DKE Energy Efficiency Improvement Report

Aidan Lane, Anrong Yan, Helena Donnelly, Kai Zhang, Xiaohan Zhou

Cornell University Department of Engineering

CEE 5051: M.Eng Project

Francis M. Vanek

December 20, 2024

Table of contents

Our team:

Aidan Lane(apl82@cornell.edu)

Aidan Lane is a Civil and Environmental Engineering M.Eng from Evanston, Illinois. He also got his B.S. from Cornell in the same program. He has broad experience in the energy industry, doing work in natural gas, waste to energy, and offshore wind. He is an avid sailor which fuels his passion for sustainability. After graduation, he plans to work as either an engineering consultant or an engineer in the renewable energy sector.

Anrong Yan(ay447@cornell.edu)

Anrong Yan is from Beijing, China. He holds a Bachelor of Science degree in Physics from UCLA. He is currently pursuing a Master of Engineering in Environmental Engineering, focusing on renewable energy systems, and is expected to graduate in May 2025. Following graduation, he intends to work in the energy sector.

Helena Donnelly(hbd8@cornell.edu)

Helena Donnelly was born in Rockville, MD and is currently an Environmental Engineering M.Eng and BS student at Cornell University. She has experience in Engineering Consulting and Local Government. She is currently a member of CU Geodata's water subteam and the secretary for the Cornell chapter of Chi Epsilon. After graduation, she plans to work in the renewable energy field in the private sector or in government.

Kai Zhang(kz368@cornell.edu)

Kai Zhang is from Lanzhou, China. He holds a Bachelor of science degree in environmental engineering from Dalian University of Technology. He has experience with atmosphere chemistry and water treatment. After graduation, he plans to work in the field of renewable energy.

Xiaohan Zhou(xz923@cornell.edu)

Xiaohan Zhou is a Civil and Environmental Engineering M.Eng from Ningbo, China. She holds her Bachelor degree in Environmental Engineering from Wenzhou University. She has experience in environmental assessment and environmental monitoring. After graduation, she plans to work in the energy sector.

1. Introduction

The Delta Kappa Epsilon (DKE) house at Cornell, a historic building constructed in 1893, presents a unique opportunity for a forward-thinking sustainability project. As one of the oldest fraternity houses at Cornell and a structure listed on the National Register of Historic Places, it embodies architectural and cultural heritage that must be preserved. However, its historical nature also makes it challenging to adapt to modern energy efficiency standards. This project seeks to bridge the gap between preserving history and advancing sustainability.

Cornell University is recognized as a global leader in sustainability, with landmark projects such as its lake source cooling system, which reduced cooling energy demands by 85%（Cornell University, n.d.). Additionally, Ithaca’s Green New Deal sets an aggressive goal of achieving community-wide carbon neutrality by 2030（City of Ithaca, n.d.), making the city a hub for ambitious climate action. As part of this environment, DKE house provides an ideal case study for implementing energy-efficient technologies in older buildings, demonstrating how historic structures can meet modern sustainability goals.

The motivation for this project is multifaceted. First, the building's outdated heating system—a gas boiler reliant on deteriorating radiators—not only increases energy demands but also contributes to greenhouse gas emissions. Lastly, the building’s insulation is significantly degraded due to age, resulting in unnecessary heat loss and excessive energy use during Ithaca’s harsh winters.

By addressing these issues, the project aims to electrify the heating system and upgrade insulation, transforming the DKE house into a model of sustainable renovation for historic properties. This project aligns with Cornell’s broader climate goals and Ithaca’s progressive energy policies, showcasing innovative strategies to reduce carbon footprints while maintaining the integrity of a historic landmark. The outcomes of this effort will serve as a replicable example for other similar buildings, reinforcing Cornell’s commitment to sustainable leadership and innovation.

2. Scope

The scope of our project aims to improve energy efficiency and reduce environmental impact by implementing key upgrades and analyses. First, the project focuses on enhancing building insulation to lower energy costs and carbon emissions, which directly contributes to reducing overall energy consumption. Second, it includes upgrading the heating system to a more efficient and sustainable solution, ensuring improved energy performance and user comfort. Besides, the assessment is conducted under specific assumptions. Firstly, we assume occupancy levels remain the same, maintaining a level of 24 people. Second, for energy consumption patterns, we’ve considered typical usage behaviors in similar buildings, ensuring our recommendations align with realistic demands while upgrading efficiency. Thirdly, we assume the local climate in Ithaca remains consistent, which includes considering the historical weather patterns, like cold winters and humid summers.

3. Market Analysis

In this section, we will explore our initial findings concerning heating systems and insulation systems, as well as other key factors within these markets.

3.1 Insulation system analysis

Our insulation system analysis focused on identifying cost-effective, sustainable, and high-performance options for improving energy efficiency in the DKE house project. Through our market investigation, three primary insulation methods were evaluated:

1. Blow-in Cellulose (Bob Vila, n.d.):
   - Made from recycled paper, it is eco-friendly and offers good thermal performance.
   - With a cost range of $0.3–$1.8 per square foot, it is one of the most affordable options.
   - The material conforms well to irregular shapes, making it ideal for attic spaces like the DKE roof. However, it may settle over time and requires periodic maintenance.
2. Spray Foam (The Spruce, n.d.):
   - Known for its excellent insulation properties (high R-value) and ability to seal gaps, it performs well in basements and crawl spaces.
   - The cost ranges from $1.00–$1.50 per board foot, but it requires professional installation and has a high upfront cost.
3. Mineral Wool (Bob Vila, n.d.):
   - This material is fire-resistant, moisture-resistant, and provides excellent thermal and sound insulation.
   - Despite its performance benefits, it comes at a higher price, $1.00–$2.50 per square foot, making it less favorable for projects with budget constraints.

After analyzing these options, blow-in cellulose insulation was selected for the DKE house due to its affordability, environmental benefits, and suitability for the attic's irregular space. This choice aligns with the project's goal of improving energy efficiency while adhering to sustainable and cost-conscious principles.

3.2 Electricity Price Analysis

The average electricity price in Ithaca is $0.17 per kilowatt-hour (kWh). However, the DKE building currently pays a lower price of $0.107 per kWh. Although DKE currently buys electricity below market rate, we still expect electricity prices to rise due to inflation and regulation. This could impact the cost of electricity for the building.

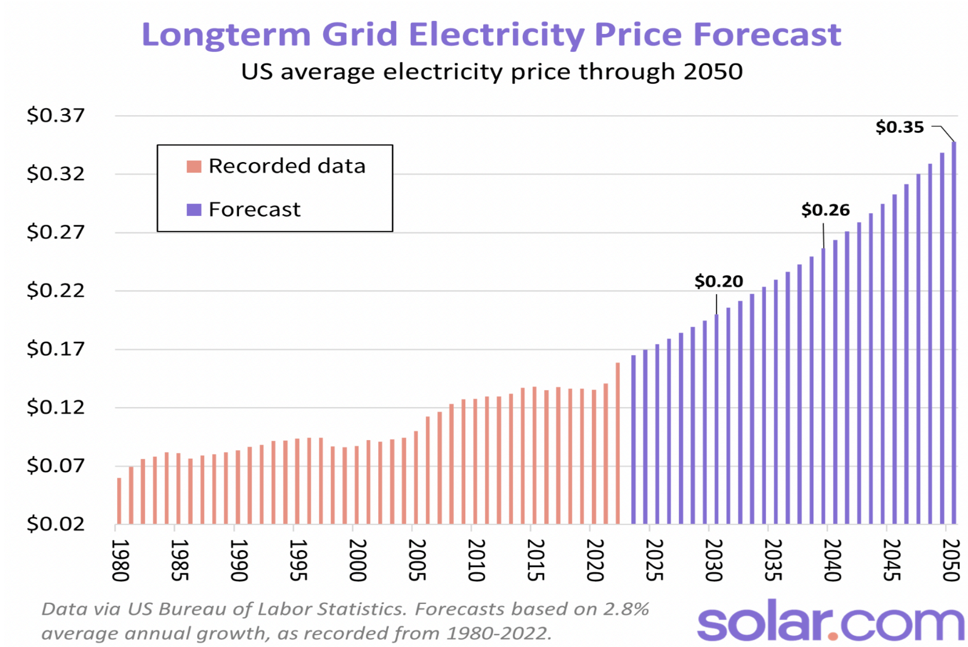

Figure 1: Electricity Price Recorded Data and Forecast

4. Current HVAC Systems

4.1 Current Heating and Cooling Systems

The DKE building is currently heated by four gas-fired boilers, each with a capacity of 300 MBH (1 MBH = 1,000 BTU/hr). The heat is distributed throughout the building using baseboard heaters and wall-mounted convectors. Domestic hot water is provided by a 100-gallon gas water heater with the same capacity. This heating system relies entirely on natural gas, which becomes less efficient during periods of high demand, especially in the colder months. In the coldest months, gas boilers struggle with high demand, heat loss through walls and pipes, and system limits, making heating less efficient. Additionally, the system's distribution infrastructure, including piping and convectors, is visible in some areas, which can impact aesthetics. (Tran & Bell, n.d.)

