 6.2 produces the anticipated outcomes. During peak heating conditions, electrical grid demand increases considerably. During peak cooling conditions, grid demand is reduced. Figure 24 provides the annual trend of adjusted baseline energy compared to the baseline grid energy from PJM.

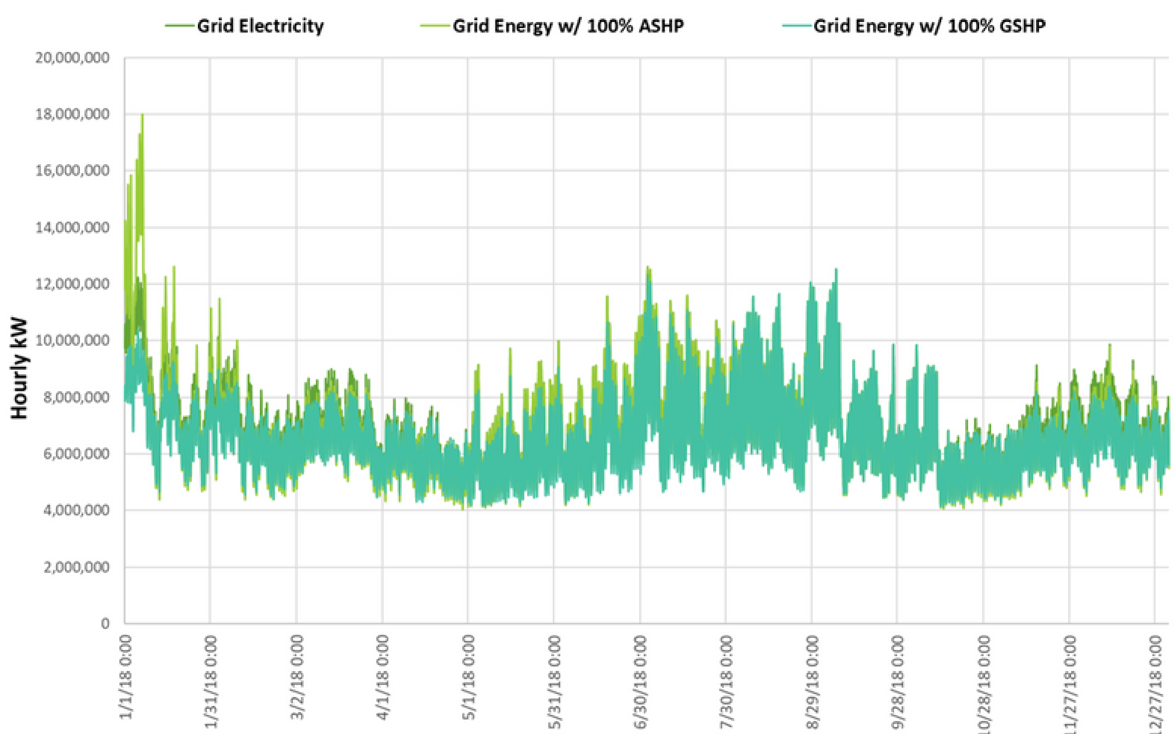


Figure 24: 2018 Annual Electricity Usage for Metered Grid Demand, Adjusted Baseline Demand, and Maximum GSHP Adoption Rate Demand

There are two observations from the GSHP data. Comparing the peak demand of ASHP, metered grid data, and GSHP it is seen that the peak demand reduction from GSHP efficiency gains is capable of fully electrifying the heating sector and reducing the peak demand from current levels. This is possible due to the high use of electric heating in MD buildings. GSHPs COP reduces the total electricity usage of the existing electrical heating systems by a large enough margin that all combustible heating fuels can be electrified without the need for additional grid capacity.

The second observation is that the peak demand condition with full GSHP adoption is shifted to cooling months, while still reducing the peak demand from the current grid demand due to higher efficiencies.

This indicates that there is diminishing return on development of GSHP systems if avoided grid infrastructure cost is used as a funding mechanism.

Further analysis of the diminishing returns of system adoption can be seen when the peak heating demand is analyzed. Figure 25 provides a view of peak heating demand.

