



Carbon Neutral Climate Control Upgrades for Seal and Serpent

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Team Member Introduction

Jiaming Yuan

Jiaming is currently a Master of Engineering student from San Francisco, California in Cornell University's Environmental Engineering program. She has an interest in water treatment processes and design, and experience particularly in drinking water as part of Cornell AguaClara's leadership team and an intern at Brown and Caldwell. She has also helped develop a building proposal standard for the City of Ithaca's existing buildings as an alumna of Cornell Engineering's Leadership Program. Her career objectives after graduation are to contribute to water treatment and resource management projects in the western United States in order to help build resiliency for small communities and climate change.

Jennifer Permenter

Jennifer is interested in sustainability, cost-effective designs and coastal engineering. As a Cornell Master of Engineering student in Civil and Environmental Engineering, she has experience with renewable energy system designs and calculations, specifically offshore wind arrays. Jennifer has been a Capture Manager at Bamforth Engineers + Surveyors for three years, navigating Federal contract responses with technical writing, and acting as an engineering intern for two years, surveying military bases and conveying site details to the design team. Her background with Engineers Without Borders and hydrologic research at Cornell helps her dive into new projects with a wide range of experience.

Gabriel Goins

Gabriel is a Master of Engineering student in Civil and Environmental Engineering at Cornell University, specializing in Sustainable Energy Systems. He holds a dual Bachelor of Science/Bachelor of Arts in Sustainable Engineering from the University of San Diego and also studied Sustainable Energy Engineering as an exchange student at University College Cork in Ireland. His academic interests span energy systems modeling, renewable energy integration, energy project finance, and infrastructure management, with extensive experience using computational tools such as GIS, microgrid/grid-connected simulation platforms, and data analytics tools to evaluate energy systems and environmental risks. Gabriel has also gained highly transferable project engineering experience as an intern at Whiting Turner Contracting Company a commercial construction firm. After graduation, he aims to work at a large Utility or a consulting firm with an energy division focusing on dispatch management, renewable capacity expansion initiatives, and he hopes to contribute to grid reliability and predictive analytics. Alternatively, he is interested in working at an independent system operator interpreting energy markets. He hopes to contribute to infrastructure projects that support an equitable transition.

Sophie Davis

Sophie is a current Master's of Engineering student at Cornell University, studying environmental engineering from Baltimore, Maryland. She plans to work in engineering consulting, specializing in environmental pre-assessments for renewable energy in Denver, Colorado, post-graduation. She studied at Cornell University for her undergraduate degree in environmental engineering, and also studied abroad at the University of Sydney. Her academic interests cover energy and water resources, in which she hopes to eventually combine to work in tidal power research. She also has an academic background in mechanical engineering and marine biology. Sophie has worked in civil and environmental consulting for two years, working for Kimley-Horn in development services and renewable energy site review.

Matt Burgos

Matt is currently pursuing a Master's of Engineering in Environmental Engineering at Cornell University. He grew up in the Bay Area, California, and is interested in sustainable infrastructure development and water resource management. He has experience designing and overseeing construction for water infrastructure projects as an intern for the U.S. Indian Health Service. Next summer, he plans to work as a Water/Wastewater Engineering Intern for Black and Veatch in the Charlotte area, working on large-scale wastewater treatment plants. He is passionate about researching ways to mitigate the effects of climate change and developing more sustainable, efficient buildings. He aspires to be a professional engineer in the future, helping to improve public health and prosperity.

Muhammad Islam

Muhammad is currently a Master's of Engineering student from Queens, New York, in Cornell University's Environmental Engineering program. He has interests in sustainable infrastructure, environmental data analysis, environmental compliance, and water resource systems. He has experience from coursework and research projects in life-cycle sustainability assessments, environmental data modeling, and infrastructure analysis. He has also contributed to research on PFAS contamination in New York's Finger Lakes region. Muhammad hopes to work on environmental engineering projects that integrate environmental compliance, sustainable infrastructure, and data-driven decision making to support resilient communities and environmental systems.

Jasper Agrawal

Jasper Agrawal is a Junior in Environmental engineering at Cornell University. He grew up in Ithaca NY and is interested in green infrastructure development and the reclamation of old waste sites. He has experience in fluid mechanics research and contaminant flow. He is

planning to intern with Labella associates in Rochester in their remediation department, and hopes to work in clean energy transition in the future.

Project Motivation

Anthropogenic climate change is a major challenge that engineers and communities must face. One of the prime contributors to climate change is the use of fossil fuels for energy. Residential buildings are the second sector with the second largest natural gas usage in the United States, accounting for about 14% natural gas usage in 2023, and over 40% energy consumption by residential buildings is natural gas (U.S. Energy Information Administration, 2021). In Upstate New York, this especially includes the use of natural gas for the heating and cooling of buildings, which is collectively referred to as the climate control system. Previous Environmental Engineering M.Eng projects included studies of EcoHouse and Redbud Hall on Cornell University's campus that suggest that the ratio of natural gas usage for climate control during the heating season (measured as November to March) compared to baseline can be as large as 70:30 or 80:20. Thus, it is a reasonable assumption that the decarbonization of the climate control system is an impactful way to improve the sustainability of Seal and Serpent.

As Seal and Serpent plan for upgrades to its historic building near Cornell's North Campus, building sustainability is important to include. The integration of carbon-neutral alternatives during scheduled upgrades and maintenance is the most seamless way to decarbonize the building as a whole. There are several potential decarbonization pathways to follow, and we want to offer stakeholders multiple feasible options to opt into to make decarbonization a seamless integration with proposed building upgrades. Evaluating these pathways while minimizing disruption to proposed renovations in the architecture drawings and scope is the core motivation for this work.

However, decarbonizing older residence halls introduces additional challenges compared to new construction. Historic masonry buildings are not built to today's environmental health and safety EHS standards or efficiency standards. These buildings may experience very high thermal losses across HVAC, plumbing distribution systems, and the building envelope. Therefore, before considering the electrification of climate control and water heating systems, efficiency-first retrofitting strategies should be the first priority to explore. These strategies may include ductwork replacement, insulation improvements, weather sealing, and pipe insulation, as they offer a promising solution to reduce overall heating and cooling demand. Another example is choosing to increase electric service to Seal and Serpent's building up to 500 Amp or even 1200 Amp, which can prepare the building to have greater capacity to potentially power the climate control system using electricity in the future. The Seal and Serpent organization is currently preparing for a major building modernization and upgrade project, so this semester's project is timely.

Additionally, electrification and a transition to renewable energy are prevailing trends for large-occupancy buildings such as campus residence buildings. Electric upgrades will prepare

Seal and Serpent as local renewable energy sources, such as solar farms, as they expand. Cornell University itself has investments in its own solar farms as well, in order to reach its commitment to carbon neutrality by 2035 (*Climate Action Plan | Sustainable Campus*, n.d.). Although Seal and Serpent is not a Cornell-owned building, its students likely share similar values of environmental sustainability, and there is the possibility of tapping into a shared grid or renewable electricity source.

Given the move toward building decarbonization and growing resources for such renovations, including precedence in historic buildings, it is important for shared and longstanding residential spaces, including Seal and Serpent, to prioritize the environmental impacts and long-term sustainability of building upgrades. By analyzing building energy use and exploring combinations of efficiency improvements and electrification technologies, the project aims to identify viable pathways for reducing the building's long-term carbon footprint.

Project Goals

This project will focus on decarbonizing the climate control system at Seal and Serpent. Climate control, especially heating during the winter, is the largest source of energy consumption for the building and greatly exceeds electrical use. Some of the most promising upgrades that contribute to decarbonizing the Seal and Serpent building are replacing the existing natural-gas-powered heating system with a ground source heat pump and switching to a renewable electricity source, such as a solar array assisted by off-site solar sources. For both major decarbonization investments, this project will present a comprehensive introduction to the following:

- Details about the functionality of selected technologies
- General review of installation feasibility for Seal and Serpent
- Perfunctory economic costs and payback period for installation and operation
- Estimated carbon dioxide emissions saved per year

The report from this project is intended to help nontechnical interested parties, such as the board of Seal and Serpent, conceptualize the benefits of decarbonization and provide a couple of initial steps in an electrification transition. A market analysis will also be presented as part of this final report to understand the current state of decarbonization initiatives in historic buildings in the U.S. as additional context and motivation for the recommended upgrades.

As diligent engineers, we value the Seal and Serpents' residents and board members' opinions on the design goals. Their goals for this project are focused on economic efficiency, durability, and redundancy of the system. These will ensure the upgrades to the house will last for future students and never fail to fully heat in the winter. Our design team hopes to provide sustainable methods of decarbonization through digital modeling of the Seal and Serpent, with the lofty goal of making it entirely carbon neutral. Finally, we hope that sufficiently motivating the decarbonization of Seal and Serpent's climate control system will allow for the building to

be used as an example for other historic buildings and residential buildings near Cornell's campus in the future.

Scoping Statement and Clarifying Assumptions

Limitations

This project is limited to Seal and Serpent as a single building, with a particular focus on its climate control system. Thus, the report will not include carbon-neutral alternatives to natural gas and other fossil fuel consumption from other use areas, such as the commercial cooktop. Carbon emissions from electricity usage that are not related to heating or cooling will not be considered in this study. Moreover, natural gas and electricity data for Seal and Serpent are limited to monthly measurements provided by New York State Gas and Electric (NYSEG) from June 2024 to January 2026.