The building does not have a centralized cooling system. Some students use window air conditioners in individual rooms, which are not energy-efficient. Areas like the Weight Room and Chapter Room rely solely on natural ventilation, such as opening windows. However, this method is insufficient during colder seasons. There is no cooling available in the corridors or upper floors, leading to discomfort during the summer months. The lack of a centralized system or other cooling solutions affects the overall indoor comfort, particularly in warmer weather. (Tran & Bell, n.d.)

4.2 Current Insulation and Electrical Supply

The DKE building has limited insulation in some areas. Walls, attics, and floors only provide basic thermal protection, and some parts of the building, like exposed structures or historical features, do not have proper insulation. This lowers the building's energy efficiency, leading to higher heating needs in winter and more cooling in summer. (Tran, n.d.)

To improve energy efficiency, insulation can be added to wall and floor cavities to reduce heat loss in winter and heat gain in summer. Attic insulation can be installed or upgraded to prevent heat from escaping, and floors, especially in the basement, can also be insulated to save energy. However, these improvements need to consider the building's design limits and the need to preserve historical features. (Tran, n.d.)

The DKE building's electricity is currently provided by NYSEG, with a 200A single-phase 120/240V system. Power is distributed to different parts of the building through four panelboards. The current electrical system is fully loaded and cannot support any additional power needs. This limits future upgrades, such as installing electric HVAC systems or other equipment. Based on the anticipated power demand, it is recommended to expand the service to a minimum of 300A, or potentially higher depending on specific equipment and system upgrades.(Cornell University, n.d.)

5. Solar Array Design

5.1 Solar Array Design Variables and Considerations

While DKE already buys its energy from a renewable energy provider, we wanted to explore the alternative option of Cornell or DKE itself supplying its own power through the use of a solar array. There are a number of choices to be made when designing such a system, including array type, array location, panel tilt, and panel spacing. In the following subsection, we will explain how we made these choices.

5.2 Solar Array Design Methods

The first two decisions to make were solar array type and location. For solar array type, the main types being considered were rooftop-mounted solar and ground-mounted solar. Due to the slope of DKE's roof, it is not ideal for rooftop solar, so it was decided to focus the design on ground-mounted solar. As for location, we choose offsite due to the lack of space on DKE's lawn, the shading of DKE's lawn, and historical preservation considerations as a solar array on DKE's lawn would likely disrupt the historic feel of DKE.

To determine panel tilt and spacing, a 10 kW basis was used for capital costs. Namely, we used $2.3/ft^2 for land (Graziose, 2023). (located outside of Ithaca due to land prices), and $1,119/kW of installed solar panels (Dummit et al., n.d.). Using PV watts, we found the expected production of the solar panels at different tilts. It was found that tilt didn't have a large impact on production, however the maximum production of the angles evaluated (every 10 degrees) was found to be 11677 kWh/yr at a 30 degree tilt.

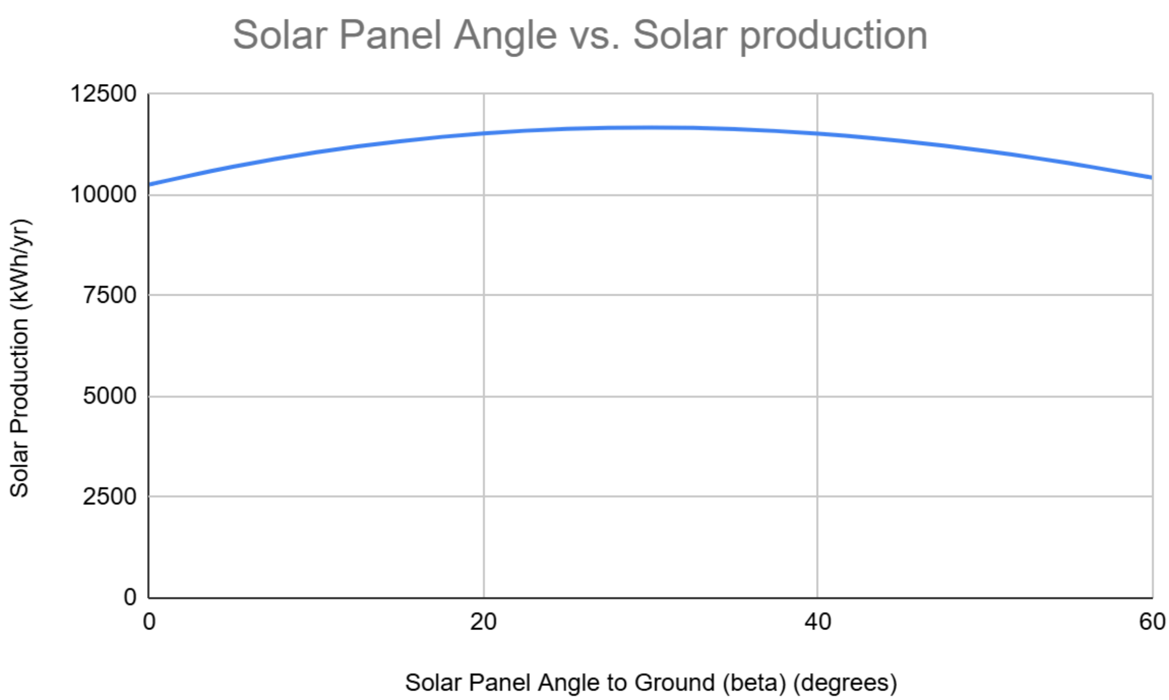

Figure 2: Solar Panel Angle vs. Solar Production

Since land in the selected area is cheap enough not to have a major effect on the LCOE of the system, a spacing distance that prevented shading was chosen. The following equations were used to find this distance (*Shade Calculator - EasySolar*, n.d.).

$$\alpha_{min} = 90° - (\varphi + 23.57°) = 90° - (42.44° + 23.57°) = 23.99°$$

Where α_{min} is the minimum solar altitude and φ is the latitude.

$$Z = L\sin(180° - (\beta + \alpha_{min}))/\sin(\alpha_{min}) = (130\ in)\sin(180° - (30 + 23.99)°)/\sin(23.99°) = 258.6\ in$$

Where L is the long side of each solar panel (130 inches in this case), β is the tilt of the solar panel, and Z is the north-south spacing distance.
Additionally, transmission costs must be considered for the final cost. In 2020, transmission was found to be $0.043kWh on average (Anderson, 2024).

The results are that, for a 10 kW array with a 30 degree tilt, 276.15 ft^2 of land would be required, with a total capital cost of $11,644.42 and a yearly payment of $1,056.81 assuming a 20 year lifespan for the panels and a 6.5% interest rate. Before adding transmission costs, the electricity would have an LCOE of $0.09/kWh, and after accounting for transmission costs, the cost would be $0.133/kWh.

6. Heating Loads Estimation

We used two different methods for estimating the heating and cooling requirements of DKE, they are both outlined below.

6.1 Method 1

Method 1 involves calculating the building's heating and cooling requirements using fundamental heat transfer principles. This method takes into account the building dimensions, wall R-values, and daily average outdoor temperature to determine the heat transfer rate. The equation used is:

$$Q = \frac{1}{R-value} \times Area \times (T_{indoor} - T_{outdoor})$$

where: Q represents the heat transfer rate (BTU/hour or Watts); R-value is the thermal resistance of the material, with higher values indicating better insulation; Area refers to the surface area through which heat transfer occurs; T_indoor ad T_outdoor represent the indoor and outdoor temperatures, respectively. The model outputs daily heating and cooling demands required to maintain an internal temperature of 65°F, allowing for individual control of building sections. Limitations of this method include the use of daily average temperatures from Ithaca airport, which may not account for microclimate variations, and the assumption of no interior walls or imperfect convection, which can increase energy loss. Additionally, wall materials (stone, brick, stucco, and roof insulation) were mapped and analyzed with respective R-values to quantify their contribution to heat transfer.

