The Electrification of the Healthy Home Lab

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Retrofix

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This report was prepared by undergraduate students at the University of Pittsburgh and was intended to fulfill the academic requirements of their Senior Design course. Please do not use any information included in this report for any purpose without consulting a Licensed Professional Engineer.

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Executive Summary

The ultimate goal of this project is to design a deep energy retrofit of the Healthy Home Lab (HHL) to be all-electric, net-zero energy, and water-efficient. The Healthy Home Lab is a living laboratory at Pitt and is not currently lived in. So, to make this project more applicable to other homes in the area, the utility usage of the home is estimated off the standard uses of a four-person family in the area. The home itself was constructed in 1860 and has since become very leaky and poorly insulated. This is mainly due to wear and tear over the past few decades as well as different building codes and regulations of the time it was built. These issues significantly raise the heating demand to be about 210k BTUh which we calculated using the software CoolCalc after conducting a blower door test. Before any upgrades can be made to the home, it must be sufficiently sealed and insulated to lower this demand.

To do this, the home would have to have its current windows replaced, be fully air-sealed, and then have the roof and basement ceiling insulated. The current windows are older, single-pane windows that would be replaced with casement windows. These have been shown to have lower air leakage rates than other windows while allowing for a good amount of intended ventilation when opened. Air sealing is a process in which areas of leakage throughout the home are sealed with tape, caulk, and spray foam to lessen the amount of air unintentionally coming into the home. It is important to note that some unintended leakage is necessary to allow the home to breathe and have good indoor air quality. Finally, once the windows have been installed and the home is properly sealed, the roof and basement ceiling can be insulated with 10.6 inches and 5.3 inches of closed cell spray foam respectively. With these improvements, we calculated that the new heating demand would be around 120k BTUh, a 57% decrease in heating demand.

With this heating demand reduction, the first project goal could officially be addressed - designing an all-electric home. The HHL only had one fossil fuel system which was its natural gas boiler. The team looked to replace this with an electric boiler to meet the goal but found it was too inefficient to be viable due to cost from the resulting increased electrical demand. The team instead pursued a heat pump design due to its significant energy efficiency capabilities. After analyzing the types of heat pump design possible for the HHL including an air source, ground source, and an air-to-water heat pump (AWHP) design, the team decided to pursue an AWHP design. This decision was made due the HHL's existing hydronic radiator heating system allowed for minimal costs to be incurred while still maintaining a high energy-efficient all-electric design. The team found the sizing criteria for AWHPs to depend on the calculated heating demand and the home location's climate conditions. After determining these specific conditions for the HHL in Pittsburgh, two alternative designs were formulated to mee the all-electric home project goal. Alternative 1 consisted installing separate heat pumps for the domestic hot water (DHW) heating and home space heating while alternative 2 combined the heating load and supplied both system from one heat pump. Analyzing the designs on their power, cost, lifespan, efficiency, capacity sizing, and operational temperature range, the combined system design proposed in alternative 2 was selected to best meet the all-electric home goal.

After the heat pump installation, a watt summary was performed to assess the increased electrical demand of the HHL. However, it's important to establish a baseline of the current electrical usage and total energy usage of the home. Upon making a watt summary of the current electrical use of the home, the team found that the home consumes 13,780 kWh/yr of electricity. However, this does not include the energy used by the gas radiator heating system. After extrapolating the gas heating demand to an electrical equivalence, the team found that the home consumes an extra 105,400 kWh/yr as an electrical equivalence. This brings the total energy consumption of the existing state of the home to 119,180 kWh/yr. Upon constructing a watt summary of the HHL with the proposed appliance upgrades and the addition of a heat pump, the team found that the home will use 28,695 kWh/yr. Comparing this value to the current energy consumption, the appliance upgrades and heat pump additions will reduce the home's energy consumption by 76%. Thus, the key takeaway is that even though the electrical consumption is increasing with the team's proposed design, the overall energy demand is decreasing heavily.

To combat the additional electricity that the HHL will be using because of the heat pump addition, the team proposes to install a rooftop solar array. Three alternatives were considered for the solar array and an alternatives matrix was constructed. Based on the alternatives matrix, alternative 3 is preferred for the HHL. This alternative uses 405-watt panels manufactured by Q Cell. These panels weigh 48.5 lbs each, take up an area of 1.96 m^2, and have an efficiency of 20.6%. Based on the roof dimensions and panel dimensions, 33 of these panels can fit on the rooftop of the HHL. Using Pittsburgh's solar irradiance value of 3.5 $kWh/m^2/yr$, the team calculated that this alternative would produce an estimated 15,330 kWh/yr. This will offset 53% of the home's electrical usage annually. Ultimately the addition of the rooftop solar array aids in increasing the HHL's efficiency and reduces the amount of electricity that is pulled from the power grid.

Looking at the water efficiency aspect, the main technologies used for residential water conservation are greywater and rainwater collection and reuse systems. Using a combination of these two systems, water from the roof, washing machine, bathroom sink, and shower would be collected. The treatment of this water is then dependent on end-use. In this project, the intended use of the reclaimed water is for flushing and lawn care. This means that the essential treatment is filtration. No disinfection is needed in this project since the water will not be used for potable uses and there is no food waste being collected in the process. Using a slow sand filter, the necessary contaminants can be removed and the water is ready for reuse. Piping is also a major consideration in this project since the pipe from the toilet, shower, and bathroom sink are all currently connected. These pipes would have to be rerouted and redone to make this system possible and ensure there is no blackwater entering the system. With the addition of these technologies, the home can reuse 32% of its water.

Overall, the project is expected to cost $98,000 with rebates and discounts and should be able to take place within a time period of 4 months. The appliances, solar panels, and water system have payback periods of 4.5 years, 9 years, and 10.5 years respectively.

The Team

From left to right - *Abigail Gerhart, Emily D'Angelo, Percy Curtis, Alex Demko, Ethan Rihn, and Lucas Ritz*

Project Overview

Project Scope

The scope of this project is to design a retrofit of the Healthy Home Laboratory to be an all-electric, net-zero energy, and water-efficient home.

Project Goals

Within the project there are six goals:

1. 100% of energy for the home electric
2. 100% of the energy for the home is produced on-site
3. >50% of water reused
4. >50% of energy demand reduced
5. Within a budget of $66,000 - $141,000
6. Within a period of 9 months

For the home to be all-electric, 100% of the energy used by the home must be electric, leading to the first goal. The second goal of producing all energy on-site is to make the home net-zero energy. Goals three and four align with Pittsburgh's Climate Action Plan in which the City of Pittsburgh intends to reduce energy and water consumption within city limits by 50% by 2030 [PO.1]. Finally, goals five and six are the average cost and time period of a deep energy retrofit of a home in the US according to the American Council for an Energy Efficient Economy (ACEEE) and our industry mentor, Bill Spohn [PO.2].

Project Assumptions & Exclusions

For our project, two main assumptions were made for our calculations and estimates. First is that the estimated utility usages in the home are based on a four-person, single-family home in this project instead of the actual utility usages of the home. This was made since the home is not currently lived in and we wanted the project to be more replicable and meaningful to any homeowner who may want to go through the process of designing a deep energy retrofit of their own home. Secondly, we assumed several elements of the top floor of the Healthy Home Lab (HHL), those being the energy usage, dimensions, and layout. This is because the top floor was inaccessible for the duration of our project due to structural instability and asbestos concerns. We did the best to ensure these assumptions were as accurate as possible by referencing a video of the space provided by Zach Roy, one of the HHL contacts, and referencing other structurally similar homes built at the same time and area.

Healthy Home Lab Baseline

Project Location & History

The site of the HHL is in the East region of Pittsburgh in the Oakland neighborhood. It is specifically located on Oakland Avenue near Pitt's main campus. The home itself was built in 1860 and has since become a living laboratory at Pitt. A living lab is where the researchers actively work in the environment that they are testing [H.1]. To reiterate, since the home is not currently lived in, the team estimated utility usage based on a four-person home in the area and temperature energy modeling as a basis for design calculations.

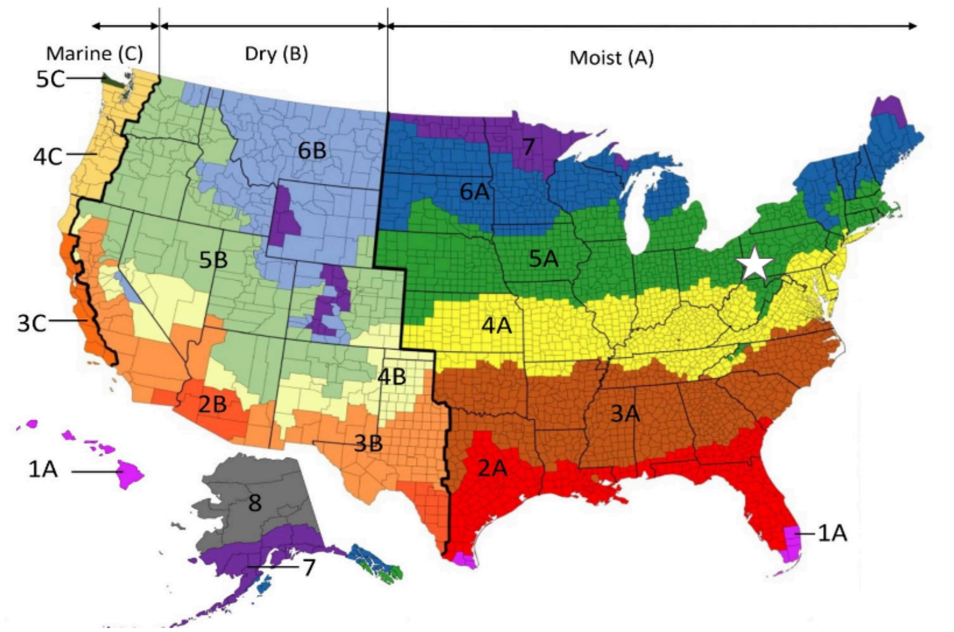

Figure H.1: IECC 2021 US Climate Zone Map

The site is also located in the International Energy Conservation Code (IECC) climate region 5A, which is a cool, humid climate noted by the star in **Figure 1**. This is important to note for our insulation and heat pump designs moving forward.

Potential Issues

On the first site visit to the HHL, we looked for potential issues to address within our project. We first found that most of the appliances currently within the home are not energy efficient, which significantly raises the home's current energy demand. This was found by researching the appliances online and observing if they were Energy Star rated as well as calculating their existing wattage based on provided volt and amp specifications. Estimates of appliance energy usage are within the Watt Summary. The second issue that was discovered was the home had a lack of insolation and a high leakage rate. There were noticeable cracks between the doors and windows where outside air was freely able to enter the home. The windows were also older, single-pane windows, which easily allowed heat to escape through conduction. Another issue noted was the current heating system within the home. An existing 200,000 BTU gas boiler system was present and operated by heating the home through a series of radiators on the first, second, and third floors. This heating system would need to be replaced with an electrical equivalent to meet the project goal of having an all-electric home. Finally, a potential issue was analyzed with the current service panel of the home and its capacity. However, the current system is rated for 200 amps, which would be sufficient for any potential upgrades that would be incurred throughout the project and thus it would not need to be replaced.

Blower Door Test

To calculate the current heating demand of the home, we first needed to quantify the amount of air leakage the home has with a blower door test. A blower door test was able to be conducted with the support of an industry expert, Rhett Major. The test creates a vacuum environment within the home, which we ran at -50 pascals, from which we got an air leakage of 9179 cfm (cubic feet per minute). We also walked around the home during the test with thermal cameras to fully see where these leaks were. The most notable locations were the basement and the ceilings. In the basement, air passed through large cracks between the door and the wall, through cracks in the walls themselves, and around the old windows to the crawl spaces underneath the back and front porches. The ceilings were also an area of concern because they are not currently insulated, creating a large area for heat to transfer into and out of the home depending on the time of day and the weather. There were also areas in the ceiling corners where there is significant air leakage, however, these are points of concern in most homes.

From all this, we calculated that there are about 15 air changes per hour (ACH) in the home, which was found by converting the leakage rate to cubic feet per hour and dividing by the volume of the HHL. In comparison, the average home is about 2-3 ACH and a passive home is at most 0.6 ACH [H.2]. This means that air leakage reduction and insulation improvements became top priorities to increase the energy efficiency of the home, helping to reduce electrical demands generated in the electrification process.

Initial Heating Demand

Heating demand is a measure of how much energy is required to heat a house. Typically, heating demand for a set address can be extrapolated from utility bills. Since the team did not have access to said bills, it was necessary to calculate an estimated baseline heating demand for the home. To do so, Manual J was used. Manual J calculates heating demand based on many parameters such as building dimensions, window sizes and types, and insulation materials. Manual J is the official mode of calculating heating demand as regulated by the Air Conditioning Contractors of America (ACCA) and it is used by HVAC professionals in the industry such as our mentor [E.1]. The only free Manual J calculator approved by ACCA is CoolCalc.net (CoolCalc), so this was the primary calculator used in the project [E.2].

However, CoolCalc had a major limitation in that it could only calculate loads for buildings constructed in 1950 or later, and its parameter inputs were based off of 1950 as a minimum building code [E.3]. This created difficulties because there were discrepancies between the HHL built in 1860 and the capabilities of CoolCalc such as not being able to input that there was no insulation in the roof. When CoolCalc was used with parameters as close as possible to the actual construction, a heating load of about 175,000 BTUh was found. This was set as the lowest realistic bound since the HHL was constructed before these building codes. Then, a second Manual J calculator was used. LoadCalc.net (created by Ocean Side Heating & Air) was selected for its robust ability to accept different parameters and ability to account for geographic location, and the modeled load was about 210,000 BTUh [E.4]. To further check this value, a third calculator was used: RemodelingCalculator.com developed by HVAC industry expert Leo Bander and his team. This calculator produced a heating load of 164,000 BTUh but specifies that it typically underestimates a contractor's estimate by 20-30%, which would put the contractor's estimate at around 196,800 - 213,000 BTUh [E.5]. After running the value by our industry mentor Bill Spohn, we determined that 210,000 BTUh was a fair estimate for the current heating demand of the HHL. Load modeling parameters and results for each calculator can be found in the Appendix under Efficiency Designs.

Efficiency Alternatives

To meet the goal of decreasing the energy demand, several efficiency upgrades were explored. Additionally, decreasing the energy demand makes producing all energy onsite more achievable. To identify target areas for improvement, an energy auditor contracted by Duquesne Light visited the HHL with the team and discussed professional recommendations for increasing the home's efficiency.

Air Sealing

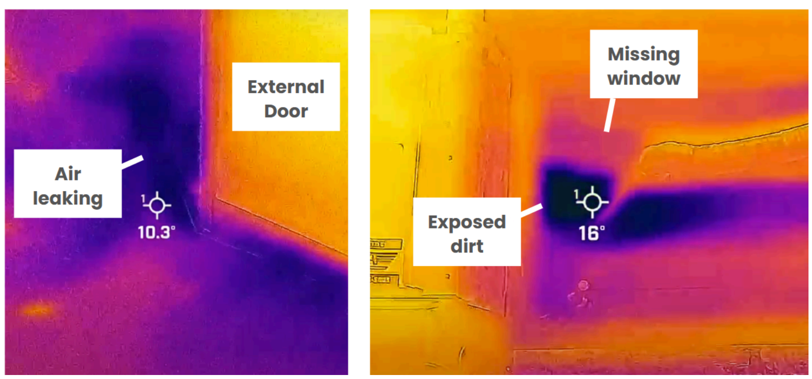

Figure E.1 - Thermal imaging of poorly sealed locations in HHL

Considering the house's high air leakage rate, the foremost recommendation was to air seal. Air sealing is the process of covering gaps and cracks with caulk, tape, and spray foam. It is essential for tightening the building envelope and preventing the exchange of conditioned air to the outdoors. Air sealing will be completed before any other efficiency upgrades to achieve the maximum efficiency for any upgrades made. As seen in **Figure E.1** above, thermal imaging of the house detected areas of poor sealing around corners, doors, and windows–these areas will be targeted. A local air sealing company such as Koala Insulation [E.6] or USA Insulation [E.7] will be contracted to complete the air sealing. The sealing will continue until a leakage rate of 3 ACH50 is achieved. Based on quotes from local companies, the cost to air seal the entire house is estimated to be about $7,000.

Insulation

Insulation Locations

Insulation Location	Heating demand reduction (BTU)	Cost ($)	Heating demand reduction per dollar cost (BTU/$)
Roof	17,363	14,660	1.18
Basement ceiling	5,450	6,120	0.891
External walls	39,922	63,152	0.632

Table E.1 - Insulation location heating demand reduction comparison and cost comparison

It was noted during the site visit by visual observation and thermal imaging that insulation was absent from key areas of the home such as the roof, external walls, and basement.

Insulation within the exterior walls was not possible due to the construction being 3 layers of solid brick with no gaps for insulation. Insulating the interior of the exterior walls was also considered but ruled out as there were space constraints within the home and to avoid removing the brick from the thermal envelope of the home–if the brick becomes too cold, it can enter a freeze-thaw cycle of icing that gradually deteriorates the brick [E.8].

The final consideration for wall insulation was to insulate the external facade of the exterior walls, thereby bringing the brick within the thermal envelope. This requires the construction of an additional frame around the house to hold the insulation, a new external facade layered on top of the insulation, and weatherization barriers. To prevent thermal bridging, which is inefficiency caused by nonuniform insulation, careful design and installation are required around doors and windows (i.e. the complexity and cost are increased). Ultimately, this route was not pursued for several reasons. To begin with, it was found that homeowners of historic brick homes may wish to preserve the vintage appearance of their home and thus not accept covering the brick [E.9], [E.10]. Second, this form of insulation is not common in the United States and local companies could not be found to perform the work (cost estimates are taken from European companies, where this insulation type is more common). Finally, the CoolCalc modeled heating demand decrease per dollar cost was lowest compared to other insulation locations as seen in **Table E.1** (spreadsheet results found in Appendix under Efficiency Designs). This model is based on achieving R-3 with an expanded polystyrene board, which is estimated to cost about $63,000. Additionally, the actual cost is likely to be higher for the HHL because it is 3 floors (requiring more scaffolding), there is a lack of competitive market for this insulation type in Pittsburgh, and the moist climate requires additional weatherization barriers.

Due to the above difficulties of external wall insulation, the energy auditor recommended two focuses of insulation to maximize return on investment: the basement ceiling and the roof. For the roof, there are two possible placement options: beneath the roof deck and above the roof deck. Insulation beneath the roof deck is conventional and common, but due to the temperature difference between the deck and the insulation, it requires ventilation to prevent moisture from accumulating. Insulation above the roof deck is the most thermally efficient as it brings the roof into the thermal envelope, but the insulation requires weatherization barriers to prevent deterioration [E.11]. Additionally, insulation above the roof deck creates complications with the solar panels and rainwater collection system. Although it is possible to mount solar panels on the insulation, special covers and mounts are required to prevent any equipment from ripping off the roof, and the penetration from the mounting risks allowing air and water to leak into the insulation [E.12]. The added height from the insulation would also require adjustment of the gutters and drain to ensure proper collection of rainwater.

Insulation Materials

Insulation Type	R-Value per inch	Cost ($/sqft)	Water Resistant
Open Cell Spray Foam	3.5	0.5 - 1.5	No
Closed Cell Spray Foam	6.5	1.5 - 2.5	Yes
Polystyrene board	3.6 - 5.8	0.25 - 1.5	No
Fiberglass	2.5 - 4	0.40 - 0.50	No
Cellulose	3 - 4	0.80 - 1.75	No

Table E.2 - Comparison of common insulation materials [E.13]

Several common insulation materials were compared for their suitability to this project based on their cost, insulating ability, and moisture resistance as seen in **Table E.2**. Insulating ability is measured by R-value (m^2K/W) per inch depth of insulation. Cellulose was considered due to its recyclability and average insulation ability, but eliminated due to its permeability to water [E.14]. Polystyrene board was considered for its relatively high insulation ability and low cost but was eliminated due to its moisture permeability and lower suitability for complex application areas. Open-cell spray foam was considered but eliminated in favor of fiberglass, which has similar properties but is less expensive.

Fiberglass was deemed to be a suitable alternative. Despite being permeable to water, fiberglass' low cost compared to the other materials makes it more viable to add a vapor barrier. Furthermore, it is one of the most common insulation materials with a high ease of installation and accessibility for purchase. It is relatively safe to install and does not have major health impacts, although the fibers can make small cuts in skin and lungs if inhaled, so PPE should be worn during installation and it should be covered from living spaces. Additionally, while it is not flammable, fiberglass will melt at 1,000 degrees F [E.15], and according to the National Fire

Protection Association, the average house fire reaches 1,100 degrees F [E.16]. Although fiberglass is not biodegradable, 3 of the largest fiberglass insulation manufacturers (Owens Corning, Schuller International, and CertainTeed) use at least 20% recycled glass, with Owen Corning reaching 30% [E.17]. Fiberglass insulation itself is technically able to be recycled, but this is energy-intensive and not commonly offered in the U.S. [E.18]. Finally, fiberglass was not considered for the above roof deck placement because it lacks the structural integrity to support the solar panels and would be at increased risk for moisture damage.

Polyurethane closed cell spray foam (ccSPF) was also selected as viable for its high insulation ability and impermeability to water. ccSPF also has the advantage of being easier to apply in complex areas with crevices, pipes, and wires since it can be sprayed in. However, ccSPF contains isocyanates which can cause skin, eye, and lung irritation and inflammation. Additionally, they contain flame retardants which may be persistent or bioaccumulate. ccSPF takes around 24 hours to cure and the premises must be vacated during curing time to prevent inhalation. However, once cured and cut to size, there are no major further health concerns [E.19], [E.20]. ccSPF also typically includes global warming potential increasing agents such as HCFCs [E.17]. Additionally, ccSPF is combustible and some mixtures will require thermal or ignition barriers to prevent flash fire spreading depending on the use of the space [E.21]. For the basement, which may be accessed as a living space or for storage, a 15-minute thermal barrier is required by international building code, whereas for the roof deck which is not in contact with a living or storage space, an ignition barrier will be applied. On the upside, it is possible to recycle ccSPF for other uses such as carpet underlay and acoustic insulation [E.22].

To meet the Department of Energy recommendations for insulation upgrades to existing homes in IECC climate zone 5, the roof will need to achieve an insulation level of R-60 and the basement ceiling will need to be R-30 [E.23]. Due to its lower R-value, the heating demand reduction of fiberglass will be less than the same depth of ccSPF. ccSPF has an R-value of around 6.5 per inch, meaning that for the basement, about a 4.75-inch depth of ccSPF is required, and for the roof, about 9.25 inches is required. In comparison, the higher-end performance of fiberglass would require 7.5 inches for the basement and 15 inches for the roof. The depth and design of the roof deck underside were unknown by our HHL contacts and we were not able to assess it ourselves due to the third floor being closed. The basement ceiling has joists with a depth of approximately 7 inches at the shallowest point, so insulation greater than this depth will require additional installation considerations.

Insulation Alternatives

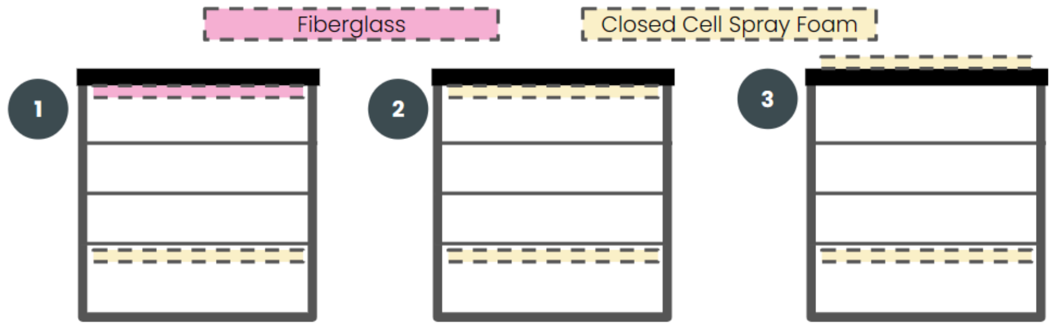

Figure E.2 - Basic schematic of insulation alternatives

3 alternatives were evaluated (as shown in **Figure E.2**):

1. Fiberglass beneath roof deck + ccSPF on basement ceiling
2. ccSPF beneath roof deck + ccSPF on basement ceiling
3. ccSPF above roof deck + ccSPF on basement ceiling

Design Criteria	**Importance Factor**	**Alternatives**		
		Alt 1	**Alt 2**	**Alt 3**
Material health impacts for humans	1	4	3	3
Compatibility with rainwater & solar design	1	4	5	1
Heating demand reduction	1	2	5	5
Moisture resistance	0.8	2	5	5
Flammability resistance	0.8	4	3	3
Cost	0.7	5	3	3
Environmental impact	0.7	4	2	2
Rankings (/30)		21.1	22.9	18.9

Table E.3 - Design selection matrix for insulation alternatives

To compare the alternatives, a design matrix was constructed by the team. Each design criterion was given a weighting factor from 0 (no importance) to 1 (highest importance) based on its necessity to achieve project goals, and each alternative was then rated 1 (worst) to 5 (best) for their performance in the category based on our research and judgment. Based on these ratings, the second alternative was selected. A notable advantage of this alternative compared to the second highest rated alternative (alternative 1) is that the use of ccSPF for the roof will be easier to install than fiberglass when considering potential complications the roof may have such as lacking depth or having a complex joist structure.