Economic calculations included in this report are for informational purposes and only suitable for relative comparison between different alternatives, not to be used as absolute value estimates. The market analysis portion of the project does not include projections for future trends or changes. Policy and incentives relevant to the decarbonization of historic buildings are discussed as considerations to keep in mind, and are not assessed for their definite applicability to Seal and Serpent.

Additionally, this is a short-term conceptual study spanning four months of work for a Master of Engineering project as part of Cornell's environmental engineering program. Due to these limitations, this report is a preliminary assessment showing potential for decarbonization. Practicing engineers and/or contractors should be consulted for professional guidance before deciding on any building upgrades for the Seal and Serpent residence building.

Assumptions

In order to constrain this project to a reasonable scope for the M.Eng project, several assumptions were made about the available data and technical calculations:

- Solar generation is considered sufficient if annual generation meets annual energy consumption. Seasonal differences are assumed to be stored or supplied to ensure overall demand is met over the entire year. Alternatively, it is assumed that net metering is an option, so that the property can generate extra kWh of electricity in the summer to cover the shortfall in the winter.
- Carbon emissions from natural gas consumption are estimated using the EPA emissions calculator (EIA, 2023b, EPA, 2024) and no additional estimation methods are used.
- All electricity used by upgrades such as the heat pump is assumed to be from 100% renewable electricity from offsite solar photovoltaic arrays. Contributions to carbon emissions from increased electricity consumption are assumed to be zero.

Finally, we also assume that energy prices and available incentive programs are constant throughout the project lifetime. For the ground source heat pump levelized cost analysis, we assumed 5% interest over a 20 years lifetime for the annualization. We also assumed a 7 month long heating season, a coefficient of performance of 3.9, the energy operating cost of heat delivered as \$0.10 per kWh, and the non-energy operating cost of heat delivered to be \$0.01 per kWh. These values were assumed from broad generalizations or Ithaca-specific values to aid in the accuracy of our analysis.

Proposed Research Questions

- What combination of systems would enable the Seal and Serpent to achieve carbon neutrality while remaining economically viable?
- What challenges might arise when transitioning the Seal and Serpent building from fossil fuel-based climate control systems to electrified alternatives?
- How could renewable energy integration help reduce the overall carbon footprint of the Seal and Serpent building?

Market Analysis

Policy & Climate Commitments

It is common for existing buildings to undergo a carbon-neutral transition at the same time as they perform necessary maintenance upgrades and renovations. There are several local and state incentives to support building decarbonization. In the immediate vicinity of Seal and Serpent, both Cornell University and the City of Ithaca have established carbon neutrality commitments. Cornell has a goal to be carbon neutral by 2030, and is aggressively pursuing its goal through the exploration of geothermal heating, investments in off-site solar farms, and energy efficiency upgrades to its new campus buildings and additions. Even if Seal and Serpent are not Cornell-owned buildings, the increase in solar-powered electricity service to the university is likely to make renewable electricity more easily accessible to the Seal and Serpent buildings as well because of the close vicinity. Additionally, the Cornell students who live there are likely to reflect Cornell's priorities of sustainability.

The City of Ithaca also has initiatives to decarbonize existing buildings. The Ithaca 2030 District is a voluntary coalition of residential and commercial building owners who commit to reducing carbon emissions from their buildings by 50% by 2035. There are several historic buildings that participate in this organization, including but not limited to the Clinton House in downtown Ithaca. While all new buildings and large additions in Ithaca are already regulated by building performance standards (BPSs), there is a push originating from the City of Ithaca and the 2030 District to implement a BPS for existing buildings as well. With the entire community moving toward electrification, costs will be mitigated, and convenience increased for sourcing local but off-site renewable electricity. Organizations such as the 2030 District can also be a

low-stakes opportunity for Seal and Serpent to seek support with upgrades to achieve a carbon-neutral building, since experience and contacts can be shared through that network.

On the state level, the New York State Energy Research and Development Association (NYSERDA) offers Clean Heat incentives to aid building owners in the electrification process. From offering tax credits, which can be claimed in a different form by tax-exempt entities such as Seal and Serpent, to connecting building owners with reliable and knowledgeable contractors, NYSERDA incentives and grants are promising programs that Seal and Serpent may be eligible to benefit from. For example, subsidies exist to offset the upfront costs associated with both ground-source and air-source heat pumps, with additional benefits rewarded for the decommissioning of an old fossil fuel system. The replacement and installation of other appliances, such as water heaters compatible with a heat pump system or enhanced weatherization of the building, can also qualify for NYSERDA Clean Heat incentives. These incentives can translate to up to tens of thousands in aid to the building, depending on the current conditions. The various incentives and programs mentioned in this market analysis, among others, reflect the importance of building decarbonization even for existing buildings, and demonstrate the willingness of public and private entities to invest in carbon-neutral upgrades that will serve their buildings well now and into a more sustainable future.

Economic and Demographic Drivers

Decarbonizing a building's thermal profile serves as a strategic financial hedge against the inherent instability of global energy markets. Volatile fossil fuel prices—frequently driven by geopolitical shifts and supply chain disruptions—introduce a level of budgetary risk that makes forecasting annual operating expenses nearly impossible for owners of traditional gas or oil systems. By shifting toward high-efficiency electric alternatives like heat pumps, owners can stabilize their long-term cost structures and future-proof themselves against rising utility rates. The long-term operational cost savings are driven by the mechanical advantage of heat transfer over combustion. A boiler is limited by the fuel it burns. An electric heat pump can provide significantly more thermal energy per dollar spent because only a minor percentage of the total heat energy comes from electricity that must be purchased; most of the heat energy is already available in the air or ground and simply needs to be moved to the higher-temperature location. Electrifying homes can reduce the homeowner's risks from economic uncertainties in the fossil fuel industry. Studies show that replacing HVAC systems with the proper heat pump can reduce energy bills for 90% of American households (US DOE, 2024).

From an infrastructure perspective, the move to decarbonize makes financial sense as the market is shifting towards electrification. In 2022, heat pump sales in Europe grew by 40% (IEA, 2022). This shift toward electrification is expected to continue, and technologies associated with electrification will continue to decrease in price. Maintaining legacy boilers is a losing financial battle as maintenance costs are rising due to a shrinking pool of specialized technicians and the increasing scarcity of replacement parts. This is a primary concern for inefficient steam systems, which are notorious for leaking massive amounts of energy through

failing traps, valves, and uninsulated piping long before the heat ever reaches its destination. Instead of pouring capital into repairing a failing system, forward-thinking owners should modernize with streamlined electric systems. This transition bypasses the high-maintenance requirements of steam and replaces them with reliable, low-waste technology that ensures the building remains mechanically sound for the next thirty years.

A few demographic factors to consider are the increasing student population, year-round occupancy patterns, and higher comfort expectations for residences. Users of this proposed upgrade to Seal and Serpent would be the fraternity members living at the house, a number that is directly proportional to the Cornell student population. Cornell University currently has roughly 26,000 undergraduate and graduate students enrolled, which has increased by 30% from a decade ago. We can extrapolate that the users at the Seal and Serpent have also increased by 30% from the previous decade and might increase by 30% in the next decade. To support this population growth, regardless of house bedroom limitations, the Seal and Serpent's decarbonization must factor in an increased energy usage from an increased future enrollment. On a yearly basis, residents of the house live there seasonally, leaving the building mostly empty in the summer and significantly reducing energy consumption then. A final demographic or use factor to consider is the higher comfort expectations from students concerning their dorms and residences. The Seal and Serpent is an older building, meaning that it will starkly contrast with the newer dorms Cornell has built, competing for potential residents. Students today expect efficient insulation, on-demand heating and cooling, clean and usable kitchens, and new furniture. With a historic house, many of these are more challenging to attain and can influence the number of residents using energy, along with the amount of energy they use.

Barriers & Constraints

Historic Preservation Guidelines

The primary regulatory constraints to consider are the City of Ithaca's historic preservation guidelines. Seal and Serpent's residence hall is located in the Cornell Heights historic district, similar to Triphammer Cooperative, which was the subject of a previous Cornell University Master of Engineering project. Although not designated as a historic building itself, Seal and Serpent faces similar restrictions on renovations to its exterior in order to preserve the historic appearance of the neighborhood at large. In general, no changes can be made to the facade, and renovations must use materials that are the closest match to the original. The City of Ithaca Historic District and Landmark Design Guidelines (HGLDG) provide further detail on building materials suitable for building upgrades. These guidelines largely concern themselves with external features, including roofs, windows, exterior siding, and landscaping, among others. These guidelines can be accessed on the City of Ithaca's historic preservation website.

The historic preservation laws may impact the extent and type of building upgrades that are feasible. For instance, Seal and Serpent's roof is made of slate, which makes it unsuitable for rooftop solar panel installation. Because the roofing materials cannot be changed, rooftop

solar will not be a feasible decarbonization strategy for this building, and off-site renewable energy sources must be considered. Similarly, because renovations impacting the landscaping of the building are also regulated, the installation of above-ground air-source heat pumps may also be challenging to implement. City officials enforcing these guidelines may need to be consulted if large-scale upgrades such as heat pumps or insulation are to be considered.

Financial, Operational, and Information Constraints

The main financial constraint to decarbonization is upfront capital costs, especially for those who wish for complete electrification. If funding is limited, efficiency first is the best approach. Efficiency upgrades such as improved insulation, door and window replacements, smart thermostats, etc., pose low capital costs compared to installing new systems that don't use natural gas. Heat pumps and solar panels will have higher upfront costs, but long-term environmental and cost benefits. The capital costs may be unfeasible for a student co-op such as Seal and Serpent, where financial access is limited. Infrastructure projects usually have strict budget allocations, and there may be restrictions on what the available funds can be used for. Decarbonization may not be a priority for co-op alumni and board members, making it difficult to gather the needed capital for heat pumps or solar panel arrays.