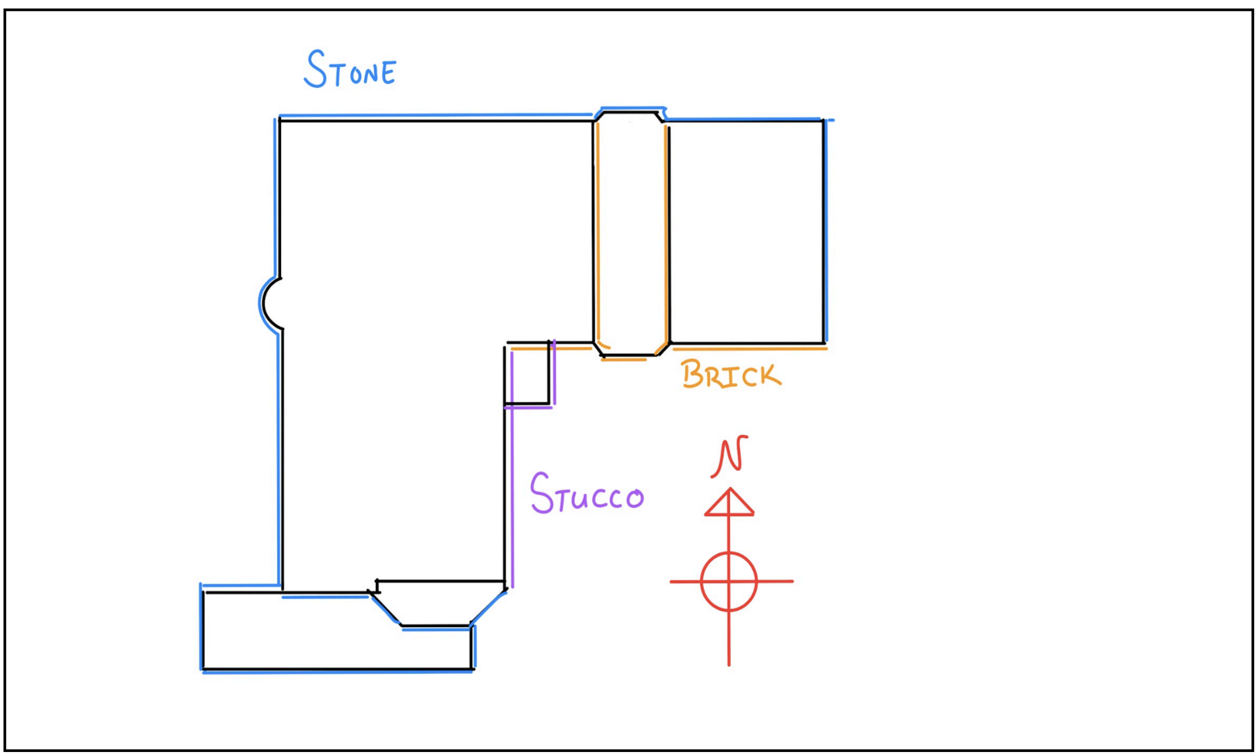

Figure 3: Wall Materials Map

Table 1: R-values of Different Materials

Material	Description	R-value(ft^2 °Fh/BTU)
Stone	6'' stone veneer over 12'' brick	2.88
Brick	4'' white brick veneer over 8'' brick	2.4
Stucco	Stucco on metal over 8'' brick	1.6
Roof	Wood sheathing + asphalt shingles + insulation	20

Figure 2 and Table 1 shows the R-values we used for walls and roof.

6.1.1 Estimated Monthly Heating and Cooling Demand Based on Method 1

Table 2: Monthly Heating and Cooling Demand for Year 2022 and 2023

Month	buildingHeat 2022	buildingHeat 2023	buildingCool 2022	buildingCool 2023
	kWh	kWh	kWh	kWh
January	69,731	49,187	0	0
February	53,367	46,190	0	0
March	44,066	46,872	0	0
April	30,006	23,132	0	1,418
May	9,856	17,344	3,206	1,276
June	4,102	5,038	5,081	4,458
July	507	414	11,347	9,919
August	1,023	2,114	9,339	4,224
September	7,980	8,575	2,270	2,860
October	23,025	19,302	0	926
November	33,134	40,120	278	0
December	52,344	42,113	0	0
Total	329,140	300,400	31,521	25,080

Table 2 shows the monthly heating and cooling demand for the DKE building based on method 1, calculated using Heating Degree Days (HDD) and Cooling Degree Days (CDD). These metrics reflect the difference between outdoor temperatures and a reference indoor temperature of 65°F. The heating demand for 2022 and 2023 totaled 329,140 kWh and 300,400 kWh, respectively, with the highest heating loads occurring in January and February. Cooling demand, recorded only from April to October, totaled 31,521 kWh in 2022 and 25,080 kWh in 2023, peaking in July. The presence of both heating and cooling demand in the same month, particularly during transitional periods like May to September, occurs due to temperature variations across days and within a single day. During these months, daytime temperatures can rise above the reference indoor temperature of 65°F, requiring cooling, while nighttime or early morning temperatures may drop below 65°F, requiring heating. Additionally, fluctuating weather patterns, such as cold fronts or heat waves, can cause temperatures to oscillate around 65°F over several days, contributing to both heating and cooling needs. Since the model calculates heating and cooling demand on a daily basis, it reflects these variations. The maximum heating load was determined to be 140 kW, while the maximum cooling load reached 35 kW, based on the extreme temperature condition.

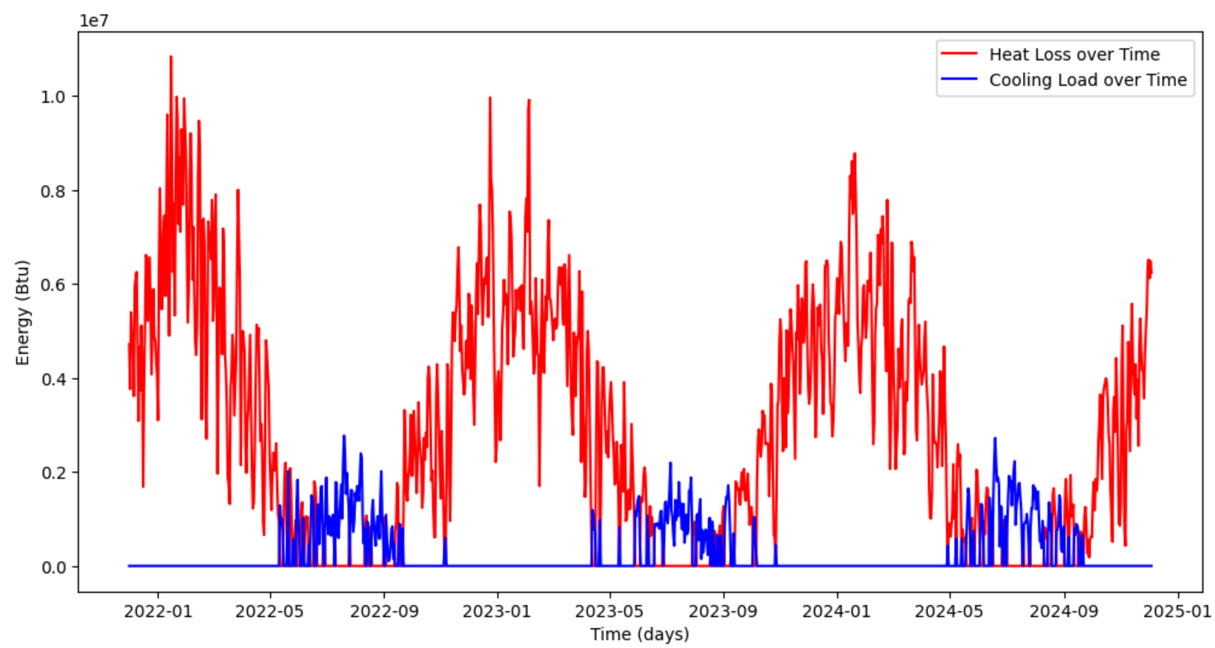

Figure 4: Estimated Daily Heating and Cooling Demand

Figure 3 and Figure 4 are the estimated daily and monthly energy demand. The values in Figure 3, originally in Btu, were converted to kWh in Figure 4. This conversion was done using the standard factor of 1 kWh = 3,412 Btu. The monthly energy amounts in Btu were summed up and divided by 3,412 to obtain their equivalent values in kWh.

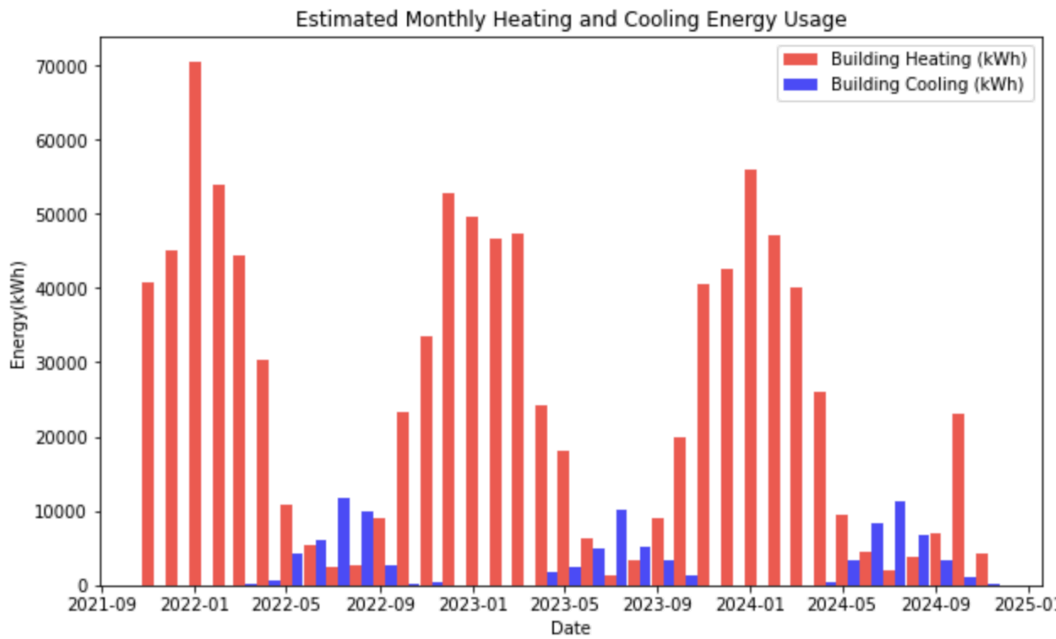

Figure 5: Estimated Monthly Heating and Cooling Demand

6.1.2 Chapter Room Isolation

The Chapter Room is a specific room in the DKE house that is usually only occupied once per week for chapter meetings. It is also particularly isolated from all the other rooms in the DKE house, being on the far east side of the house, on the other side of an archway that the driveway runs through. There is also a lot of heat loss through the Chapter Room as it is exposed on all four sides. Due to this, we decided to investigate if energy could be saved by only heating the Chapter Room when in use. For this, we assumed that the room would be in use for one day per week. For the other six days of the week, the chapter room would not be heated, and on the one day it is used, it would both need to be heated up to 65°F and then maintained at that temperature throughout the day. We found that by only heating the Chapter Room one day per week, we could reduce the heat loss of the chapter room from 108 MMBtu per year to 17 MMBtu per year. This 91 MMBtu decrease in heat loss from the Chapter Room equals roughly an 8% decrease in total heat loss. Therefore, we recommend having the chapter room on a separate heating system if possible.