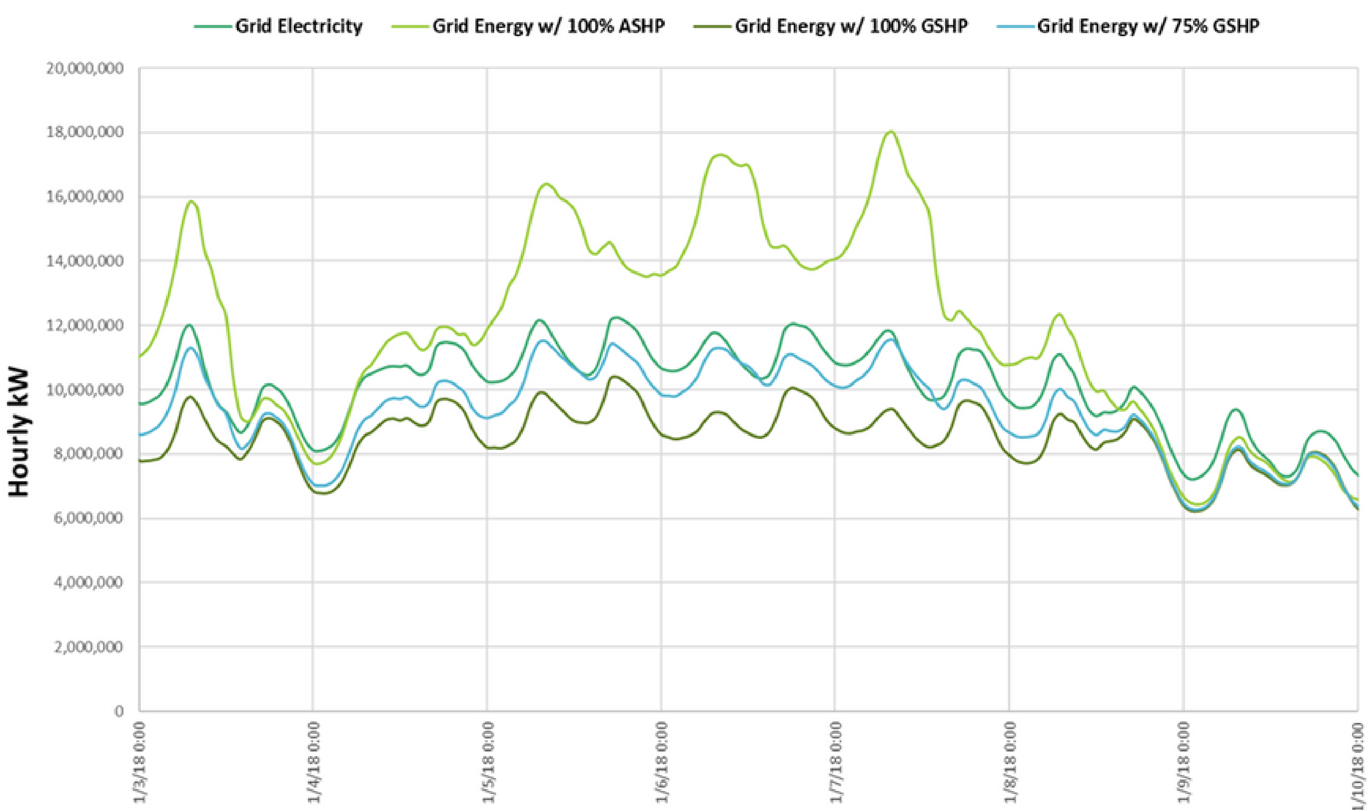


Figure 25: 2018 Peak Heating Electricity Usage for Metered Grid Demand, Adjusted Baseline Demand, and Maximum GSHP Adoption Rate Demand

Comparing the peak demand conditions or the scenarios, the ASHP scenario creates the largest peak, at just over 18GW. As mentioned in section 6.3, the grid peak demand is currently 12.6 GW. The best-case scenario for peak demand reduction yields a winter heating peak of just over 10GW, or 20% reduction compared to the current grid demand and a 45% reduction compared to the ASHP scenario. The 75% adoption rate scenario is highlighted because any additional use of GSHP systems above this level no longer results reduced peak heating demand over the current levels. The cooling peak demand impact is less notable but highlighted in Figure 26.

While no immediate impact is found with the adoption of ASHP systems, there is about an 8% reduction in cooling peak demand with the use of GSHP systems. Most notably, the peak demand for the year is shifted to cooling demand days, which align more with renewable energy production patterns. While this outcome is favorable, the adoption rate of GSHP systems to realize the peak benefit is not likely achievable in a time frame consistent with State of Maryland Sustainability Goals.

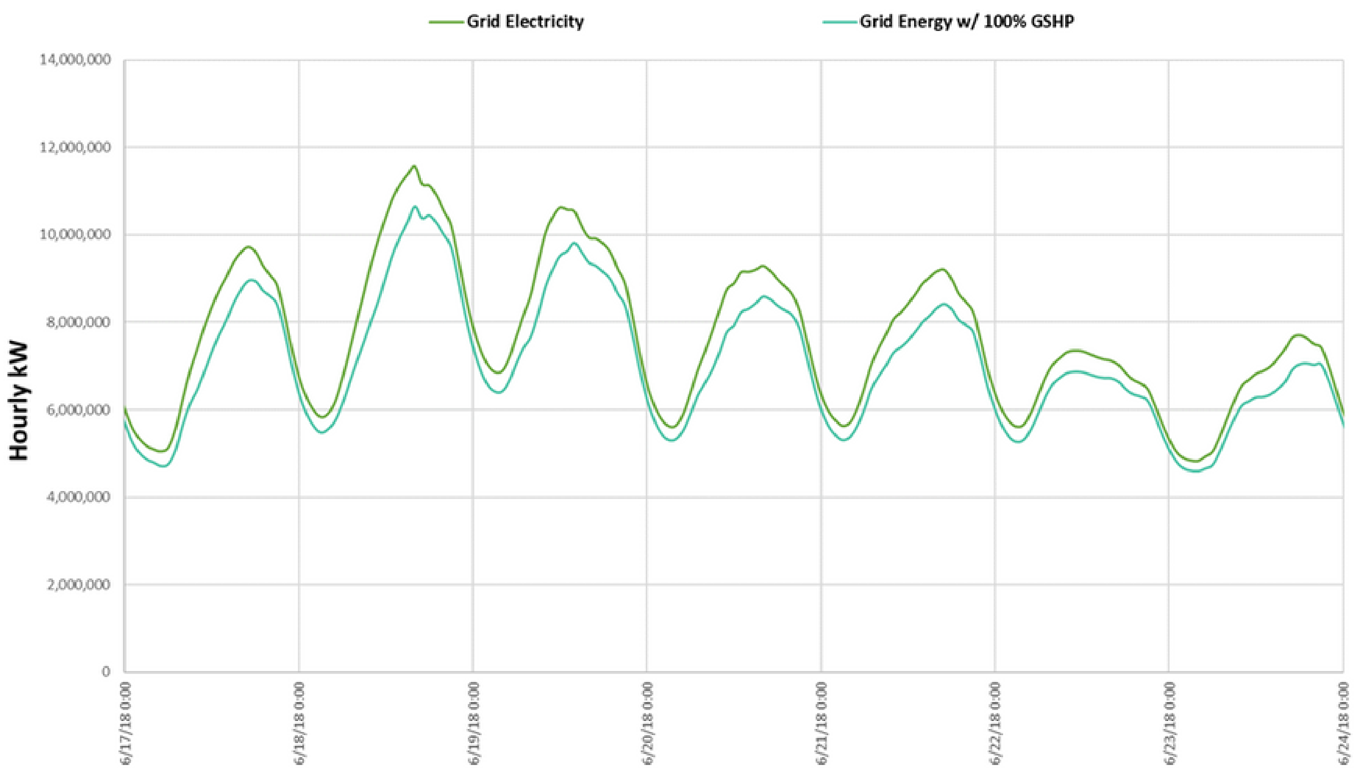


Figure 26: Peak Cooling Demand for Grid Baseline and GSHP Maximum Adoption Scenarios

7.4 Summary of GSHP Impact

For the scenarios provided, a summary of the overall impact is provided in Table 15.

Key observations include:

- Greater than 5 GW of peak demand reduction can be achieved by widespread implementation of GSHP over ASHP technology.
- Peak demand compared to current grid use is no longer impacted by GSHP after approximately 75% adoption rate.
- Approximately 12% adoption rate will result in 1 GW of peak demand reduction compared to the ASHP scenario.
- For all scenarios analyzed, combustion heating sources can be electrified, and the overall electricity use can be reduced compared to current grid energy use. This is possible due to the high rate of resistance electric heating currently being used in the State and the considerable reduction in energy use associated with any type of heat pump in most operating conditions.

Table 15.