Managing decarbonization projects within a student co-op introduces unique operational hurdles that revolve around the rigid academic calendar and high-density living. Construction timing is the most significant constraint, as major invasive work—such as installing heat pump piping or replacing central boilers—must typically be condensed into the short summer window or winter break to avoid coinciding with midterms or finals. This creates a high-pressure environment for contractors and leaves little room for delays. Furthermore, occupant disruption is a constant concern in a communal living setting. Unlike a traditional commercial building, a co-op is a 24-hour residence where noise, temporary loss of heating, or restricted access to common areas can directly impact student wellbeing and academic performance. To mitigate these risks, co-ops might consider phased implementation, breaking a total decarbonization plan into manageable stages over several years. For instance, a house might prioritize weatherization and solar array installation in year one to reduce the building's load, followed by a room-by-room heat pump rollout in year two, allowing the community to spread out the financial burden and minimize the number of residents displaced at any given time.

Lastly, data limitations make it difficult to gauge and predict the impact of proposed projects. NYSEG provides readings on a monthly basis for natural gas and energy consumption. Historic data may not be accessible, and it is difficult to quantify how decarbonization policies will affect carbon emissions and the monthly utility bill. While two years of utility data (therms and time-of-use electricity consumption) provide a strong recent baseline, this period may not fully capture interannual variability in heating demand due to weather fluctuations, occupancy changes, or operational shifts. As a result, projected savings and electrification sizing should be interpreted within the context of baseline uncertainty.

Historical Energy Usage and Considerations

Baseline Energy Consumption

Seal and Serpent currently relies on natural gas for major building functions, including heating and cooking. The following plot shows the building's natural gas usage for the 2024-2025 year (Figure 1). Taking October through April as the heating season and assuming average usage between May and September is a representative baseline (non-heating use), the total natural gas consumed for heating during this year was 7164.12 therms. With a baseline natural gas usage during non-heating months of only around 53 therms/month, the ratio of heating to non-heating natural gas usage is 95% to 5%. For context, the building was compared to two other local examples with known energy profiles, namely the Ecovillage at Ithaca Cohousing community and the Redbud Student Residential Cooperative on the Cornell Campus, which had a ratio of 75% to 25% and 80% to 20% respectively. Seal and Serpent's very high ratio of 95% to 5% may not be the exact value over multiple years of data, but it still suggests that heat loss and space heating are extremely inefficient and by far the greatest contributors to the building's natural gas consumption.

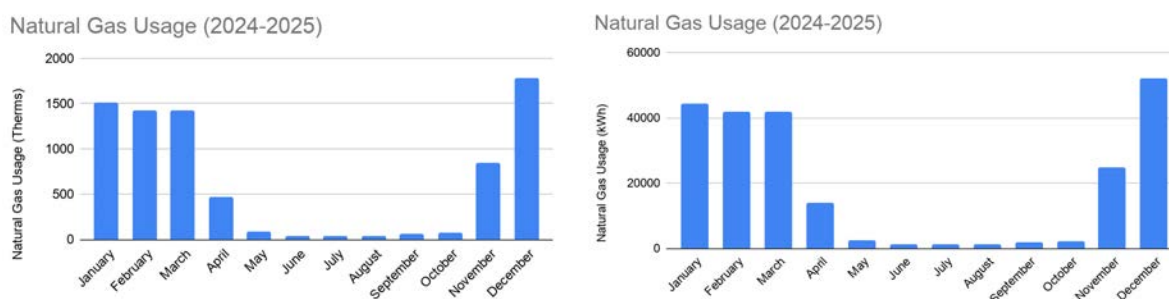


Figure 1. Bar chart displaying Seal and Serpent's monthly natural gas usage for 2024-2025. Left is in Therms, and right is in kWh.

By contrast, the amount of energy used for electricity is significantly less than that of natural gas. Figure 2 shows the annual electricity consumption for the same 2024-2025 year, which is nearly one order of magnitude lower than the kWh natural gas consumption seen in Figure 1. The total annual energy consumption in kWh is approximately 228,558 kWh from natural gas and 51,712.5 kWh from electricity, which is 4.4 times more energy consumed from natural gas compared to electricity. Even during the non-heating months, energy consumption of natural gas remains five times higher than the amount consumed for electricity. The various electrification upgrades discussed in the remainder of this report will substantially increase the electricity consumption of the Seal and Serpent building, but a comparison of the current energy consumption highlights how electricity is much more efficient than natural gas. Potential future electricity consumption levels are not considered in this report, but it is certain to still be major reductions in overall energy consumption compared to continuing to rely on natural gas.

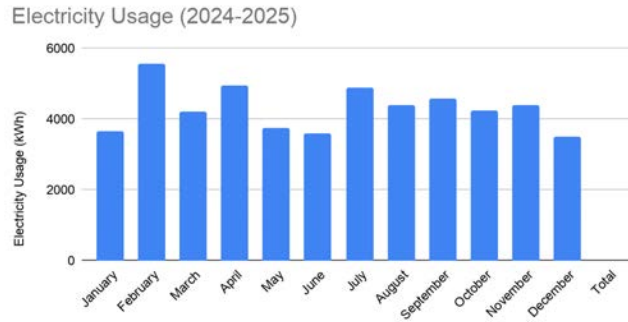


Figure 2. Bar chart displaying Seal and Serpent’s monthly electricity usage for 2024-2025.

Baseline CO₂ Emissions

The current annual CO₂ emissions for both the heating season and annual electricity is equivalent to approximately 255,000 pounds of carbon dioxide, or 116.65 metric tons. This approximation is derived from data from Seal & Serpent (a total gas consumption of 804 MMBtu and electricity demand of 232000 kWh per year), an average natural gas boiler emission rate of 120 pounds of carbon dioxide per MMBtu, an average emissions from grid energy of 0.683 pounds of carbon dioxide per kWh, and a conversion factor of 2205 pounds of carbon dioxide per metric ton. All of the average emissions values were found from past or current New York based metrics.

As discussed in the previous section about the baseline natural gas usage, a majority of the carbon emissions are due to space heating requirements. This is common for most residential buildings in the Northeast region, which experiences long, cold winters that make up a long heating season. It also highlights the high potential for carbon emissions savings with even partial upgrades to the building’s current heating system and supply.

For the baseline and future emission calculations, we only considered Seal and Serpents’ direct emissions from natural gas heating and a grid-based electric system. Due to this, our estimations may not fully encompass the true emissions from implementing new systems. For example, the heat pump would require extensive construction processes to install, and those emissions were not considered.

Partial Decarbonization Option

Efficiency Upgrades & Demand Reduction (Efficiency-First)

Efficiency-first retrofit strategies focus on reducing a building’s overall energy demand before implementing electrification technologies. For older masonry buildings such as Seal and Serpent, these measures are particularly important due to significant heat loss through building envelopes and inefficient HVAC distribution systems. By lowering heating demand, efficiency

upgrades can improve system performance, reduce operating costs, and enable smaller and more cost-effective electrification solutions.

Energy savings from improving building insulation can be estimated by utilizing the thermal conductivity (k) of building walls, roof, and insulation in a simple heat transfer model of the Seal and Serpent building. In this model, the Seal and Serpent is simplified as a box with dimensions given from the gross square footage of the building and the number of floors. Heat loss from the walls, roof, windows, and doors is estimated by the number of each dimensional component and the heat transfer coefficient to calculate the heat loss per day. The following table shows the results of the heat transfer model calculations with estimates of the current insulation of Seal and Serpent. The thermal conductivity values used for each dimensional component are listed below, using values used in previous studies or estimated by AI:

- Walls: 0.077
- Roof: 0.154
- Basement: 0.400, estimate assuming a 4-inch concrete basement with $k = 0.1 \text{ Btu}/(\text{deg F})(\text{ft}^2)(\text{hr})$ per inch of thickness
- Windows: 0.5, maintained value from Fall 2025 Redbud study of twice the $k = 1 \text{ Btu}/(\text{deg F})(\text{ft}^2)(\text{hr})$ for single-pane windows
- Doors: 0.25, maintained value from 2023 Llenroc study (Environmental Engineering M.Eng Team, 2023)

Table 1. Breakdown of estimated heat loss from walls, roof, windows, and doors given the current Seal and Serpent construction and insulation.

Component	Area	Flow	Heat loss	Per day
Units:	ft ²	Btu/ft ² -F-h	Btu/F/h	Btu/F/Day
Walls	3420	0.077	263	6312
Roof	8180	0.154	1258	30194
Basement	4400	0.400	1760	42240
Windows	800	0.5	400	9600
Doors	60	0.25	15	360
			Total	88706

Applying a 1.25 multiplier for other losses and accounting for 80% efficiency of converting natural gas to delivered heat, the estimated total natural gas consumption currently is 1,148.94 THM/heating season month, which is slightly higher than, but well within the margin of error for annual variability, the observed amount of 1076.485 THM/month from Seal and Serpent's 2024-2025 natural gas billing data. Note that due to the varying winter conditions, there is no expectation that the heat transfer model will match the observed energy consumption, but the model is useful for providing a qualitative comparison between adding insulation or not. Table 1 also shows that the areas for which improved insulation would be most impactful are the roof

and basement, which have the highest heat loss due to large surface area and large estimated heat flow rates.