The cost and depth of this design were estimated using a listing for Stanley Supercoat Spray Foam Insulation which has an R-value of 5.66 [E.24]. For the basement ceiling, a 5.30-inch depth of ccSPF is required, and for the underside of the roof deck, about 10.6 inches is required. The material cost is $4,450 for the basement and $8,910 for the roof. The basement ceiling will be coated with a 15-minute thermal barrier and the roof with an ignition barrier, both of which we will consider in our installation cost because the amount of sealant needed is dependent on the complexity of the surface, not just the area. Using a low-end estimate of the installation cost for the basement of $\$1.5/ft^2$ since the layout is relatively simple and a high-end estimate of $\$5/ft^2$ for the roof to be conservative since the layout is unknown, taking the area of each to be about 1,000 ft^2, the cost of installation would be $1,500 for the basement and $5000 for the roof [E.13]. Thus, the total cost of insulation is expected to be approximately $20,000.

Windows

Window Type	Cost per Window	Unintentional Air Leakage (cfm/lfc)	Ventilation Ability (% of window area)
Sliding	$500	0.72	50%
Fixed	$600	0.0	0
Casement	$700	0.23	100%

Table E.4 - Comparison of window types [E.25] , [E.26] , [E.27]

The majority of windows in the HHL are currently single pane, single hung windows (sliding), and fixed windows. In replacing the windows, we sought to minimize the unintentional air leakage (which was measured by cfm air leaking per linear foot of window crack) to decrease the heating demand. Out of concern for the indoor air quality, we sought to maximize the homeowner's ability to manually ventilate the home (which is measured by the area able to be ventilated compared to the total window area). Through research, it was determined that casement windows provided the best reduction of unintentional air leakage while allowing for the greatest manual ventilation and was thus chosen as the best alternative. Replacing the majority of the windows in the HHL with double-pane casement windows is estimated to cost $20,000 [E.27].

Post-Efficiency Upgrades Heating Demand

Following air sealing the home to 3 ACH50, insulating the roof to R-60 and basement ceiling to R-30, and replacing the windows with double pane casement windows, the Manual J parameters were adjusted accordingly (see Appendix under Efficiency Designs). The new heating demand was calculated to be approximately 120,000 BTUh, which is a 57% decrease from the previous demand of 210,000 BTUh.

Energy Alternatives

Heating Source

As previously mentioned, the HHL had an existing natural gas boiler which also was the sole fossil fuel system present that required replacing to meet the all-electric project goal. The gas boiler is a Dunkirk DXL-200 that has a heating capacity of 200,000 BTUh and operates at an 82% AFUE rating [HP.1]. AFUE, or Annual Fuel Utilization Efficiency, is a measure of how efficiently a furnace or boiler transfers fuel energy into usable heating energy. In the pursuit of providing an electric alternative, the team initially looked at simply substituting an electric boiler to meet the goal. Further researching this avenue, it was discovered that electric boilers can have AFUE ratings up to 100% and on average have comparatively lower installation costs with similar capital costs. However, their operation costs are significantly higher than gas boilers since the full energy input provided by the gas is now being provided by electricity, which has a comparatively larger cost [HP.2]. For example, in the US Energy Information Administration's 2009 residential energy survey report, the average 2,000 sq. ft. Pennsylvania (PA) home was found to use nearly 48 million BTUs per year, which for an electric boiler equates to over 14,000 kWh used per year, which would be over 135% of the average PA home's electricity usage [HP.3]. Due to this high electricity demand issue, efficiency became a significant factor to consider in electrification as a more efficient system would use less electricity for heating and thus incur less costs and environmental impacts.

With further research, the team discovered an alternative electric heating system known as a heat pump. Heat pumps operate uniquely as they do not use their energy source to generate heat but rather move it from one location to another, similar to how a refrigerator functions. This heating application results in a dramatic increase in efficiency for heat pumps compared to boiler systems. Rather than being measured by an AFUE rating, the efficiency of a heat pump is measured by a metric known as a coefficient of performance (COP). A COP is the ratio of heating energy delivered by the heat pump to the electrical energy supplied to produce that heat [HP.4]. Heat pumps on average have COP values ranging from 3 to 4, meaning heat pumps can be 300% to 400% efficient in their energy use to supply heating [HP.5]. After further research, there did not appear to be any other electric alternatives that outpaced heat pumps on the metric of efficiency thus making them an ideal choice.

However, since efficiency is important due to its prevalence in reducing annual heating energy consumption, the team wanted to first ensure this technology maintains its dominance from a life cycle perspective. For reference, a simple comparison of average lifespans was found to show that both gas boilers and heat pumps last around 10-15 years while electric boilers can last around 15-25 years on average [HP.6]. However, it proved difficult to find a comparison of these systems on a life cycle basis as two primary factors must considered which are the house size and heating load, which further considers the location, design indoor temperature, insolation, leakage rate, etc. thus complicating conducting a full life cycle analysis (LCA). However, a 2022 LCA study by the Technical University of Munich was found to have been able to standardize these factors for a life cycle comparison of air-source heat pumps and gas boilers [HP.7]. Comparing a gas boiler with an 88.7% AFUE and an air-source heat pump with a seasonal COP of 3.26 to heat a single-family home in Straubing, Germany with a 150 m^2 area, the annual electricity and gas consumption was calculated for the life cycle inventory. Extending this data across each system's lifespan as well as extrapolating the electric boiler's energy consumption assuming a 100% AFUE, then a life cycle comparison of the energy consumption for each system, which is shown in **Table HP.1**.

Energy Consumption (operation phase)	Air-Source Heat Pump	Gas Boiler	Electric Boiler
Electricity (kWh/y)	2,874	22	-
Natural Gas (m^3/y)	0	907	-
Total Energy (kWh/y)	2,874	10,121	8,978
Net Operation Phase energy usage (kWh)	43,110	151,819	134,664

Table HP.1 - Heat Pump and Boiler LCA Inventory Energy Consumption Comparison

Based on this life cycle inventory comparison for the modeled environment, it shows heat pumps are the most efficient electric heating system to install as an alternative to the existing gas boiler so the all-electric project goal may met.

Heat Pump

As heat pumps were decided to be the most suitable electric system for the HHL, further research was needed to determine the best type of heat pump to use. Heat pumps operate using a refrigerant piping system with indoor and outdoor heat exchangers. The refrigerants have extremely low boiling points, typically ranging from -15 °F (-25 °C) to -55 °F (-49 °C), thus allowing them to absorb energy through a latent heat transfer when passed through a heat exchanger medium, even in sub-freezing conditions [HP.5]. When heating a home in winter, the refrigerants can absorb heat from the outdoor heat exchanger medium using this property and are then sent to an electric compressor to pressure the fluid, and by the ideal gas law, this further increases the refrigerant's temperature. The pressurized, heated refrigerant is then sent to the indoor heat exchanger medium to provide heat throughout the house. After losing this energy, it is depressurized as it moves through an expansion valve and loses any remaining energy that prevents it from repeating the process at the outdoor heat exchanger medium. It should be noted this process is reversible for cooling in the summer by using a reversing valve that changes the direction that the refrigerant moves heat through the system [HP.8]. Although this heat movement process is uniform across all heat pumps, the heat exchanger medium on the indoor and outdoor units can vary which significantly alters the system cost, efficiency, lifespan, and installation requirements, and thus each must be considered.

The most common form of heat pump is known as an air-to-air heat pump (AAHP), which uses the ambient outdoor and indoor air as its heat exchange mediums. For a ducted AAHP, the refrigerant lines are coiled in an outdoor unit with a fan forcing air on it to induce a heat transfer from the outdoor air. This setup is similar for the indoor unit where a fan forces the indoor air to pass through the coiled refrigerant lines and move through the home's duct system that distributes the temperature-changed air. Alternatively, for households without ductwork present, a mini-split AAHP system is commonly used where multiple smaller capacity AAHPs are installed on the exterior surface of a home and a short line is sent through the wall inside to connect to an indoor unit that will heat or cool that room or zone of the house. A mini-split AAHP is more expensive than installing an AAHP in an existing house with ductwork since the homeowner must purchase multiple AAHPs [HP.9]. However, the mini-split AAHP system is much more cost-effective compared to installing new ductwork in a home which involves high capital and installation costs.

Less commonly used are ground-to-air heat pumps (GAHP) due to their high capital costs. GAHPs operate similarly to AAHPs except for the outdoor air exchange medium which instead uses ambient ground temperature for heat transfers. This seasonally provides a higher efficiency than AAHPs since the ground is warmer during the winter, providing a greater energy source to pull from, and it is cooler during the summer, providing a more accepting location to transfer heat. GAHPs can be set up horizontally by coiling refrigerant pipes underground, typically requiring an area ranging from 6,500 to 12,900 ft^2 depending on the required heating capacity. Alternatively, GAHPs can be installed by drilling and placing the refrigerant line vertically, which can range from depths of 230 to 390 feet depending on the required heating capacity [HP.10]. However, either system setup requires a high capital cost from the installation and material requirements.

The final common and applicable heat pump system design used in the industry is known as an air-to-water heat pump (AWHP). Converse to GAHPs, an AWHP maintains the ambient air as the outdoor heat exchanger medium but instead uses water for the indoor heat exchanger. The refrigerant is sent through a water tank where energy is exchanged and the temperature-altered water is typically piped through a hydronic radiator and/or underfloor heating system [HP.11]. After the water is used in the indoor system, it is piped back to the water tank to be reused. The AWHP is comparable to the AAHP in terms of a retrofit as it is likely only applicable if there is an existing hydronic heating system as there would be high capital costs to install a new one otherwise, just as there was for ductwork installation.

Observing these potential heat pump designs, metric research was conducted on their average efficiency, lifespan, capital cost, and operation and maintenance costs to provide a basis for comparison. A substantial amount of this information was able to be collected through GreenMatch, a UK-based online research organization specializing in the publication of data collection on HVAC and sustainable home infrastructure components. The summation of this metric research on AAHPs, GAHPs, and AWHPs is shown in **Table HP.2**.

Metric	AAHP	GAHP	AWHP
Efficiency (COP)	2.5 - 4	3.5 - 4.5	2 - 4
Lifespan (years)	10 - 15	50 - 100	10 - 15
Capital Cost ($)	$3,000 - $11,100	$29,300 - $61,800	$10,600 - $15,600
Annual O&M Costs ($/year)	$1,200 - $3,300	$880 - $1,800	$740 - $1,650

Table HP.2 - Heat Pump Design Metric Comparison [HP.12], [HP.10], [HP.11]

Based on the compiled metric data, GAHP proved to be the most energy-efficient design while AAHP served as the most cost-effective design. However, the GAHP design's high capital cost range provides a high risk of pushing this project out of its budget range goal. Additionally, the required plot area for horizontal installation is not available and the vertical drilling depth would require multiple approved permits by the city of Pittsburgh, which risks moving the project out of its desired duration. Therefore, for these reasons, the GAHP design was not selected for the HHL. Additionally, the AAHP would not be viable for a ducted system as there is no existing ductwork in the HHL. A full-home duct installation of a house of similar proportions as the HHL would incur a cost of around $27,000, which similarly could risk pushing this project's budget goal [HP.13]. Alternatively, installing a mini-split system would involve forming 4 to 5 zones throughout the HHL, which results in a cost estimate of $24,000 to $30,000, providing the same budget risk [HP.14]. Due to these concerns, the AAHP design was not chosen for the HHL. However, the AWHP does provide a relative middle-ground design for efficiency and cost. Additionally, there is an existing cast iron radiator hydronic heating system in the HHL which is compatible with an AWHP installation. Given these benefits and the system compatibility, an AHWP design was chosen for the HHL.

With the selection of an AWHP installation design, the team further investigated the component sizing criteria to determine the most appropriate design. This resulted in a multitude of factors being determined for the correct sizing criteria used to formulate the required design elements. Heat pump sizing was determined to primarily depend on the existing manual J calculation and the required ambient air operating range necessary to function in the local environment [HP.15]. As previously discussed, the manual J calculation considers a multitude of factors including the home size, layout, window type and number, insulation type and thickness, natural heat emitters present, design indoor temperature, etc. to determine the heating and cooling loads required to meet desired temperature comfort needs of the home. The resulting energy load calculation is used to select the appropriate heat pump that can supply and meet that load requirement. Furthermore, selection significantly depends on the outdoor climate conditions where the heat pump is installed. It must be sized so that it can operate successfully at the extreme cool and warm ambient temperatures that it will face throughout the year, otherwise, it will face high inefficiencies.

As previously mentioned, the HHL's manual J calculated heating load was reduced to 120,000 BTUh with insolation and window improvements. This serves as the basis of the heating load used in heat pump selection. However, it should also be noted the Air Conditioning Contractors of America, who formulated and certify all manual J methods, allow for a 10% undersizing limit and 15% oversizing limit for heat pump selection, as manufacturers are not guaranteed to supply a heat pump capable of producing the precise load necessary [HP.15]. With these allotments, the HHL's heat pump may be allowed to have a load capacity ranging from 108-138 kBTUh.

It should be noted that if a heat pump is undersized, it will operate with high inefficiencies as it will not be capable of meeting the home's energy requirements and thus must constantly operate at full capacity without breaks. Conversely, if a heat pump is oversized, it experiences a phenomenon known as 'short-cycling' where it will send a large burst of heat or cooling and will sense the desired temperature has been reached even though it did not operate long enough, thus resulting in poor comfort conditions and increased costs [HP.16]. It was found that these issues were prevalent in the 1960s as contractors were unfamiliar with how to properly calculate the sizing of heat pumps, thus resulting in a stigma that they are unreliable in the industry as most installations led to improperly sized systems [HP.17]. This stigma against heat pump installation still appears to hold in Pittsburgh as contractors today do not typically recommend heat pumps, citing reliability and costs as reasons against it [HP.18]. However, this project has found those beliefs to be misconceptions as technology has advanced, standardized industry sizing tools have long removed prior sizing issues, and government subsidies are available to support cost reductions.

For Pittsburgh's climate conditions, ENERGY STAR has determined a heat pump design must be able to operate within a temperature range of 5°F to 87°F to successfully function in Allegheny County's climate [HP.19]. It is this temperature range and the aforementioned energy load range that are the key components in sizing a heat pump in accordance with ACCA's

Manuel S. Manuel S uses these components alongside the product manufacturers' performance data and specifications to determine if the selected heat pump is suitable to meet the location needs. However, it was found that ACCA's Manuel S capabilities are currently limited to sizing AAHPs and do not extend to AWHPs, so a complete Manuel S was not conducted for the HHL's AWHP system but still applied the same sizing criteria for system selection [HP.20].

It should be noted that in sizing the AWHP, the aforementioned temperature and heating load ranges were primarily considered, however, a cooling load was not calculated or used in the process. This was intentionally done as the existing radiator system is cast iron and does not have thermostatic radiator valves (TRVs) to regulate temperature thus restricting its cooling capabilities. Furthermore, implementing cooling aspects to the cast iron system would require installing condensate lines throughout the full house, which would incur similar installation costs as ductwork due to material and labor requirements. Additionally, a radiator cooling system provides marginal benefits as it does not address the absence of ventilation in the HHL, increasing the risk of indoor air quality issues, and an alternative system would have to be installed. However, as there is no existing central ventilation system and the AWHP has been selected, the cooling component has been deemed out of scope for the set project goals but does remain a concern to be addressed in further work on this project.

Based on the determined sizing criteria for AWHPs for the HHL in Pittsburgh, two alternative designs were determined to be appropriate for the HHL. Alternative 1 is to replace the existing gas boiler with a Daikin DFH120 AWHP and to the existing electric-resistance domestic hot water (DHW) heater with an indoor Rheem ProTerra heat pump. Each system's key manufacturer performance specifications are shown in **Table HP.3** and were found to best match the required heating load and temperature range requirements. It should be noted that the Rheem ProTerra's temperature operating range is not within that required for Pittsburgh, however, it is an indoor unit and the ambient temperature inside is not expected to exceed either range. A 65-gal unit was selected as was determined a four-person family on average required a 50 to 75-gallon HW tank given high usage rates, so this was deemed as an appropriate unit [HP.21]. Additionally, the Daikin model was selected as it was found to be amongst the very few residentially available systems that could solely handle the HHL's significant heating load within Pittsburgh's temperature range. For implementation, the design involves a simple removal of the existing systems, including gas lines, and an installation of the proposed systems with reconnecting to the existing pipe networks.

System Element	Rheem ProTerra DHW	Daikin DFH120 Space Heating
Heating Capacity (BTUh)	4,200	116,000
Temperature Operation Range (°F)	37 - 145	-5 - 105
COP	4.05	3.4
Power (kW)	5	10.41
Cost ($)	$2,230	$9,400
Storage Capacity (Gal)	65	-

Table HP.3 - Alternative 1 Heat Pump Performance Specifications [HP.22], [HP.23]

Alternative 2 looks to combine the DHW and space heating systems to be supplied by a singular AWHP heat pump. This requires the new unit to be capable of handling the combined heating load which rounds to 125,000 BTUh requirement. An Aermec ANKH150 heat pump system was found to be within the necessary sizing ranges and its key manufacturer performance specifications are shown in **Table HP.4**. An Aermec system was chosen as it was the only provider found to capably supply the HHL's heating high load in its climate. Trane's LEAF unit was found as the only other capable AWHP system to meet the HHL's heating load, but currently has not been officially released on the market. However, this issue is only a comment on the current heat pump market's capacity to handle older homes with high leakage rates than it is an issue with the HHL's Pittsburgh location.

Aermec ANKH150 Combined System	
Heating Capacity (BTUh)	122,500
Temperature Operation Range (°F)	-4 - 108
COP	3.02
Power (kW)	11.89
Cost ($)	~$13,000

Table HP.4 - Alternative 2 Heat Pump Performance Specifications [HP.24]

Additionally, for alternative 2, minor source-level pipe alternations would need to be made to connect the existing radiator and DHW pipe networks to the same heating source to distribute water. This would require the addition of a buffer tank to contain the daily required amount of hot water so usage requirements may be met even during high usage periods and colder ambient outdoor temperatures. To account for this, the buffer tank volume (V) was calculated using the heating load ($Q_{Heat\ Pump}$), combined heat extraction rate demand (q_{Load}), the tank's temperature rise between heating cycles (ΔT), and the typical duration of a heating cycle (t). These are the variables required to determine volume in the buffer tank volume equation for a hydronic heating system shown below [HP.25].

$$V = \frac{t\left(Q_{Heat\ Pump} - q_{Load}\right)}{500(\Delta T)}$$

To find the heat extraction rate, length-width measurements were taken of the HHL's cast iron standard radiators so the area of each section column could be determined. The total number of sections was counted so a net area could be calculated. The existing HHL radiator designed water temperature was found to be 120°F which equates to a heat emission rate of 50 BTUh per ft^2 [HP.26]. Multiplying the net section area per radiator, the heat emission rate per unit area, and the number of radiators in the HHL resulted in the combined heat extraction rate demand shown in **Table HP.5**. It should be noted that the heat extraction load for sinks and showers were not included in this calculation as an intentional factor of safety as utilizing a smaller heat extraction load in the buffer tank equations equates to a larger volume size to be maintained at the design temperature, hence accounting for any potential hot water capacity issues.

Heat Extraction Load Calculation	
Length (in)	26.5
Width (in)	7.69
Area (ft^2)	1.41
Number of Sections	28
Heat Emission Rate (BTUh) per sq. ft @ 120F	50
Heat Extraction Load per Radiator (BTUh/unit)	1980.6
Number of Radiators	14
Total Extraction Load (BTUh)	27,728

Table HP.5 - Total Extraction Load Calculation Variables

Furthermore, a minimum water temperature of 100°F was chosen for the system to cycle on to reheat the tank to 120°F was chosen to maximize comfort levels. For an Aermec system, a 10-minute minimum cycle time is required to achieve this [HP.27]. With these design parameters, performance specifications, and existing HHL conditions, the required buffer tank volume was calculated to be 95-gallons to handle the HHL's hydronic heating system as shown in **Table HP.6**.

Buffer Tank Volume	
Heating Load (BTUh)	120,000
Minimum Cycle (min)	10
Design Water Temperature (F)	120
Minimum Water Temperature (F)	100
Total Extraction Load (BTUh)	27,728
Tank Volume	92.27
Rounded Volume	95

Table HP.6 - Buffer Tank Volume Calculation Variables

With these buffer tank calculations and AWHP selection, a design diagram was constructed through HydroSketch to represent how these designed alterations would result in the existing HHL system, which is shown in **Figure HP.1**.

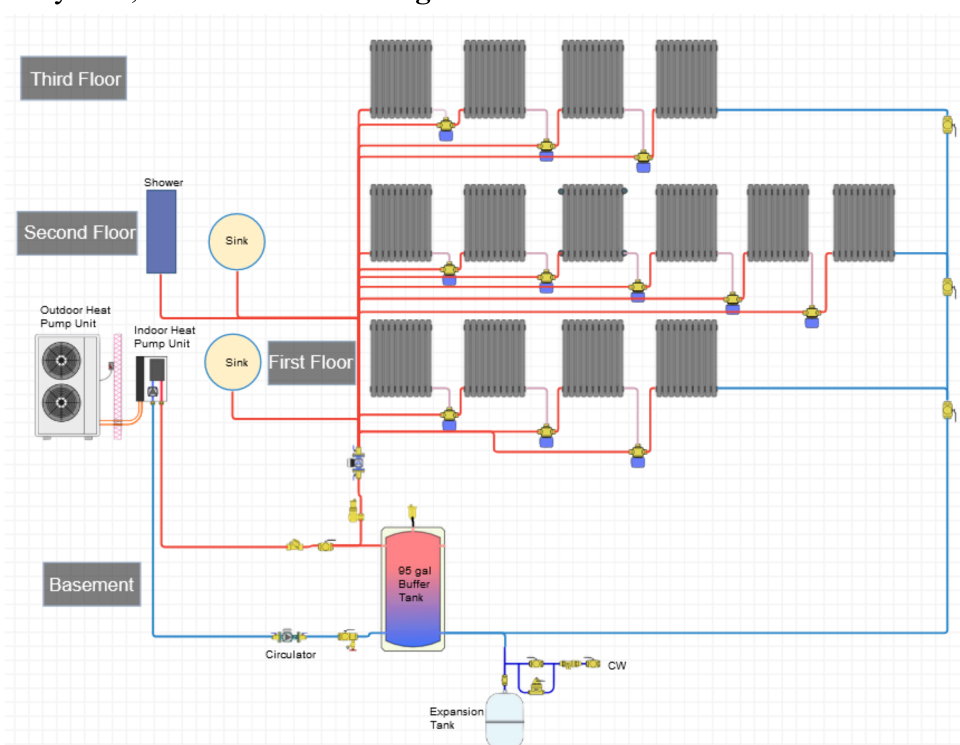

Figure HP.1 - Alternative 2 Hydronic Heating Network Design

As previously mentioned, on the DHW and hydronic heating piping on the heat source level was reworked to connect to the installed buffer tank. 14 existing cast iron radiators in the HHL are connected in parallel but do have three-way exchange valves to supply fresh hot water after passing through each radiator. An expansion tank was joined to the buffer tank inflow pipe to account for volume and pressure changes due to heating. For a similar purpose, an air vent was installed on top of the buffer tank to allow vapors to off-gas as needed. A purging valve was placed at the bottom outflow pipe of the buffer tank to account for situations where water must be drained from the system. Finally, ball valves were placed at each floor outflow intersection to close off areas serviced as needed for maintenance or replacements.