Analysis of Heating Technology Grid Impact

	Current Grid	Grid Peak Demand w/ 100% ASHP	Grid Peak Demand w/ 10% GSHP	Grid Peak Demand w/ 25% GSHP	Grid Peak Demand w/ 50% GSHP	Grid Peak Demand w/ 75% GSHP	Grid Peak Demand w/ 100% GSHP
Peak Demand (kW)	12,618,301	18,001,110	17,139,916	15,848,124	13,695,138	12,534,548	12,534,629
Season	Winter	Winter	Winter	Winter	Winter	Winter	Winter
Percent Increase	**0**	**143%**	**136%**	**126%**	**109%**	**99%**	**99%**
Increase from Baseline (MW)	0	5,383	4,522	3,230	1,077	-84	-84
MW Reduction from ASHP Scenario	5,383	0	861	2,153	4,306	5,467	5,466
Annual Electric Usage (GWh)	62,086	60,727	60,518	60,206	59,684	59,163	58,641

While the benefits of widespread adoption of GSHP heating systems is compelling, the practicality of implementation at large scale is unfavorable. This is briefly discussed in Section 9, however smaller scale metrics for implementation impacts are provided below.

Analyzing the peak heating loads experienced by all commercial and residential buildings, it is calculated that the total statewide heating system consumes heat at a rate of approximately 105 million MBH, or 8.7 million tons using units that heat pumps are typically sized in. Comparing this heating rate to the peak demand reduction in Table 13, the **following conclusions** can be made:

- Impact of GSHP adoption scales linearly between 0 and 75% adoption.

- For any adoption rate in this linear range, the heating peak tonnage and heating grid demand can be easily interpolated.

- Interpolating for the 10% adoption scenario, approximately 0.87M Tons of GSHP capacity equates to 861 MW of grid demand reduction, or approximately 1012 Tons GSHP installed per MW of grid demand reduction.

- This simplifies to approximately **1kW of demand reduction for each ton of GSHP technology installed.**

This simplification of results is a powerful approximation for estimating impact of GSHP systems across areas of the state. Some approximations to help interpret this finding:

- It can be estimated that 1MW of peak demand reduction can be achieved for every 250 single family homes that are connected to a GSHP system.

- 1 MW of demand reduction can be achieved for every 400,000 SqFt of commercial office space that is connected to GSHP heating.

These approximations assume an average of 4 tons of heating capacity for the average single-family home and 400sqft/ton design conditions for commercial space.

8. ECONOMIC ANALYSIS

8.1 Estimated Energy Savings and Demand Reduction for Various Building Types

The state of Maryland has an average electric rate of 17 ¢/kWh for residential users, and 12.5 ¢/kWh for commercial users.[31] [32] The average cost of utility gas in Maryland is $1.444 per therm.

Gasoline has an average rate of $3.69 per gallon. Using these values and an assumed low cost of $2,791/ton and a high cost of $40,443/ton,[33] as well as the annual usages for electricity; natural gas; and other fuels, the low and high GSHP installed costs for each typology was calculated.

Table 16.

Installed Cost of GSHP ($)

Building Type	Tool	GSHP (Tons)	Low $/ton	High $/ton	Distribution (%)	Low Cost	High Cost
Full Service Restaurant	Comstock	1,463	2,791	40,443	1.19%	48,700	705,600
Hospital	Comstock	2,719	2,791	40,443	2.22%	168,100	2,435,900
Large Hotel	Comstock	5,963	2,791	40,443	4.86%	808,500	11,715,800
Large Office	Comstock	15,986	2,791	40,443	13.02%	5,810,700	84,200,700
Medium Office	Comstock	13,070	2,791	40,443	10.65%	3,884,700	56,291,100
Outpatient	Comstock	2,391	2,791	40,443	1.95%	130,000	1,884,400
Primary School	Comstock	8,495	2,791	40,443	6.92%	1,641,200	23,781,200
Quick Service Restaurant	Comstock	391	2,791	40,443	0.32%	3,500	50,300
Retail Standalone	Comstock	12,892	2,791	40,443	10.50%	3,779,300	54,764,200
Retail Strip Mall	Comstock	8,311	2,791	40,443	6.77%	1,570,800	22,761,100
Secondary School	Comstock	10,924	2,791	40,443	8.90%	2,713,700	39,323,600
Small Hotel	Comstock	704	2,791	40,443	0.57%	11,300	163,400

[31] Maryland Average Residential and Commercial Utility Rate
[32] Maryland (Baltimore) Average Utility Rates
[33] HEET BH Report

Building Type	Tool	GSHP (Tons)	Low $/ton	High $/ton	Distribution (%)	Low Cost	High Cost
Small Office	Comstock	8,474	2,791	40,443	6.90%	1,633,00	23,662,500
Warehouse	Comstock	30,955	2,791	40,443	25.22%	21,789,100	315,735,500
Mobile Home	ResStock	4,360	2,791	40,443	0.96%	117,300	1,699,100
Multi-Family w/ 2 to 4 Units	ResStock	8,497	2,791	40,443	1.88%	445,300	6,452,900
Multi-Family w/ 5+ Units	ResStock	53,064	2,791	40,443	11.73%	17,367,100	251,657,400
Single-Family Attached	ResStock	92,182	2,791	40,443	20.37%	52,410,600	759,455,900
Single-Family Detached	ResStock	294,414	2,791	40,443	65.06%	534,615,900	7,746,854,100
Total	-	-	-	-	-	**648,900,000**	**9,403,600,000**

Table 16 illustrates the full installed cost for GSHPs by building typology. Distribution denotes what percentage of the total floor area that space type represents. ResStock types begin at “Mobile Home” and those percentages are for ResStock space types only.

$$Tons\ HVAC = \left(GSHP\ Peak\ Electricity\ Demand\ \times 3412\frac{BTU}{hr} \div 12{,}000\frac{BTU}{ton}\right)$$

$$Tons\ HVAC\ \times\ Low\frac{\$}{ton} \times\ Distribution\ (\%) =\ Low\ Cost$$

$$Tons\ HVAC\ \times\ High\frac{\$}{ton} \times\ Distribution\ (\%) =\ High\ Cost$$

Table 17, following, calculates the energy consumption cost savings using the percentage that a particular space type occupies, the consumption of various fuels, and the respective costs associated with those fuels. The projected annual savings is $2,482,800,000.