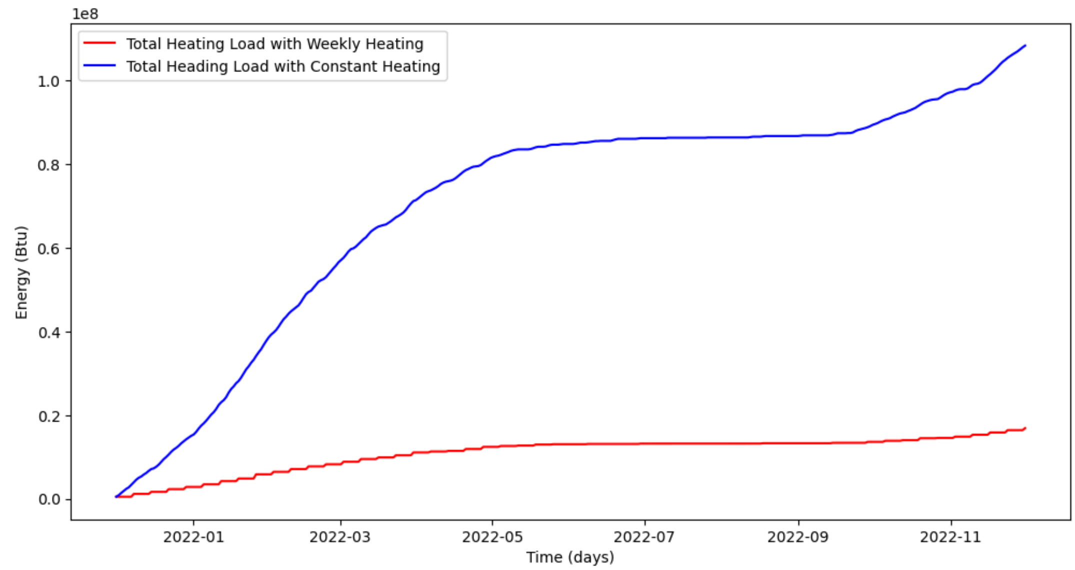

Figure 6: Chapter Room Heat Loss with Constant and Weekly Heating

6.2 Method 2

Method 2 used real gas usage to predict heating demand. To get estimated gas to heating, we used average monthly heating demand over the past four years and subtracted estimated gas for hot water and cooking. To get estimated gas used for hot water and cooking, we took the average across the summer months when no gas would be needed for heating. With this method, the average total heating demand across a year was 272,000 kWh.

Month	Average Natural Gas Consumption	Average Natural Gas Consumption	Estimated Hot Water + Cooking	Estimated Hot Water + Cooking	Estimated Heating	Estimated Heating	Percent of Max Heating
	(therms)	(kWh)	(therms)	(kWh)	(therms)	(kWh)	(%)
January	2,385	69,870	458	13,405	1,927	56,465	100.00%
February	2,132	62,474	458	13,405	1,675	49,068	86.90%
March	1,704	49,933	458	13,405	1,247	36,528	64.69%
April	1,108	32,463	458	13,405	650	19,058	33.75%
May	643	18,827	458	13,405	185	5,422	9.60%
June	436	12,789	436	12,789	0	0	0.00%
July	445	13,040	445	13,040	0	0	0.00%
August	491	14,387	458	13,405	34	982	1.74%
September	531	15,561	458	13,405	74	2,155	3.82%
October	640	18,740	458	13,405	182	5,334	9.45%
November	2,166	63,474	458	13,405	1,709	50,068	88.67%
December	2,050	60,051	458	13,405	1,592	46,646	82.61%

Figure 7: Estimated Monthly Heating Demand

7. Recommendations & Specifications for HVAC Systems

7.1 Heating Methods

There are a few heating options for the DKE building, each with pros and cons. Electric resistance heating is easy to install and converts electricity to heat efficiently, but high energy losses in power generation and transmission make it costly to run. Active solar heating offers incentives for installation but requires solar collectors and hot water storage, which might not be allowed since DKE is a historic building. Additionally, Ithaca does not receive much solar radiation during the winter when heating demand is at the highest. The existing furnace heating runs on natural gas, which is not very efficient. Heat pumps are a great option because they use up to 65% less electricity than furnaces, but ducted systems are hard to install, and ductless systems can be costly to maintain. Choosing the right option will require balancing cost, efficiency, and what is practical for the building.

7.2 Heating and Cooling Options

Among the above heating methods, we considered the heat pumps as our heating and cooling option. There are two common types of heat pumps, Air-Source Heat Pumps (ASHP) and Ground-Source Heat Pumps (GSHP). ASHPs extract heat from the outdoor air, even in colder climates, and are more cost-effective to install as they avoid the need for underground components. However, their efficiency can fluctuate with changing outdoor temperatures. On the other hand, GSHPs extract heat from the ground, delivering consistent performance throughout the year. Despite their higher upfront installation costs due to the need for ground loop systems, GSHPs offer greater efficiency and lower operational costs over time. The comparison underscores the trade-off between the two systems, with ASHPs providing a more affordable initial investment and GSHPs delivering higher long-term reliability and energy savings (*Air Source Vs Ground Source Heat Pumps*, 2024).

7.2.1 Air Source Heat Pumps

Two types of ASHPs are evaluated based on their efficiency and cost-effectiveness. According to our calculated max heating load based on method 1, the capacity was chosen to be 140kW. Since the max cooling load is much smaller than the max heating load, this capacity value would also be enough for cooling.

7.2.1.1 Packaged ASHPs System

In a packaged system, all the components (compressor, condenser, and evaporator) are contained in a single unit, typically installed outdoors, either on the roof or on the ground near the building. Packaged systems deliver conditioned air directly to the indoor space through ductwork.

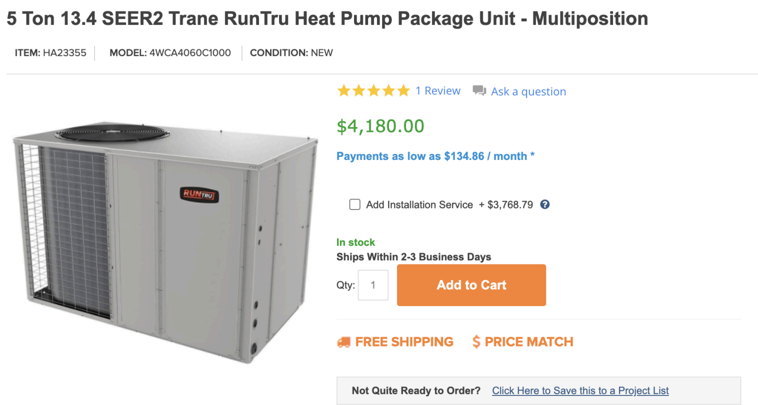

Figure 8: 5-Ton Package Unit

The 140kW Packaged heat pump system has an initial cost of $63,584, which includes installation and a warranty covering 5 years for parts and 10 years for the compressor. It has a coefficient of performance (COP) of 1.97 for heating and 3.35 for cooling, and a life span of 15 years. The difference in COP values for heating and cooling is due to the varying temperature differences during the respective periods. The temperature difference would be higher during the winter period, resulting in a lower COP value. For the LCOE calculation, we used the average heating and cooling demand values from 2022 and 2023, based on our Python model. The heating period spans the entire year, while the cooling period runs from March to October. Given that the max cooling load is one-fourth of the max heating load, we allocated one-fifth of the initial cost to cooling and four-fifths to heating. The electricity rate of $0.107/kWh was determined using the average rate from DKE's current NYSEG bill, and we applied an inflation rate of 2.5%. This resulted in levelized costs of energy (LCOE) of $0.0670/kWh for heating and $0.0668/kWh for cooling.

7.2.1.2 Split ASHP System

Ductless split systems consist of an outdoor unit and one or more indoor units that are directly connected via refrigerant lines. Each indoor unit can be individually controlled.