Analyzing these proposed alternatives, the team determined a variety of metrics to compare them using standardized criteria across a qualitative scale shown in **Table HP.7**. However, reduced energy consumption and cost were prioritized first since each primary component of this project's goals for energy efficiency and set budget constraints. The lifespan, operating temperature range, and percentage away from the designed heating load was still prioritized higher as well since each are key element to ensure the design is operational in the HHL. The lifespan must match at least industry averages, the alternatives can work within if not further past Pittsburgh's temperature range, and the alternatives are as close as possible to the designed heating load. Lastly, the COP was prioritized lowest as it was recognized for its importance in keeping the alternatives energy efficient, but each system found in the research was found to be in the same range and thus did not provide a significant influence between each system. Based on these criteria, reasoning, and the presented information on each alternative, the design selection matrix in **Table HP.7** was produced. This determined that alternative 2 is considered the preferred heat pump alternative design to meet this project's goal of retrofitting an existing home to an all-electric house.

Design Criteria	**Importance Factor (0 to 1)**	**Alternatives (0 to 5)**	
		Separate	Combined
Power	1	2	4
Cost	1	4	3
Operating Temperature Range	0.8	5	5
Lifespan	0.8	3	4
% Under/Oversized	0.7	4	5
COP	0.5	5	4
Ranking (/24)		17.7	19.7

Table HP.7 - All-Electric HHL Heating Design Selection Matrix

Energy Consumption

Since the Healthy Home Laboratory is currently used by the University of Pittsburgh as a research facility, the current electrical demand of the home is not reflective of an average single-family in Pennsylvania. In addition to this, the team was unable to access the utility bills for the home after repeated attempts to obtain them by contacting the University of Pittsburgh's facilities department. Due to these two compounding factors, the team needed a way to estimate the home's annual electrical demand. To achieve this, a watt summary was created with the existing appliances in the home. A watt summary is a model used to estimate the electrical consumption of a building. The annual electrical usage of each appliance is calculated and then summed to get the yearly electrical demand for the home.

To create the watt summary of the existing appliances, the team performed calculations using the data given by the specs list on the back of each appliance. Each appliance lists the amperage and voltage it uses; these two values can be multiplied together to obtain a wattage. Then, the wattage was multiplied by the average number of hours of use per day to obtain a watt-hour per day. The average number of hours of use per day values are given by a company called Warren Rural Electric Cooperative Corporation on their website [EC.1]. Finally, the units were converted to kilowatt-hours per year. The calculations for each appliance's electrical consumption are shown below.

$$Volts \times Amps = Watts$$
$$Watts \times \frac{1kW}{1{,}000W} \times \frac{Hr\ of\ Use}{Day} \times \frac{365\ Day}{1\ Year} = \frac{kWh}{Year}$$

Calculation EC.1 - The calculation that is is applied to each existing appliance in the HHL.

$$115\ Volts \times 6\ Amps = 690\ Watts$$
$$690\ Watts \times \frac{1kW}{1{,}000W} \times \frac{6\ Hr}{Day} \times \frac{365\ Day}{1\ Year} = 1{,}511 \frac{kWh}{Year}$$

Calculation EC.2 - Refrigerator annual electricity consumption

$$240\ Volts \times 20\ Amps = 4{,}800\ Watts$$
$$4{,}800\ Watts \times \frac{1kW}{1{,}000W} \times \frac{1\ Hr}{Day} \times \frac{365\ Day}{1\ Year} = 1752 \frac{kWh}{Year}$$

Calculation EC.3 - Clothes dryer annual electricity consumption

$$120\ Volts \times 20\ Amps = 2{,}400\ Watts$$
$$2{,}400\ Watts \times \frac{1kW}{1{,}000W} \times \frac{1\ Hr}{Day} \times \frac{365\ Day}{1\ Year} = 876 \frac{kWh}{Year}$$

Calcualtion EC.4 - Clothes washer annual electricity consumption

$$240\ Volts \times 4\ Amps = 9{,}600\ Watts$$
$$9600\ Watts \times \frac{1kW}{1{,}000W} \times \frac{1\ Hr}{Day} \times \frac{365\ Day}{1\ Year} = 3{,}504 \frac{kWh}{Year}$$

Calculation EC.5 - Electric stove annual electricity consumption

The above calculations are only for homeowner appliances, refrigerator, clothes dryer/washer, and the electric stove. Since the team used the HHL to model a single-family home, there is going to be additional electrical usage throughout the year contributed by lighting, entertainment systems, and the hot water boiler. These calculations were performed in a fashion similar to the ones above however the wattage did not need to be manually calculated because it was given by the spec sheet.

$$Total\ number\ of\ Bulbs\ in\ HHL\ =\ 52$$
$$Wattage\ Per\ Bulb\ =\ 15$$
$$Total\ Bulb\ Wattage\ =\ 52\ \times\ 15\ =\ 780\ Watts$$
$$780\ Watts\ \times\ \frac{1kW}{1{,}000W}\times\frac{4\ Hr}{Day}\times\frac{365\ Day}{1\ Year}\ =\ 1,139\frac{kWh}{Year}$$

Calculation EC.6 - LED lighting annual electricity consumption

Entertainment Appliances			
Appliance	**Watts**	**Hours of Use/Day**	**kWh/day**
50” LED TV	120	5	0.6
Roku	2.99	5	0.015
Nintendo Switch	26.6	2	0.053
PS4	20.66	3	0.062
Desktop Computer	200	10	2
Desktop Computer (sleep mode)	5	12	0.06
Laptop	40	10	0.4
Total Entertainment Appliance kWh			3.19

Table EC.1 - The estimated entertainment appliances in the HHL along with their respective wattages and the estimated hours of use per day. The last column of the table shows the kilowatt-hours per day calculated by multiplying the watts by hours of use per day and converting the units to kilowatts.

$$3.19\ kWh\ \times\ \frac{365\ Day}{1\ Year}\ =\ 1,165\frac{kWh}{Year}$$

Calculation EC.7 - Entertainment annual electricity consumption.

$$3,500\ Watts \times \frac{1kW}{1{,}000W} \times 3\frac{Hr}{Day} \times \frac{365\ Day}{1\ Year} = 3,833\frac{kWh}{Year}$$

Calculation EC.8 - Electrical resistance water heater annual electricity consumption.

HHL Estimated Total Annual Electrical Usage	
Appliance	**kWh/yr**
Refrigerator	1,511
Clothes Dryer	1,752
Clothes Washer	876
Electric Stove	3,504
LED Lighting	1,139
Entertainment	1,165
Water Heating	3,833
Total kWh/yr	13,780

Table EC.2 - The total estimated annual electrical usage of the Healthy Home Lab.

After conducting a watt summary of the existing appliances in the HHL, the team found the total to be 13,780 kWh/yr. This value is to be used as a baseline value for the electricity use. To make the HHL more energy efficient, the team proposes to replace the existing appliances with the United States Department of Energy (DOE), ENERGY STAR-rated appliances. Those appliances that have an ENERGY STAR rating means that they are much more energy efficient and consume less electricity than their non-ENERGY STAR-rated counterparts. The following table shows the total kilowatt-hour per year usage of each new proposed upgraded appliance, given by the DOE [EC.2].

DOE ENERGY STAR Rated Appliance Replacement	
Appliance	**kWh/yr**
Dishwasher	114
Refrigerator	360
Oven & Stove	195
Clothes Washer	105
Clothes Dryer	217
Total kWh/yr	991

Table EC.3 - The table shows the kilowatt-hour per year for the proposed DOE ENERGY STAR-rated appliance replacement in the HHL

New HHL Estimated Total Electrical Use: ENERGY STAR Appliances, Lighting, Entertainment	
Appliance	**kh/yr**
Dishwasher	114
Refrigerator	360
Oven & Stove	195
Clothes Washer	105
Clothes Dryer	217
LED Lighting	1,139
Entertainment	1,165
Total kWh/yr	3,295

Table EC.4 - The estimated total electrical usage of the HHL with the replacement of the existing appliances with ENERGY STAR-rated appliances along with LED lighting and entertainment. LED lighting and entertainment kWh/yr are the same values shown in **Table E.2**.

Table E.4 shows the new HHL estimated annual electrical usage without adding the combined heat pump system, which uses electricity to operate. To calculate this value, the team created a bin model. This was necessary since the HHL is being modeled as a four-person household, thus the current utility bills would not be representative of the heating demand usage that would be required by a four-person household. Therefore, a bin model had to be generated to most accurately model the annual heating load of the heat pump and its associated electrical usage it will require in Pittsburgh conditions.

Generating a bin model is the most appropriate method to estimate the heating demand as it accounts for (1) the non-linearity of energy consumption per temperature increase due to decreasing efficiency attributed to Carnot's Theorem and (2) the heat pump's energy consumption rate reaching a maximum rate once the system is pushed past heating load capacity [EC.3]. A bin model is set up by acquiring hourly temperature data for all 8,760 hours of the year for a location and organizing it into temperature ranges, or bins, that count the hourly frequency that temperatures appear within that temperature range. Each bin now contains the number of hours in the year that the specified location was at that temperature. Then using the heat pump's performance data indicating its energy consumption rate in kilowatts at a specified temperature, each bin can be multiplied by the energy consumption the heat pump uses at that temperature. This provides the total energy in kilowatt-hours that the heat pump would use during the year while at that temperature when at full capacity.

However, a heat pump system runs on varying cycles at varying durations throughout the day to heat the home to the design temperature when needed. Therefore, this change in time at capacity is accounted for by determining the percentage of the time the heat pump is operating, based on the number of cycles per hour and minutes per cycle, at each temperature and multiplying it by the total energy the heat pump uses at each temperature. The summation of these resulting energy values gives the total annual energy used by a heat pump at a specified location. This method was applied to Pittsburgh by collecting annual hourly temperature from 2003 to 2023 for Pittsburgh from the Iowa Environmental Mesonet and averaging it to get an accurate representation of Pittsburgh's annual temperature conditions. This was binned as previously described and multiplied by the energy consumption rate at each temperature interpolated from the performance data provided by the selected heat pump system alternative. Based on conversations with industry professionals and applied engineering judgment, the team estimated cycles per hour and minutes per cycle at each temperature value so the percent of operation at full capacity could be calculated. This was multiplied by each energy value found at each temperature bin and the final results were summed to get a value of 25,400 kWh/year used by the heat pump system to meet the necessary heating demand in Pittsburgh for the HHL. The calculation table showing this process for the HHL in Pittsburgh may be found in the Appendix under the energy design calculation headline.

New HHL Estimated Total Electrical Use with Combined Heat Pump System	
Appliance	**kh/yr**
Dishwasher	114
Refrigerator	360
Oven & Stove	195
Clothes Washer	105
Clothes Dryer	217
LED Lighting	1,139
Entertainment	1,165
Combined Heat Pump	25,400
Total kWh/yr	28,695

Table EC.5 - The new HHL estimated total annual electrical use with the addition of the combined air and water heat pump system.

From the above table, the new annual electrical demand for the HHL with the appliance upgrades and the addition of a heat pump is 28,695 kWh/yr. This value is approximately 2.08 times higher than the existing electrical demand of the HHL which is 13,780 kWh/yr. However, the existing electrical demand does not accurately represent the HHL's energy usage. This is because not all of the energy currently used by the HHL is electric; the radiator boiler system is fueled by gas. The units of gas usage and electrical usage are different, thus gas usage was not included in the watt summary shown in **Table EC.2**. To make an accurate comparison of the HHL's electrical consumption pre-upgrades and post-upgrades, the gas energy used by the radiator boiler system must be calculated in terms of electrical equivalence. To do so, the team consulted Dr. Tony Kerzmann, a faculty mentor in the Mechanical Engineering Department at the University of Pittsburgh. Upon consultation, it was established that the electrical demand of the heat pump can be used to back-calculate how much gas the electricity is equivalent to. The calculation is shown below.

$$Heat\ Pump\ kWh/yr \times Heat\ Pump\ COP \times Gas\ Radiator\ Eff. = Gas\ Electrical\ Equiv.$$
$$25,400\ kWh/yr \times 3.4 \times 0.82 = 105,400\ kWh/yr$$

Calculation EC.9 - The calculation of the gas electrical equivalence. The heat pump's electrical demand is multiplied by its COP (Coefficient of Performance) and gas radiator efficiency.

$$Gas\ Elec.\ Equiv. + Existing\ HHL\ Elec.\ Demand = Total\ Existing\ HHL\ Energy\ Demand$$
$$105,400\ kWh/yr + 13,780\ kWh/yr = 119,180\ kWh/yr$$

Calculation EC.10 - The total existing HHL energy demand accounting for the gas energy electrical equivalence.

From **Calculation EC.10** above, the total existing energy demand of the HHL is 119,180 kWh/yr accounting for gas heating. Because of this, an accurate comparison can be made between the existing energy demand and the new energy demand with all highly efficient, electric appliances. There is a clear distinction between the energy demand and the electrical demand of the HHL. Referencing **Table EC.2**, the existing electrical demand of the HHL is 13,780 kWh/yr. Referencing **Table EC.5**, the new electrical demand of the HHL is 28,695 kWh/yr. However, when comparing the existing energy demand of 119,180 kWh/yr and the new energy demand which is equivalent to the new electrical demand of 28,695 kWh/yr, a vast improvement is shown. The existing energy demand of the HHL is approximately 4.15 times higher than the new energy demand with upgrades. The key takeaway is that even though the electrical demand of the HHL is increasing the total energy demand is decreasing by approximately 76%.

Solar Design

Referencing the previous section, and noting the increased electrical demand of the HHL, the team proposes to install a solar array to offset this. Three separate alternatives are proposed by the team with their respective calculations, information, and specifications. To calculate the estimated solar energy production of each alternative, the team consulted Dr. Tony Kerzmann. The overview of the calculation is shown below.

$$Solar\ Irradiance \times Panel\ Eff. \times Panel\ Area \times \#\ Panels \times Elec.\ Loss = Energy\ Prod.$$

Calculation S.1 - This equation was used to calculate the solar energy production in kWh/yr of each rooftop solar array alternative.

To better understand the above equation, it’s important to know what the variables mean. Solar irradiance is the value of the amount of sun energy contacting the Earth in units of kWh/m^2/day, which is variable per location. In Pittsburgh, the value of Solar Irradiance is 3.5 kWh/m^2/day which is given by the National Renewable Energy Laboratory [S.1]. The panel efficiency describes the amount of solar energy that the panel can absorb and convert to electrical energy. Most solar panels fall in the range of 15% to 20% efficiency. The last variable is electrical loss. This variable describes the amount of electrical converted, solar energy that is lost through the panel inverters, and the old knob and tube wiring found inside of the HHL. The value of the electrical loss is assumed to be 0.9. This means that there is a 10% electrical loss, or in other words, 90% of the captured solar energy is usable. When designing the alternatives for the rooftop solar array, the team used a modeling software called OpenSolar [S.2]. This software was recommended by Dr. Tony Kerzmann and can change the azimuth, panel angle, and panel orientation among a plethora of other things. OpenSolar also gives cost and electrical production estimates of the chosen array, however, the team used OpenSolar only to determine the amount of panels that can theoretically fit on the rooftop.

Alternative 1

The following specs are given by the manufacturer datasheet, aside from cost [S.3].

Alternative 1 Specs	
Manufacturer	Q Cell
Wattage	385 W
Efficiency	19.1%
Weight	48.5 lbs/panel
Panel Area	1.96 m^2
Number of Panels	33
Cost per Watt – Total Cost	$3.00 – $38,100

Table S.1 - Solar alternative 1 specifications.

Figure S.1 - Model of solar alternative 1, given by OpenSolar. The pink lines represent the panel connections to one another, also called strings.

$$Solar\ Irradiance \times Panel\ Eff. \times Panel\ Area \times \#\ Panels \times Elec.\ Loss = Energy\ Prod.$$
$$3.5\ kWh/m^2/day \times 0.191 \times 1.96m^2 \times 33 \times 0.9 = 39\ kWh/day = 14,235\ kWh/yr$$

Calculation S.2 - The calculation of the estimated energy production of Solar Alternative 1.

$$Alternative\ 1\ Energy\ Production \div HHL\ New\ Elec.\ Consumption = Elec.\ Offset$$
$$14,235\ kWh/yr \div 28,695\ kWh/yr = 49.6\%\ Electrical\ Offset\ Per\ Year$$

Calculation S.3 - The calculation of the electrical offset per year for Solar Alternative 1.

Alternative 2

The following specs are given by the manufacturer datasheet, aside from cost [S.4].

Alternative 2 Specs	
Manufacturer	Trina Solar
Wattage	605 W
Efficiency	22.4%
Weight	74.3 lbs/panel
Panel Area	2.7 m^2
Number of Panels	24
Cost per Watt – Total Cost	$3.20 – $46,500

Table S.2 - Solar alternative 2 specifications.

Figure S.2 - Model of solar alternative 2, given by OpenSolar. The pink lines represent the panel connections to one another, also called strings.

$$Solar\ Irradiance \times Panel\ Eff. \times Panel\ Area \times \#\ Panels \times Elec.\ Loss = Energy\ Prod.$$
$$3.5\ kWh/m^2/day \times 0.224 \times 2.7m^2 \times 24 \times 0.9 = 45.7\ kWh/day = 16,680\ kWh/yr$$

Calculation S.4 - The calculation of the estimated energy production of Solar Alternative 2.

$$Alternative\ 1\ Energy\ Production \div HHL\ New\ Elec.\ Consumption = Elec.\ Offset$$
$$16,680\ kWh/yr \div 28,695\ kWh/yr = 58\%\ Electrical\ Offset\ Per\ Year$$

Calculation S.5 - The calculation of the electrical offset per year for Solar Alternative 2.

Alternative 3

The following specs are given by the manufacturer datasheet, aside from cost [S.3].

Alternative 3 Specs	
Manufacturer	Q Cell
Wattage	405 W
Efficiency	20.6%
Weight	48.5 lbs/panel
Panel Area	1.96 m^2
Number of Panels	33

Cost per Watt – Total Cost	$3.00 – $41,000

Table S.3 - Solar alternative 3 specifications.

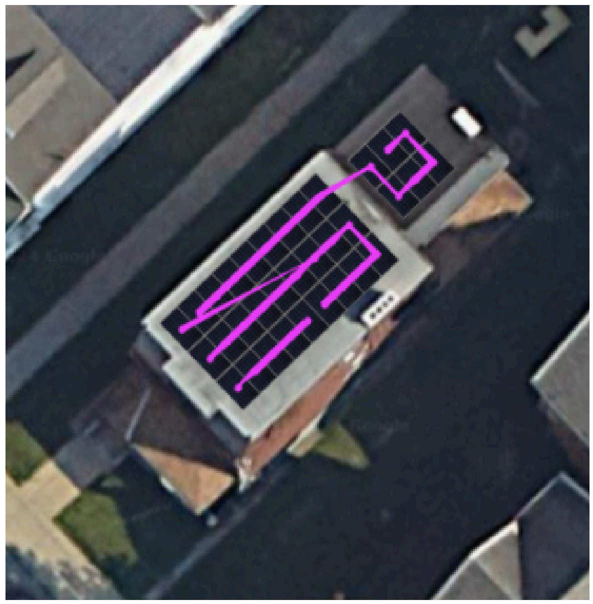

Figure S.3 - Model of solar alternative 3, given by OpenSolar. The pink lines represent the panel connections to one another, also called strings.

$$Solar\ Irradiance \times Panel\ Eff. \times Panel\ Area \times \#\ Panels \times Elec.\ Loss = Energy\ Prod.$$
$$3.5\ kWh/m^2/day \times 0.206 \times 1.96m^2 \times 33 \times 0.9 = 42\ kWh/day = 15,330\ kWh/yr$$
Calculation S.6 - The calculation of the estimated energy production of Solar Alternative 3.

$$Alternative\ 1\ Energy\ Production \div HHL\ New\ Elec.\ Consumption = Elec.\ Offset$$
$$15,330\ kWh/yr \div 28,695\ kWh/yr = 53\%\ Electrical\ Offset\ Per\ Year$$
Calculation S.7 - The calculation of the electrical offset per year for Solar Alternative 3.

Alternatives Matrix

To assess the three different alternatives, the team created an alternatives matrix. Within this matrix, the following design criteria were assessed: electricity production, cost, commercial availability, efficiency, weight, roof space utilized, and lifespan. The three most important factors which are electricity production, cost, and commercial availability were weighted 1 on a 0 to 1 scale, meaning they contribute the most to the decision. Based on each criterion's importance factor and rank, alternative 3 is preferred.

Design Criteria	Importance Factor	Alternatives (0 to 5)		
		Array 1	Array 2	Array 3
Electricity Production	1	3	5	4
Cost	1	4	2	3
Commercial Avail.	1	5	1	5
Efficiency	0.9	3	5	4
Weight	0.8	2	1	2
Roof Space Utilized	0.7	3	4	3
Lifespan	0.6	4	4	4
Ranking (/30)		24	21	25

Table S.4 - This table represents the alternatives matrix for the Solar Array designs. Based on the ranking criteria, Alternative 3 is preferred.

Roof Structural Concerns

Due to the installation of a solar array, there will be an additional 1,600 lbs on the rooftop. The team was not able to access information such as roof age, material, and condition. Additionally, there are no structural engineers on the team qualified to assess the structural integrity of the roof. With all of these things compounded (additional weight, inaccessible information, lack of qualifications) the team is unsure if the roof will be able to support the additional weight of solar panels. However, before the installation of the array, the solar installation company will perform a structural analysis of the roof and determine if a replacement is necessary.

Water Alternatives

Technologies

Greywater System

Greywater systems are technologies commonly employed to recycle household water for non-potable reuse. The water collected in these systems can come from a variety of sources including bathroom sinks, showers, kitchen sinks, laundry machines, and dishwashers. It is important to note that these systems do not include the collection or reuse of blackwater, so collection from the toilet is not applicable. These systems, however, are mainly used to pump water back into toilets and for irrigation purposes. In doing this, greywater can conserve up to 60% of household water use. [W.1]

Greywater systems are a way to conserve water by collecting once-used water, treating it, and redistributing it. The treatment of greywater systems is different from that of drinking water because the standard that it must meet is much different. The end use is for flushing and lawn care, rather than for consumption or use in washing dishes or laundry. The main water quality concerns for this water system are that there are no large solids, or properties that will lead to clogging in the piping system. Additionally, it is necessary to make sure there are no biological contaminants that will be released into the air when toilets are flushed. The main methods of treatment are filtration and disinfection. There are a multitude of methods for treating greywater, which will be further evaluated. After this treatment process occurs, the water is then able to be used for flushing and yard care.

Rainwater System

Rainwater systems are similar to greywater systems, however the water is collected from rooftops rather than from inside the house. This is a technology that has been used for centuries and is extremely effective in water conservation efforts as well as a way to prevent sewer overflows. Rainwater collection is something that is not federally legal, so it is important to look into state regulations before investing in a system. In Pennsylvania, though, it is legal and encouraged to collect rainwater. For example, in Philadelphia, there are incentives for collecting rainwater. The city offers stormwater grants for homeowners who choose to implement this technology. [W.2]

Similarly to greywater systems, there are not many regulations for the quality of water being produced. The necessary quality mainly depends on the intended end use. Filtration is an important step of this process because debris is often collected along with the rainwater. Some benefits of harvesting rainwater include cost efficiency, sustainability, improving drainage, and backing up water supply in case of emergency.

Composition

Lab Results

When looking at designing a combined rainwater-greywater system, it was important to analyze the quality of the water leaving the house. To do this, water was collected from the shower and bathroom sink in the HHL. Additionally, water was collected from a gutter in a neighboring home. In addition to these samples, a mock effluent was created using small amounts of body soap, hand soap, and shampoo. These were selected based on the locations that are being filtered into the treatment system and were scaled down to be the same concentration that would be present leaving the house. This water was then tested for common contaminants and quality values. This analysis was done to confirm the assumption that the HHL has average water quality.