A brief overview of building insulation research was conducted to provide further recommendations on insulation type and potential CO₂ savings. From the building walkthrough, it appears that insulating the roof will be difficult due to the absence of an attic space and resident living quarters and staircases directly beneath the roofing facade of the building. Basement insulation may also be challenging since the kitchen, dining room, and other common spaces are located on the basement floor. Locating the kitchen, which is likely to be kept warmer for cooking at the stovetop, in the basement can lead to high amounts of heat loss through the large and poorly-insulated basement space, as demonstrated by the heat transfer model. Because of this, adding spray or rigid foam insulation with a thermal conductivity coefficient of 0.185 (equivalent to an R-value of 5.4) to the interior of the basement can lead to substantial energy savings of approximately 293.81 THM/month, less than the current heat transfer model estimate of 1,148.94 THM/month, a 26% reduction (InsulationRValues.com, 2026). This shows that significant savings can be made without intensive renovations or upgrades, as installing rigid foam insulation in the basement can be done without any special equipment using easily-accessible materials.

Additionally, other common efficiency retrofit measures include **duct sealing, pipe insulation, building envelope insulation, window and door upgrades, low-flow fixtures**, and improvements to **HVAC distribution systems**. These strategies target both thermal losses and system inefficiencies that are common in older buildings.

- **Duct sealing** is the most cost-effective efficiency measure. In many older buildings, duct systems can lose 20–30% of conditioned air due to leaks and poor connections. Sealing ducts can significantly improve system efficiency and typically have a payback period of approximately 2–5 years, depending on building conditions (U.S. Department of Energy, n.d.).
- **Pipe insulation** is another low-cost, high-impact measure, particularly for buildings with hydronic or steam systems. Uninsulated or poorly insulated pipes lose heat before it reaches occupied spaces, increasing energy demand. Insulating pipes can reduce heat loss by up to 80% and often achieve a payback period of 1–3 years (U.S. Department of Energy, n.d.).
- **Building envelope improvements**, including wall insulation, roof insulation, and air sealing, address one of the largest sources of energy loss in historic masonry buildings. Although more capital-intensive than duct or pipe improvements, these upgrades can significantly reduce heating demand and improve occupant comfort. Similarly, upgrading windows and doors or adding weatherstripping can reduce air infiltration and heat loss, especially in buildings with older single-pane windows. For the specific case of Seal and Serpent, since it is in a historical neighborhood, window upgrades would require extra care to ensure that it achieves high energy performance without sacrificing the aesthetic appeal of the original window designs.

- **Low-flow fixtures**, such as efficient showerheads and faucets, contribute to reduced hot water demand, which in turn lowers energy consumption associated with water heating. While individually smaller in impact, these measures are cost-effective and easy to implement as part of broader retrofit efforts.
- **Upgrading HVAC distribution systems**, including ductwork replacement or conversion from steam to hot water systems, can further improve overall system efficiency and compatibility with modern electrification technologies. Many heat pump systems operate more efficiently with low-temperature distribution systems, making these upgrades an important enabling step for electrification.

Among the efficiency-first upgrades in the aforementioned list, duct insulation appears to be an important first step in adding insulation to the Seal and Serpent building. Heat losses from ducts and pipes are likely to reduce the amount of heat lost through the walls or roof in the heat transfer box model, since they indirectly affect the amount of heat lost aboveground. The picture on the left was taken during a walkthrough of the Seal and Serpent building, and shows exposed ductwork, while the picture on the right shows what a properly insulated duct looks like. Starting with duct insulation can be an accessible efficiency-first upgrade for Seal and Serpent to consider.

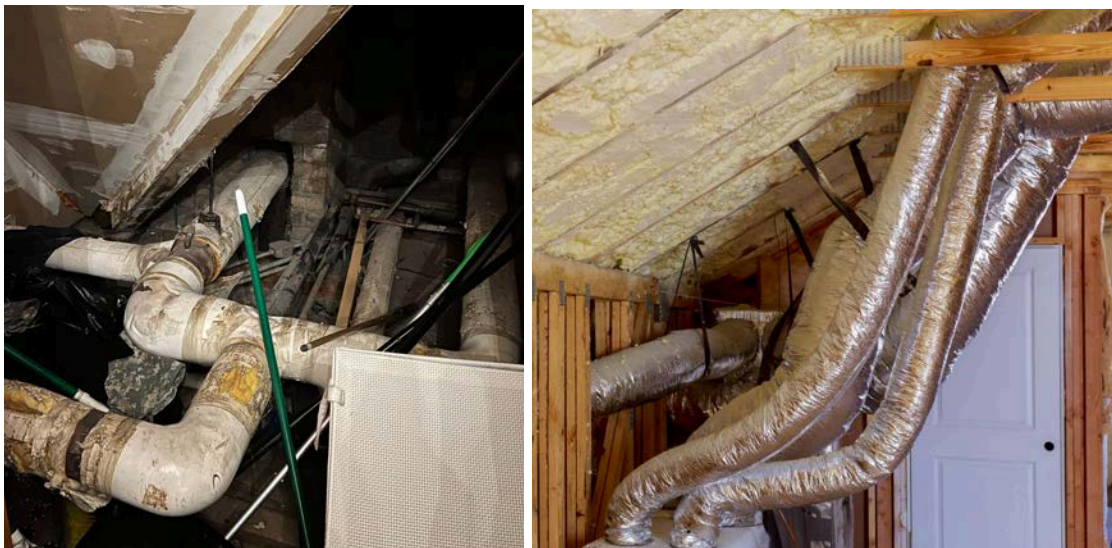


Figure 3. Pictures of building ducts for comparison. Left: an uninsulated duct on the top floor, taken during a building walkthrough. Right: a properly insulated duct, from Smit (2024).

From an economic perspective, efficiency-first strategies provide a strong foundation for decarbonization. By reducing overall heating load, these measures directly decrease the required capacity of heat pump systems and water heating equipment. This reduction in system size lowers upfront capital costs and improves the financial feasibility of electrification projects. Additionally, many of these upgrades qualify for incentives through programs such as NYSERDA Clean Heat and weatherization assistance programs, further improving their

cost-effectiveness. Efficiency upgrades represent a crucial first step in the decarbonization pathway. They provide immediate energy savings, relatively short payback periods, and enable more scalable and economically viable electrification solutions in historic buildings.

Ground Source Heat Pump (GSHP) to Meet Partial Demand

In addition to improving building insulation and energy efficiency, CO₂ emissions from heating can be directly eliminated through the installation of one or more GSHP units, which achieve space and water heating by tapping into geothermal heat beneath the soil surface. See the full section on GSHPs in the Full Decarbonization section for more details on how GSHPs function, installation considerations, and the sizing necessary to completely transition Seal and Serpent's current natural gas usage for heating to clean GSHP generation. However, Seal and Serpent may also choose to install one GSHP unit, or otherwise fewer units than necessary to cover its entire heating demand, and still offset a large portion of CO₂ emissions without full investment in a large GSHP system. A typical vertical well from a ground source heat pump can extract 15.2 W/ft during a heating cycle (Michopoulos et. al, 2013). Assuming a coefficient of performance of 3.9, the total heat provided by a heat pump well, including electricity and ground extraction, is approximately 20.5 W/ft. For a single well, lengths can range from 100 feet to up to 10,000 feet (Sunbelt Drilling, 2025). Residential homes typically install wells in the hundreds range. If Seal and Serpent were to install a single 500 ft well, they could produce approximately 10.25 kW of heat. This is around 29% of Seal and Serpents overall heating demand during the months that require heating. Seal and Serpent can reap significant benefits by installing heat pumps to meet partial demand. While a smaller system will not fully decarbonize the building, they will have a greater return on investment because they have the capability to operate at full capacity for longer.

Full Decarbonization Options

Ground Source Heat Pumps (GSHP)

Ground source heat pumps (GSHP), also known as geothermal heat pumps, are an electrification technology that can replace natural-gas-based heating systems in buildings. Instead of generating heat through combustion, GSHP systems transfer heat between a building and the ground using electricity. Because underground temperatures remain relatively stable throughout the year, the system can efficiently provide heating in winter and cooling in summer (U.S. Department of Energy, n.d.).

GSHP systems operate by circulating a fluid through underground pipes known as ground loops. In winter, the fluid absorbs heat from the ground and delivers it to a heat pump, which upgrades the heat and distributes it throughout the building. In summer, the system reverses and transfers excess heat from the building back into the ground. Since the technology moves heat rather than producing it through fuel combustion, it can deliver several

units of heat for every unit of electricity consumed, making it significantly more efficient than conventional heating systems (Whole Building Design Guide, n.d.).

From an implementation perspective, GSHP systems require several key conditions. Installation involves placing underground piping through vertical boreholes or horizontal trenches, depending on site conditions and available land area. The building must also have a compatible heating distribution system, such as hydronic heating or forced air. Buildings that currently rely on steam systems may require conversion to lower-temperature hot-water systems for compatibility with heat pumps. In addition, adequate electrical capacity is necessary to power the heat pump equipment.

One of the primary advantages of GSHP systems is their ability to substantially reduce or eliminate natural gas consumption for space heating. Because the system operates entirely on electricity, building heating demand can be supplied by renewable electricity from the grid or from off-site sources such as community solar programs. Geothermal heat pumps can also use approximately 25–50% less electricity than conventional heating and cooling systems, resulting in lower long-term operating costs and reduced greenhouse gas emissions (U.S. Department of Energy, n.d.).