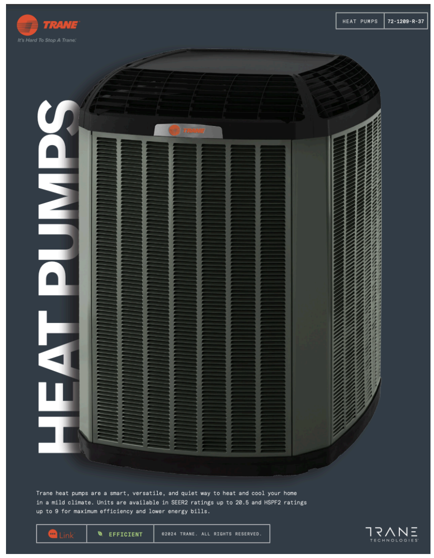

Figure 9: 5-Ton Split Unit

The 140kW split heat pump system has an initial cost of $100,800, which includes installation and a warranty covering 10 years for the compressor. It has a coefficient of performance (COP) of 2.29 for heating and 3.58 for cooling, and a life span of 15 years. To calculate the LCOE, the same electricity rate and inflation rate as those used for the packaged system were applied, resulting in an LCOE of $0.0633/kWh for heating and $0.0797/kWh for cooling.

7.2.1.3 Comparison Between Package and Split Systems

For both systems, the LCOE for heating is higher than for cooling, which is due to the lower COP values for heating compared to cooling. The packaged system has a higher LCOE for heating but a lower LCOE for cooling when compared to the split system. Between these two systems, we recommend the packaged system because the split system is prone to potential refrigerant leakage issues. Such leaks can occur due to corrosion, improper installation, or physical damage, leading to refrigerant loss and reduced system efficiency. Additionally, refrigerant leaks can cause damage not only to the building but also pose risks to its occupants. The maintenance costs associated with repairing refrigerant lines are extremely high, making the split system less favorable.

7.2.2 Ground Source Heat Pumps

There are three types of GSHPs, horizontal loop, vertical loop, and lake source. Lake source is not viable for DKE due to the lack of a body of water in close proximity, therefore we are only considering horizontal loop and vertical loop systems. Similar to ASHPs, the capacity was chosen to be 140kW when carrying out calculations.

7.2.2.1 Horizontal Loop System

Horizontal loop loop systems run coolant in lines roughly one to two meters below the surface. They require roughly 800ft^2 of area per ton of heating to operate efficiently (1 ton of heating is equivalent to roughly 3.5 kW). The usable land area around DKE is roughly 12,000ft^2, meaning the maximum system size would be 52.5 kW.

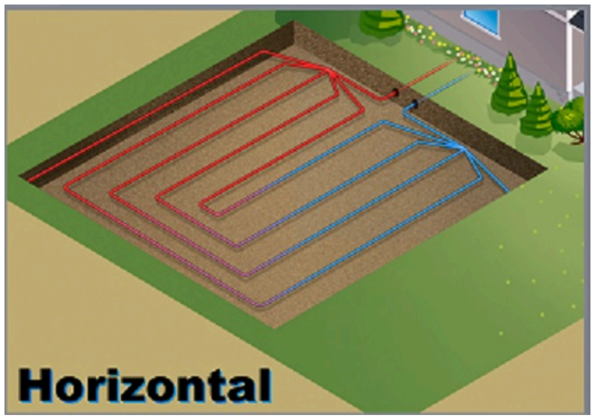

Figure 10: Horizontal Loop System Diagram

Since the majority of the cost for ground source heat pumps is the installation and land surveying, there is a wide range of costs. Estimated horizontal loop system costs for a typical house needing five tons of heating is anywhere from $15,000-34,000 (Maday, 2022). Our system would need to be eight times larger than, but with possible returns to scale, we estimated that the total cost would be somewhere between four and eight times this amount. COPs for a horizontal loop system are 4.2 for heating and 7.2 for cooling on average, but depend on the temperature of the ground. The piping for coolant circulation has a lifespan of 50 years while the heat pump itself has a lifespan of 25 years. Using average values for capital cost, an electricity rate of $0.107/kWh, and an inflation rate of 2.5%, we calculated an LCOE of $0.057 for heating and $0.075 for cooling.

7.2.2.2 Vertical Loop System

Vertical loop loop systems run coolant through a system of wells which are sized to handle the total capacity needed by the heat pump. Since the wells can hypothetically be dug as deep as needed, land area is not a constraint on the size of the system. However, in some locations vertical loop systems may not be possible due to the rock structure possibly limiting depth.

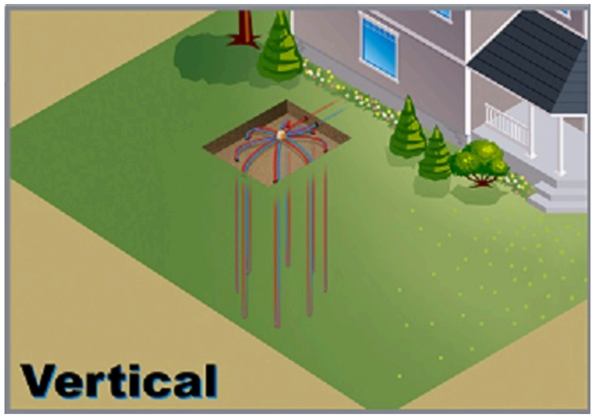

Figure 11: Vertical Loop System Diagram

Estimated vertical loop system costs for a typical house needing five tons of heating is anywhere from $20,000-38,000 (Maday, 2022). COPs for a vertical loop system are 4.5 for heating and 7.5 for cooling on average, higher than horizontal loop systems since the ground temperature is more constant but it still depends on the temperature of the ground. The wells have a lifespan of 50 years while the heat pump itself has a lifespan of 25 years. Using average values for capital cost, an electricity rate of $0.107/kWh, and an inflation rate of 2.5%, we calculated an LCOE of $0.062 for heating and $0.087 for cooling.

7.2.2.3 Comparison Between Vertical Loop and Horizontal Loop

Horizontal loop GSHPs have lower LCOEs than vertical loop systems due to having lower upfront capital costs, even though vertical loop systems have higher COPs. The difference would likely be made greater by Cornell's use of union labor, as most of the capital cost is labor cost. It is also impossible to know whether a vertical loop system is possible until professional tests are done on the ground beneath DKE. Due to these two factors, we recommend horizontal loop systems.

8. Summary of Final Design

8.1 Final HVAC Design

Since ground source heat pumps (GSHPs) are more cost-effective than air source heat pumps (ASHPs), we aimed to maximize the use of GSHPs. Figure 10 illustrates the available area around the DKE building for GSHP installation. However, due to limited space, we could only install a 52 kW GSHP system. To optimize costs, we selected the more affordable horizontal loop configuration. To meet the total capacity requirement of 140 kW, we supplemented the system with a 88 kW packaged ASHP to fulfill the remaining demand.

Our final HVAC design incorporates a hybrid system consisting of a 52 kW horizontal loop ground source heat pump and a 88 kW packaged air source heat pump. The total initial cost of the system is $122,240, which includes $82,500 for the ground source heat pump and $39,740 for the air source heat pump. The air source heat pump requires replacement every 15 years at a cost of $39,740, while the heat pump portion of the horizontal loop system needs replacement every 25 years at a cost of $28,125. The overall system achieves a levelized cost of heating (LCOH) of $0.06325/kWh and a levelized cost of cooling (LCOC) of $0.07/kWh. This design optimizes both performance and cost-effectiveness by leveraging the consistent efficiency of the ground source heat pump and the lower installation costs of the air source heat pump.

Figure 12: Available Area Around the DKE Building for GSHP Installation

8.2 Alternative Vertical Loop Design

A system combining horizontal loop GSHPs and packaged ASHPs produces the lowest LCOEs for both heating and cooling, however, due to DKE being a historic building, installing ASHPs to supplement the horizontal loop system may not be feasible. Therefore, we have also created a design using vertical loop GSHPs to meet DKE's entire heating and cooling requirements. 1 vertical loop borehole can typically provide 6 kW of heating with a depth of 200-650 ft (*How Much Space Does a Ground Source Heat Pump Need*, N.D.). This would require 24 boreholes to be drilled. Boreholes must also be placed at least 20 ft apart from each other for system efficiency to be unaffected from thermal drawdown. We propose one area of 10 boreholes in a 5 by 2 layout, and another of 15 boreholes in a 5 by 3 layout. Depending on depth of boreholes, more or less land area may be required. This system would have an upfront cost of $324,000. Additionally, the heat pump would need to be replaced every 25 years for a cost of $75,000. The overall system achieves a levelized cost of heating (LCOH) of $0.062/kWh and a levelized cost of cooling (LCOC) of $0.087/kWh.