The first test was simply done with Pool and Spa test strips to find hardness, chlorine, bromine, pH, alkalinity, and cyanuric acid levels. The most important values garnered from these test strips were pH, hardness, and alkalinity levels due to concerns with buildup in pipes. The other metrics were useful in determining if there were any additional contaminants in the water to note. The results from this test are shown below in **Table W.1**.

	Sink	Shower	Gutter	Contaminated
Total Hardness (ppm)	100	100	66.7	100
Total Chlorine (ppm)	0	0	0	0
Total Bromine (ppm)	0	0	0	0
Free Chlorine (ppm)	0	0	0	0
pH	6.8	6.6	6.2	6.2
Total Alkalinity (ppm)	40	40	40	40
Cyanuric Acid (ppm)	0	0	0	0

Table W.1 - Results from Pool & Spa test strips. The results follow the assumption that water is at normal levels of hardness, pH, and alkalinity.

The second test conducted was another test strip used to compare the results from the Pool & Spa test strips. These strips tested for the same values as the first, but included additional values like copper, iron, lead, nitrite, nitrate, and carbonate. To conduct this test, the strips were dipped into water and then the color of the strip was compared to the colors on the back of the bottle. These colors correspond to an amount of each specific metric that is present in the sample. It is important to note that some of the values from these tests are ranges. This is due to some uncertainty in the test strip colors compared to the colors listed on the bottle. **Table W.2** lists the results.

	Sink	Shower	Gutter	Contaminated
Ntriate (ppm)	10	0	10	0
Nitrite (ppm)	0	0	1	0
Total Hardness (ppm)	37.5	25	25	25
Free Chlorine (ppm)	0	0	0	0
Total Chlorine (ppm)	0	0.17	0	0
Bromine (ppm)	0	0	0	0.7
MPS (ppm)	0	1	0	0
Copper (ppm)	0	0	0	0.3
Iron (ppm)	0	0	0	0
Lead (ppm)	0	0	0	23.3
Nickel (ppm)	6.7	3.3	0	6.7
Sulfite (ppm)	0	0	10	0
Cyanuric Acid (ppm)	0	0	0	0
Carbonate (ppm)	40	40	40	40
Total Alkalinity (ppm)	40	40	40	40
pH	6.4	6.4	6.4	6.5

Table W.2 - Results from the second brand of test strips.

The results are very similar to the results in the previous table. A notable difference is the total hardness between the two tables. The results in **Table W.1** are much higher than the results in **Table W.2**. However, both of the hardness tests resulted in fairly normal values; neither of which are of major concern. Additionally, the pH and alkalinity are both in the range of standard values. Nothing seen in these results indicates that additional treatment will be needed for this water to achieve the necessary water quality for flushing and lawn care.

Additionally, the water samples were tested for conductivity and turbidity using a Fisher Accumet conductivity meter and a 2100P turbidity meter. Turbidity is a measure of how clear a liquid is and it is measured in NTU. During this test, each sample was compared to average turbidity values to ensure there were no major complications. Conductivity measures how well electricity or heat can pass through the water sample. The results from these tests are pictured below in **Table W.3**. The outcome from these was the affirmation that the water samples were as expected. The conductivity values were in the ranges of a typical river or lake according to the Environmental Protection Agency (EPA). While the values are high compared to pure water, this water is still going to be filtered before returning to the plumbing system and it has been found that filtration effectively removes conductivity [W.3]. As for turbidity, the ranges were very low for the water collected straight from faucets. For the gutter and contaminated water, the turbidity values were slightly higher, but this was to be expected as they had many more chemicals and solids in them. Still, with these increased values there is no issue in using this for non-potable uses, especially since these values are pre-filtration.

	Sink	Shower	Gutter	Contaminated
Conductivity (muS)	187.2	142.3	60.6	186.9
Turbidity (NTU)	0.61	0.74	15.7	4.97

Table W.3 - Values of turbidity and conductivity for each of the water samples. Higher values in turbidity in the contaminated and gutter water samples are seen. Low values of conductivity are seen in the gutter sample.

The next set of tests conducted was to find the amount of total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS) that are present in the water samples. These tests were all conducted in conjunction with each other. The results of these tests showed that the water if anything had small amounts of solids when compared to averages. Ultimately all of the tests reaffirmed the assumption that basic filtration would be sufficient to treat the greywater rainwater system at hand with no additional treatment methods. These results are seen in the table below.

	Sink	Shower	Gutter	Contaminated
Total Solids (g)	0.00354	0.00357	0.00198	0.00247
Total Suspended Solids (g)	0.00031	0.00013	0.02176	0.00000
Total Dissolved Solids (g)	0.00288	0.00367	0.00308	0.00247

Table W.4 - The amount of solids present in each sample in grams. There are fairly small values in the sink, shower, and contaminated samples. The values are larger in the gutter sample which is to be expected with the debris and dirt present.

Storage

Sources

The storage tank sizing was fairly simple to determine. The average outflow of washing machines, bathroom sinks, and showers for a four-person home as defined by Pennsylvania State University was about 117 gallons of water per day. [W.4] Then, using data from the National Weather Service, it was estimated that 64 gallons per day of rainwater would be entering the system, coming to a total of 181 gallons per day. [W.5]

Using the same information above, it was calculated that 32 gallons of water per day would be used for flushing purposes. Plus, there was an additional 96.2 gallons per day recommended for lawn care to take into account. [W.6] Another factor that was important to consider in a place like Pittsburgh that has such variable temperatures is the amount of water coming in versus the amount of water being used each month. Dividing the year into "warm" and "cold" months, this difference was able to be accounted for. In the warm months of April through August, lawn care would be needed but in the colder months of December through March, lawn care is not a priority. Looking at these differences showed no need for the collection of rainwater in the colder months since there is not as much water needed for lawn care.

As for the sizing of the storage tank, a safety factor of 1.1 was used to determine a tank size of 200 gallons. The storage tank is only used to briefly hold water before it is used for its intended purpose. After a brief search, a 200-gallon tank from RainHarvest Systems was found. This tank comes at a fairly low price of $450 and would work well for this intent. [W.7]

Filtration

Underdrainage

One component that stays consistent with each filter is the underdrainage system. The underdrainage is underneath a filter to help collect filtered water. Underdrainage systems help to prevent clogging as well by not allowing water to pool at the bottom of the gravel. The underdrainage is composed of a manifold and multiple laterals with perforations. The laterals push water through the small perforations and the manifold helps to ensure proper flow through the underdrainage system. The underdrainage system for this tank was calculated following a tutorial from the Walchand Institute of Technology. [W.8] The necessary underdrainage is to contain a manifold 2 inches in diameter and four laterals on either side of the manifold, shown below in **Figure W.1**. Each of these laterals should have four to five perforations, totaling 36 perforations in all. These values were calculated using the diameter of the tank.

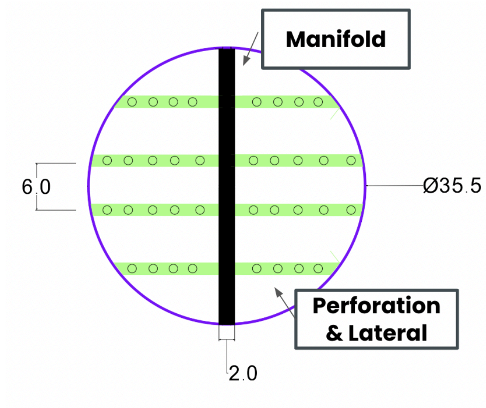

Figure W.1 - This figure depicts the underdrainage system used for all filtration models. There are 4 laterals each 6 inches apart and 15 mm in diameter.

The cost of this underdrainage system is approximately $90. The manifold is about half that cost at $45 if purchased from Lowe's. This one specifically has four ports (for each lateral) and can handle both hot and cold water lines. There are then eight total pipes that leave the manifold. These pipes can be made of PVC which costs about $8.3/ft. [W.9] Then since each pipe is approximately two-thirds of a foot long, which means that the cost of the pipes is in total about $45. Making the total underdrainage cost to be approximately $90 per tank.

Slow Sand

The first filtration system under consideration is the slow sand filter. Slow sand filters (SSFs) are commonly used filtration systems for treating drinking water. The main components of this system are sand and gravel. This filter is comprised mainly of sustainable materials which is a major benefit of this first alternative. Along with being comprised of sustainable materials, this alternative does not require any additional energy from the house, as it operates on gravity alone.

SSFs are also able to remove a high percentage of the contaminants that are present in greywater and rainwater. This technology has mainly been used on a larger scale for water treatment facilities globally for over a century. When the untreated water first enters the system it goes through biological filtration while passing through the fine sand layer. An important piece of this layer is known as the schmutzdecke, which is a thin layer of biological matter that forms on top of the sand. The schmutzdecke is an integral part of the SSF because it removes viruses and bacteria from the water. This layer also begins the process of removing unwanted solids, color, and odor from the influent.

Next, the water goes through the sand and gravel layers. In this alternative, the sand layer is almost two feet (47.3 inches) deep. Solid particles are absorbed by the fine grain sand and this in turn improves the water quality. In this design, the particle diameter of the sand where 10% is smaller, or the D_{10} is 0.2 millimeters. This qualifies the sand as fine sand particles. The uniformity coefficient for this sand is designed to be 3, meaning that the soil is poorly graded and all particles are around the same size. Then, the water is led into the gravel layer. The gravel is composed of three different layers of varying sizes that increase in size as the water passes through them. The D_{10} of these layers are respectively 1mm, 4mm, and 16mm. The water is then effectively filtered and can be pumped out to the lawn area and the toilet bowl for flushing. Below is an AutoCAD rendering of the tank and its dimensions.

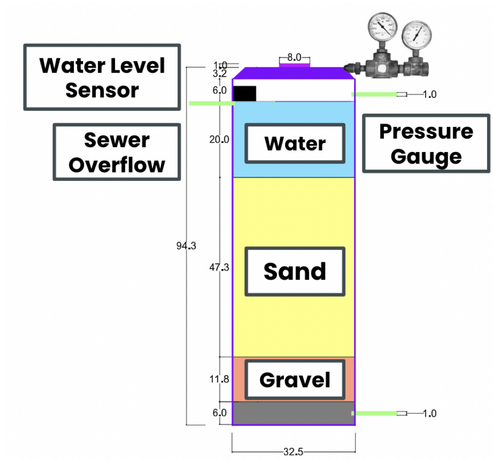

Figure W.2 - Image of the slow sand filtration system as drawn in AutoCAD. Features include sand, gravel, water level, and above-water level depths. Locations of the water level sensor, sewer overflow valve, outflow pump, and pressure gauge are all included.

The dimensions of this tank were calculated using the daily inflow of water as well as the velocity in the system. This calculation helped determine a commercially available tank that would be able to account for the filtration media.

$$Flow\ (Q)\ \div\ Velocity\ (v)\ =\ Surface\ Area\ (A)$$

$$200\ (gal/d)\ \div\ 7.9\ ft^3/ft^2/d\ =\ 4.3\ ft^2$$

Calculation W.1 - The calculation for slow sand required surface area.

$$Number\ of\ 50\ lb\ Bags\ of\ Sand\ =\ (Volume\ Required\ *\ Density\ of\ Sand)/50\ lbs\ per\ bag$$

$$[(5.6\ ft2\ *\ 3.94\ ft)\ *\ 90\ lbs/ft3]/50\ lbs\ per\ bag\ =\ 40\ bags$$

$$Number\ of\ 50\ lb\ Bags\ of\ Gravel\ =\ (Volume\ Required\ *\ Density\ of\ Gravel)/50\ lbs\ per\ bag$$

$$[(5.6\ ft2\ *\ 0.98\ ft)\ *\ 91\ lbs/ft3]/50\ lbs\ per\ bag\ =\ 10\ bags$$

$$Tank\ +\ Sand\ +\ Gravel\ +\ Underdrainage\ =\ Total\ Cost$$

$$\$555\ +\ (40\ bags\ *\ \$45/bag)\ +\ (15\ bags\ *\ \$96/bag)\ +\ \$90\ =\ \sim\$3500$$

Calculation W.2 - The cost calculation for slow sand filtration alternative

The additional features of the tank, as seen above, include a water level sensor, outflow valve, and pressure gauge. The water level sensor and sewer overflow valve are connected in the sense that they are both used when water levels are too high for the tank and water needs to be released to the sewer. The pressure gauge in the tank is to determine when maintenance is necessary for the tank. Maintenance of this tank is not extensive, but it is important for the longevity of the system. Maintaining the SSF mainly consists of scraping the top of the tank to prevent clogging. When the pressure indicates a significant drop, the homeowner must scrape the top 1-3cm of sand and biological matter off of the top of the system. [W.11] This process allows for the filter to continue being effective. In doing this regularly, the filter can last over a decade without the need for replacement. Even when filters need to be replaced, the only materials needed will be additional sand and gravel, which are relatively inexpensive.

Rapid Sand

Rapid sand filtration (RSF) was the second alternative considered in this project. Like the slow sand filter, it is comprised mainly of sand and gravel as its filtration media. The main differences between rapid and slow sand filtration are that RSF is a physical process whereas SSF is a biological process. [W.11] In this alternative there would be required power input to achieve a higher hydraulic loading rate in the system of 16.4 $ft^3/ft^2/d$. The required surface area that was calculated for this filter was 1.6ft^2, however, the actual area is much larger at 4.74ft^2. This is due to the availability of tanks on the market not being made to have such a small surface area with enough depth to effectively filter out all contaminants.

$$Flow\ (Q)\ \div\ Velocity\ (v)\ =\ Surface\ Area\ (A)$$

$$200\ (gal/d)\ \div\ 16.4\ ft^3/ft^2/d\ =\ 1.6ft^2$$

Calculation W.3. The calculation for rapid sand required surface area.

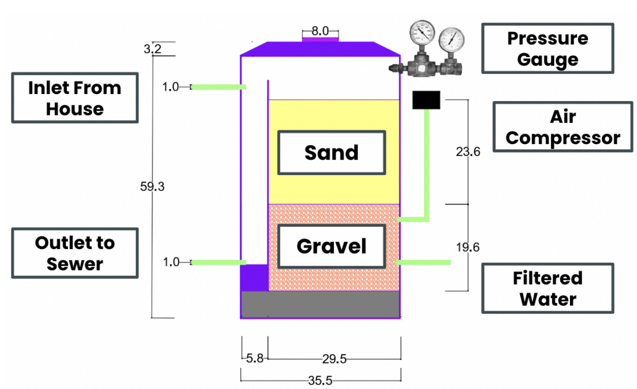

Figure W.3 - The tank design for the rapid sand filtration option. This tank includes a sand layer, gravel layer, pressure gauge, and air compressor for maintenance.

The specifications for the sand and gravel of this filter are also a bit different than those of the slow sand filter. The sand has a larger diameter in this filtration option, using a D_{10} of 0.35mm. The gravel layer consists of five different sizes of gravel ranging from 2-40mm progressively getting larger and they move toward the bottom.

The air compressor in this system is necessary because of a process known as backwashing. This is the main form of maintenance in a rapid sand filter. Backwashing is a process where water is pumped in the reverse direction through the filter to remove debris and prevent clogging. It is estimated that backwashing will have to occur for about 30 minutes every month to properly maintain the system. Backwashing makes maintenance much easier for the homeowner as it automates the process. Because of this, though there is the necessity of an air compressor and pump for this system, which are reflected in the cost calculations below. The rapid sand filtration method is unique because two tanks are required for filtration. Therefore the cost of this system must be doubled to accurately reflect the price.

$$Pounds\ of\ Sand\ Required = (Volume\ Required\ *\ Density\ of\ Sand)$$
$$[(4.75\ ft2\ *\ 2\ ft)\ *\ 90\ lbs/ft3]/50 lbs/bag\ =\ 18\ bags$$

$$Number\ of\ 50\ lb\ Bags\ of\ Gravel\ =\ (Volume\ Required\ *\ Density\ of\ Gravel)/50\ lbs\ per\ bag$$
$$[(4.75\ ft2\ *\ 1.6\ ft)\ *\ 91\ lbs/ft3]/50\ lbs\ per\ bag\ =\ 15\ bags$$

$$Tank\ +\ Sand\ +\ Gravel\ +\ Underdrainage\ +\ Air\ Compressor\ =\ Total\ Cost$$
$$2\ *\ [\$530\ +\ (18\ bags\ *\ \$45/bag)\ +\ (15\ bags\ *\ \$96/bag)\ +\ \$90]\ =\ \sim\$6620$$

Calculation W.4 - The cost calculation for rapid sand filtration alternative [W.12,13,14]

Biochar

The third filtration alternative is Biochar filtration. Biochar filtration systems utilize two layers of substrate. The top layer consists of the layer that disinfects the greywater, the biochar. Biochar is a substrate with a mulch-like consistency that is created from the burning (or charring) of natural materials such as wood chips or other plant and animal biomass [W.16]. Similar to sand, biochar does not only filter particles larger than itself but also removes smaller particles through chemical reactions [W.17]. Biochar is effective for this system as it can remove bacteria that are potentially dangerous when airborne via toilet flushing, along with 95% of total suspended solids according to the World Academy of Science [W.17.5] When sourcing this material from Arti Biochar company, these biochar particles have diameters ranging from 0.25 to 0.853 millimeters [W.18].

Using a model adapted from Niwagaba et al. (2014), the depth of biochar required to filter non-potable greywater is 60 centimeters [W.19]. Following the same model, a gravel depth of 50 centimeters is used [W.19]. This gravel will have three separate layers, the top layer with a diameter of 1 millimeter, the second with a diameter of 4 millimeters, and the third with a diameter of 16 millimeters. In this system, gravel is utilized to prevent clogging of the underdrainage by acting as a barrier between the finer biochar substance. Gravel is also used to regulate the flow through the filter by forcing water to maneuver around the coarse particles. The layering of the substrate can be visualized in Figure W.4 which was adapted from Dabholkar's Concepts & Basics Academy [W.20]. A 205-gal tank from the National Tank Outlet is used to house this system [W.20.5]. This figure also depicts the piping network used for this system. The underdrainage design is the same as used by the slow and rapid sand filters and is depicted in Figure W.4. Three main pipes are utilized to bring water into and remove water from the filtration tank to either to storage tank or to the sewage system. The fourth pipe introduces air into the system via an air compressor. This air compressor is used for maintenance purposes. Valves in these sections allow each network to be opened or closed. As depicted by Calculation W.5, approximately 300 lbs of biochar are required for this system. Additionally, this system requires approximately 750 lbs of gravel. After adding the additional costs of the tank, underdrainage, and air compressor, the final cost for this system is about $4,500.

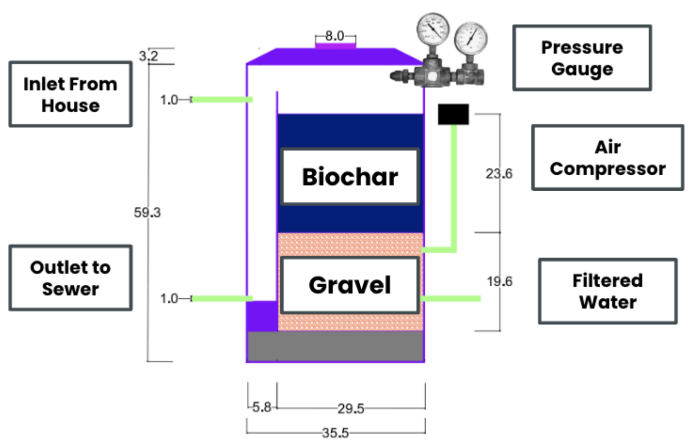

Figure W.4 - Biochar filtration system as drawn in AutoCAD. Features include biochar, gravel, inlet and outlet pipes, and air compressor. Locations of the water level sensor, sewer overflow valve, outflow pump, and pressure gauge are all included.

$$Pounds\ of\ Biochar\ Required\ =\ (Volume\ Required\ *\ Density\ of\ Biochar)$$
$$(4.75\ ft2\ *\ 2\ ft)\ *\ 31.2\ lbs/ft3\ =\ 296.4\ lbs$$

$$Number\ of\ 50\ lb\ Bags\ of\ Gravel\ =\ (Volume\ Required\ *\ Density\ of\ Gravel)/50\ lbs\ per\ bag$$
$$[(4.75\ ft2\ *\ 1.6\ ft)\ *\ 91\ lbs/ft3]/50\ lbs\ per\ bag\ =\ 15\ bags$$

$$Tank\ +\ Sand\ +\ Gravel\ +\ Underdrainage\ +\ Air\ Compressor\ =\ Total\ Cost$$
$$\$530\ +\ (296.4\ lbs\ *\ \$6.8/lb)\ +\ (15\ bags\ *\ \$96/bag)\ +\ \$90\ =\ \sim\$4500$$

Calculation W.5 - The cost calculation for biochar filtration alternative [W.23,13, 25.5]

Also seen in **Figure W.4** is a pressure gauge at the top of the system. This pressure gauge is used to determine when maintenance is required. Similar to the rapid sand filter, this biochar system can implement a backwashing system. To reiterate, backwashing should be performed when the pressure gauge reads 10 psi above the normal reading (where the normal reading is determined immediately following the last backwashing) [W.21]. Backwashing should also be performed when the water pressure is low or when the water is clouded as this can be a sign of clogging in the system [W.21]. To perform backwashing, the inlet valve is closed, preventing greywater from the house from entering the unit. The clean water from the storage tank is used for this process, so this outlet valve is opened allowing the water back into the system. After turning on the air compressor, the connecting valve is opened, creating a pressure change in the system that will pull the water up, against gravity, through the substrate layers, thus cleaning any debris caught in between the particles. The valve leading to the sewer is then opened, so all water that is used to clean the filter can be properly disposed of.

Evaluation

These filtration alternatives were evaluated using five comparison criteria. These criteria included particle removal efficiency, affordability, energy use, sustainability, and maintenance. A summary of this comparison can be seen in Table W.5 below.

Design Criteria	Importance Factor (/1)	Alternatives		
		Slow Sand	Rapid Sand	Biochar
Removal	1	2	2	2
Affordability	0.8	2	0	1
Home Energy Use	0.8	2	1	1
Sustainability	0.7	2	2	2
Maintenance	0.7	1	2	2
Ranking (/8)		7.3	6.4	7.2

Table W.5 - This table represents the alternatives matrix for the greywater and rainwater system designs. Based on the ranking criteria, slow sand filtration is preferred.

Each criterion was evaluated using a ranking of 0, 1, or 2 where the higher numbers represented a better fit. An importance factor was given to each criterion, with removal ranked as a 1 as seen in **Table W.5**, showing the highest importance.

Particle removal efficiency was ranked as the highest importance for this evaluation because if the system is unable to remove the required contaminants, the house occupants can be put at risk for negative health effects or potential plumbing issues. For particle removal efficiency, a score of 2 means that all removal needs are met, including the removal of suspended solids, odor-causing particles, bacteria that are harmful when airborne, and substances that can build up in the piping networks. A score of 1 means some, but not all, of the listed filtration needs are met. While a 0 means the filtration system does not meet the required removal needs of the system. As stated in previous sections, all of the filtration systems that were analyzed properly remove the required contaminants. As a result, all filtration systems received a ranking of 2.

Affordability was given an importance factor of 0.8. This importance factor was determined to be this high because an affordable filtration system would help to accomplish our goal of allowing the average homeowner to afford this upgrade. For affordability, a score of 2 means that the initial cost to implement this system is less than $4,000. A score of 1 means that this system costs between $4,000 to $8,000. A score of 0 means that the system is out of budget, costing over $8,000. As calculated in Calculation W.2, the slow sand filter has a total initial cost of $3,500, therefore receiving a rating of 2. Then, as calculated in **Calculation W.4**, the rapid sand filter has a total initial cost of $6,620, therefore receiving a rating of 1. Finally, as calculated in Calculation W.5, the biochar filter has a total initial cost of $4,500, therefore receiving a rating of 1.