$$\begin{aligned} &Baseline\ Energy\ Cost\ (\$)\\ &\quad = \Bigg(\left(Baseline\ Heating\ and\ Cooling\ Electricity\ (kWh)\ \times\ Blended\frac{\$}{kWh}for\ Maryland\right)\\ &\quad + \left(Natural\ Gas\ Heating\ (kWh)\ \times NG\frac{\$}{therm}\times\frac{1}{29.3}\frac{therm}{kWh}\right)\\ &\quad + Other\ Fuels\ Heating\ (kWh)\times\left(Other\ Fuels\ Blended\frac{\$}{kbtu}\times\frac{1}{3.412}\frac{kbtu}{kWh}\right)\Bigg)\\ &\quad \times Distribution\ (\%) \end{aligned}$$

$$\begin{aligned} &GSHP\ Energy\ Cost\ (\$)\\ &\quad = \Bigg(\left(GSHP\ Heating\ and\ Cooling\ Electricity\ (kWh)\ \times\ Blended\frac{\$}{kWh}for\ Maryland\right)\\ &\quad + \left(Natural\ Gas\ Heating\ (kWh)\ \times NG\frac{\$}{therm}\times\frac{1}{29.3}\frac{therm}{kWh}\right)\\ &\quad + Other\ Fuels\ Heating\ (kWh)\times\left(Other\ Fuels\ Blended\frac{\$}{kbtu}\times\frac{1}{3.412}\frac{kbtu}{kWh}\right)\Bigg)\\ &\quad \times Distribution\ (\%) \end{aligned}$$

$$\boldsymbol{Savings\ (\$) = Baseline\ Energy\ Cost\ (\$) - GSHP\ Energy\ Cost\ (\$)}$$

Table 17.

GSHP Energy Savings ($)

Building Type	Tool	Distribution ($)	Baseline Energy Cost ($)	GSHP Energy Cost ($)	Savings ($)
Full Service Restaurant	Comstock	1.2%	89,200	13,000	76,000
Hospital	Comstock	2.2%	308,000	44,700	263,000
Large Hotel	Comstock	4.9%	1,481,300	215,200	1,266,000
Large Office	Comstock	13.0%	10,646,100	1,546,300	9,100,000
Medium Office	Comstock	10.6%	7,117,300	1,033,700	6,084,000
Outpatient	Comstock	1.9%	238,300	34,600	204,000
Primary School	Comstock	6.9%	3,006,800	436,700	2,570,000
Quick Service Restaurant	Comstock	0.3%	6,400	900	5,000
Retail Standalone	Comstock	10.5%	6,924,200	1,005,700	5,919,000
Retail Strip Mall	Comstock	6.8%	2,877,800	418,000	2,460,000
Secondary School	Comstock	8.9%	4,971,900	722,100	4,250,000
Small Hotel	Comstock	0.6%	20,700	3,000	18,000
Small Office	Comstock	6.9%	2,991,800	434,500	2,557,000
Warehouse	Comstock	25.2%	39,920,600	5,798,200	34,122,000
Mobile Home	ResStock	1.0%	27,562,000	4,302,900	23,259,000
Multi-Family w/ 2 to 4 Units	ResStock	1.9%	53,712,400	8,385,400	45,327,000
Multi-Family w/ 5+ Units	ResStock	11.7%	335,429,400	52,366,400	283,063,000
Single-Family Attached	ResStock	20.4%	582,703,300	90,970,100	491,733,000
Single-Family Detached	ResStock	65.1%	1,861,053,800	290,542,800	1,570,511,000
Total	-	-	-	-	**2,482,800,000**

Table 18, following, describes the demand cost savings and excludes residential demand savings as Maryland electricity providers generally do not charge residential users for demand. The peak decreases by 1,906 MW, resulting in a net demand cost savings of $7,002,800.

$$\begin{aligned} &Demand\ Savings\ (kW) \\ &= \left(Baseline\ Heating\ and\ Cooling\ Demand\ (kW) \times Blended\ \frac{\$}{kW}\right) \\ &- \left(GSHP\ Heating\ and\ Cooling\ Demand\ (kW) \times Blended\ \frac{\$}{kW}\right) \end{aligned}$$

Table 18.
Demand Savings ($)

Building Type	Baseline Heating and Cooling Demand (kW)	GSHP Heating and Cooling Demand (kW)	Demand Savings (kW)	$/kW	Demand Savings ($)
Full Service Restaurant	27,900	5,100	22,800	3.67	83,800
Hospital	51,800	9,600	42,200	3.67	155,000
Large Hotel	113,600	21,000	92,600	3.67	340,200
Large Office	304,500	56,200	248,300	3.67	912,100
Medium Office	249,000	46,000	203,000	3.67	745,700
Outpatient	45,600	8,400	37,200	3.67	136,600
Primary School	161,800	29,900	131,900	3.67	484,500
Quick Service Restaurant	7,400	1,400	6,000	3.67	22,000
Retail Standalone	245,600	45,300	200,300	3.67	735,800
Retail Strip Mall	158,300	29,200	129,100	3.67	474,200
Secondary School	208,100	38,400	169,700	3.67	623,400
Small Hotel	13,400	2,500	10,900	3.67	40,000
Small Office	161,400	29,200	131,600	3.67	483,400
Warehouse	589,700	108,900	480,800	3.67	1,766,100
Mobile Home	-	-	-	3.67	-
Multi-Family w/ 2 to 4 Units	-	-	-	3.67	-
Multi-Family w/ 5+ Units	-	-	-	3.67	-
Single-Family Attached	-	-	-	3.67	-
Single-Family Detached	-	-	-	3.67	-
Total	**-**	**-**	**1,906,400**	**-**	**7,002,800**

8.2 ECONOMIC IMPACTS OF GEOTHERMAL PROJECT INVESTMENTS

Investments in geothermal energy will have impacts to Maryland's economy and are anticipated to generate employment opportunities, such as for HVAC technicians, well drillers, and electricians.[34] [35]

These impacts can be estimated through economic impact analysis, a methodology that quantifies the cumulative sum of economic activity within a defined region resulting from an initial change in the economy. Households, businesses, and local and tribal governments are connected in a web of interdependent relationships based on producing, selling, purchasing, and taxing goods and services.

[34] Careers in Geothermal Energy
[35] Maryland Eyes Expansion of Geothermal Industry

An initial change in one sector creates ripple effects through other sectors.

Economic impacts can be categorized into three buckets:

- **Direct Impacts:** onsite impacts of operation/construction expenditures,
- **Indirect Impacts:** industry-to-industry transactions, or supply chain impacts,
- **Induced Impacts:** impacts resulting from new in-region spending associated with increased household income.

The indirect and induced impacts are referred to as the “multiplier effect”. These inter-industry relationships within a defined economy are captured using an input/output (I/O) model which estimates how spending in one industry impacts other sectors. Resulting multipliers measure the re-spending of dollars in an economy and are used to calculate the indirect and induced impacts.

Once the relationships between households, firms, and government in the economic region are defined, a change in the economy can be introduced in the model to estimate how the region will be affected based on those relationships.