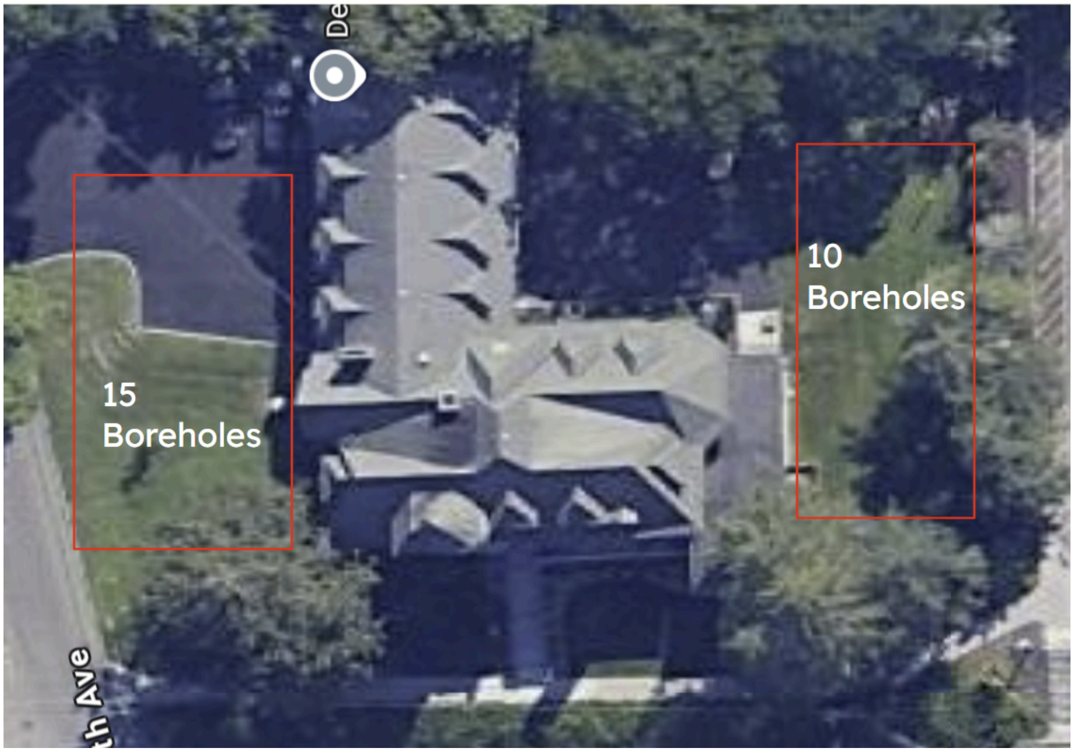

Figure 13: Proposed Land Use for Vertical Loop GSHP

8.3 Final Solar Array Design

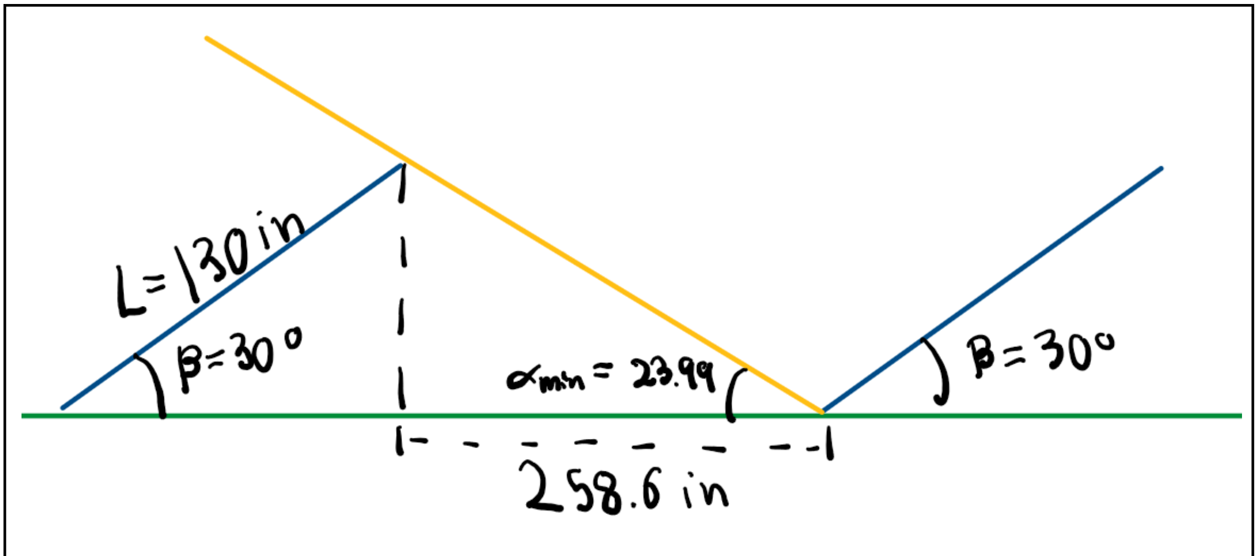

Figure 14: Solar Panels Tilted Angles and Spacing.

For our final design, the panels would be tilted at a 30 degree angle with a spacing of 258.6 inches on the south-north axis with no shading between panels on the east-west axis. As mentioned previously, these calculations were done on a 10 kW basis, however this can easily be scaled up. The cost of energy would be expected to remain $0.133 /kWh regardless of sizing, while the upfront cost would be $11644.42 /kW of installed capacity, or about $1.00 /kWh-year.

9. Future Research

While our goal was to provide precise results to support our recommendations, the precision of our results could be improved with access to more resources and data.

Among these improvements, we could improve the heat budget if we had more information on the R-values and sizes of DKE's windows, since windows can lose a large amount of heat. Depending on the R-values of the current windows, upgrading them could also insulate the building and reduce heat load, however we were unable to make recommendations on this front due to lack of information about the windows.

Additionally, heating degree days may be different in the future as climate change is expected to increase temperatures. Unfortunately, the exact level of this effect, especially on such a local scale is hard to predict. Finally, many DKE residents use window air conditioners during summer and early fall, however the number of these units in use and their energy consumption is unknown. As this system would also cool the building, it is expected that these units would not be required, saving energy, however the extent of this effect is currently unknown.

10. References

Air source vs ground source heat pumps. (2024, February 27). Energy Saving Trust. Retrieved December 16, 2024, from https://energysavingtrust.org.uk/air-source-heat-pumps-vs-ground-source-heat-pumps/

Anderson, J. (2024, November 24). *US power transmission, distribution costs seen outpacing electricity production costs*. S&P Global. https://www.spglobal.com/commodity-insights/en/news-research/latest-news/natural-gas/112421-us-power-transmission-distribution-costs-seen-outpacing-electricity-production-costs#:~:text=After%20adjusting%20for%20inflation%2C%20major,in%202020%2C%20the%20EIA

Cornell University. (n.d.). *13 South Ave, Delta Kappa Epsilon Electric Upgrade Feasibility Study*.

Cornell University. *Sustainability at Cornell*. Retrieved from https://sustainablecampus.cornell.edu

Dummit, K., Ellis, C., Peng, P., Benoliel, P., Hendrickson, T., Feldman, D., Ramasamy, V., Woodhouse, M., Zuboy, J., Desai, J., Walker, A., Braid, J., Jost, N., & Cooper, E. (n.d.). *Solar Photovoltaic System Cost Benchmarks*. Department of Energy. Retrieved December 16, 2024, from https://www.energy.gov/eere/solar/solar-photovoltaic-system-cost-benchmarks

Graziose, J. (2023, March 5). *How Much Does an Acre of Land Cost in Upstate New York?* Gerber Homes. Retrieved December 16, 2024, from https://www.gerberhomes.com/rochester-area-new-york-building-blog/how-much-to-spend-on-land-rochester-ny

How Much Space Does a Ground Source Heat Pump Need. (n.d.) HeatPumpHouse. Retrieved December 16, 2024, from https://heatpumphouse.com/guides/space-ground-source-heat-pump/

Maday, R. (2022, November 23). *How Much Does a Geothermal Heat Pump Cost?* Bob Vila Retrieved December 16, 2024, from https://www.bobvila.com/articles/geothermal-heat-pump-cost/

Shade Calculator - EasySolar. (n.d.). EasySolar APP. Retrieved December 16, 2024, from https://easysolar.app/en/shading-calculator/

Tran, H., & Bell, J. (n.d.). *13 South Ave, Delta Kappa Epsilon Electric Upgrade Feasibility Study*.

Tran, H. P. (n.d.). *Cornell University – 13 South Ave Heating Study (Building 4719)*.

11. Appendix (Market Analysis Report)

DKE Market Analysis

Aidan Lane, Anrong Yan, Helena Donnelly, Kai Zhang, Xiaohan Zhou

Cornell University Department of Engineering

CEE 5051: M.Eng Project

Francis M. Vanek

October 4, 2024

Background

Delta Kappa Epsilon (DKE) is one of the oldest fraternities at Cornell, with the Cornell chapter starting in 1870, just two years after the first fraternity started a chapter at Cornell. The DKE house that is still standing to this day was built in 1893. In 1899 President Theodore Roosevelt, then Governor of New York, planted two Norwegian Spruce trees that are still alive (*Timeline of ΔKE at Cornell – Delta Chi Chapter of Delta Kappa Epsilon*, n.d.). A little less than a century after its construction was added to the National Register of Historic Places and is one of only two Cornell fraternity houses included in the register (*NPGallery NRHP Archive Search*, n.d.). In 1963 DKE sold the house to Cornell for $1, but DKE members continued to live in the house.