Home energy use was given a similar importance rating of 0.8. Again, these criteria will help us to accomplish one of our fundamental goals, to accomplish a 50% energy reduction. For energy use, a score of 2 means that the system does not require any energy input. A score of 1 means that this system requires an energy input under 10 kilowatt hours annually. While a score of 0 means that the system uses over 10 kilowatt hours annually. The air compressor used to perform backwashing does require energy. Using a generic eight-gallon air compressor that can be purchased online via Uline.com, a total annual energy requirement of 5.6 kilowatt hours per year is determined [W.22]. This value was calculated in Calculation W.6. Since rapid sand filtration and biochar filtration both use air compressors, they both receive a ranking of 1. Slow sand filtration does not require an energy source, instead relies on gravity and, therefore receives a ranking of 2.

$$Kilowatt\ hours/year = [(Amps\ x\ Volts) * Hours/Year]/1000$$
$$[(7.5\ amps * 120\ volts) * 6\ hours/year]/1000 = 5.6\ kWh/year$$

Calculation W.6 - Energy usage from air compressor [W.27]

Following home energy use, sustainability was given an importance rating of 0.7. One of our major goals was to help contribute to Pittsburgh's Climate Action Goals, and the use of sustainable materials would help to accomplish this goal. Sustainability was determined on a two-point system, either the system received a rating of 2 if the filter used renewable substrates, or the system received a rating of 0 if the substrates were not renewable. All of the systems use sand, gravel, and biochar which are all naturally occurring materials. Therefore, all of the systems received a ranking of 2.

Finally, maintenance was given an importance rating of 0.7. This system should be able to be implemented into the average Pittsburgh home, and as a result, the average homeowner must be able to fix any problems that arise. For maintenance, a score of 2 means that maintenance can be easily accomplished through backwashing. A score of 1 means that the system does require labor-intensive maintenance but only every 10 years. While a score of 0 means that maintenance is labor-intensive and occurs every year. In this analysis, labor-intensive is defined as requiring the homeowner to remove the layered substrates and replace them with new ones. Backwashing occurs when the homeowner turns off the inlet valve from the house, and opens the valve to the sewage system and air compressor, and turns the air compressor on, this is estimated to be a 30-minute process that occurs monthly [W.21]. Since rapid sand filtration and biochar filtration both utilize backwashing, they both received a ranking of 2. Slow sand filtration does require the homeowner to scrap the top layer of material in the event of clogging. However, if built properly, this maintenance should only occur every 10 years. As a result, slow sand filtration received a ranking of 1.

Following the summation of the points acquired by each filtration alternative, slow sand filtration was chosen as the ideal filtration option for this system. This filtration option helps to achieve this project's fundamental goals including a 50% reduction of the homes energy demand, having the entire project being within a budget of $66,000 - $141,000, and contributing to Pittsburgh's Climate Action Goals.

Routing

Piping and Pumping

To implement this greywater and rainwater harvesting system in the Healthy Home Lab, rerouting of the current piping network is required. To find the existing piping in the house, infrared cameras were used. After turning on the hot water from the sink and shower, and flushing the toilet, which were all located in the second-story bathroom, the piping network could be determined. The washing machine located in the basements was not hooked up. The rainwater gutter systems were located on the exterior of the house and were currently directly routed to the sewer system. A visual model of this piping network was created using Revit software and is pictured in Figure W.5 below.

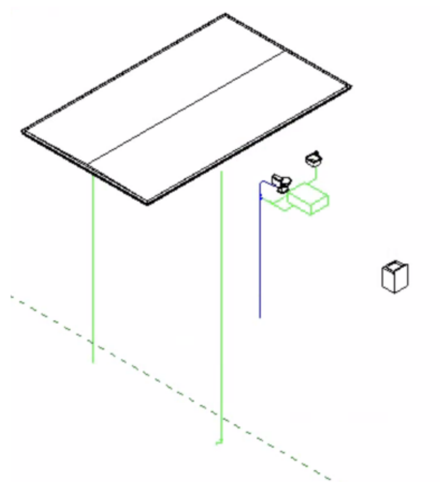

Figure W.5 - Visualization of the current piping network in the Health Home Lab. The model is used only for visualization purposes. Created by Revit software.

To implement the combined greywater and rainwater system, the pipes leading from the rain gutters, shower, sink, and washing machine must be rerouted to the filtration unit located in the basement. Then, following filtration and storage, the clean water must be pumped back up to the garden located on the ground level, and the toilet located on the second story. A visualization of this new piping network can be seen in **Figure W. 6**.

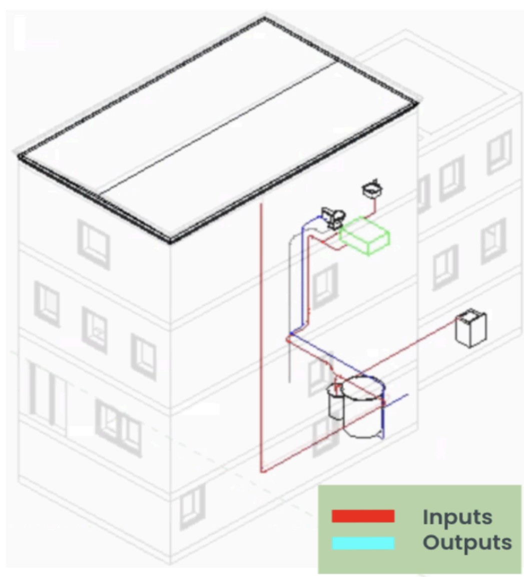

Figure W.6 - Visualization of the rerouted piping network in the Health Home Lab. The model is used only for visualization purposes. Created by Revit software. Red pipes represent water going into the filtration system, blue represents water coming out of the filtration system.

The implementation of this rerouting was divided into a four-step plan of action. This plan of action included the demolition and replacement of the drywall covering the pipes, the rerouting of the shower, sink, and laundry pipes, the rerouting of the pipes used for rainwater collection, and the returning of the filtered water to the garden and toilet.

To access the current pipes, drywall will need to be removed and following the rerouting, these walls will need to be replaced. After receiving an estimate from a local company and using Calculation W.7, this step has an estimated cost of $300.

$$Demolition = \$1/ft2. \ * 25\,ft2 = \$25$$
$$Installation = \$2/ft2. \ * 25\,ft2 = \$50$$
$$Labor\ Costs\ (2\,person\,\$20/hr) = \$40/hr \ * \ 5.5\,hrs = \$220$$
$$Demolition + Installation + Labor\ Costs = Total\ Cost$$
$$\$25 + \$50 + \$220 = \$295$$

Calculation W.7 - Cost calculation for drywall demolition and replacement [W.23][W.24][W.25]

The next step involved the rerouting of the shower, sink, and laundry pipes. This process starts by removing the current piping network which, as determined by the infrared cameras, currently intersects with the line leading from the toilet straight to the sewage system. Once these pipes are separated, a new 1-inch PVC pipe leading from the sink and shower to the filtration unit is added. Using the Revit model, it was determined that approximately 50 feet of new piping would need to be added. With the addition of the cost of hiring a plumber, this step is estimated to cost $2,000. This calculation is done in Calculation W.8.

$$Removal = \$1500$$
$$Replacement = \$0.85/ft. \ * 50\,ft2 = \$42.50$$
$$Labor\ Costs\ (1\,person\,\$70/hr) = \$70/hr \ * \ 5.5\,hrs = \$385$$
$$Removal + Replacement + Labor\ Costs = Total\ Cost$$
$$\$1500 + \$42.50 + \$385 = \$1927.50$$

Calculation W.8 - Cost calculation for rerouting sink, shower, and laundry piping [W.26][W.27][W.28]

Similar to this step, the pipes used for rainwater harvesting must also be rerouted. Currently, these pipes are on the exterior of the Healthy Home Lab and lead directly from the roof of the building to the sewage system. For this new system, the rainwater must instead be routed to the filtration unit in the basement. The current pipes were unattached from the sewer in the previous stage, now an addition of approximately 10 ft of 3 inch PVC pipe will be used to move the water to its destination. The addition of gutter mesh around the perimeter of the roof will also be implemented to prevent large particles such as leaves, sticks, and other organic materials from clogging the system. The cost of this process is calculated in Calculation W.9 and is approximated to be about $150.

$$Replacement = \$3.80/ft \ * \ 10\,ft = \$38$$

$$Gutter\ Mesh\ =\ \$1/ft\ *\ 124\ ft\ perimeter\ =\ \$124$$
$$Replacement\ +\ Gutter\ Mesh\ =\ Total\ Cost$$
$$\$38\ +\ \$124\ =\ \$162$$
Calculation W.9 - Cost calculation for rerouting rain gutter piping [W.29][W.30]

The final step in this plan involves the returning of the filtered water to the garden on the ground level, and the toilet on the second story. To accomplish this about 50 feet of 1 inch PVC pipe is added. Since the water must be pumped up, against gravity, a pump is required. Using a head elevation change of 25 feet, it is determined that a 0.1 horsepower pump is required. This calculation can be reviewed in Calculation W.10. The total cost for this step is about $200, as depicted in Calculations W.11.

$$Pump\ Power\ =\ (Flow\ *\ Specific\ Gravity\ *\ Head)\ /\ (Conversion\ Factor\ *\ Efficiency)$$
$$(200\ gal/day\ *\ 1/24\ day/hr\ *\ 1/60\ hr/min\ *\ 1\ *\ 25\ ft)\ /\ 3960\ *\ 0.4\ =\ 0.001\ HP$$
A 0.1 HP pump will be sufficient

Calculation W.10 - Pump horsepower requirement calculations. Approximating that the pump is pumping water 25 ft. [W.31]

$$Replacement\ =\ \$0.85/ft.\ *\ 50\ ft2\ =\ \$42.50$$
$$Replacement\ +\ Pump\ =\ Total\ Cost$$
$$\$42.50\ +\ \$150\ =\ \$200$$
Calculation W.11 - Cost calculation for return water pipes to toilet and garden [W.27][W.31]

Project Plan/Management

Project Cost

The total cost of the project is estimated to be about $118,000. The cost split into categories is in **Figure PM.1**. The estimated costs of each component were found in several ways. Some, like the air sealing and window replacement categories were found by researching the average costs of the product. The appliance, heat pump, and water system costs were found by finding specific products on the market. Finally, the insulation and solar panels were estimated by having a known cost per unit of material and multiplying it by the amount needed for our designs.

The largest portions of our cost estimate come from the solar panels and the thermal envelope improvement which include air sealing, insulation, and window replacement. These have a total cost of $45,000 and $47,860 respectively. This is about 78.7% of the total project cost in these two areas.

Category	Item	Cost	Rebates & Discounts
Air Sealing	Energy Audit/Blower Test	$1,000	-
	Air sealing	$7,000	$1,600
Insulation	Basement Insulation	$5,950	-
	Roof Insulation	$13,910	-
Window Replacement	Window installation	$6,000	-
	Windows	$14,000	-
Appliances	Dishwasher	$1,300	-
	Refridgerator	$1,400	$85
	Oven & Stove	$1,100	$550
	Clothes Washer	$1,200	-
	Clothes Dryer	$1,100	-
Heat Pump	Heat Pump Installation	$1,000	-
	Heat pump & Water Heater	$9,400	$5,620
Solar Panels	Solar Panel Installation	$4,000	-
	Solar Panels	$41,000	$12,300
Greywater System	Greywater Tank	$450	-
	Filtration Tank	$3,500	-
	Piping Network	$1,940	-
Rainwater System	Gutter rerouting	$2,900	-
	TOTAL	**$118,150**	**$20,155**
	TOTAL w/ rebates	**$97,995**	

Figure PM.1 - Cost Estimate Table

Tax Credits and Discounts

Fortunately for the project, there are many tax credits and discounts associated with some of these improvements from the government and local utility providers. For instance, the Inflation Reduction Act includes a tax credit of 30% for installing a solar panel system in your home, which was found by Rewiring America [PM.1]. Rewiring America is a program that helps and supports individuals and communities to go fully electric by educating them on what they can make electric and letting them know of any incentives that might come along with these improvements. Additionally, Duquesne Light, the electric provider for the HHL, offers a multitude of rebates on appliances, heat pumps, and weatherization projects through some of their programs [PM.2]. Altogether, we estimated that our project would receive a total of around $20,000 in rebates, mostly for the solar panels and the heat pump. So, the overall project cost with rebates is estimated to be about $98,000. This is well within the budget of $66,000 to $141,000 that was set as one of the goals.

Payback Periods

It is important to look at the long-term benefits and benefits of each of these systems since they use less money that would have otherwise been spent. In general, these payback periods were found by taking the total cost of the system and subtracting the total amount saved each year. It should be noted that fluctuations in utility prices and inflation were not accounted for in these payback periods. All tables of the payback periods will be in the appendix.

Appliance Payback Period

Looking at the appliances, their initial price is estimated to be $5,465 with an energy reduction of 6634 kWh per year. With the distribution charge at $0.0878/kWh and supply charge at $0.0992/kWh, the electricity costs roughly $0.187/kWh as sourced from Duquesne Light and one of the team member's electricity bill [PM.3]. Thus, there is an annual savings of about $1,240 and a total payback period of 4.5 years.

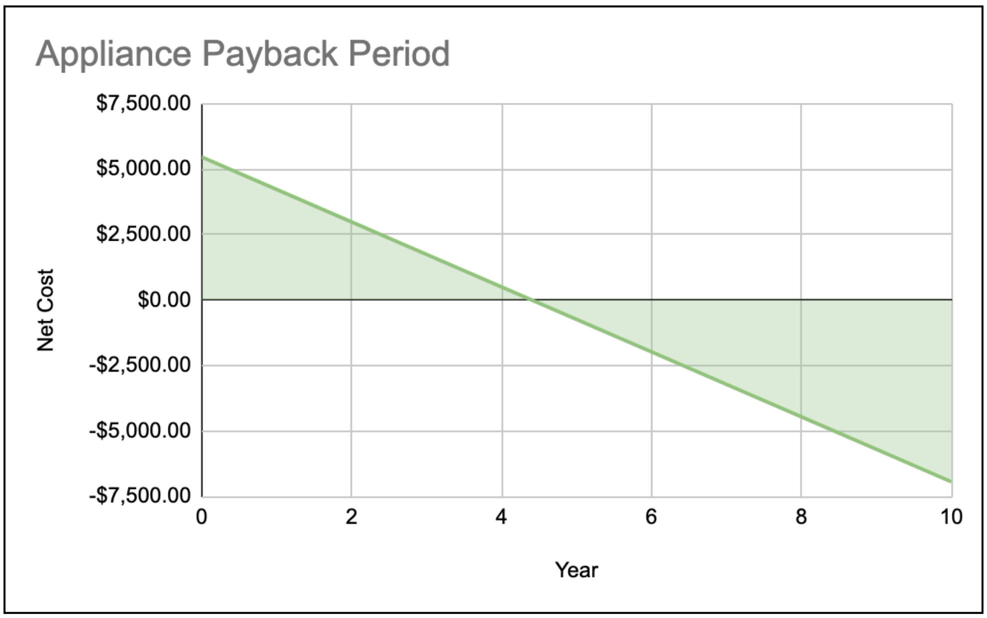

Figure PM.2 - Appliance Payback Period

Solar Payback Period

The solar payback period is similar to that of the appliances. The initial cost of the system with rebates is $32,700 with a production of about 15300 kWh per year of electricity. That comes to about $2,860 in savings a year from just the cost of electricity. However, the energy produced can be sold as a solar renewable energy credit (SREC) to get even more out of the solar system. SRECs are currently sold at $40/MWh of electricity produced, giving an additional $600 in annual savings. Finally, the upgrades to the home lower the cost of electricity by the provider by $0.0045/kWh which may seem insignificant, but with an estimated annual electricity usage of 28700 kWh per year, that is a total savings of almost $130 annually. Altogether, the solar system saves $3,590 annually, giving a payback period of about 9 years.

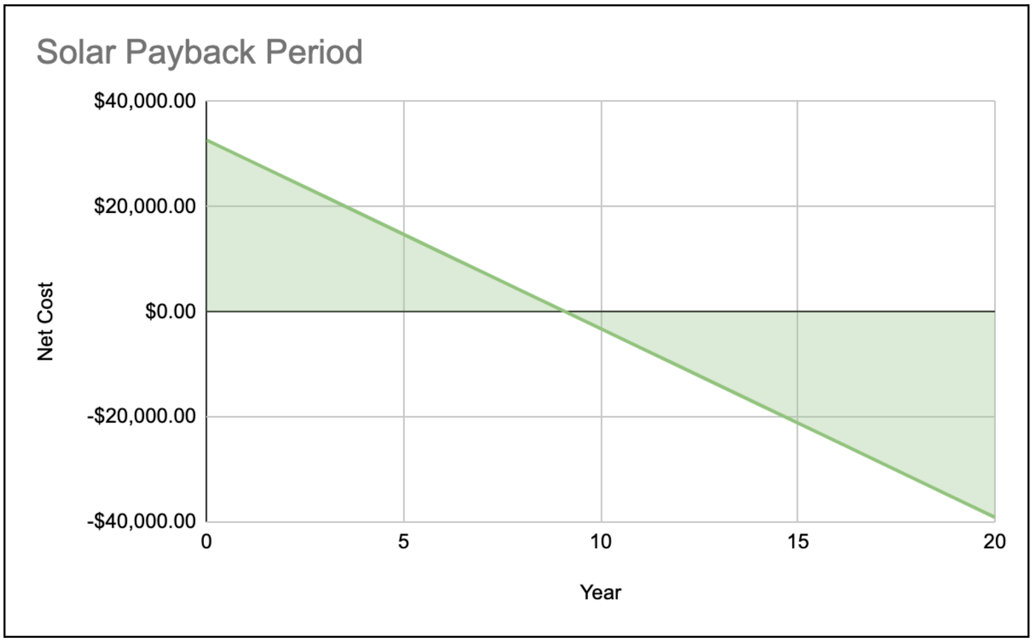

Figure PM.3 - Solar Payback Period

Water Payback Period

The combined rainwater-greywater collection system costs roughly $6,350 to install. With the system saving an estimated 3840 gallons of water per year and the cost per 1000 gallons of water at $16.38, there is a total annual savings of $590 [PM.4]. That gives a return period of 10.5 years for this system.

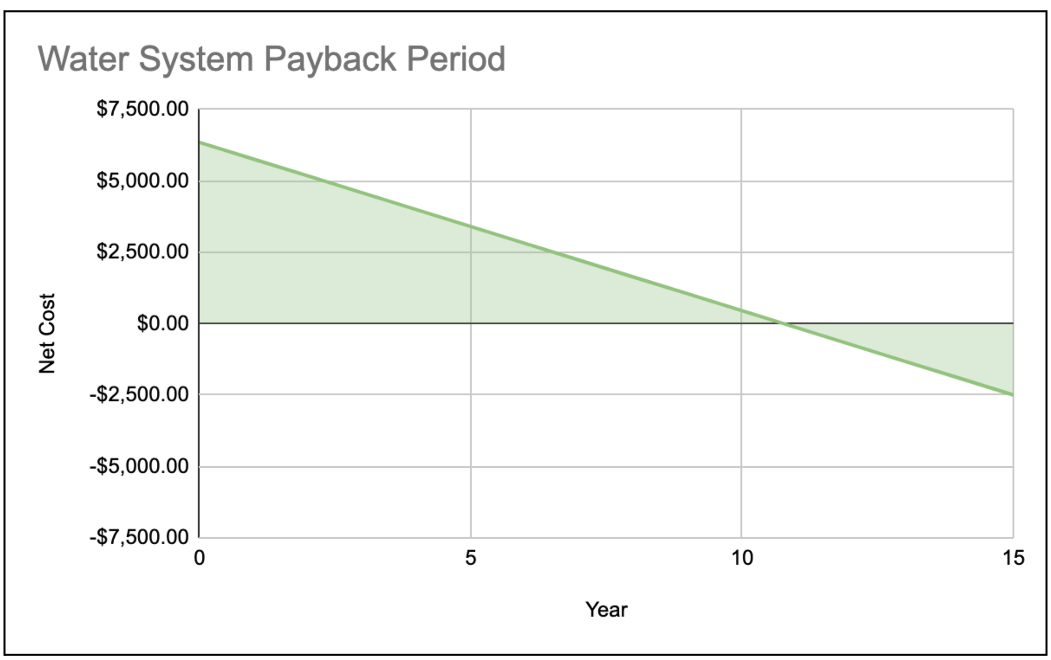

Figure PM.4 - Water Payback Period

Project Schedule

The Gannt chart below is the estimated project schedule for the project. Since the energy side of the project is almost entirely separate from the waterside, they have two different schedules that can happen at roughly the same time. In green is the energy system and blue is the water system. In total, the whole project should be able to be completed within a 4-month period, which is well within the goal of 9 months.

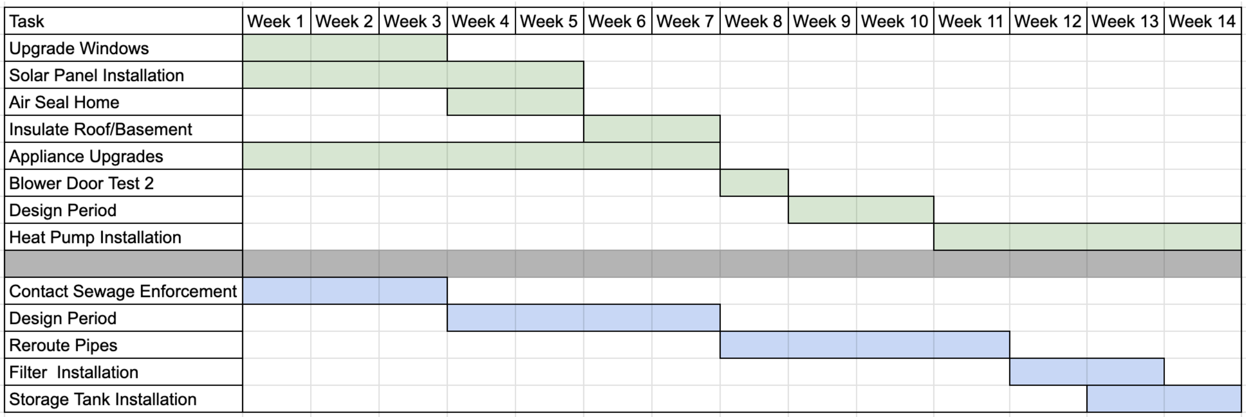

Figure PM.5 - Gannt Chart of Project Schedule

Starting with the energy system, after the original energy audit and blower door test that was done during this project, the next immediate step would be to start improving the thermal envelope and efficiency within the home. This includes ordering and installing the new energy-efficient appliances as well as installing the solar panels and replacing the windows. The next step is air sealing the home, which is intentionally done after the solar panel and window installations to seal any holes or cracks that were missed or created during those processes. After air sealing is complete and the appropriate ACH level is achieved, the roof and basement can be insulated. Insulation must occur after air sealing. If not, the insulation could get in the way of the problem areas that air sealing can solve. So installing the new insulation afterward is crucial to increasing the overall efficiency of the home. Now that all the efficiency improvements are done, a second blower door test can be done to ensure that the home is adequately sealed with reduced air leakage.

Using the air leakage rate from the second blower door test, the new heating demand can be calculated to correctly size the heat pump, which would then be ordered and installed. The largest portion of time on this project comes from waiting for the suppliers to ship the materials to the home. The actual working time in the home would be around a month in total.

As for the water side of the project, since the water samples have already been tested, the next step would be to contact the sewage enforcement to let them know that the home intends to install a greywater system. Once that is over, all that needs to be done is have the pipes in the home to be rerouted and the filtration and storage tanks to be ordered and installed in the basement.

Risk Management

There are not many concerns or risks within the project, but there does need to be an emphasis on worker safety. **Figure PM.6** is the risk management contingency table our team created. With the impact and probability categories ranging from 1-10, the risk was then measured on a scale of 1-100. A range of 1-33 was low-risk, 34-66 moderate risk, and 67-100 high risk. The two main categories of risk for our project were then seen as worker safety and structural integrity.

Risk Event	Impact	Probability	Risk	Cost	Preventable?	Contingency
Falling off roof during solar installation	10	7	70	$33,600	Y	Use a JHA and ensure workers are following proper PPE and Safety protocols.
Electrocution during wiring	10	7	70		Y	
Coming in contact with hazardous materials in old homes (ie. asbestos)	7	10	70		Y	
Roof structurally inadequate for solar panels	10	7	70	$7,000	Y	Hire contractor to run a structural analysis on the roof. If roof inadequate, replacement necessary.
Inclement weather during outdoor construction/installation	8	6	48	$420	N	Push back work, allow time between different phases of project.
Supply chain delays	6	6	36		N	Ensure materials are available and adjust schedule accordingly if any issues occur.