There are three main types of wells for GSHP. The first are shallow horizontal wells. They are buried around six feet deep and are installed through horizontal trenches. Their surface area for heat exchange comes from repeated circular coils, and they're generally the most cost-effective for residential homes where land is available. The second type is vertical wells, which extend far deeper into the ground, anywhere from 100 to 10,000 feet (Sunbelt Drilling, 2025). These are ideal for larger buildings and when available land area is limited. The third type is pond/lake heat collectors, which are similar to horizontal wells, except the heat exchangers are placed in a body of water instead of underground. For Seal and Serpent, vertical wells are ideal. The 23-bedroom house is much larger than typical residential homes, and there isn't enough land in the yard to place horizontal wells. Heat from the GSHP is passed to the pipe network of the existing heating system to distribute heat to all parts of the building, with no need to change the existing heat distribution structure.

To meet full decarbonization, we sized the GSHP to meet heating demand in the most extreme conditions possible. Utilizing the box model with an outside temperature of -15°F and an inside temperature of 70°F, the heat pump needs to deliver 115 kW of heat. Assuming a coefficient of performance of 3.9, only 25.9 kW of power would need to be consumed per 115 kW of heat delivered. Installing a heat pump of this capacity would significantly improve Seal and Serpent's energy efficiency, and it would eliminate the house's reliance on natural gas for heating. Figure 4 shows more detailed heat pump sizing calculations.

Coefficient of Performance (COP)	3.9
Degree Difference (F)	85 (-15 outside, 70 inside)
Heat Loss (kW/F)	1.1
Multiplier for Other Losses	1.25
Heat Delivered (kW)	115
Electricity Consumed (kW)	25.9

Figure 4. Sizing Calculations to Meet Full Decarbonization with a GSHP

As mentioned earlier, the GSHP should be sized to 115 kW. Also, each well should be placed 20 feet apart to ensure efficient heat exchange (U.S. Department of Energy, n.d.). Assuming the same load and depth as the singular well in the partial decarbonation pathway, there needs to be approximately 12 wells to meet the demand of Seal and Serpent's heating for full decarbonization. However, a geotechnical engineer would have to come and survey and perform soil samples (borings) before construction and placement of the wells to test bearing capacity and see what's in the soil, as the wells are dug 500 feet deep into the ground. Moreover, more information on the soil should be gathered to determine the actual heating load of the soil. Figure 5 below shows our assumed layout of the wells on the Seal and Serpent's property before any input from the geotechnical engineer. Also, the wells would not go against the historical preservation guidelines for the house and neighborhood, as the wells would be barely visible.

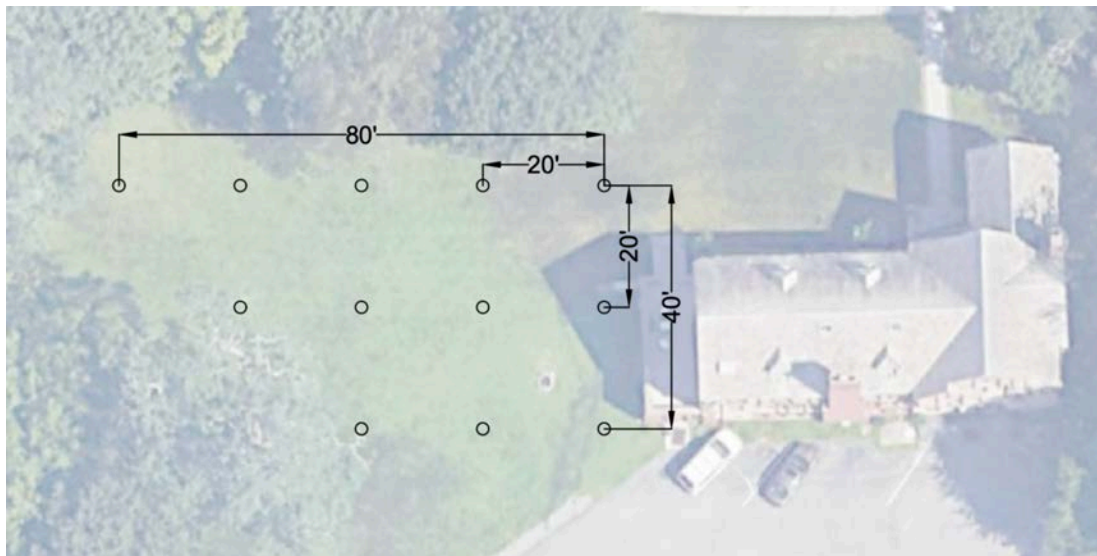


Figure 5. Potential Layout of Heat Pumps for Full Decarbonization

We used the assumptions detailed previously, along with the Seal and Serpent's usage data, to find the levelized cost of electricity (LCOE). From the data, the house's coldest month requires 52,200 kWh of electricity, and the average month requires 19,050 kWh. The annualized

capital cost of GSHP was first found by calculating the entire capital cost, \$195,647.39, and multiplying it by the determined capital recovery factor. The annualized capital cost was computed to be \$15,699.25. Then, the operational cost was found by multiplying the average kWh of heat needed per season by the assumed operating cost per kWh, coming out to \$1,333.63 per season. The electricity cost followed the same calculation, with the average kWh of heat needed multiplied by the assumed electricity cost, resulting in \$13,336.31 per season. Summing the capital, operational, and electricity costs, we found that GSHP costs \$30,369.20 per year, or \$0.23 per kWh in the heating season.

Financial incentives further support the adoption of GSHP systems. In New York State, programs under NYS Clean Heat provide rebates for geothermal installations, and state tax credits may cover up to 25% of installation costs (up to \$10,000). These incentives can significantly reduce upfront capital costs and improve the economic feasibility of electrification retrofits in existing buildings (New York State Energy Research and Development Authority, n.d.). However, there is significant complexity and uncertainty involved in drilling geothermal wells, so there is a risk that the actual cost may be higher than the value estimated above, potentially making the project not financially feasible.

Overall, GSHP systems provide a pathway to electrified heating that reduces reliance on fossil fuels while improving energy efficiency. Although installation requires suitable site conditions and a higher upfront investment, the technology offers long-term environmental and economic benefits for buildings seeking to transition away from natural gas heating. GSHP systems were chosen for this project out of concern that air-source heat pumps would be difficult to integrate into the exterior of the building without a negative aesthetic impact. However, if the ground source option proved too expensive, the organization might revisit this choice and explore whether it would be possible to sufficiently blend airsource heat pumps into the exterior.

Renewable Electricity Supply: Solar

Renewable energy sources can provide cleaner electricity, decarbonizing the energy consumption of projects both during and after construction. Common sources of renewable energy for electricity in upstate New York include solar, wind, hydroelectric, biomass, and geothermal. The limitation to these sources of energy comes from the size constraints on the project; for small-scale projects, there would be no need to build a source of energy that would cost more than the project itself. For this analysis, small-scale projects include those like Seal and Serpent, where the project entails one building with low-cost, economical solutions. Hydroelectric, biomass, and geothermal require large power generation sites, which can be expensive. Wind can be implemented in smaller amounts than the previous three, but is not optimally efficient unless built into large wind farms (which require large amounts of space and certain land conditions). So, for small-scale projects with diverse land needs, the only implementable source of energy narrows down to solar.

Implementation of solar comes in two forms: community and rooftop. Community solar includes access to energy on a solar farm, often run by an outside company. An individual building can opt into usage, rather than investing long-term in its own panels. After paying the opt-in fee, the homeowner can get significant reductions on their electricity bill. On the other hand, rooftop solar builds solar panels on top of the building's roofs. This gives homeowners complete control over their own panels and their own power source. Each type has strong advantages and disadvantages depending on the homeowner's needs.

For Seal and Serpent, the best model to choose would be the community solar option. This option would reduce any upfront costs, especially for any structural analysis or construction needed on the roof. The community solar would reduce the electricity bill, but to determine overall decarbonization effects, other calculations would need to be completed. Community solar could either supplement the entire or partial energy demand, allowing for flexible options in implementation. This makes community solar an ideal option alongside another decarbonization tactic, allowing for a change in energy consumption carbon footprint without high economic costs.

Calculations for the size and price of a solar farm are detailed in Appendix A.1, broken down by coverage of either just heating load, just electricity load, or the combined heating and electric demand. The model predicts the required size to be approximately 206 kW, with 500 panels required.

Economically, the price per kWh equals \$0.089 and the overall price per heating season equals \$92,488.80. This price includes full construction, maintenance, decommissioning, and other costs, most of which would not be paid if attached to existing community solar. Realistically, Seal and Serpent would enter a community solar program with the Cornell Snyder Road Solar Farm, the nearest and most accessible solar location nearby. The Snyder Road Solar Farm has a capacity of 1.8 MW, so the energy demand for S&S could be easily covered by the existing infrastructure. A reference sketch of the specifications of the solar panel layout dimensions (which were used in the calculations of Appendix A.1) is included in Appendix B.1. In addition to fitting under the existing power infrastructure of Snyder Road, the required footprint for the panels to meet S&S demand is also much less than the footprint of Snyder Road. The total Snyder Road area is almost 2.5 million square feet, while the S&S panels would require an approximate area of 20,500 square feet (less than 1% of the total area). A quick birds-eye view of the layout is shown in Figure 6 below.