There are multiple sources available for economic impact multipliers, including IMPLAN, RIMS II, and others. These multipliers are available at various geographies and for specific industries. Using IMPLAN I/O tables as underlying inputs, the 2020 report, “Job Creation Estimates Through Proposed Economic Stimulus Measures” by the Political Economic Research Institute (PERI) aggregates various industries to develop multipliers for specific types of infrastructure investments, including geothermal energy programs.[36] [37] AECOM has used the PERI economic impact multipliers to estimate direct, indirect, and induced job impacts for the low- and high-cost scenarios (see Table 19, following).

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[36] As an example of the industry aggregation: the industries included in the multipliers for onshore wind include construction, machinery, fabricated metal manufacturing, plastics manufacturing, electrical manufacturing, and research and development. PERI used detailed cost inputs to estimate the proportion of project spending towards these impacted industries.
[37] See Table 2A) [Job Creation from Clean Energy Programs: Direct, Indirect, and Induced Jobs]

Table 19.

Job Impacts of the Low-and High-Costs by Scenario

			Job Impacts							
			Low-Cost Impacts				High-Cost Job Impacts			
Scenario	Low Cost ($)	High Cost ($)	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
Per/1,000 Tons	4,000,000	10,000,000								
10% GSHP	3,266,916,559	8,711,777,490	12,100	10,500	15,700	**38,300**	32,200	27,900	41,800	**101,900**
25% GSHP	7,622,805,304	15,245,610,608	28,200	24,400	36,600	**89,200**	56,400	48,800	73,200	**178,400**
50% GSHP	13,938,843,984	30,491,221,215	51,600	44,600	66,900	**163,100**	112,800	97,600	146,400	**356,800**
75% GSHP	19,601,499,353	45,736,831,823	72,500	62,700	94,100	**229,300**	169,200	146,400	219,500	**535,100**
100% GSHP	24,392,976,972	60,982,442,431	90,300	78,100	117,100	**285,500**	225,600	195,100	292,700	**713,400**

Notes: Job impacts are rounded to the nearest 100. Job impacts are estimated using national economic impact multipliers for geothermal energy programs from "Job Creation Estimates Through Proposed Economic Stimulus Measures" (Political Economic Research Institute, 2020).[38]

There are several limitations to the use of the PERI multipliers. This includes the vintage of the data, which is as of 2018 and pre-COVID economic conditions. However, as noted in the PERI report, changes in multipliers are relatively modest year-over-year. As an example, for the clean energy sectors analyzed in the report, the multipliers changed -0.4% annually on average over between 1995 and 2007. Additionally, these multipliers reflect national-level figures, which both capture a larger share of impact, and do not account for regional industry make-up. Therefore, impact to the Maryland economy specifically resulting from this investment would differ. Finally, this data source only reflects direct, indirect, and induced jobs multipliers and does not include indirect and induced impacts on earnings or value added.

[38] Job Creation Estimates Through Proposed Economic Stimulus Measures

9. DISCUSS BROADER IMPACT

9.1 Scalability of Ground Source Geothermal Systems

The overall benefits of ground-source heat pump systems, to both the electric grid and the individual consumer, are well established in Sections 7 and Section 8. From a technical and efficiency standpoint, there are few arguments against widespread adoption of GSHP technology. The primary issue with scaling the technology lies in the upfront cost with system installation. As estimated in Section 8.2, using a conservative average system size of 4 tons, the cost range for fully installed systems can range from $16,000 to $40,000 for a single-family home. Compared to the typical ASHP system, this cost is 2x – 8x more expensive,[39] and with the primary benefits only occurring in peak heating conditions (see Section 7), the cost savings associated with GSHP for an individual consumer do not result in a significant return on investment at current implementation costs without additional incentives considered.

CGSHP systems can help solve this issue for the consumer, with the cost of drilling wells, distribution of water, and maintenance of the systems is covered by the utility providing the service.

The cost to access the geothermal loop will need to be priced such that the electric cost savings compared to equivalent ASHP systems are not completely offset, which theoretically can be achieved. The largest hurdle with CGSHP systems will be establishing the proper incentives to drill sufficient wells, installing distribution systems in the public right-of-way, and installing branch piping to buildings for the heat pumps to connect to. The funding to develop this infrastructure will require public incentives, theoretically based on avoided grid infrastructure and clean energy investments, and projected system lifetime revenue based on consumer access rates. If the proper development incentives can be determined, and installation costs optimized, GSHP systems can be scaled broadly across nearly all areas of the state; however, multiple factors will limit the rate at which the technology can be scaled.

[39] “How Much Does Heat Pump Installation Cost? (2023 Guide)”

Factors affecting implementation include:

- **Geological considerations:** This analysis does not include evaluation into the suitability of all areas of the state for heat exchange with a ground source system. Most population centers in the state are likely suitable for GSHP systems; however, the cost to install systems will vary greatly depending on bedrock formations, groundwater, soil types, and other factors. Additional study into suitability and cost for implementing high-capacity thermal wells is needed to fully evaluate technology.

- **Environmental barriers:** These barriers pose significant challenges to the widespread adoption of GSHPs, with notable concerns encompassing environmental impact and urban planning considerations. The drilling and installation process of GSHP systems could carry the risk of introducing groundwater contaminants if not executed with stringent environmental precautions. Furthermore, GSHP systems can pose challenges in urban planning due to potential noise issues associated with their installation and operation. Addressing these concerns requires a balanced approach, considering environmental preservation and urban planning considerations to ensure the smooth integration of GSHPs.

- **Existing vs. New Construction:** If considering networked GSHPs, infrastructure can be installed simultaneously with other required utilities, and new planned developments can be designed with CGSHP systems at a fraction of the cost per home compared to a retrofit of an existing neighborhood. Incentives could be developed to encourage developers to complete the groundwork and distribution systems when other utilities are being installed.

- **Site constraints:** The physical footprint necessary for GSHPs is another limitation to this technology. Urban areas, especially those with high population density and limited available land, may face challenges in accommodating the extensive ground loops or borehole fields essential for GSHP systems. The competition for space in urban environments, where land use is carefully planned and regulated, can hinder the feasibility of large-scale GSHP installations. Stringent regulations or restrictions on drilling depths, setback requirements, and noise levels may limit the scope and design flexibility of GSHP installations. Compliance with these regulations becomes a critical factor in determining the feasibility of implementing GSHP systems in a given location.

- **Availability of Implementation Resources:** Drilling wells is the largest cost and most specialized trade that will limit implementation of GSHPs. While capacity to install systems should continue to expand, the current availability of drilling equipment will limit large scale adoption of any GSHP technology.

- **Efficiency Variability:** The efficiency of GSHP systems can be influenced by factors such as soil conditions, ground temperature, and the quality of the ground heat exchanger. Variability in these conditions can lead to fluctuations in system efficiency, making it challenging to achieve consistent performance across diverse sites. In urban environments, the Urban Heat Island (UHI) effect can impact the efficiency based on the increase in ground temperature. This may reduce the overall efficiency of the heat exchange process between the GSHP system and the ground.