Figure PM.6 - Risk Management Contingency Table

Risks in worker safety include workers falling off the roof during solar installation, possible electrocution during wiring, and possible contact with hazardous materials found in old homes like asbestos. These risks are fortunately preventable. By using a job hazard assessment (JHA), we can ensure that workers on site are following proper PPE and safety protocols. However, in the case of an accident occurring, there is a contingency cost of $33,600 found by multiplying the risk of these accidents occurring and the average cost of a worker injury, $42,000 [PM.5].

Additionally, there are structural concerns with the integrity of the roof since the home is so old. If the roof is not tested beforehand, the additional weight of solar panels could cause the roof to collapse causing significant damage to the home. Thus, a structural analysis of the roof is necessary before installing the solar panels. If the roof is found to be inadequate, a replacement would be needed, at an average cost of $10,000, adding a contingency cost of $7,000 [PM.6]. This totals the contingency cost of the project to be about $41,000 total.

Goal Assessment

Looking back at the original goals, only some of them were able to be attained in the duration of this project. The following are the goals and their assessments:

1. 100% of energy for the home electric: This was achieved with the replacement of the original gas boiler system with the heat pump in the home.
2. 100% of the energy for the home is produced on site: The designed solar system is only able to produce 53% of the energy needed. This is mainly due to space constraints and how the solar panels can only be placed on the roof. If the home were either smaller or had more land around it, net-zero energy could become more feasible.
3. >50% of water reused: The water system is only able to reuse 32% of the water in the home. This is constrained by the limited uses of non-potable water within a home. Current legislation only permits non-potable water to be used for gardening purposes and flushing toilets. These uses just do not make up enough of the water usage to get to that goal. However, if the greywater system were to be installed in an office or educational building, the percentage of water used by toilets greatly increase thus improving this system's efficiency.
4. >50% of energy demand reduced: This goal was greatly surpassed with a total energy reduction of 76% from the project. The initial energy demand was calculated to be about 118,800 kWh per year, over 4 times higher than the average PA home. With the efficiency upgrades and the addition of the heat pump, the total energy demand is reduced to 28,700 kWh per year.
5. Within a budget of $66,000 - $141,000: With a total cost of $98,000, the project is well within the budget.
6. Within a period of 9 months: The project is expected to take about 4 months to complete. Even with some shipping delays for materials, the project should be able to be completed within 9 months.

Acknowledgments

Throughout this project, we had a vast amount of help and support from both our mentors and industry contacts. We'd like to thank our industry mentor, Bill Spohn, for being the inspiration of our project and helping to guide us through the whole process of designing a deep energy retrofit for a home. We'd also like to thank our faculty mentors Dr. Bilec, Dr. Wang, and Dr. Kerzmann for guiding our design process and aiding us through our calculations. Finally, we'd like to acknowledge all the help we had from our industry contacts: Clint Noack and Kartik Ganjoo from Duquesne Light, Pam Toto and Zach Roy from the Healthy Home Lab, Rhett Major the Energy Doctor, and Russ King from KwikModel.

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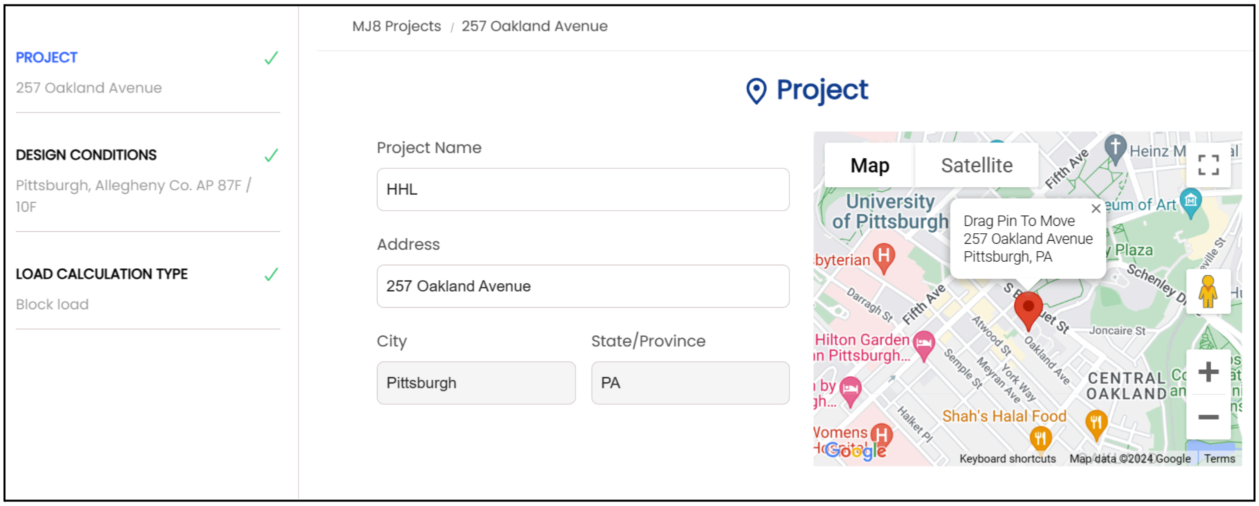
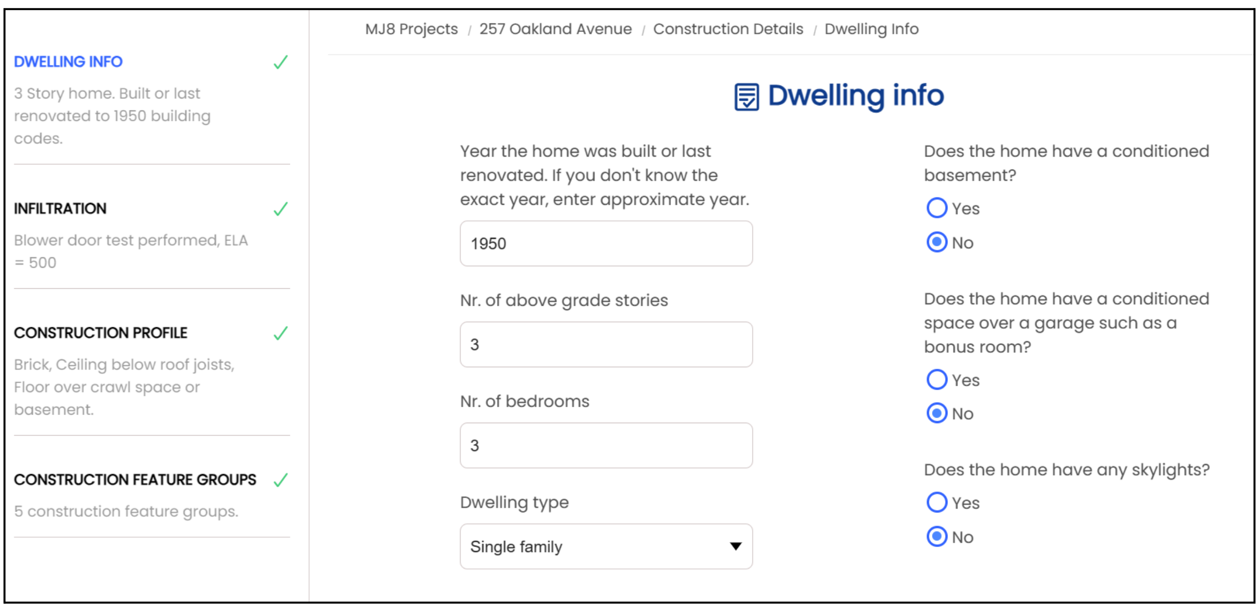
Appendices

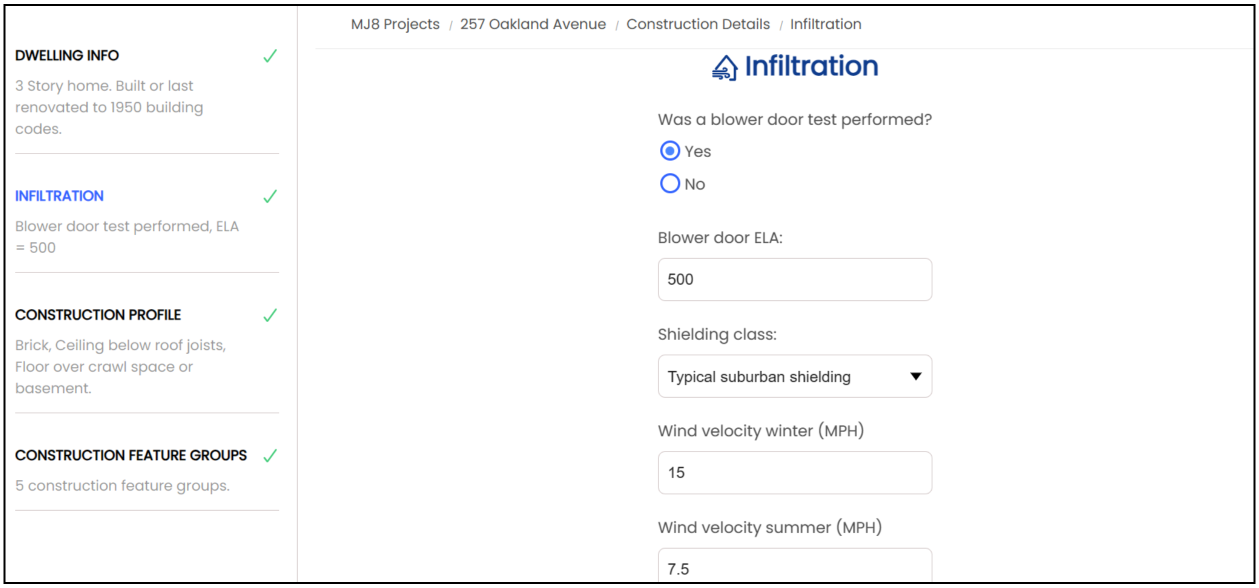
Calculations

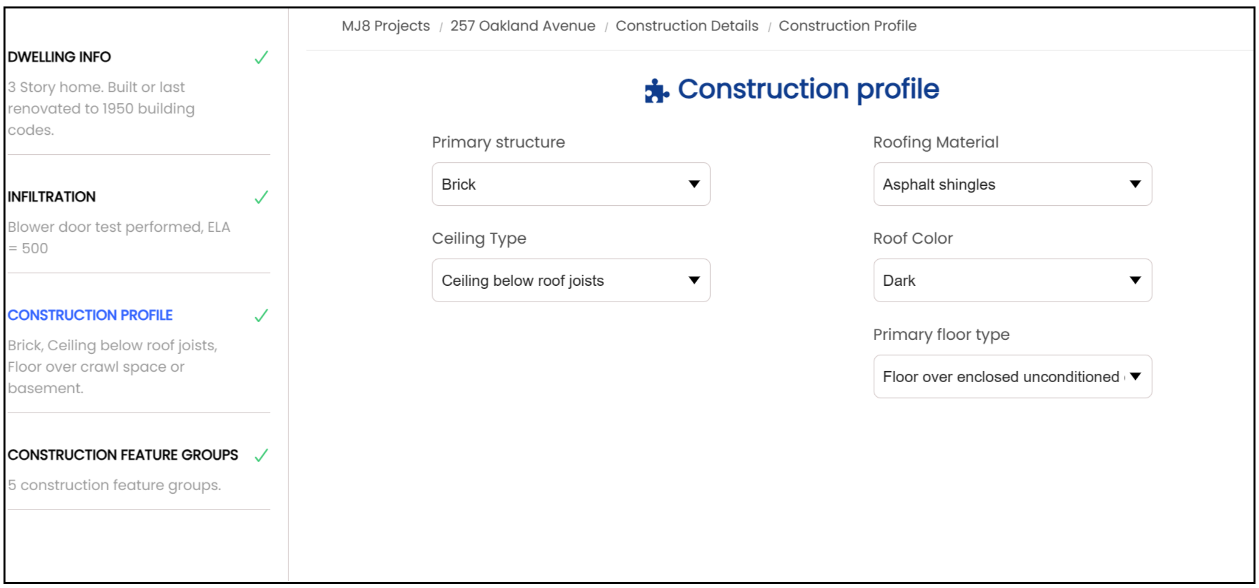
Efficiency Design

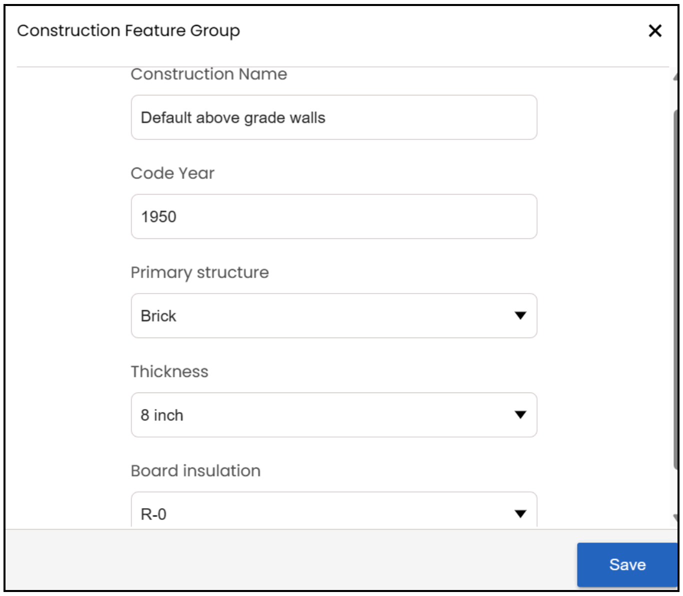
Initial Heating Demand: CoolCalc

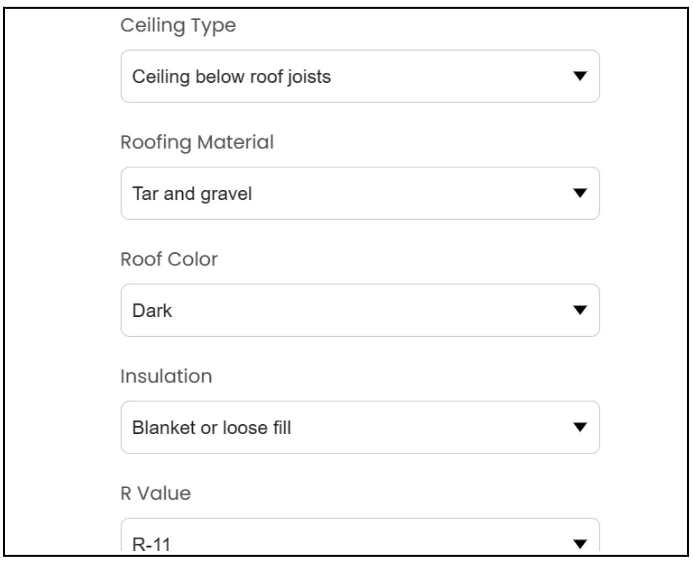





MJ8 Projects / 257 Oakland Avenue / Construction Details / Infiltration
DWELLING INFO
3 Story home. Built or last renovated to 1950 building codes.
INFILTRATION
Blower door test performed, ELA = 500
CONSTRUCTION PROFILE
Brick, Ceiling below roof joists, Floor over crawl space or basement.
CONSTRUCTION FEATURE GROUPS
5 construction feature groups.
Infiltration
Was a blower door test performed?
Yes
No
Blower door ELA:
500
Shielding class:
Typical suburban shielding
Wind velocity winter (MPH)
15
Wind velocity summer (MPH)
7.5


MJ8 Projects / 257 Oakland Avenue / Construction Details / Construction Profile
DWELLING INFO
3 Story home. Built or last renovated to 1950 building codes.
INFILTRATION
Blower door test performed, ELA = 500
CONSTRUCTION PROFILE
Brick, Ceiling below roof joists, Floor over crawl space or basement.
CONSTRUCTION FEATURE GROUPS
5 construction feature groups.
Construction profile
Primary structure
Brick
Roofing Material
Asphalt shingles
Ceiling Type
Ceiling below roof joists
Roof Color
Dark
Primary floor type
Floor over enclosed unconditioned


Construction Feature Group
Construction Name
Default above grade walls
Code Year
1950
Primary structure
Brick
Thickness
8 inch
Board insulation
R-0
Save


Ceiling Type
Ceiling below roof joists
Roofing Material
Tar and gravel
Roof Color
Dark
Insulation
Blanket or loose fill
R Value
R-11

Floor type

Floor over enclosed unconditioned crawl space or b

Basement or Crawl Space Wall Insulation

None

Radiant floor heat

false

Floor insulation

None

Floor cover

Carpet or hardwood

Window Type

Window

NFRC Rated

true

Glass Type

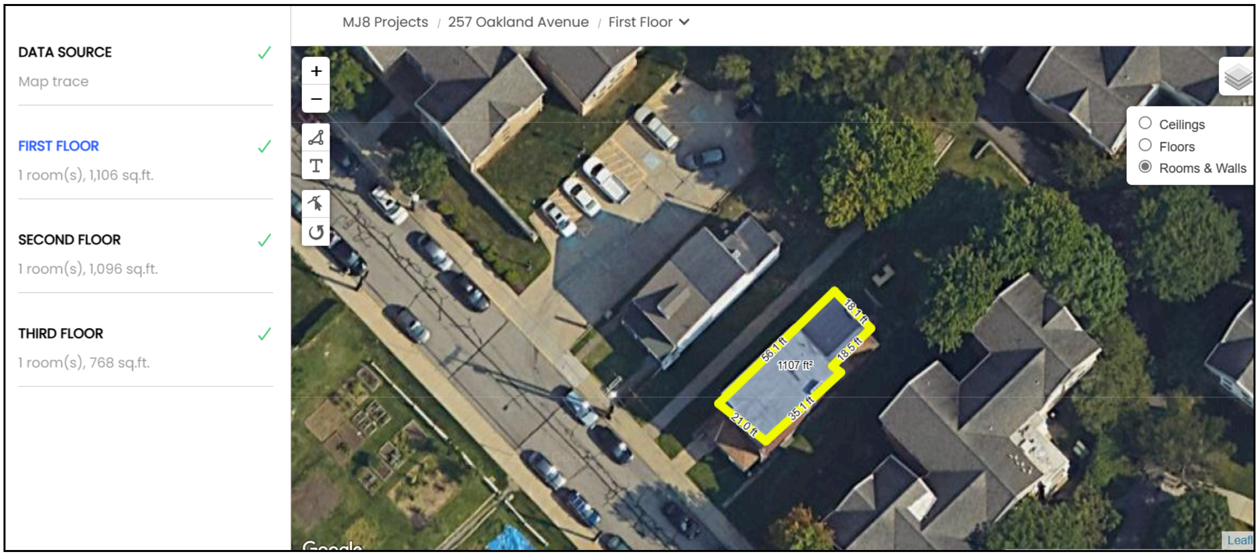
Clear glass

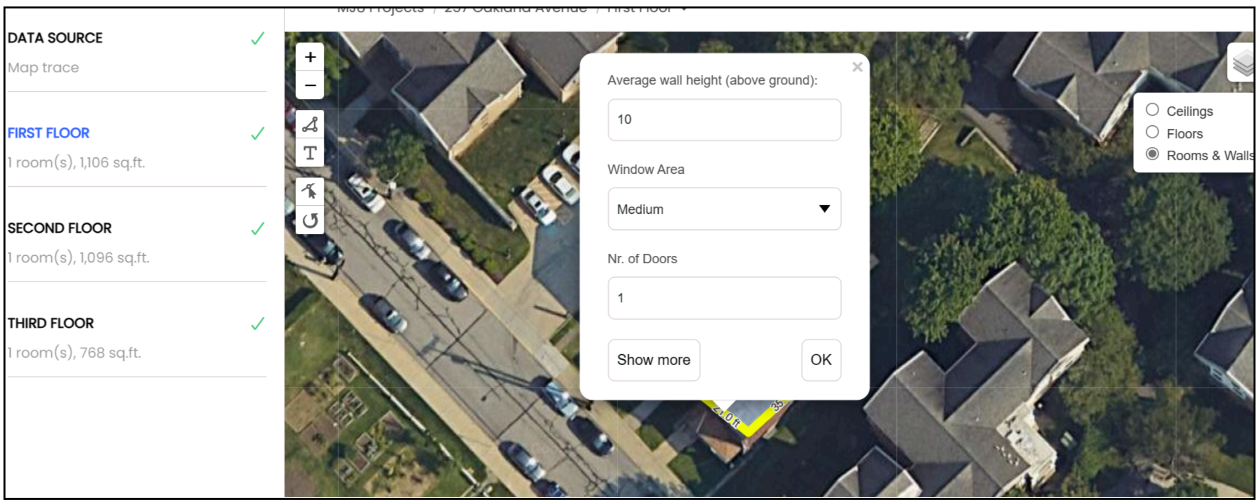
U-Value

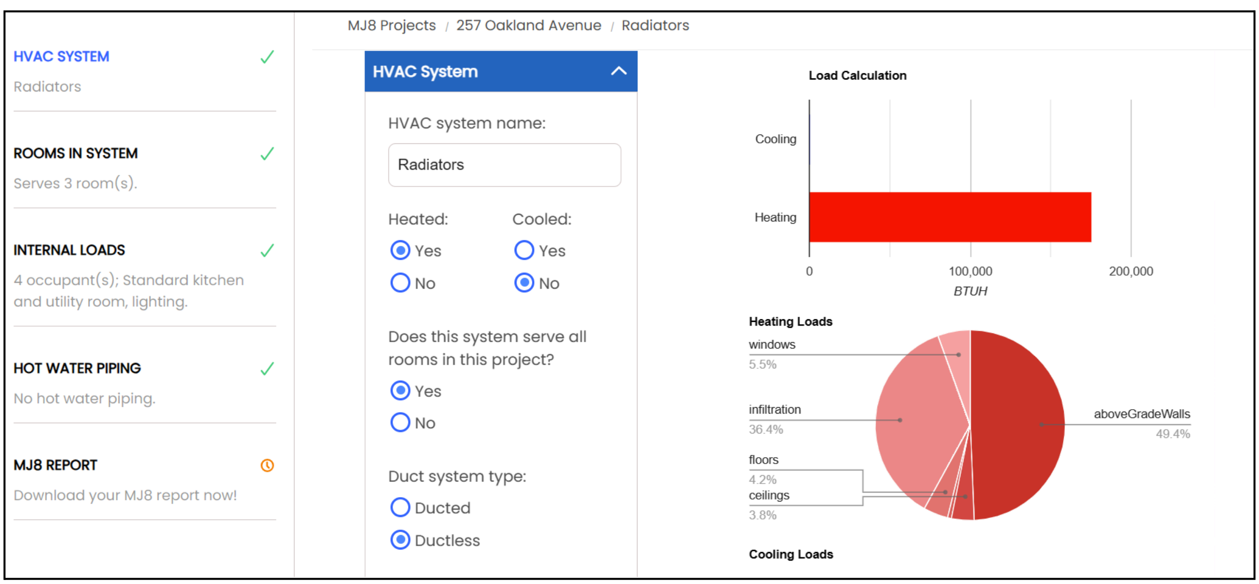
0.87

SHGC

0.67







Heating Demand: 175,006 BTUh

Initial Heating Demand: LoadCalc

Structure types

Outside Walls 1: Brick-no insulation
Outside Walls 2:
Windows 1: single pane - blinds
Windows 2: double pane - blinds
Glass Doors 1: single pane slider no internal shade
Glass Doors 2:
Floors 1: Concrete slab no edge insulation
Floor 2: open crawl or garage carpet or hardwood no insulation
Ceiling 1: Ceiling under roof joists R-0
Ceiling 2:
Doors: Wood solid core
Skylights:
Basement Walls:
Basement Floor:
Win ht.: 5' 0" Overhang: 1.5' Top to overhang: 2'

Design Indoor Cooling Temp. : 75 °F	HHL	Design Indoor Heating Temp. : 70 ° F
Design Outdoor Cooling Temp. : 88 ° F	257 Oakland Ave	Design Outdoor Heating Temp. : 7 ° F
Temp. Difference Cooling :13°F	Area: Pittsburg Allegheny Airport, PA	Temp. Difference Heating :63° F
Indoor Humidity: 50 Grains difference: 24	Front Door Orientation South West	Block Load

Whole House Block Load

TD:Cool:13°F Heat:63°F	Sq. ft. -types 1 and 2	shading	Sq. ft.- types 1 and 2	shading	Sq. ft.- types 1 and 2		Sq. ft.
Outside Wall: North	1: 0 2: 0	Windows →	1: 0 2: 0	Glass Doors x	1: 0 2: 0	Doors	0
Outside Wall: South	1: 0 2: 0	Windows U	1: 36 2: 39.5	Glass Doors U	1: 0 2: 0	Doors	49
Outside Wall: E & W	1: 0 2: 0	Windows U	1: 176.5 2: 62.5	Glass Doors U	1: 0 2: 0	Doors	0
Outside Wall: NE & NW	1: 1891 2: 0	Windows →	1: 0 2: 0	Glass Doors x	1: 0 2: 0	Doors	0
Outside Wall: SE & SW	1: 1891 2: 0	Windows U	1: 0 2: 0	Glass Doors U	1: 0 2: 0	Doors	0
Floor - (linear ft. if slab)	1: 1000 2: 0	Ceiling	1: 1300 2: 0	Appliances 3	Fireplaces 0		
Sky Lights	N: 0 S: 0	E-W: 0	NE-NW: 0	SE-SW: 0			
Number of People	3	Conditioned Sq. ft.	3000	Cubic Ft.	27000		

Basement **Above grade:** Walls 4 Cubic Ft. 3900	**Below grade:** walls 4 Floor 1300 sq. ft. width 23ft. or l below: 6 ft.