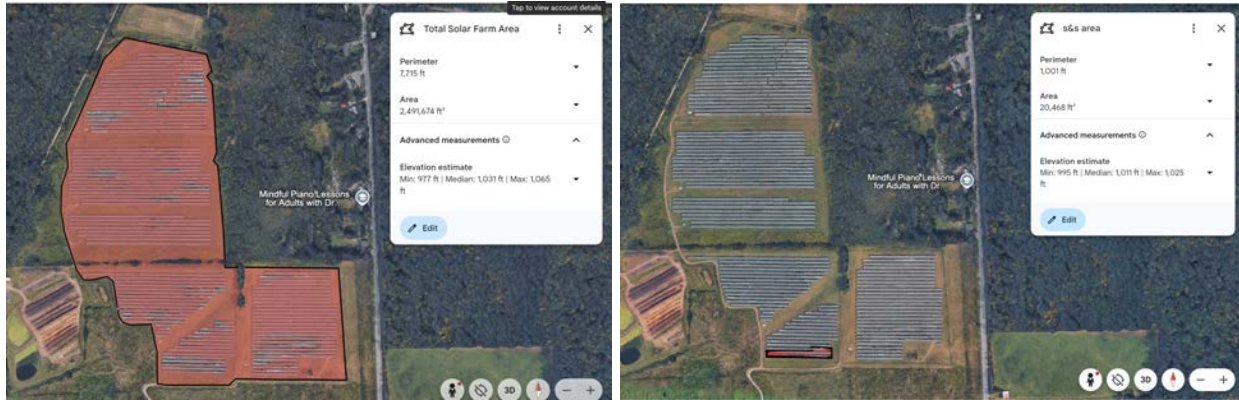


Figure 6. Comparison of Snyder Road Solar Farm size to size of a farm to meet S&S demand

Model Validation with Xendee

Summary of Methods Full Decarbonization

To validate the feasibility of the proposed full decarbonization pathway, a simulation-based analysis was conducted in Xendee using the combined electrified building load profile, proposed ground source heat pump (GSHP) sizing, and community solar sizing estimates developed in previous sections. The purpose of the Xendee model was to evaluate system operational behavior, renewable energy utilization, grid dependence, and the adequacy of proposed system sizing under hourly load conditions throughout the year. Because Xendee operates using a single electrical demand profile or a single thermal profile, the building's baseline electric demand and thermal heating demand were combined into one integrated electrified load profile representing full building electrification via heat pumps. Because Xendee does not simultaneously simulate separate electric and thermal demand streams within the same configuration, both loads were integrated into a single electrified demand profile.

We leveraged Xendee's built-in load curves for space heating and electricity only. First, tabulating monthly baseline energy demand from NYSEG into the electricity-only load curve and then tabulating monthly heating demand into the space heating load curve. These inputs can be referenced in Figures 7 and 8.

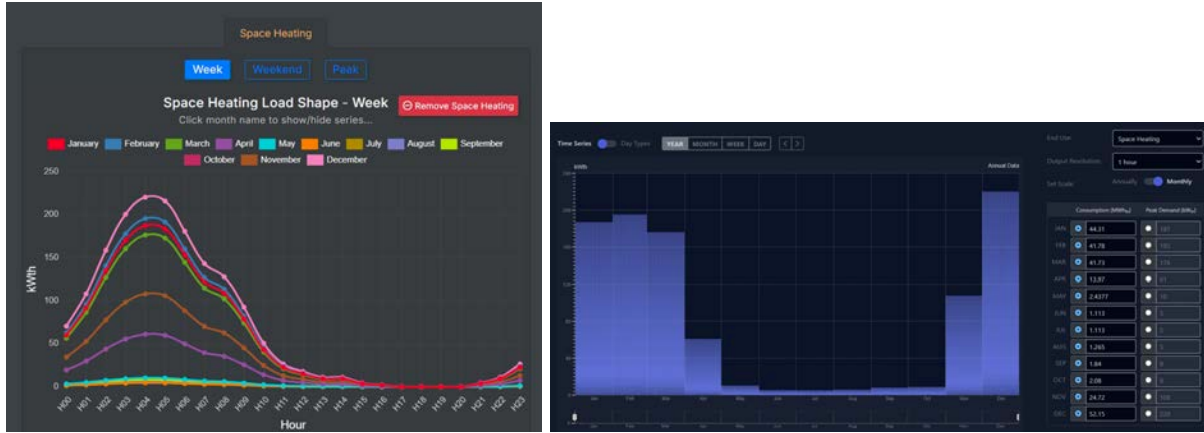


Figure 7. Heating load shape and monthly demand

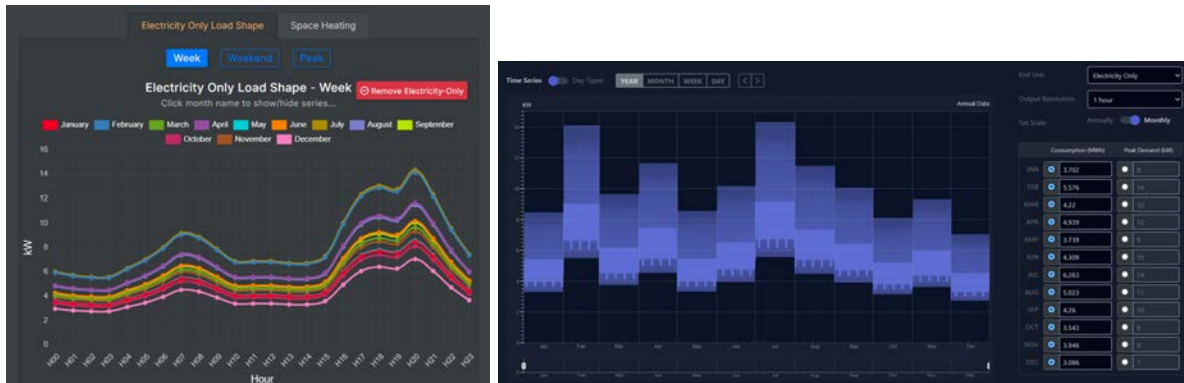


Figure 8. Electricity load shape and monthly demand

We then exported these separate load curves from XENDEE for external processing as CSV files. The resulting thermal heating demand was converted into equivalent electrical demand using a heat pump coefficient of performance (COP) of 3.9. Because a heat pump delivers more thermal energy than the electrical energy it consumes, the electrical input required to satisfy heating demand was calculated by dividing the thermal heating load by the COP at each timestep. The resulting electricity baseline was taken as is. The converted heating load profile was then combined with the baseline electrical demand profile to create a single integrated electrified load curve for the simulation. This methodological approach preserves the temporal variability, seasonal behavior, and peak demand characteristics and accurately represents a combined electrified load profile. This final load profile can be seen in Figure 9.



Figure 9. Combined heat and electric load profile

The proposed GSHP and solar array sizing was then implemented within the Xendee simulation environment. From our GSHP sizing, we used the sizing to meet peak demand for the coldest month which was 62510 Btu/hr or 18.3 kW. The solar array sizing for the full decarbonized/fully electrified model was 205 kWDC. These were input directly into Xendee for the validation simulation and results.

Full Decarbonization

Figure 10 shows the typical electricity dispatch for the fully decarbonized model for the coldest month of January. These dispatch results indicate that the proposed solar array produces substantial excess electricity during midday hours, particularly between approximately 9:00 and 16:00. Simultaneously, significant grid purchases occur during nighttime and early morning hours when solar production is unavailable, and heating demand remains elevated. This operational pattern suggests that while the proposed renewable generation capacity is sufficient to offset a large portion of annual energy demand, system performance is constrained by the temporal mismatch between solar generation and winter heating loads.

This temporal mismatch indicates that this configuration for the fully decarbonized pathway would benefit significantly from investment in battery energy storage solutions. This would inherently do three things: reduce midday curtailment in midday hours, shift excess solar generation in high-demand heating hours, and also reduce grid purchase.

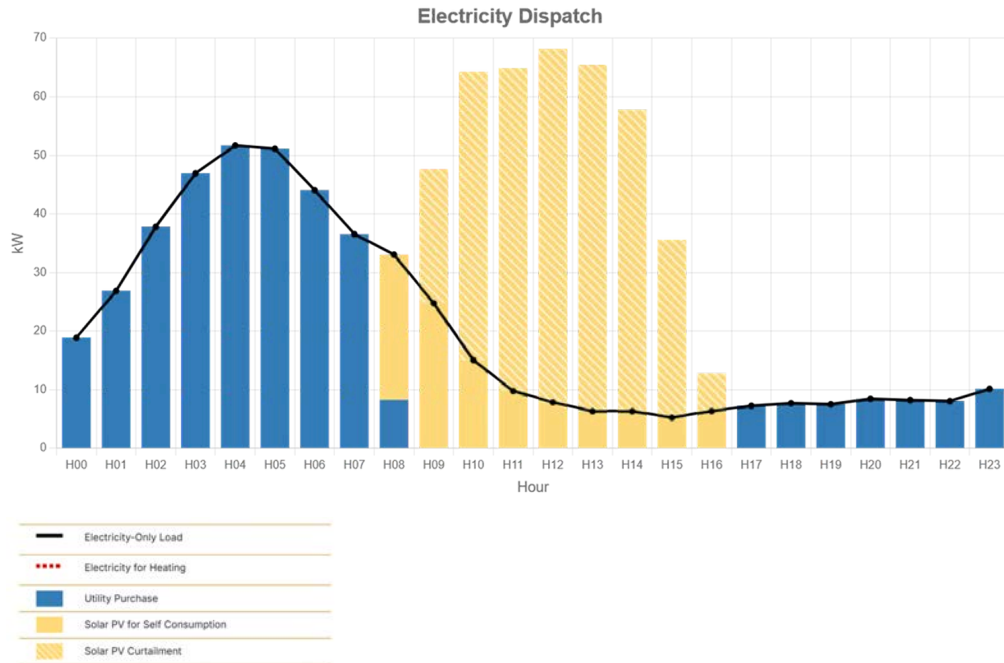
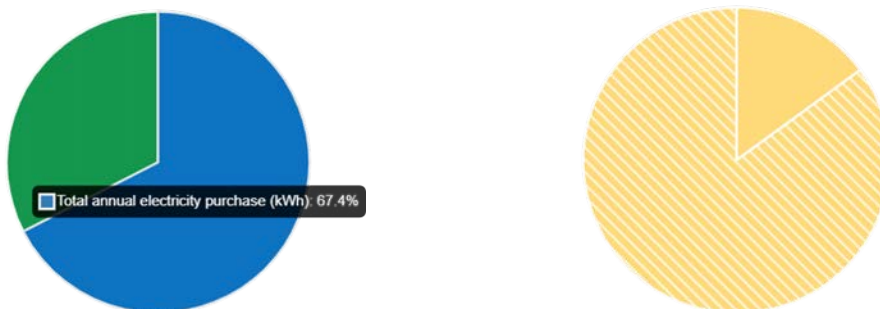


Figure 10. Results from validation model - Full Decarbonization

Finally to get a clearer picture of model performance and if our sizing is adequate it is helpful to look at annual consumption grid purchase as well as on site generation as well generation and curtailment which Figures 10 and 11 depict.