- **Thermal Degradation:** Thermal degradation occurs when certain sections of the ground experience excessive heating or cooling, while adjacent areas remain relatively unchanged. This imbalance creates a situation where the ground surrounding the boreholes or ground loops becomes thermally depleted or overloaded. Such thermal imbalances may negatively impact the system's ability to extract or dissipate heat efficiently, diminishing the overall effectiveness of the GSHP technology.

- **Advances in Energy Storage Technology:** GSHPs are essentially seasonal batteries. The premise of this analysis is that leveraging stored thermal energy will allow for a shift in investments from electrical grid expansion to thermal loop expansion.

- A significant reduction in chemical energy storage costs, such as battery energy storage systems, could alter this calculation. If low-cost energy storage becomes available, systems could be installed in buildings and programmed to act as a buffer to reduce grid demand. Such a configuration would allow for lower cost ASHP systems to operate in peak conditions and minimize strain on the grid. Similar avoided grid infrastructure cost metrics could be considered to offset the cost of these systems.

9.2 Advantages of Community Ground Source Heat Pumps (CGSHPs)

While both Ground Source Heat Pumps (GSHPs) and Community Ground Source Heat Pumps (CGSHPs) share similarities in utilizing the stable temperature of the ground for heating and cooling, the distinctions between the two can be advantageous in various aspects, potentially leading to greater efficiency.

1) Economies of Scale: One of the primary advantages of CGSHPs lies in economies of scale. Serving a community allows for larger, centralized installations, which can result in cost efficiencies in terms of equipment procurement, installation, and maintenance. The collective use of resources and the ability to distribute costs across a larger user base can contribute to overall cost-effectiveness.

2) Optimized System Design: CGSHPs offer the opportunity for optimized system design tailored to the specific needs of a community. This includes the design of the heat distribution network and the overall layout of the system. By strategically planning and coordinating the system on a community level, efficiency gains can be achieved through streamlined operations and minimized energy losses.

3) Load Diversity: Community settings often exhibit diverse heating and cooling load profiles due to varied occupancy patterns and building types. CGSHPs can leverage this load diversity to better match the overall demand with the system capacity, potentially reducing the need for oversized equipment and enhancing overall efficiency.

4) Shared Ground Resource Management: In a community scenario, the ground resource is shared among multiple users. Properly managed, this shared resource can lead to optimized utilization, minimizing thermal interference and enhancing the efficiency of heat exchange.

5) Centralized Control and Monitoring: CGSHPs allow for centralized control and monitoring, facilitating more sophisticated energy management strategies. This centralized approach enables better coordination in responding to demand fluctuations, implementing energy-saving measures, and optimizing the overall system performance.

6) Reduced Environmental Impact: By serving multiple buildings or residences, CGSHPs may reduce the need for individual systems, leading to a smaller environmental footprint. This centralized approach can contribute to energy efficiency and sustainability goals.

The diversified advantages arising from these distinctions encompass a broad range of characteristics that make CGSHPs more attractive than standalone GSHPs. First, the cost-effectiveness inherent in economies of scale realized by CGSHPs allows for projects to be more attractive to investors. Second, the centralized nature of CGSHP installations not only fosters substantial cost savings in equipment procurement and maintenance but also facilitates optimized system design tailored to the specific needs of a community. This tailored design, in turn, contributes to load diversification and more efficient matching of overall demand with system capacity, mitigating the risk of oversizing equipment that might be prevalent in individual GSHP setups.

Furthermore, the shared resource management inherent in CGSHPs signifies not only a more effective utilization of the ground's thermal capacity but also a reduction in the potential for thermal interference between systems, leading to enhanced heat exchange efficiency. The centralized control and monitoring capabilities of CGSHPs allow for real-time adjustments and strategic energy management, amplifying operational efficiency.

Finally, beyond technical aspects, CGSHPs offer a unique platform for community engagement and sustainability initiatives, encouraging collective responsibility for energy conservation practices among residents. This amalgamation of benefits underscores the multifaceted efficiency potential inherent in the innovative design and application of Community Ground Source Heat Pump systems, positioning them as a sustainable and economically viable solution for diverse and interconnected energy needs.

9.3 Impacts on Statewide Carbon Emissions

Figures from Maryland Department of the Environment show total emissions in million metric tons of carbon dioxide equivalent ($MMTCO_2e$) for various sectors dating back to 2011.

These show overall downwards trends, but there are significant remaining needs for reducing residential, commercial, and industrial point use.

Reduction in statewide carbon emissions from full electrification of the heating sector is significant, even ignoring electrical grid decarbonization scenarios.

Section 3 demonstrates that heat pump systems with high COP can use 70%-90% less energy than combustible fuel burning systems operating at 85% efficiency.

Even with current electric grid carbon composition[41] it can be estimated that overall carbon emissions will fall by 20%-40% as electric heating technologies are adopted at greater rates. As the electric grid continues to shift to zero-carbon generation sources, these numbers can reach 80%-99% depending on electrification of other fuel consuming sectors.

Table 20.
Maryland Department of the Environment Emissions By Sector[40]

Sector	2011	2014	2017	2020
	$MMTCO_2e$	$MMTCO_2e$	$MMTCO_2e$	$MMTCO_2e$
Electricity Use	37.88	33.84	24.37	18.33
Residential, Commercial, and Industrial (RCI) Fuel Use	15.37	15.99	13.88	13.64
Waste Management	9.57	9.37	8.39	8.38
Industrial Processes and Product Use	8.12	6.68	6.71	7.27
Fossil Fuel Industry	3.64	4.09	3.93	4.59

[40] MDE Greenhouse Gas Inventory
[41] Emissions & Generation Resource Integrated Database (eGRID)

10. CONCLUSION

10.1 Summary of Results

The results presented in this report show the potential impact of various high efficiency electric heating technologies on the statewide electricity grid. The impact of ground source heat pumps is shown to have significant potential to reduce both heating and cooling peak electricity demand from not only other alternative electrified heating technologies, but also a reduction from the current electricity grid peak demand not considering electrification of combustible fuel heating sources.

Analysis of the current grid peak demand shows that the winter heating peak is 12.6 GW. Comparing the peak demand conditions to the various electrified heating scenarios, the air source heat pump scenario creates the largest peak demand, at just over 18GW. The best-case scenario for peak demand reduction, which is full adoption of GSHP systems, yields a winter heating peak demand of just over 10GW, or 20% reduction compared to the current grid demand and a 45% reduction compared to the ASHP scenario. The 75% adoption rate scenario is highlighted because any additional use of GSHP systems above this level no longer results in reduced peak heating demand over the current levels.