Motivation

Cornell is one of the global leaders in sustainability innovation, already having implemented a lake source cooling system that cut cooling energy demands by 85% (Houghton, n.d.) as well as trying to implement geothermal energy in a location that by all accounts is a terrible place to implement geothermal energy. On top of this, Ithaca's Green New Deal is the most aggressive climate plan adopted by any city in the US, aiming for community wide carbon neutrality by 2030. As climate goals have been set across the country, one thing that has become clear is that newer buildings are often able to adapt and reduce their carbon footprint but older buildings struggle. All of these factors combine to make DKE an ideal location for a forward facing sustainability project. It is in a location with aggressive climate goals, it is one of the hardest types of buildings to renovate, especially considering its historic relevance, and it is owned by an institution that aims to be a global leader in sustainable innovation.

Cooling

Currently, DKE has no central cooling system with the only cooling coming from individuals who choose to install window AC units. Since most students do not stay over the summer, the need for cooling only exists for a few weeks at the start of the fall semester and end of the spring semester (depending on personal preference), but with the earth heating up, this window is expanding. Additionally, if DKE was to have a more comprehensive cooling system, it would open up the possibility of renting out the house for summer events which would provide some extra funding for the fraternity.

There are many cooling system options that could make sense for DKE, each with their own set of pros and cons. The easiest option would be to not install any new cooling systems and just keep letting DKE residents individually choose whether they want to install window AC units. The upside of this is that it has the lowest up-front cost and is the easiest option, but it is also the least efficient and negatively impacts DKE's aesthetic.

Of all the standard cooling methods, a central AC system would be the most efficient and would also have the added benefit of being fairly quiet. However, due to the building being made of stone, it may not be possible to hide the air ducts, making the inside of the building less appealing. This is better than ruining the outside appearance of the building but is still not ideal. Additionally, allowing for individual rooms to have independent temperature control is expensive which could become a problem in a house of 20-30 students.

The middle ground option between these two is a ductless mini-split system using a heat pump. It has much higher efficiency than window AC units but not quite as high as central AC, it allows for easier individual room control, and does not require ducts which helps with the interior aesthetic. The downside is that the installation is very complicated, but with a project as large as this one, that shouldn't be too big of an issue. Additionally, since the system is powered by heat pumps, it would double as a heating system, removing the need for having separate heating and cooling (Krarti & Howarth, 2020).

Finally, Cornell could expand its lake source cooling system to include DKE. The Law School, which is already cooled with this system, is only 75 yards away so connecting the system wouldn't be too difficult. This would also be by far the highest efficiency, at roughly 6-8x central AC. The downsides are that individual room control would be extremely difficult and that cooling response time would be long. Additionally, lake source cooling is not able to meet all of Cornell's demand on the hottest days, so it would occasionally add strain to the system, but even district cooling with the backup chillers is higher efficiency than single building central AC (Houghton, n.d.).

Heating

There are a number of heating methods available that each have their own benefits and drawbacks:

The most common heating method is furnace heating, which often relies on the burning of oil or gas but can also be designed to be electric. While electric furnaces could be run on renewable energy, they are still less efficient than heat pumps. The main benefit of furnace heating is that it is often already installed, meaning only maintenance and electricity would be required (*Furnaces and Boilers*, n.d.).

Another common heating method is electric resistance heating, which uses electricity and resistors to generate heat. The main drawback here is that this type of heating often relies directly or indirectly on coal or oil although they can use renewable energy. Additionally, these systems can be expensive to install and maintain. The main advantage of this type of system is that they are nearly 100% efficient after power is generated (*Electric Resistance Heating*, n.d.).

On some buildings and in some locations, active solar heating systems can be a good choice. This system uses solar collectors around the outside of the building to heat it. The main drawback is that these solar collectors may violate building regulations or HOA rules. In this case this may rule them out as the DKE building is a historical building. If solar collectors can be installed however, there are available incentives for their installation and they by default use renewable solar energy (*Active Solar Heating*, n.d.).

The final heating method that may be useful for DKE is heat pumps. Installing heat pumps can reduce heating electricity usage by 65% and they can be run on renewable energy. That said, the most efficient heat pumps require ducts, which would need to be installed. There are ductless heat pumps available however if this cannot be done (*Heat Pump Systems*, n.d.).

Current Heating Method(s) and Cost

The building is heated by four natural gas boilers, each delivering 240,000 BTUs per hour. These boilers provide warmth throughout the entire structure. Additionally, hot water for the building is generated by a natural gas water heater with an output of 275,000 BTUs per hour. The kitchen appliances, such as the stove, oven, and fryer, as well as the laundry machines, like the clothes dryers, also run on natural gas (Tran & Cornell University, 2021, 3).

In the basement, heating is managed by a hydronic system with baseboard heaters. The Chapter Room, partially underground, is heated by hot water fan coil units, which are connected through wall-mounted insulated pipes that are not aesthetically pleasing. This system is less than ideal because there is no mechanical ventilation. Deke's rooms (B01, B02, and B04), with an area of about 970 square feet, also use baseboard heaters linked to the gas-fired hydronic boiler, but like the Chapter Room, they lack mechanical ventilation. The weight room, which covers around 210 square feet, has a similar baseboard hydronic system but does not have heated mechanical ventilation for colder months (Tran & Cornell University, 2021, 3).

Heating Cost

Switching the building's heating system from natural gas to electric power is projected to add 344kW of electrical load, based on a direct conversion of BTUs per hour to watts. A more energy-efficient alternative would be to install a ground source heat pump system for both the boilers and the hot water heater, which is estimated to have an efficiency of 250%. With this system, the additional load would be closer to 138kW. The transition of the kitchen and laundry appliances to electric power is expected to increase the load by approximately 45kW and 11kW, respectively. Altogether, converting the heating, hot water systems, and kitchen and laundry equipment to electric would require an additional electrical load ranging from 194kW to 400kW (Tran & Cornell University, 2021, 2).

Heating potential damages

The potential damages associated with installing heat pumps in the Deke building require careful consideration. While heat pumps can reduce heating electricity usage by up to 65% and can be powered by renewable energy, their efficiency can significantly drop in extremely cold temperatures. In regions like Ithaca, where winter temperatures often plunge below freezing, traditional heat pumps may struggle to provide adequate heating, necessitating the use of backup electric resistance heating. This could lead to higher energy bills, undermining the intended energy savings of the installation (*Heat Pump Systems*, n.d.). Additionally, the requirement for ductwork can complicate installations in older buildings like the Deke house.

Retrofitting ducts may damage historic features, potentially leading to structural issues. The added stress on the building could result in cracks or other damages, especially in the presence of moisture from condensation, which can become a significant issue during cold months. As warm air from the heat pump meets cold surfaces, it can lead to increased condensation, fostering mold growth and deteriorating the integrity of building materials. Ductless heat pumps, while a viable alternative, may not distribute heat evenly across larger spaces. In the extreme cold of Ithaca winters, this could result in cold spots, making some areas of the building uncomfortable. Furthermore, the noise produced by outdoor compressor units can also pose a concern in a residential setting, particularly during winter when windows are typically closed.

Electricity price

The current electricity rate in Ithaca is approximately $0.17 per kilowatt-hour, with anticipated increases due to inflation and regulatory changes. Various factors influence electricity prices, with two major contributors being supply and demand fluctuations and fuel costs, particularly natural gas. The majority of electricity is generated by thermal power plants, which rely on natural gas or coal, making fuel prices a critical factor. Peak demand typically occurs during the winter months, and natural gas prices often spike due to external events such as hurricanes or geopolitical tensions, further driving up electricity prices (*Markets*, n.d.). Although this analysis is based on data from New England, similar trends can often be observed in other regions, such as New York State, given that both areas rely heavily on natural gas for electricity generation. However, it is important to note that regional differences, including energy policies and infrastructure, can result in variations in how these factors affect local electricity prices. Inefficient buildings can increase electricity costs, but by implementing energy efficiency measures, electricity consumption can be reduced significantly. As electricity prices are projected to continue rising, potentially reaching $0.35 per kilowatt-hour by 2050 (Wigness, 2023), we recommend adopting energy-efficient measures and exploring renewable energy incentives.

Insulation

Upgrading insulation is critical for enhancing energy efficiency and reducing heating and cooling demands. The Deke house is a three-floor building with a basement, totaling 15,541 square feet and is able to house approximately 67 residents. The building includes 103 rooms, which consist of bedrooms, hallways, and circulation spaces(Tran & Cornell University, 2021, 1). Several insulation options are well-suited for this historic building.

First, blown-in cellulose, made from recycled paper, is eco-friendly and ideal for walls and attics. It provides good thermal performance, but due to its tendency to absorb moisture, it may settle over time and require periodic top-ups. The cost is approximately $0.30 to $1.80 per square foot (Crail & Saddler, 2022).

Next, spray foam insulation offers excellent insulation with its high R-value and creates a moisture barrier, making it effective for basements and crawl spaces. It’s more expensive, at

$1.00 to $1.50 per board foot, and requires professional installation which may lead to a higher front cost (Scalisi & Tynan, 2023).