Overall this validation model shows that our sizing calculations for this configuration performed well and is sufficient. Although it also shows that future battery storage deployment could improve self sufficiency. Below in Figure 11 we can see that due to temporal imbalance the energy purchase was 67.4% of the total demand meaning renewables met 32.6% of energy demand. On the other hand in figure 9 over 85% of the energy produced from renewables was curtailed meaning that in future iterations net metering or NEM could help the long term financial cashflow where the ROI would reach higher potential.



Total annual electricity purchase (kWh)	74,974
Total annual on-site generation from renewables (kWh)	36,227
Total	111,201

Electricity Consumed On-site	36,227
Electricity Curtailed	206,222
Total	242,449

Figure 11. Annual electricity purchased from grid as a percentage of total usage - Full decarb scenario

Partial Decarbonization

Given total electrification can be an investment that occurs in phases it is also helpful to validate our partial decarbonization scenarios. Starting with the heating only scenario using previous sizing calculations for our solar array and our heat pump we will model inputs and focus on results to minimize redundancy. The things that changed from the full decarbonization scenario was that we used the heating load curve and tabulated monthly heating demand, we used a 159 kW dc array and our heat pump size was kept as 18.32kWth. The electricity dispatch results for our heating only scenario is shown in Figure 12. For this analysis, baseline electricity load was excluded and solar performance is evaluated only on the thermal load.

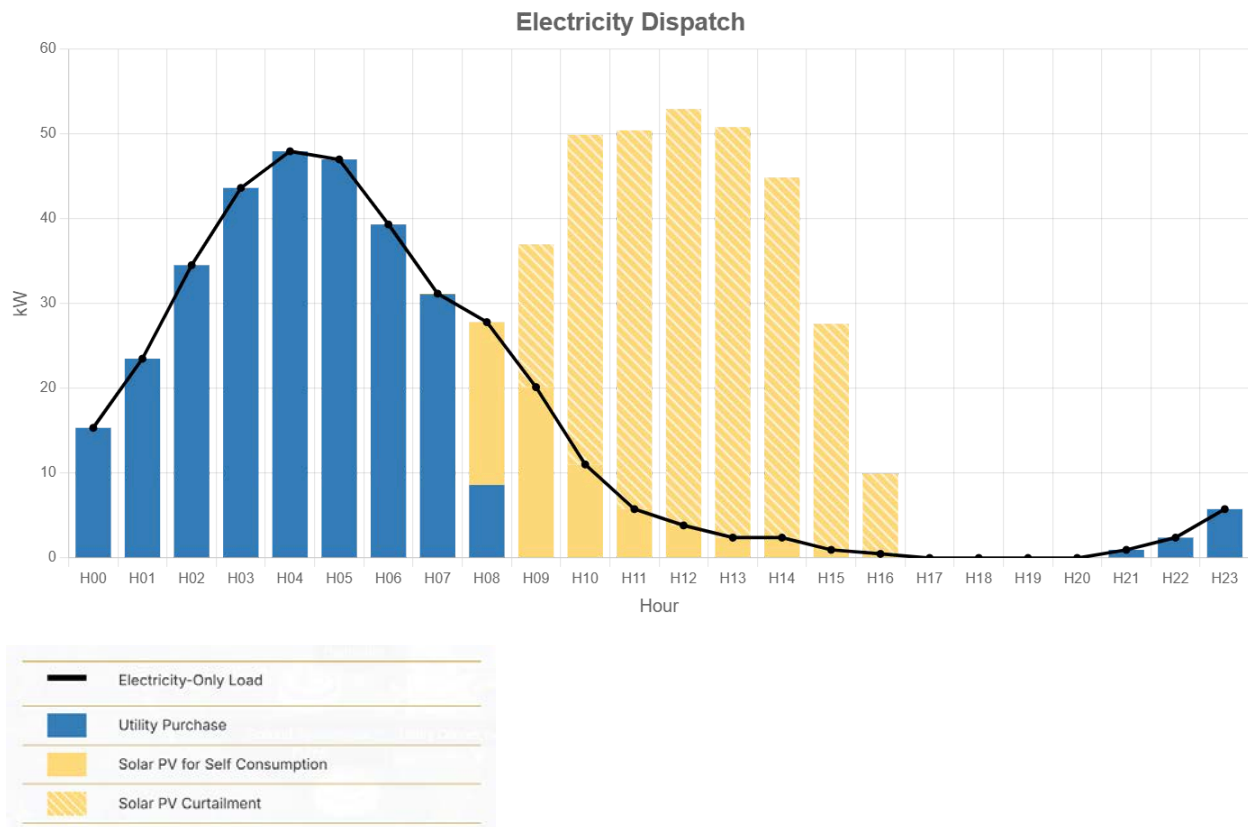


Figure 12. Results from validation model - heating-only scenario

Annual Electricity Balance (kWh) Annual PV Electricity Balance (kWh)

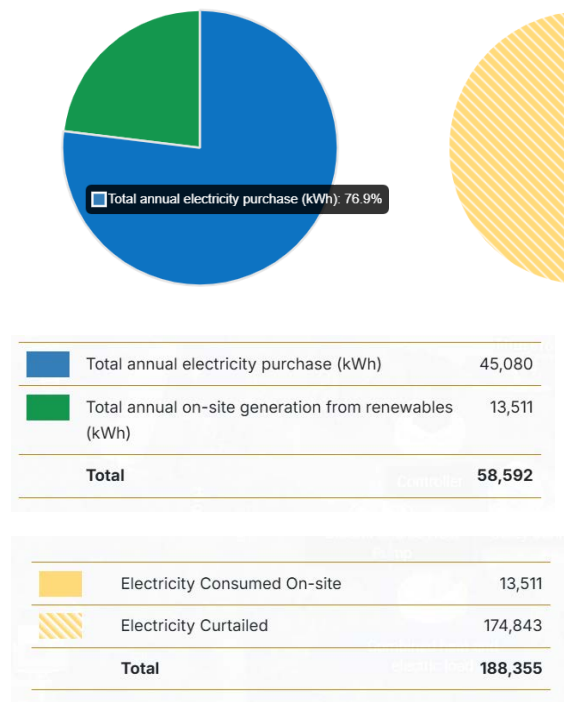
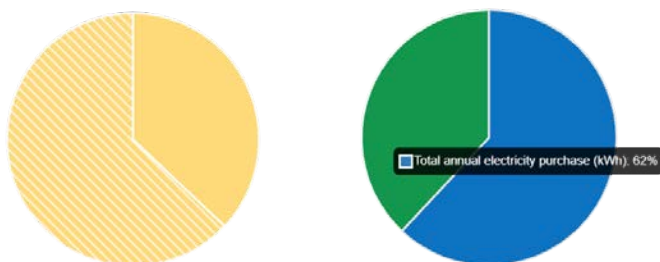


Figure 13. Annual energy purchased, consumed, and curtailed - Heating only scenario

In this scenario we observe a decrease in model performance. This is due to the increase in electricity purchase as a share of the total electricity consumption at 76.9% and the increase in electricity curtailed as a share of total electricity generated on site at 92.8%. The heat only scenario demonstrated poorer renewable utilization compared to the full electrification case due to strong concentration of thermal loading during winter nighttime periods which increased temporal mismatch with solar production.

Finally, for the baseline electricity only scenario there is no GSHP associated with the configuration. The solar array sizing was changed to 45.9kWdc and the electricity baseline load curve was used with the tabulated monthly electricity usage. This scenario temporally matched solar resources and resulted in the lowest electricity purchase share and the lowest curtailment share.

Annual PV Electricity Balance (kWh) Annual Electricity Balance (kWh)



	Electricity Consumed On-site	20,011
	Electricity Curtailed	34,036
	Total	54,048

	Total annual electricity purchase (kWh)	32,598
	Total annual on-site generation from renewables (kWh)	20,011
	Total	52,609

Figure 14. Annual energy purchased, consumed, and curtailed - Baseline electricity scenario

Overall the Xendee calculated avoided emissions from the full decarbonization scenario, the heating only scenario, and the baseline electricity scenario is 31 metric tons, 19 metric tons, and 13 metric tons respectively. Avoided emissions was estimated assuming electricity demand displaced grid electricity with the average NYSEG emissions factor or was directly supplied by on-site renewable generation. Although the baseline electricity only scenario has the best temporal match with solar resources it also results in the lowest avoided emissions.