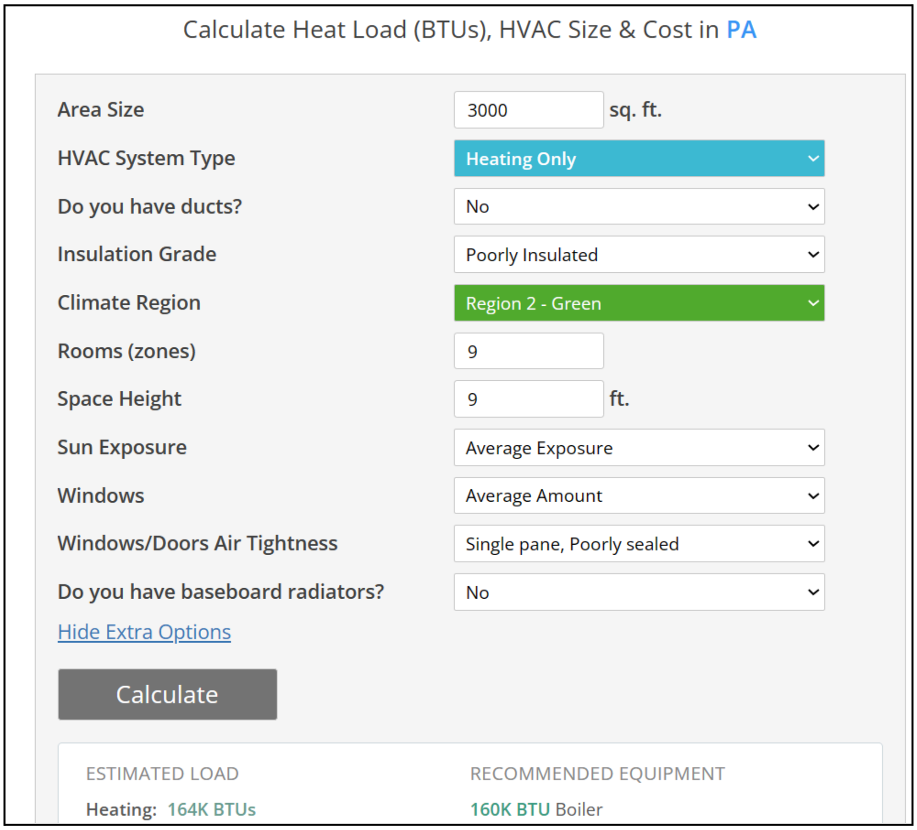
Fresh air recommended: 26cfm → 130 CFM	Construction: very poor	Duct system: ------------ ------------ ------------

	Total Btu's Cooling	Sensible Load	Latent Load	Total Btu's Heating
Calculate Load	54681	49577	5104	207139

Change State | Change City | Clear Data | Print | Comments | Change Structures | Calculator | Size Equipment | Help | Save Work

Heating Demand: 207,139 BTUh

Initial Heating Demand: RemodellingCalculator



Heating Demand: 164,000 BTUh

Roof Insulation and Basement Ceiling Insulation Cost Estimate

Area req	1000					
Roof r-value	60		Basement r-value	30		
	Amazon.com: STANLEY Supercoat Spray Foam Insulation Kit - Closed Cell Spray Foam Covers Up to 2					
	Roof			Basement ceiling		
	R	5.66		R	5.66	
	ft2 per can	20		ft2 per can	20	
	depth req	10.60070671		depth req	5.300353357	
	cans for area	50		cans for area	50	
	cans for depth	10.60070671		cans for depth	5.300353357	
	cans total	530.0353357		cans total	265.0176678	
	pack size	24		pack size	24	
	packs req	22.08480565		packs req	11.04240283	
	pack cost	420		pack cost	420	
	Cost	9660		Cost	4620	
				Total cost	14280	

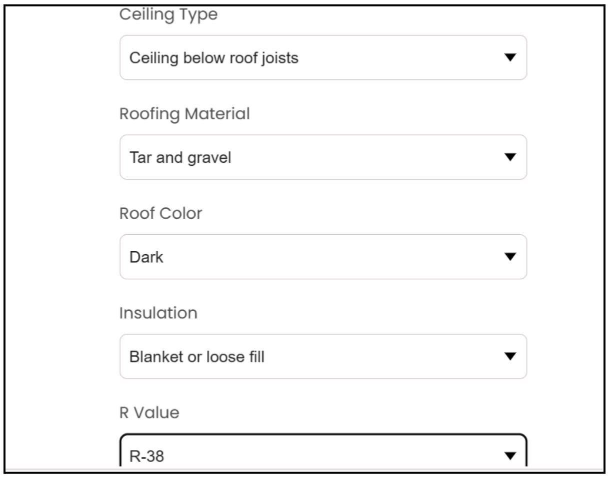
	Akfix Thermcoat Spray Foam Insulation Kit- Insulation Foam Spray, Polyurethane Spray Foam, Heat Insu					
	Roof			Basement ceiling		
	R	5.76		R	5.76	
	ft2 per can	20		ft2 per can	20	
	depth req	10.41666667		depth req	5.208333333	
	cans for area	50		cans for area	50	
	cans for depth	10.41666667		cans for depth	5.208333333	
	cans total	520.8333333		cans total	260.4166667	
	pack size	24		pack size	24	
	packs req	21.70138889		packs req	10.85069444	
	pack cost	405		pack cost	405	
	Cost	8910		Cost	4455	
				Total cost	13365	

	FROTH-PAK Low GWP 650 Spray Foam Sealant Insulation Kit 12031907 - The Home Depot					
	Roof			Basement ceiling		
	R	6.5		Roof cost alone is more expensive		
	ft2 per can	200				
	depth req	9.230769231				
	cans for area	5				
	cans for depth	9.230769231				
	cans total	46.15384615				
	pack size	1				
	packs req	46.15384615				
	pack cost	400				
	Cost	18400				

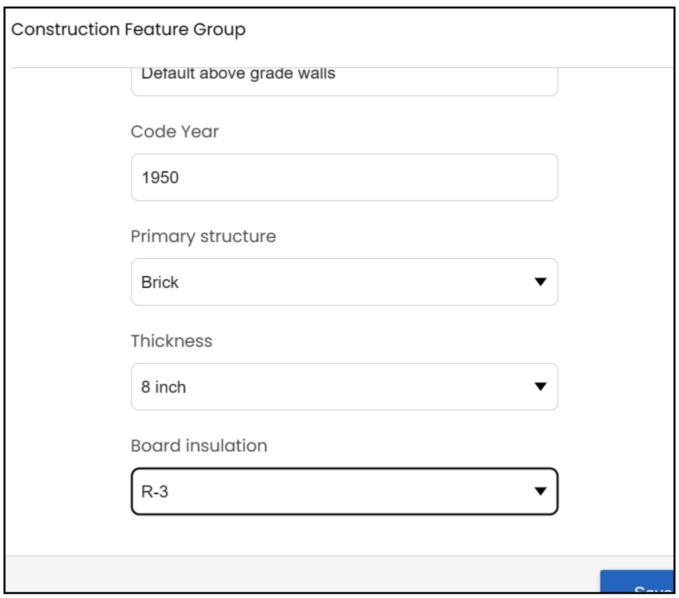
Outsulation Cost Estimate

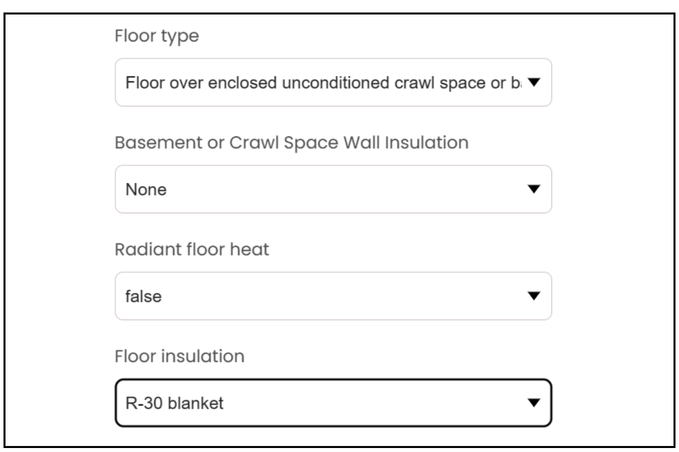
House SA estimate		
Length (ft)	55	
Width (ft)	20	
Height (ft)	28	
Window area (ft2)	314.5	
SA (ft2)	4200	
SA (m2)	390	
Europe avg cost	100 gpb/m2	
Europe avg total cost (USD)	48578	
Mineral wool		
	140	gbp/m2
	54600	gbp total cost
	68000	USD total cost
EPS board		
material alone	9	gbp/m2
labor + material	130	gpb/m2
	50700	gpb/m2
	63152	USD total cost

Insulation Demand Decrease per dollar Cost Comparison



- <u>Note</u>: limitations of software, max roof insulation is R-38 so the demand decrease may be underestimated (although there are diminishing returns with increasing R-value).





Modeled value for comparison			
	Heating load	224066	
Roof only			
	Heating load	206703	
	Demand decrease	17363	
	Decrease per dollar cost	1.18	BTU/$
Basement only			
	Heating load (w/ roof)	118462	
	Heating load (w/ roof + basement)	113012	
	Demand decrease	5450	
	Decrease per dollar cost	0.891	BTU/$
Outsulation only			
	Heating load (w/ roof + basement)	113012	
	Heating load (w/ roof + basement + siding)	73090	
	Demand decrease	39922	
		0.632	BTU/$

Post-efficiency Upgrade Heating Demand:

- ELA→100
- Roof + basement ceiling updated as seen above
- Window values updated

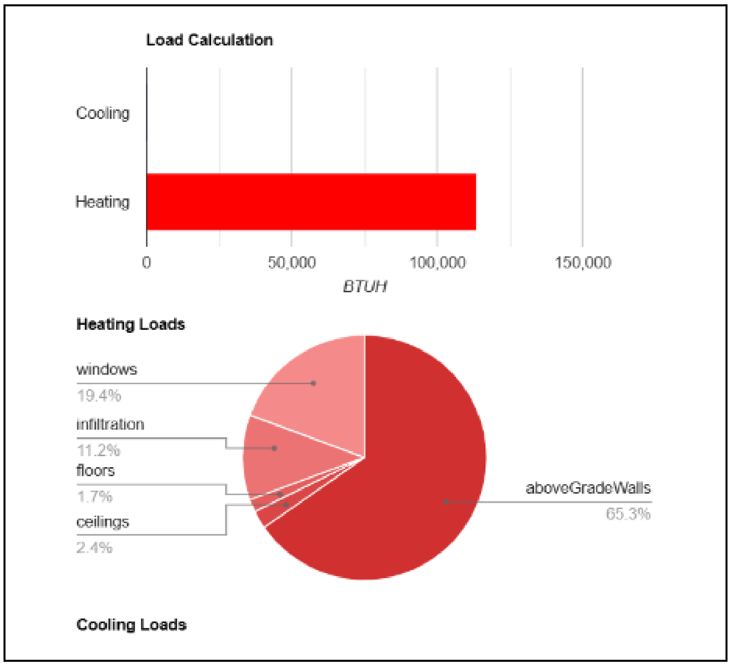
U-Value

0.48

SHGC

0.76

Updated Demand:



<u>*Energy Design*</u>

Bin Model determining Heat Pump Electrical Load

Temp Bin (F)	Frequency (Hours)	kW	mins/cycle	cycle/hr	% time @ Capacity	Time @ Capcity	kWh
20	0	8.62	15	3	75%	0	0
21	5	8.67	15	3	75%	3.8	32.5
22	19	8.72	15	3	75%	14.3	124.3
23	39	8.77	15	3	75%	29.3	256.6
24	52	8.82	15	3	75%	39	344.1
25	87	8.88	15	3	75%	65.3	579.1
26	119	8.93	15	3	75%	89.3	796.7
27	134	8.98	15	3	75%	100.5	902.2
28	156	9.03	15	3	75%	117	1056.4
29	157	9.08	15	3	75%	117.8	1069.1
30	161	9.13	12	3	60%	96.6	882
31	166	9.18	12	3	60%	99.6	914.5

32	168	9.23	12	3	60%	100.8	930.7
33	178	9.28	12	3	60%	106.8	991.6
34	167	9.34	12	3	60%	100.2	935.4
35	214	9.39	17	2	57%	121.3	1138.3
36	211	9.44	17	2	57%	119.6	1128.4
37	203	9.49	17	2	57%	115	1091.5
38	189	9.54	17	2	57%	107.1	1021.7
39	178	9.59	17	2	57%	100.9	967.4
40	132	9.64	13	2	43%	57.2	551.5
41	134	9.69	13	2	43%	58.1	562.8
42	111	9.74	13	2	43%	48.1	468.7
43	124	9.8	13	2	43%	53.7	526.3
44	109	9.85	13	2	43%	47.2	465.1
45	128	9.9	12	2	40%	51.2	506.7
46	137	9.95	12	2	40%	54.8	545.2
47	139	10	12	2	40%	55.6	556
48	134	10.05	12	2	40%	53.6	538.7
49	142	10.1	12	2	40%	56.8	573.8
50	131	10.15	17	1	28%	37.1	376.8
51	138	10.2	17	1	28%	39.1	399
52	148	10.26	17	1	28%	41.9	430
53	142	10.31	17	1	28%	40.2	414.7
54	155	10.36	17	1	28%	43.9	454.9
55	137	10.41	15	1	25%	34.3	356.5
56	139	10.46	15	1	25%	34.8	363.5
57	138	10.51	13	1	22%	29.9	314.3
58	116	10.56	13	1	22%	25.1	265.5
59	127	10.61	13	1	22%	27.5	292
60	142	10.66	10	1	17%	23.7	252.4
61	145	10.72	10	1	17%	24.2	258.9

62	148	10.77	10	1	17%	24.7	265.6
63	159	10.82	10	0.5	8%	13.3	143.3
64	194	10.87	10	0.5	8%	16.2	175.7
65	225	10.92	10	0.5	8%	18.8	204.7
66	257	10.97	10	0.3	5%	12.9	141
67	232	11.02	10	0.2	3%	7.7	85.2
68	212	11.07	10	0.15	3%	5.3	58.7
69	201	11.12	10	0.1	2%	3.4	37.3
Total kWh / yr							25,425

Cost Estimate Tables

Table PM.1: Appliance Payback Period Calculation

Year	Net Cost	Savings
0	$5,465.00	$0.00
1	$4,224.22	-$1,240.78
2	$2,983.45	-$1,240.78
3	$1,742.67	-$1,240.78
4	$501.89	-$1,240.78
5	-$738.88	-$1,240.78
6	-$1,979.66	-$1,240.78
7	-$3,220.44	-$1,240.78
8	-$4,461.22	-$1,240.78
9	-$5,701.99	-$1,240.78
10	-$6,942.77	-$1,240.78

Table PM.2: Solar Payback Period Calculation

Year	Net Cost	Savings
0	$32,700.00	0
1	$29,109.25	-3590.7549
2	$25,518.49	-3590.7549
3	$21,927.74	-3590.7549
4	$18,336.98	-3590.7549
5	$14,746.23	-3590.7549
6	$11,155.47	-3590.7549

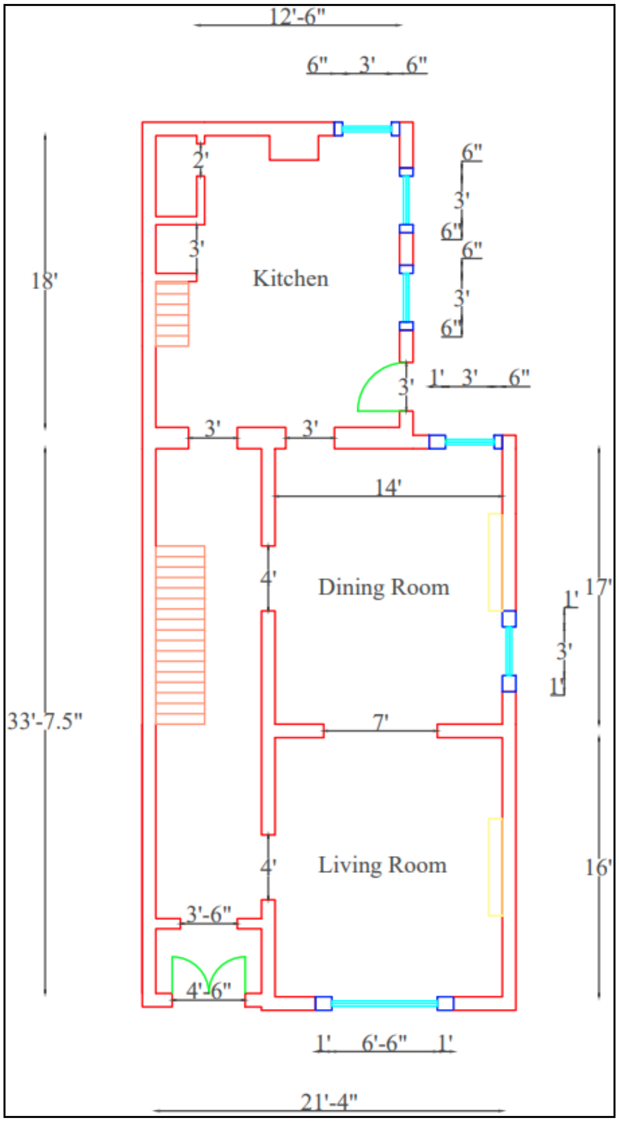
7	$7,564.72	-3590.7549
8	$3,973.96	-3590.7549
9	$383.21	-3590.7549
10	-$3,207.55	-3590.7549
11	-$6,798.30	-3590.7549
12	-$10,389.06	-3590.7549
13	-$13,979.81	-3590.7549
14	-$17,570.57	-3590.7549
15	-$21,161.32	-3590.7549
16	-$24,752.08	-3590.7549
17	-$28,342.83	-3590.7549
18	-$31,933.59	-3590.7549
19	-$35,524.34	-3590.7549
20	-$39,115.10	-3590.7549

Table PM.3: Water Payback Period Calculation

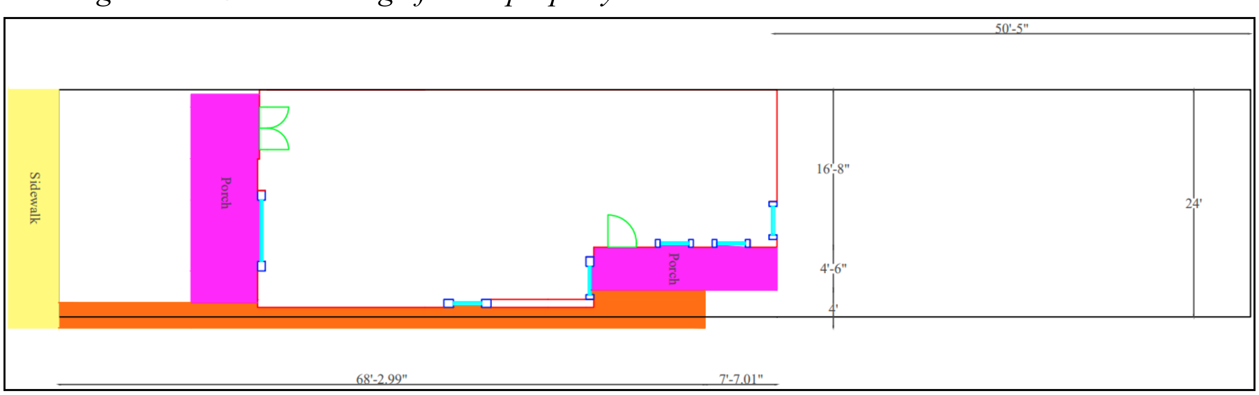
Year	Net Cost	Savings
0	$6,350.00	$0.00
1	$5,760.32	-$589.68
2	$5,170.64	-$589.68
3	$4,580.96	-$589.68
4	$3,991.28	-$589.68
5	$3,401.60	-$589.68
6	$2,811.92	-$589.68
7	$2,222.24	-$589.68
8	$1,632.56	-$589.68
9	$1,042.88	-$589.68
10	$453.20	-$589.68
11	-$136.48	-$589.68
12	-$726.16	-$589.68
13	-$1,315.84	-$589.68
14	-$1,905.52	-$589.68
15	-$2,495.20	-$589.68

Healthy Home Lab Drawings

Drawing 1: AutoCAD drawing of HHL first floor

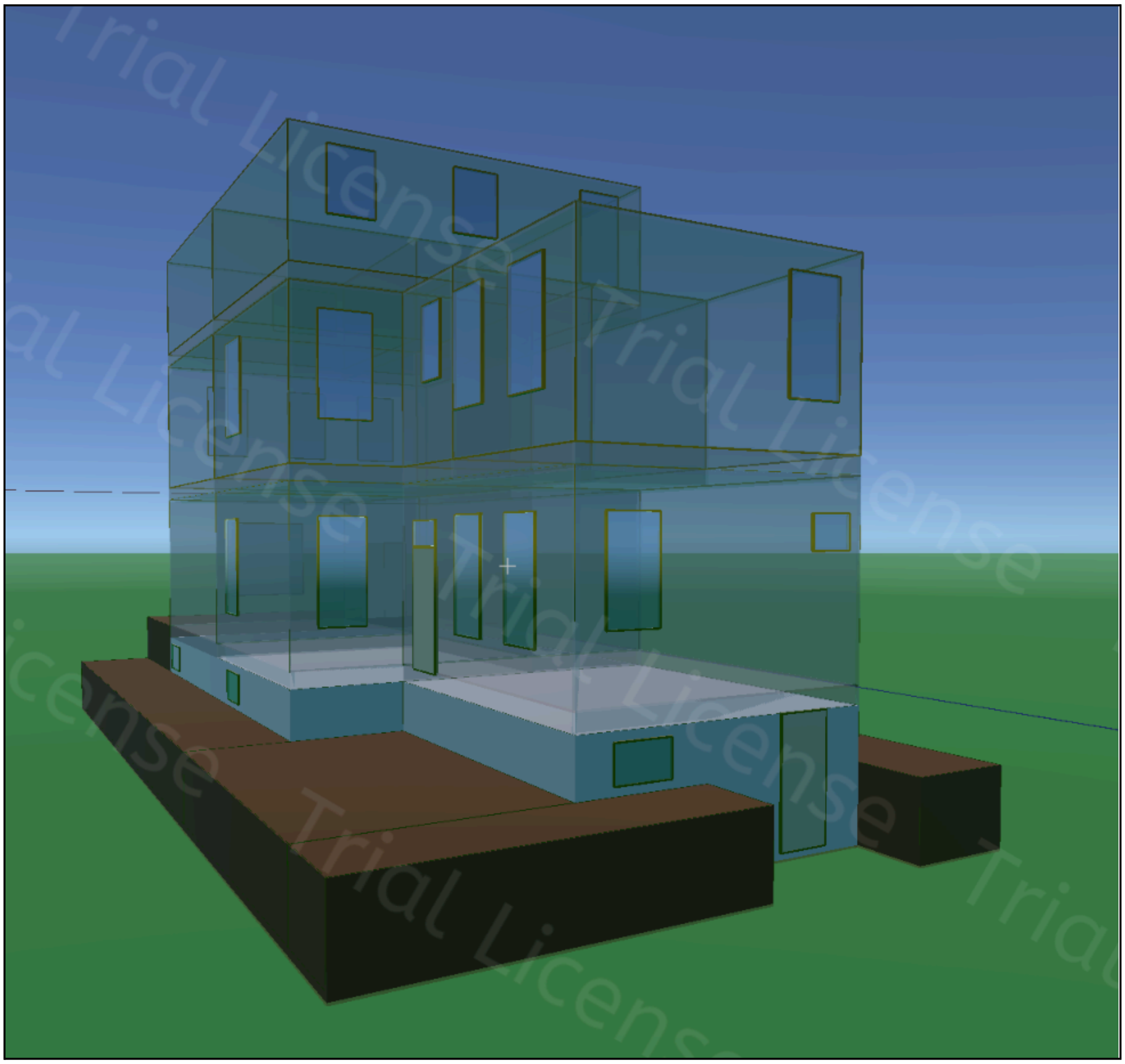


Drawing 2: AutoCAD drawing of HHL property



Drawing 3: KwikModel 3D rendering of HHL front view

Drawing 4: KwikModel 3D rendering of HHL back view



Meeting Minutes
Bill Spohn (Industry Mentor)
Date: 1/29 10:15 AM
Location: Zoom

Attendees: Bill Spohn, Abigail Gerhart, Ethan Rihn
Absentees: Percy Curtis, Emily D'Angelo, Alex Demko, Lucas Ritz