Analyzing the peak heating loads experienced by all commercial and residential buildings, it is calculated that the total statewide heating system consumes heat at a rate of approximately 105 million MBH, or 8.7 million tons using units that heat pumps are typically sized in. Comparing this heating rate to the peak demand reduction, an approximation can be made that **1kW of demand reduction can be achieved for each ton of GSHP technology installed.**

Reduction in statewide carbon emissions from full electrification of the heating sector is significant, even ignoring electricity grid decarbonization scenarios. Because of the high efficiency of heat pump systems compared to any combustible fuel heating system, which can equate to 70%-90% reduction in energy use, even with current grid carbon composition it can be estimated that overall carbon emissions will fall by 20%-40%. As the electric grid continues to shift to zero-carbon generation sources, these numbers can reach 80-99% depending on electrification of other fuel consuming sectors.

It is recognized that the best and-worst case scenarios presented in Section 7 have several barriers to implementation that will prevent large scale adoption of the technology. Barriers to implementation include:

- Technical issues such as geological conditions, environmental barriers, and physical limitations for end users to install and connect to GSHP networks.

- Logistical concerns such as lack of equipment, limited workforce to implement at scale, and gaining access to public and private land to drill wells and install distribution infrastructure.

- Financial limitations such as high cost to implement GSHP infrastructure and integrate buildings compared to alternative heating technologies, or limited revenue for GSHP system operators to cover cost of initial investments.

- Technology advances such as low cost distributed energy storage that provide comparable benefits to grid demand reduction.

Even considering the barriers to implementation, proper policy design can alleviate any non-physical limitation to implementation. A current example of policy design is The Inflation Reduction Act (IRA) of 2022, which provides a 30% tax credit for ENERGY STAR-rated Ground Source Heat Pumps (GSHPs) through 2032, and the eligibility of commercial GHP systems for the Investment Tax Credit.[42]

Establishing proper incentives that creates positive return on investment for consumers, encourages investment from utility providers in GSHP system development, and helps to develop a properly trained workforce to install high efficiency heating systems will push adoption to significantly greater rates and ultimately smooth the transition to a carbon-free economy.

Additionally, identifying the locations experiencing a 3% coincident load during the peak electrical demand and encouraging the adoption of networked GSHP systems in those specific areas would yield the most significant impact on the grid load. This targeted strategy would ensure the optimal design and operation efficiency for these systems.

[42] Geothermal Heat Pump Information for Consumers | Department of Energy

10.2 Next Steps Toward Change

AECOM, MEA, and the State of Maryland are actively exploring multiple pathways to achieve carbon reduction in the State. Decarbonization of the heating sector remains a primary focus of this effort. To build on the results presented in this analysis, the following next steps should be considered:

- Economic analysis of avoided cost/MW of grid capacity.
- Development of grid demand requirements when considering electrification of other sectors such as transportation, domestic water heating, and light industrial heating equipment.
- Selection of site for CGSHP pilot study, detailed economic analysis of implementation
- Expanded modeling of coincident load occurrences and optimal selection of location for pilot study.
- Modeling of utility business case for installing and managing GSHP networks
- Additional scenario development and dynamic analysis over multiple adoption rate schedules
- Grid nodal analysis to identify areas of greatest impact.
- Integration with renewable energy

This study concludes that GSHP and CGSHP technologies—while statewide viability is currently unclear at large scale due to high upfront costs to implement—can play an important role in the overall electrification of the heating sector and should be incentivized through public policy in such a way that barriers to implementation are reduced. Thoughtful design and implementation of incentives to facilitate GSPH adoption can aid the State of Maryland in achieving its 2045 goal of zero carbon emissions.

APPENDIX A: ASHP & GSHP EFFICIENCY CALCULATIONS

After establishing the groundwork for the assumptions guiding our calculations, we acquired the design conditions tailored to the state of Maryland according to ASHRAE Standard 169: Climatic Data for Building Design Standards. The tabulated results are presented below.

Table 21.

ASHRAE Standard 169: Climatic Data for Building Design Standards. State of Maryland

		Heating DB (°F)		Cooling DB/MCWB (°F)				HDD 65	CDD 65
No.	Location	99.60%	99%	0.4% DB	0.4% MCWB	1% DB	1% MCWB	TOTAL	TOTAL
1	Ocean City	15.8	19.5	90.2	76.6	87.6	76.2	4198	1229
2	Salisbury	13.9	18.5	93.1	76.1	90.6	75.4	4225	1275
3	Bishops Head	18.8	23.2	88.1	N/A	86.1	N/A	3930	1546
4	Cambridge Harbor	16.9	21.3	91	N/A	88.8	N/A	3907	1546
5	Cambridge Dorchester	17.8	20.6	91.2	76.7	90.1	75.8	4124	1294
6	Webster Nolf	16.6	20.6	92.9	77.2	90.3	76	3847	1559
7	Patuxent River NAS	17	20.7	92.7	76.4	90.1	75.7	4006	1467

		Heating DB (°F)		Cooling DB/MCWB (°F)				HDD 65	CDD 65
No.	Location	99.60%	99%	0.4% DB	0.4% MCWB	1% DB	1% MCWB	TOTAL	TOTAL
8	Cove Point LNG Pier	17.2	21.5	88.7	N/A	86.2	N/A	3935	1446
9	Stevensville	17.9	20.9	91	75.6	89.5	75.1	4092	1448
10	Annapolis US Naval Academy	17.6	21.1	91.3	76.4	89.1	75.7	3996	1522
11	Jug Bay	14.1	18.7	93.4	77.9	90.9	76.7	4269	1364
12	Andrews AFB	14	18.1	93.7	74.8	91	74.1	4348	1300
13	College Park	14.9	19.1	95.2	74.2	92	73.6	4197	1450
14	Gaithesburg Montgomery	10.1	15.7	91.2	75.5	89.9	74.8	4742	1161
15	Baltimore-Washington	13.5	17.5	94	75	91.3	74.2	4475	1314
16	Tolchester Beach	16.1	20.6	89.3	N/A	87.2	N/A	4243	1378
17	Baltimore Harbor	15	19.3	92.6	N/A	90.1	N/A	4109	1560
18	Baltimore Downtown	16.8	20.7	95.5	75.6	92.9	74.3	3858	1785

		Heating DB (°F)		Cooling DB/MCWB (°F)				HDD 65	CDD 65
No.	Location	99.60%	99%	0.4% DB	0.4% MCWB	1% DB	1% MCWB	TOTAL	TOTAL
19	Carrol County Regional	9.3	13.5	93.2	75.3	90.9	74.5	4667	1410
20	Camp David	5.4	9.9	86.7	69.4	84.2	68.6	5446	781
21	Hagerstown	11.4	15.6	92.1	72.9	89.6	72.3	4842	1179