Conclusion

Recommendations

Building decarbonization is the direction that most large residential and commercial buildings are moving in the current environmental and socioeconomic climate. Electrification allows for greater reliance on local renewable energy sources, stable prices, and lower carbon emissions from building operations. Maintenance of the current Seal and Serpent building is ongoing, which makes it the perfect time to consider energy efficiency and electrification upgrades to achieve carbon-neutral building operations into the future. Analysis of the 2024-2025 energy consumption data highlights the dominance of heating on the building's current energy and especially natural gas consumption. Thus, major reductions in carbon emissions and overall energy consumption would result from a focus on renovations and upgrades in the climate control system.

To achieve full decarbonization of the climate control system – which includes space heating – a GSHP can be implemented to replace the existing natural gas system. A GSHP was recommended to account for historical preservation guidelines that prevent major changes to the building facade, and also the space requirements for residential wells that Seal and Serpent is able to provide. Additionally, Seal and Serpent can switch to a renewable electricity supplier to ensure that the electricity used to power the GSHP and the rest of the building is from a carbon-neutral source. Options for that include opting into a community solar farm or acquiring a portion of a solar farm from either Cornell University or other partners. Switching to a renewable electricity source will also fully decarbonize Seal and Serpent's baseline electricity consumption.

Several efficiency-first building upgrades can also be considered as a first step to decarbonization by reducing the heat loss and required load to the building. Insulation of the roofing, basement, and ducts has the potential to reduce current energy consumption during the heating season by upwards of 25%, which is a substantial return for relatively minor

upgrades. By starting with these efficiency-first upgrades, Seal and Serpent can begin improvements and carbon reductions even without changing their electricity supplier or installing any heat pumps, and thus reduce the peak heating load that is required for the heat pump to provide, and allow for a smaller and more affordable heat pump to cover the building's needs. We recommend Seal and Serpent consider implementing better insulation as a method to achieve reduced carbon emissions while starting discussions about the possibility of fully decarbonizing the climate control system via GSHP installation and solar electricity.

No matter the pathway taken, any implementation of either solar or the heat pump will reduce Seal and Serpents carbon emissions. The addition of the heat pump would reduce emissions from natural gas by approximately 44 tons per heating season, 38% of the total emissions for the house. Emissions from the current grid electricity account for the other 62% for a total of 71.87 tons per year. Full implementation of solar would reduce the electric emissions to zero, but full implementation of solar instead of grid energy can be costly. So, even partial implementation of half solar and half grid energy can cut the emissions in half to 35.94 tons per year. In other words, for every one percent of the energy comes from solar, Seal and Serpents electric emissions decrease by one percent (0.72 tons per year) and their overall emissions decrease by 0.62 percent. Overall, any implementation of either the heat pump or solar will aid in decarbonization.

Contributions from Seal and Serpent Student Liaison

As the president of Seal and Serpent I worked closely with the team of M.Eng students as a liaison between the board of directors to communicate the goals of the project and make sure that everyone involved had all the information they needed. To contextualize the work I did, the Lodge is undergoing substantial renovations that have been in the works for years. Because of these plans and the work that had already been done it made finding the niche for this project to be useful a task unto itself. The project we decided would be the most useful would be a rework and decarbonization of the heating and climate control system.

Future Work

This report is meant to be a high-level overview of potential decarbonization strategies that can help inform Seal and Serpent's future building maintenance and upgrades to consider sustainability. All cost and sizing estimates are for demonstration purposes, and a building-specific site assessment and in-depth cost-benefit analysis should be conducted by licensed and experienced engineering professionals to better understand real-world costs and timelines. Carbon emissions reduction estimates are also approximate and can be modeled more intensively. An analysis with multiyear data for Seal and Serpent's energy consumption may also better inform the building's current energy consumption baseline.

Additionally, ongoing conversations with the students and alumni of Seal and Serpent should be maintained in order to understand the role of environmental sustainability in the

community's priorities. Building durability and cost appear to be the top considerations of the board when considering current maintenance and upgrades, so further study can be done to demonstrate the long-term sustainability, cost effectiveness, and savings from electrification. Ultimately, more in-depth analysis is required to fully illustrate the benefits of decarbonization and specific renovations that are possible for the Seal and Serpent house.

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https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php](https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php)

Appendix A - Excel Models for GSHP and Solar Farm Estimates

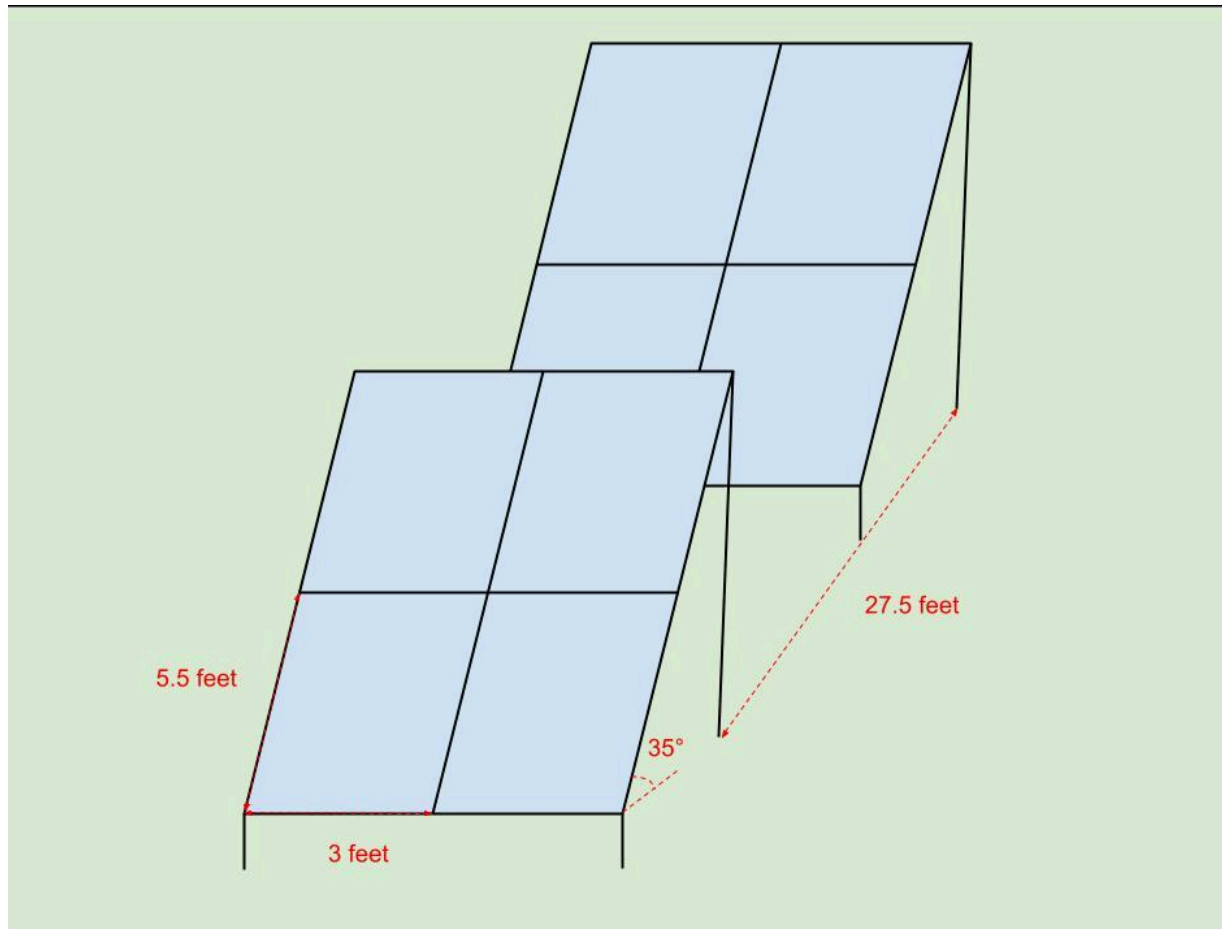
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Appendix A.1: Ground Source Heat Pump Levelized Cost Calculations

A1	Assumptions				
	A	B	C	D	E
1	Assumptions		Conversions		
2	0.05	interest	30	days in one month	
3	20	years	24	hours in one day	
4	1,700	heat pump cost (\$/kW)	0.10	MMBTu per therms	
5	115	kW heat pump system	1,000,000.00	Btu per MMBTu	
6	7	months long heating season	0.03	month per day	
7	3.9	COP	0.04	day per hours	
8	0.1	\$/kWh of heat delivered, energy operating cost	3412	Btu per kWh	
9	0.01	\$/kWh of heat delivered, non-energy operating cost			
10					
11	From data:		Changeable		
12	1780.1	therms/month	Calculated		
13	650.05	therms/month			
14					
	Calculations:				
	Heating hours:	5040	hours per season		
	(A/P, 5%, 20 yrs):	0.08024258719			
	Max heat demand heat needed:	392708.7125	Btu per hour		
		115.0963401	kW		
	Heat Pump System:				
	Cost of system	\$195,500.00	\$		
	Cost of seal	\$195,647.39	\$		
	Annualized Capital Cost	\$15,699.25	\$ per year		
	Average kWh heat needed per season:	4550.35	therms per season		
		455035000	Btu per season		
		133363.1301	kWh per season		
	Operational Cost:	\$1,333.63	\$ per season		
	Electricity Cost:	\$13,336.31	\$ per season		
	Total Cost:	\$30,369.20	\$		
		\$0.23	\$ per kWh		
	TOTAL COST				
		\$0.23	per kWh		

Appendix B - Solar Panel Specifications

Appendix B.1: Specifications for Snyder Road Solar Farm



Appendix C - Seal and Serpent blueprint scans