Finally, mineral wool is made from natural minerals. It is fire- and moisture-resistant, with high sound-dampening properties, but comes at a higher cost, ranging from $1.00 to $2.50 per square foot (Lee, 2023). For our project, we recommend using blown-in cellulose for walls and attics to maintain the building's aesthetics, and applying spray foam in basements to address moisture issues.

Insulation potential damages

When upgrading insulation in Deke house using a combination of blown-in cellulose for walls and attics along with spray foam insulation in the basement could lead to several potential damages. First, while spray foam offers excellent moisture protection in the basement, blown-in cellulose is prone to absorbing moisture, which could result in mold, mildew, and even structural rot if not properly controlled. Over time, this could weaken the building's structure and reduce the insulation's effectiveness. Additionally, cellulose tends to settle in vertical spaces, potentially creating gaps that reduce thermal performance, leading to cold spots that would require periodic maintenance. Another concern is thermal bridging, where gaps between the spray foam in the basement and the cellulose in the walls may allow heat to escape, decreasing overall energy efficiency. Moreover, the installation of blown-in cellulose requires drilling into walls (*8 Reasons To Avoid Blown-In Cellulose*, n.d.), which could damage the Deke house's historic aesthetic, while the expansion of spray foam, if not carefully applied, might cause cracks or other damage to the original materials. The difficulty of removing spray foam in the future also poses a challenge for any future renovations or repairs, potentially increasing costs and complexity (*Common Spray Foam Insulation Problems (and What to Do About It)*, 2024). Additionally, although cellulose is treated with fire retardants, it remains more flammable than other materials, raising concerns about fire risks if not properly installed in critical areas. Finally, cellulose can attract pests if not maintained well, especially in a large building like the Deke house, leading to potential infestations that could damage the insulation and reduce its effectiveness. These potential issues highlight the need for professional installation, thorough moisture control, and ongoing maintenance to preserve both the building's energy efficiency and its historic character.

Incentives

There are a number of programs in place to encourage the adoption of more sustainable heating and weatherization.

NYSERDA Weatherization Incentives: After receiving a consultation from a contractor, and selecting an improvement package, incentives ranging from $1,600 to $4,000 are available to reduce the price of sealing and insulation. There also may be additional rebates depending on other factors (*Funding Available for Insulation and Weatherization Upgrades In Your Renovation Project - NYSERDA*, n.d.).

New York State Clean Heat Incentive: This program provides rebates for heat pumps, offering $2,000 to $3,000 for whole-home systems, and $100-400 for systems that only cover part of the home (*NYS Guide to Inflation Reduction Act Savings - NYSERDA*, n.d.).

IRA Tax Credits: IRA tax credits are available for weatherization and heat pumps.

For air source, geothermal and hybrid water heater heat pumps, a credit is available for 30% of the cost, although air source and hybrid heat pumps are limited to $2,000 per year.

For weatherization including 30% credits for insulation, window replacement, exterior door replacement. Insulation tax credits are capped at $1,200 while windows are capped at $600, and exterior doors have tax credits capped at $250 per door or $500 total (*Inflation Reduction Act Tax Credits*, n.d.).

Solar offset

Solar energy is a key renewable energy option, but for the DKE fraternity house, the roof's architectural features—such as dormers and chimneys—limit the available space for solar photovoltaic installation. Additionally, historic preservation regulations prevent changes to the building's exterior, which makes installing solar panels on surrounding areas unviable. Given these constraints, we recommend exploring off-site renewable energy options. For instance, participating in community solar projects or purchasing Renewable Energy Certificates (RECs) can offset electricity consumption without compromising the building's structure.

Conclusion

Reducing DKE's dependence on fossil fuels would help to achieve goals set by both Cornell and the City of Ithaca. As with most residential buildings, heating and cooling are major contributors to DKE's energy use and therefore reducing the electricity required to do so and/or using renewable energy can significantly contribute to this goal.

Currently, DKE does not have a central cooling system, however many residents use window AC units. It may be possible to install a central AC system, or provide more efficient AC units for each room, however both processes are expensive and may increase energy consumption. Alternatively, a heat pump system could be installed, which would be more efficient and could be used for heating and cooling.

DKE already has a gas-powered boiler driven heating system, which does have the advantage of not costing additional money to install, but does require gas which costs money and releases greenhouse gasses. There are other heating systems available, including active solar heating, electric resistance heating, and using an electric furnace/boiler. Another option would be to use a heat pump which would have an install cost like the others, but is often more efficient, and can be used to heat and cool the building.

Since Ithaca is often cold, improving the building's insulation can also reduce heating load. While there are a variety of insulation types including blown-in cellulose, spray foam, and mineral wood, each with their own benefits and drawbacks, we recommend blown-in cellulose for walls and spray foam for the basement. Blown-in cellulose is sustainable and cost-effective, however spray foam is better suited for basements, which often present moisture issues.

There are a number of federal and state incentives available to help pay for weatherization and heat pump installations. Namely, IRA tax credits are available for many types of weatherization and heat pumps, although there are caps on this. Additionally, the state of NY offers rebates on heat pumps and weatherization.

While we will likely recommend insulation and heating/cooling improvements, the building will still need to use electricity for climate control. It is impractical to install solar panels, so we will likely need to incorporate solar offsets.

References

Cornell University. Sustainability at Cornell.(n.d.)

https://sustainablecampus.cornell.edu

City of Ithaca. Ithaca Green New Deal Overview.

https://www.cityofithaca.org

Bob Vila. (n.d.). Blown-In Insulation Cost Analysis.

https://www.bobvila.com/articles/blown-in-insulation-cost/

The Spruce. (n.d.). Spray Foam Insulation: Pros, Cons, and Costs.

https://www.thespruce.com/spray-foam-insulation-overview-1822002

Active Solar Heating. (n.d.). Department of Energy. https://www.energy.gov/energysaver/active-solar-heating

Common spray foam insulation problems (and what to do about it). (2024, July 2). Snugg. https://www.snugg.com/blog/common-spray-foam-insulation-problems-and-what-to-do-about-it

Crail, C., & Saddler, L. (2022, September 26). *Blow-In Cellulose Insulation: Facts To Know – Forbes Home*. Forbes. https://www.forbes.com/home-improvement/home/blow-in-cellulose-insulation/

8 Reasons To Avoid Blown-In Cellulose. (n.d.). Garrity Insulation. https://garrityinsulation.com/8-reasons-to-avoid-cellulose/

Electric Resistance Heating. (n.d.). Department of Energy. https://www.energy.gov/energysaver/electric-resistance-heating

Funding Available for Insulation and Weatherization Upgrades In Your Renovation Project - NYSERDA. (n.d.). nyserda. https://www.nyserda.ny.gov/ny/Weatherization-in-Renovation

Furnaces and Boilers. (n.d.). Department of Energy. https://www.energy.gov/energysaver/furnaces-and-boilers

Heat Pump Systems. (n.d.). Department of Energy. https://www.energy.gov/energysaver/heat-pump-systems

Home Heating Systems. (n.d.). Department of Energy. https://www.energy.gov/energysaver/home-heating-systems

Houghton, J. (n.d.). *How Lake Source Cooling Works | Facilities and Campus Services*. Facilities and Campus Services. https://fcs.cornell.edu/departments/energy-sustainability/utilities-production-distribution/cooling-home/cooling-production-home/lake-source-cooling-home/how-lake-source-cooling-works

Inflation Reduction Act Tax Credits. (n.d.). NYS Clean Heat. https://cleanheat.ny.gov/inflation-reduction-act-tax-credits/

Krarti, M., & Howarth, N. (2020, September 31). Transitioning to high efficiency air conditioning in Saudi Arabia: A benefit cost analysis for residential buildings. *Journal of Building Engineering*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7185004/

Lee, M. (2023, July 27). *Mineral Wool Insulation: Pros & Cons (+Alternatives) — Rmax*. Rmax. https://www.rmax.com/blog/mineral-wool-insulation-pros-cons

Markets. (n.d.). ISO New England. https://www.iso-ne.com/about/key-stats/markets

NPGallery NRHP Archive Search. (n.d.). NPGallery. https://npgallery.nps.gov/NRHP

NYS Guide to Inflation Reduction Act Savings - NYSERDA. (n.d.). nyserda. https://www.nyserda.ny.gov/Featured-Stories/NYS-Guide-to-Inflation-Reduction-Act-Savings

Scalisi, T., & Tynan, C. (2023, August 24). *Spray Foam Insulation Buying Guide – Forbes Home*. Forbes. https://www.forbes.com/home-improvement/home/spray-foam-insulation-buying-guide/

Timeline of ΔKE at Cornell – Delta Chi Chapter of Delta Kappa Epsilon. (n.d.). Delta Chi Chapter of Delta Kappa Epsilon. https://dke-cornell.org/timeline/

Tran, H., & Cornell University. (2021, November 12). *Cornell University – 13 South Ave Heating Study (Building 4719)*.

Wigness, S. (2023, December 21). *Will Electricity Prices Go Down in 2024?* Solar.com. https://www.solar.com/learn/will-electricity-prices-go-down/