This data provided us with a more comprehensive insight into the heating and cooling loads prevalent across the entire state of Maryland. Calculating the COP for ASHPs followed a straightforward process. We extracted the COP values from the AHRI catalog and matched each value to its respective temperature. As an illustrative example, we selected an ASHP with an Energy Efficiency Ratio (EER) of 12.5 at 95°F and a heating COP of 1.8 at 5°F. Additionally, it is established that ASHPs exhibit their highest rated efficiency between 45°F and 65 °F. Leveraging this information, we employed linear interpolation between the known COPs and temperature data points to ascertain the missing efficiencies.

$$COP = \frac{EER}{3.41214}$$

$$COP\ @\ 95°F = 3.66$$

$$COP\ @\ 45°F - 65°F = 5.86$$

$$COP\ @\ 5°F = 1.8$$

Table 22.

Outside Air Temperature and Corresponding Calculated Coefficient of Performance

OAT (°F)	COP
95	3.66
90	3.97
85	4.29
80	4.60
75	4.92
70	5.23
65	5.54
60	5.86
55	5.86
50	5.86
45	5.86
40	4.59
35	4.18
30	3.77
25	3.37
20	2.96
15	2.55
10	2.14
5	1.80

To derive the efficiencies of Ground Source Heat Pumps (GSHPs), we delved into a more in-depth analysis of the heating and cooling loads observed in the state of Maryland. This exploration is grounded in the understanding that the effectiveness of heat transfer between the GSHP and the ground hinges on the cumulative heat added or subtracted over the course of its operational duration. The results seen on Table 23, are organized in descending order according to heating load. As we can observe, the percentage energy difference varies from 36.74% in Webster Nolf to 74.92% in Camp David. Following our calculations, a concern arises as the system energy balance—defined as the difference between annual heating and cooling loads met by GSHP systems—should ideally remain within 10 to 15 percent for optimal performance. It becomes apparent that this criterion poses a challenge, indicating that no location in the state can effectively accommodate a Geothermal system without the incorporation of an additional heat bank. This supplementary measure would be utilized to preheat the ground temperature before the onset of the winter season.

We proceeded to scrutinize diverse configurations of GSHPs to comprehend the distinct efficiencies, capabilities, as well as strengths and weaknesses inherent in each system. Our focus narrowed to the GLHP version, chosen for its simplicity in installation, versatility in application, and conservative heating and cooling efficiencies relative to its counterparts (WLHP & GWHP). With our equipment prepared, we accessed efficiency data from the AHRI catalog and allocated efficiencies according to the identified information.

Table 23.

Cities Organized in Descending Order Depending on Thir Percent Difference Between Heating and Cooling Load

Descending by Percent Difference Between Heating and Cooling Load			% Dlff.
No.	HDD65	CDD 65	
20	5446	781	74.92
21	4842	1179	60.84
14	4742	1161	60.66
19	4667	1410	53.60
15	4475	1314	54.60
12	4348	1300	53.97
11	4269	1364	51.57
16	4243	1378	50.97
2	4225	1275	53.64
1	4198	1229	54.71
13	4197	1450	48.65
5	4124	1294	52.23
17	4109	1560	44.96
9	4092	1448	47.73
7	4006	1467	46.39
10	3996	1522	44.84
8	3935	1446	46.26
3	3930	1546	43.54
4	3907	1546	43.30
18	3858	1785	36.74
6	3847	1559	42.32

The Full Load Cooling EER stands at 21.9, while the Full Load Heating is 4.1. It's worth noting that the maximum efficiency for heating is recorded at 4.81, and for cooling, it reaches 10.35. Using these data points, we were prepared to allocate efficiencies for the first day of the month, considering both heating and cooling loads. To initiate this process, we calculated the HDD65 using the data employed in the electric demand analysis. This approach allowed us to assess the annual trends in heating and cooling demands. Subsequently, our calculations led to the creation of the following table:

Table 24.

Calculated HDD65

Year	Month	HDD 65
2018	1	1019.63
	2	638.28
	3	790.71
	4	421.51
	5	-117.04
	6	-226.02
	7	-358.82
	8	-374.62
	9	-226.72
	10	177.29
	11	625.86
	12	763.43

Referring to Table 25, the heating season initiates relatively mildly in October but intensifies through November and persists until April. Drawing on this insight and considering the information from the Department of Energy, which underscores that "GSHPs leverage the consistent temperature of the shallow earth (40–70°F/4.5–21°C) to facilitate efficient temperature exchange for heating homes in the winter and cooling homes in the summer," we opted to establish a reference point of 70°F for the beginning of October and 40°F for the onset of May. Subsequently, based on the heating and cooling load, we adjusted the ground temperature accordingly. The outcomes are detailed below:

Table 25.

Modeled Ground Temperatures Based on HDD 65

Year	Month	HDD 65	Ground T Start of the Month
2018	1	1019.63	59.41
	2	638.28	52.51
	3	790.71	48.20
	4	421.51	42.85
	5	-117.04	40.00
	6	-226.02	40.79
	7	-358.82	42.32
	8	-374.62	44.75
	9	-226.72	47.28
	10	177.29	70.00
	11	625.86	68.80
	12	763.43	64.57

As we can appreciate, without a heat bank, the ground temperature will not rise to the expected levels once October begins again. Based on the reference points, HDD65 information, and ground temperature, we were able to extrapolate the corresponding heating and cooling COPs, presented following.

Table 26.
Modeled Heating and Cooling COP Based on HDD 65

Year	Month	HDD 65	Ground T Start of the Month	Heating GLHP COP Start of the Month	Cooling GLHP COP Start of the Month
2018	1	1019.63	59.41	4.58	7.89
	2	638.28	52.51	4.44	8.76
	3	790.71	48.20	4.34	9.31
	4	421.51	42.85	4.23	9.99
	5	-117.04	40.00	4.17	10.35
	6	-226.02	40.79	4.19	10.01
	7	-358.82	42.32	4.22	9.35
	8	-374.62	44.75	4.27	8.30
	9	-226.72	47.28	4.33	7.20
	10	177.29	70.00	4.81	6.54
	11	625.86	68.80	4.78	6.69
	12	763.43	64.57	4.69	7.23

Ultimately, we successfully allocated COPs to the grid data, contingent on the date or OAT. This enabled us to prepare the comprehensive assessment of the demand disparity between the deployment of full ASHP heating and various adoption scenarios for GSHPs as a heating source.

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