Notes:
Bill knows Kurtzman- did a "Going Solar" campaign
Recommends the thermal tool test
- Is willing to loan us the equipment
    - He offered to allow us to tour the house
    - Group called RewiringAmerica.org
        - Another source of funding, using IRA is used to equitable & responsible rewire houses
            - CEOs for Electrification
            - ASHRAE (150 year organization)
                - for IAQ 62.2
                - Robert Bean (Whale Diagram, deals w/ thermal entropy & helps w/ reducing waste energy in heating)
                - Write standards used by engineers & technicians to use for human comfort, air quality, different types of locations, etc.
    - Energy Models-
        - for calculating the heating and cooling load there is a manual j (coolcalc.com)
        - created by ACCA
        - Current revision is 8
            - can assess all the internal and external loads
        - Be able to properly size the AC units
            - CoolCalc.net- free basic load calculations
            - Manual S

IMPORTANT to avoid oversizing units
- You want to hit your design temperature
    - Different for different locations

Passive house
- PHPP- passive house planning package
    - Mixes and matches building components (not free, CoolCalc.com is the free version of this)
    - KWIKModel.com

        - Builds a 3D model from house plan & can make several calculations
        - Russ and Collin King- Made this modeling software- would be a contact we could receive if we are interested in system sizing
            - He wrote the book HVAC 1.0 book
    - Manual J by ACCA (allows you to assess all the elements on a load on a residence for heating & air conditioning systems) (CoolCalc.net)
        - Very helpful with correctly sizing equipment

Watt diet

- Tom Kabat
    - Electrical loads, you may not need a panel/ service upgrade
        - Concept that you are not running all the electrical loads at one time
    - Sean Armstrong (Red Wood Energy)
        - California electric retrofitting- has many free pdf's available
- If can understand electrical loads, then may often not need to upgrade panel

Smart panel- by SPAN

- at the circuit level have intelligence built in so that you do not go over capacity
- Switches parts off to not go beyond amp capacity
- Expensive installation & capital

Energy cost estimating tool: GETDuckling.com

Has a contact that could provide us with the latest home estimates tools 237.CO

- Electrify America may have more related information
- ResStock Model (NREL)- Residential model that allows you to insert different parameters in different regions
    - Residential house stock model, can put certain parameters and will give approximate energy consumption based on their research

The air leakage is so so so critical so the Blower Door test is so critical

- Thermal envelope, minimizing them. Common places to look
    - Thermal Bridging
    - Thermal Breaks
    - Duct Leakage (especially through exterior walls)
- Air Leakage (key to reduce energy loss)

AERO Seal/Barrier: A polymer mist that runs to the exits and will collect at the edges of the leak and path it up-

- Barrier (more for a new construction or for a gut rehab)
- Seal (for any air duct)
- Not cheap

Passive house windows- Normal sliding windows are a leakage point- these use clamshell opening

Aging in Place: Mean Radiant Temperature (MRT)

- When you go into a room and you feel the heat coming through the window or losing heat in the night time- deals with getting the thermal aspects in control

Bill Qualifications
- Trained as a mechanical engineer- bachelor and master from rochester
- 1981-1999 has experience with building
- Last 40 years has done testing and selling technologies
    - Sale/Distribution of test & measurement instruments
        - TruTechTools
            - HAM: Heating Air Monitors. Deals mostly with residential buildings
                - Heating/Air/Moisture
            - Provide tools for contractors to help maintain
            - Residential & commercial customers
- Starting the Better HVAC Alliance: Goal is to take all the knowledge and create a non commercial movement
- Treasurer of the Building Performance Association: Goal is to get the IRA funding to work in the states in a responsible manner
    - Get contractors trained and do better work
- Experience in Mechanical systems & construction of high-performance residential houses
    - His house is all monitors so he can provide reference on how things are monitored and what this data looks like
- Has a podcast

Tasks:
- Schedule a meeting to go over 60 minute presentation he has created- Has offered to record but thinks we should be able to interact
    - **10am on 2/5**
- Review these notes and come to presentations with questions

Date: 2/5 @ 10:00 AM
Location: Zoom

Attendees: Dr. Bilec, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Topics to Discuss:
- Bill's presentation for us
- Need to setup date for blower door test

Notes:
- Presentation is being recorded
- Intro/Background Summary
    - 

    - 312 Church Lane, Pittsburgh, PA, 15238
        - Bill's house, good example of high efficiency
    - Pearl Certification (help figure out your home's green score, & encourages contractors to make progress toward it over time)
    - Recommendations:
        - A Pattern Language by Chris Dorsi
        - Theprettygoodhouse.com
        - Homediagnosis.tv
        - Ecocraft / IBACOS Home Construction
            - May be good later for getting info for estimation
        - https://www.peninsulacleanenergy.com/all-electric-homes/
    - Consider US DOE climate zone when doing design
    - Consider if possible (or necessary) to make a computer fluid dynamic model of the air system
- HVAC Notes:
    - Manual J allows sizing pick for climate zone/even city
    - PHPP is similar to Manual J but allows for swapping out of design components

- Windows, doors, etc.
- Air Source Heat Pump (ASHP) - easiest to use
- CoolCalc.com
  - Uses Manual J system/logic to conduct calculations for the energy load
- KWIK Model
  - Goes through Manual J load calculations & forms a model for the house
- Blower Door
  - ACH50: Air changes per hour based on 50 pascal pressure
- Load Control
  - Starts with getting the envelope under control, reduces leakage
- Design Conditions
  - Not reached most of the time
  - It's when assuming the system is running 100% of the time
  - If go over design conditions, then system is not…
  - Real goal is to have system match the needed load
  - Can have single-staged, multi-staged, or inverter systems
- A thermostat system (controls temperature only) does not achieve needed comfort than a system that controls temperature & humidity
- Every 12,000 BTUh = 1 ton of heating/cooling, amount of heat needed to melt a ton of ice in 24 hours
- Elevate outdoor heat pumps to prevent snow/water from entering and damaging it
- Moving heat instead of creating heat, so look at Coefficent of Performance (COP)
- # of outlets depends on the load for each zone (if divided house into different zones)
- Slower that you can move a larger amount of air through a filter, more effective it is

Date: 2/21/2024 10:00 AM
Location: Google Meet

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart

Absentees: Ethan Rihn, Lucas Ritz

Topics to Discuss:

-

Notes:

- ERV and HRV
    - Conditioning HRV - has a small heat pump in it
- Heat pump clothes dryer recycles air used
- Limit infiltration points to have solid thermal seal
    - Need to have ventilation though
- ZipTape on window frames
- Radon concerns with tight envelope
    - Especially a problem in Western PA
    - Can use active fan to depressurize beneath the slab of the basement
    - Radon fan very effective
- Resistance heat more energy intensive than moving heat
- Try to stay in design range of temperature for majority of the time but can be out of range for say, 1%
- When you design a redesign look for an efficient plumbing plan
- Solar
    - NREL can do production estimate. It was 14.7 kWh for Bill and his actual was 14.85 kWh
    - Financial benefits: local solar coop pricing, one and done permitting, SRECs (solar renewable energy credit)
    - Federal tax credit only if you are the owner of the panels
        - IRA seems to be around until 2032?
        - Pay back period of 7.7 years (7-8 years about)
            - Payback includes avoided cost of buying electricity + SRECs
            - For SRECs: PA is a solar carve out state, 0.5% of energy must be solar
                - Does not need to be net positive production
- In general, more energy to heat in Pgh than cool
- Batteries not needed, energy credits make up for energy not-stored

Date: 3/18/24
Location: Zoom

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Bill Spohn

Absentees: Abigail Gerhart, Ethan Rihn, Lucas Ritz

Topics to Discuss:
- Project updates

Notes:
- U-values for windows may not be as useful, focus on type of window (i.e. casement windows)
    - The house itself is very shaded so air sealing has higher priority than solar heat gains
- Russ King able to help give insights with Retrofit work
- Greg winks good resource for solar installation if we need
- Water sampling modeled occupancy
    - What are they doing (cooking, cleaning, bathing)
    - American Home Appliance good source of estimates
- Solar irradiation
    - PV Watts, program that uses site characteristics for energy estimate
    - Government modeling program
    - Don't get lost in the details
- Can take meter readings for utility estimates
    - Can compare change in meters to the weather/occupancy for a better estimate

Date: 4/1
Location: Zoom

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Lucas Ritz, Bill Spohn

Absentees: Ethan Rihn

Topics to Discuss:

- Project updates leading into final presentation

Notes:

- Schedule
    - Create dependencies
    - What has to happen in order for the next step to occur

Dr. Bilec (Faculty Mentor)
Date: 1/22 9:30AM
Location: Zoom

Attendees: Dr. Bilec, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Notes:
Design component- building energy model as baseline, energy petal

Bilec concerned that there will not be enough design components to the project
Past group that attempted similar project with same industry mentor took too long to determine site location, so the end result was mostly a cost analysis

Need to find client - bill not a client more just a helper

"We shouldn't be boxed into the petal route"
Suggested focus: Electrification and reduction of energy use (ex. Window and doors, insulation, roof. For existing home, can do energy assessment w/ infrared cameras), How to get to net-zero carbon for a home

Need to find a location!!
Design concept for components such as heat sources: tradeoffs for options, break even point?
Ex. Solar panels: how many needed for a house, given embodied carbon - how many years to break even?
Ex. Electric vs gas stove: carbon, electricity, and air quality balance

Life cycle analysis & energy assessment (of the existing home)
Energy equity issues for "aging in place" (refers to being able to safely remain in your home as you grow older: Aging in Place: Growing Older at Home | National Institute on Aging (nih.gov))

Healthy Home Lab (Faculty leader Jonathan Pearlman, also worked in by Dr. Haig, Mima, Isaiah)
Rebuilding Together Pittsburgh (which Prof. Sebastian is on the board of) has an agreement with Duquesne Light and other providers to do upgrades to homes (at no cost to homeowners) to be healthier (indoor air quality - random thought)

Tasks:

- Reflect on scope
- Find Client
- Create a new paragraph of refined scope
- Send new scope to Dr. Bilec who will also share w/ other faculty for approval

Date: 1/29 11:30AM
Location: Zoom

Attendees: Dr. Bilec, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Notes:
- Bilec connecting us with HHL, will send email to Alex to set up meeting
- Blower Door Test
    - Dr. Haig currently doing testing in the home - have to coordinate with her and the facilities management people
- Must make sure HHL wants to do this with us
- eQuest not ideal for residential homes
- Consider utilization of land beside HHL for solar panels
    - Consider Geothermal (consider shallow geothermal options)

Tasks:
- Tour Healthy Home Lab (Bilec will reach out to Zach)
    - Bilec will email Alex
- Split into Sub-Teams
    - Divide assignments into supply (solar panels, heat pumps) and demand (appliances, HVAC, insulation)
- Begin Energy Model (2 people possibly)
    - Figure out the best software to utilize (Revit + an add on)
- Use Microsoft Project or Excel (Gantt Chart) to create a project schedule (theoretical and what we should actually use)
    - Add presentation days
- Email Dr. Wang
    - Introduce project and inquire about his expertise

Date: 2/5 @ 9:30AM
Location: Zoom

Attendees: Dr. Bilec, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Topics to Discuss:
- Updates with Bill
- Research on topics (supply/demand sides of technology)
- Building modeling software
  - BEopt
    - Made by the NREL
    - Can model single use, residential homes
    - Provides parametric sweeps & cost based optimizations
    - Only runs on PC
  - Energy Plus
    - Mac friendly
    - Seems to be made for HVAC systems, plug loads, and lighting mostly
  - ResStock
    - Not necessarily building model
    - "identifies which home improvements save the most energy and money"
- Project schedule
  - Need to get things going with HHL

Notes:
- May need to take dimensions for HHL
- Allegheny county tax assessment database & Western Pennsylvania databases to get floor plan info
  - Age, lot size, square footage, drawings
  - Western Pennsylvania Regional data Center
  - Allegheny County Real Estate Portal
- The project schedule looks good/looks like what it should visually look like (confirmed by Dr. Bilec and Prof. Sebastian)
- Dr. Bilec's thoughts on building modeling software:
  - BEopt: great, products from NREL are really good, can be tricky to run. Uses Energy Plus to run
  - Energy Plus: Used in Dr. Bilec's research group, not very user friendly
  - ResStock: Not the right way to go

Tasks:

- Dr. Bilec will correspond with Dr. Vidic and see if we should ask him to be more involved/meet with him
- Dr. Bilec will reach out to facilities to see if they have HHL floor plans
    - Zach will have this information if it exists
    - Prepare a list of what information we would like and send to Dr. Bilec
- Reach out to Duquesne Lights
- Reach out to Federika and Isabella Cicco for help with software
- Figure out what 3D model we want to use for energy modeling and home modeling
    - Dr. Bilec thinks AutoCAD is good
    - Note: KWIK Model also makes a 3D model

Date: 2/5 @ 9:30AM
Location: Zoom

Attendees: Dr. Bilec, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Topics to Discuss:

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- Figure out what 3D model we want to use for energy modeling and home modeling
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    - Note: KWIK Model also makes a 3D model

Date: 2/19
Location: Zoom

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz, Dr. Bilec, Dr. Wang

Absentees: N/A

Topics to Discuss:
- Updates on things we have from HHL (ie. Architectural dwgs)
- Blower door test scheduled - March 4th, 2:30 pm

Notes:
- Bilec knows Dante and is going to try to help with the utility bills
    - From facilities
- Do we need to implement a treatment process for greywater system?
    - What do we need to remove?
    - Suspended particles?
        - Sedimentation
- Rainwater collection system
    - Valve switch to add to greywater system
    - Excess runoff pipe?
    - Solar panels should not affect collection system

Date: 2/19
Location: Zoom

Attendees: Percy Curtis, Emily D’Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz, Dr. Bilec, Dr. Wang

Absentees: N/A

Topics to Discuss:
- Updates on things we have from HHL (ie. Architectural dwgs)
- Blower door test scheduled - March 4th, 2:30 pm

Notes:
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        - Sedimentation
- Rainwater collection system
    - Valve switch to add to greywater system
    - Excess runoff pipe?
    - Solar panels should not affect collection system

Date: 3/18/24
Location: Zoom

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Dr. Bilec, Dr. Wang

Absentees: Abigail Gerhart, Ethan Rihn, Lucas Ritz

Topics to Discuss:
- Project updates

Notes:
- High heating loads high - can use offsets to make project net-zero
- Risk management
    - Since its an older home potential environmental concerns
        - Lead paint
        - Asbestos
    - Structural safety concerns with the third floor
    - Air quality data
    - Worker safety on the roof
- Synthetic water samples for greywater testing

Date: 4/1/2024
Location: Zoom

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Topics to Discuss:
- Show final presentation

Notes:
- Make a map at the bottom of slides in order to help the audience visualize our alternatives and what we will talk about next.

Dr. Wang (Faculty Mentor)
Date: 2/2 @ 1:00 pm
Location: BEH 702

Attendees: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Topics to Discuss:
- Basic intro on who we are
- Project intro
- How can he help us?

Notes:
- Should consider how to make this design more general (not too house-specific)
- Evaluate the feasibility of achieving net zero in Pittsburgh
    - Compare this feasibility if the location is changed to climates different from PGH
- Broaden the scope of the project to include a water/waste/net zero CO2
- Smart switches and smart sensors for electricity
- Concern that the project is more analysis than design
- Big supporter of adding a water component
    - Has much more design
    - Collect rainwater, point-of-use water systems…
        - Maybe not legal lol - check into this
        - Consider a gray water system
    - Wastewater, soil as a natural filter?
    - Compost for solid waste & to fertilize
- Not only having energy components but also considering a self-sustainable house
    - Similar to PETALS but avoiding the certification because it is not flexible enough
- Solar panel efficiency decreases over time- account for this

Tasks:
- Ask about adding a water component
    - Present this idea to Dr. Bilec and emphasize that Dr. Wang is a big proponent
- Look into the legality of recycling/ treating water in PA
- Send schedule to Dr. Wang

Date: 3/14 3pm
Location: Zoom

Attendees: Emily D'Angelo, Abigail Gerhart

Absentees: Percy Curtis, Alex Demko, Ethan Rihn, Lucas Ritz

Topics to Discuss:
- Planning process presentation

Notes:
- More details between the anaerobic and aerobic tanks
    - These are for wastewater - in greywater there prob isn't enough organics
        - Filtration is a more suitable method probably - not biological or chemical processes
    - Could do alternative designs
        - Which has lower costs and which makes more sense with energy
    - Get designs for anaerobic and aerobic tanks
- Look for high amounts of surfactants in water

Tasks:
- Waiting for utility bills
- Testing water in house
    - TOC, TSS

Dr. Kerzmann (Faculty Mentor)
Date: 1/24 9:30am
Location: 512 Benedum Hall

Attendees: Dr. Kurzman, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A

Notes:
Heat pump cycle = thermodynamics

- Coefficient of performance - kurzman focused on thermodynamics

Spreadsheet of natural gas consumption of a home?

US energy information administration - Residential Energy Consumption Survey

- How much energy is Consumed
- How much is natural energy
- Will provide us with a spreadsheet of (on average) how much gas is being used for each aspect of a house- could be used to decide what design aspects are most important when converting to electric

What area/region will we be focusing on? - will we expand our HHL lab model to other homes in the region

A furnace heats natural gas- not perfect- high eff furnace is 95%

Heat Pump → COP = Heat Out / Power In = 3 to 5

BTU of natural gas is cheaper than a BTU of electricity; electricity is 3-5 times more efficient that natural gas; would save 33% heating by solar, normal = breaking even

- Then you can relate this back to environmental impact

Design

- Choose a site and evaluate that
    - Use as site and design system around that
- Air to air heat pumps vs. ground heat pumps vs. water heating pumps
- Retrofit additional insulation
- Increase overhangs off the sides of buildings
- Compare design A (cost effective) vs. design B (if you add solar panels, power wall; carbon neutral)
- No matter what use some sort of a tool that person A could plug in their electric use to allow for an estimate on how much they are saving/how much it would cost to replace an aspect

- What would happen if you replaced the windows- equipment bilec was talking about

Energy building modeling- Equest- Energy Plus
- You can insulate the attic
- You can test different heat pumps (water, heating and cooling)
- Natural gas range adjustment

Designing a Solar Panels system
- Open Solar (software) https://www.opensolar.com/
- Plug in data that is collected from Healthy Home Lab
- Add some panels (nice roof for solar)
- Add an inverter (solar edge is a common inverter)- can handle 1.5 times the power in the panels
- After done designing– can create a report
  - Connect positive to negative to each panel
- Go to PDF proposal
  - Estimated energy production per year
    - Compare this to what is currently being used
- Could even add batteries (no advantage at the moment but something to consider)

May want to figure this out for multiple buildings
- Maybe this is the northeast example, then design one for different regions

Mr. Cool 4 ton heat pump - convert S to COP
- Find specs for heat pump, use this to convert to COP

Compare carbon emissions

Tasks:
- Watch videos attached in emailed presentation
- Practice EQuest

Date: 2/21/24 10am
Location: 512 Benedum Hall

Attendees: Ethan Rihn, Lucas Ritz, Dr. Kerzmann

Absentees: N/A

Questions:

40% East or (South) West? facing, slight slant in that direction

Explain to Kerzmann that we don't energy use stuff yet about the home specifically

- Solar
    - The structural integrity of the roof for solar panels?
    - Rebates for solar installation
    - Help with solar intensity data (to estimate Watt & Energy info)
    - How to get these deliverables?
        - # of Pannels, Energy Usage, Cost, Orientation, efficiency reduction over time, battery storage capacity?, snow and snow removal
            - Find an LCA on solar pannels
            - Cost-Benefit Analysis (capital vs. savings)
    - HelioScope
    - OpenSolar
    - Rule of thumb - tilt for maximum
        - Want to tilt at the angle of your latitude
        - Our electricity demand will increase using the electricity heating/cooling & water systems
        - 2-4lbs/ft^2 for solar panels + 3.5 per in. of snow
    - Weight of solar poanels almost never an issue according to Kerzmann
    - Solar installers bring out structural engineer to make sure
    - Tier1 solar panel company
    - Storage capacity
        - How to judge how much to store
            - Dont store anything because its connected to the grid
            - Net metering
- Heat Pumps
    - Existing Gas Boiler System → Air-to-Water System
        - Efficiencies for different types of a-w systems for residential homes
    - Sizing of heat pumps assuming we know the heating demand
    - Rebates for heat pumps
    - What will get us net zero carbon and all-electric?

        - Ground source (geothermal) - WHAT'S THE SIZE REQUIREMENT of yard
            - How are size & heating capacity related?
                - Look at the R-values and difference of desired inside temp and colded tmep in last 10 years. Use to find heat loss, and can use to help with sizing the system
                - WATCH FOR UNITS
                - Ask bill about how its affected by infiltration
        - Efficiencies in cold climates of heat pumps

Notes:

Cooling: mini splits
- Mr. Cool has DIY mini splits
    - Outside condenser coil
    - Requires small hole to be drilled in walls to run lines from mini split to outside unit

May not be possible to completely seal home thus we may not have to worry about ventilation
- 2-3 layers of brick, no true exterior insulation (has an R-value in range of 0.8-1.2)
- Interior (plaster and lathe) - lathe absorbs quite a bit of heating
- Rough estimate of r-value in entire wall is ~10

Hot Water Heater
- Likely ours is a resistive system, so has an expensive 1:1 electric heating system
- Very inefficient (0.92 heating factor, opposed to have a 4 COP)
- Suggest creating a COMBINED system for boiler & Hot Water Heater?

Look at a heating & cooling system w/ AWHP system?

Ground source heat pumps much more efficient than air-air

Russ King
Date: 2/13
Location: Zoom

Attendees: Russ King, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Absentees: N/A
Notes:

- Left to right workflow in KwikModel
- Step by step process will walk us through (he emailed this already)
- Compass can be spin by clicking or typing in ##
- "Front is down on the plans"
- North arrow is essential
    - Direction glass is facing effects the load calculations because of solar heat
- Bottom left has architectural plans
- Thickness of walls included in area of house
- Libraries tab is where surfaces types are kept
    - Window, door, floor, etc.
    - Defaults are highlighted in green
- Import floor plan from floor plan tab
    - Put in file from file library (use the floor plan Abbie drew)
    - Will import any type of image file
- Scale Floorplan
    - Be in 2d mode and look from the top
    - Use the longest dimension you can find on plans to make it more accurate
    - Use the horizontal arrow and line it up then type the length and click scale
    - Check this by turning the grid on
        - Dimensions should match the grid (each square is 1'x1')
- App called cubicasa
    - Wants us to use this instead of what Bill had us use
- To add a room
    - Click room tab
    - Choose room type
    - Press alt key and click where you want the room to go
    - Include hallways and any other areas on plan that do not have a "register"
    - Go to exterior surface of room when drawing in rooms
    - Look for vaulted ceilings keep rooms with vaulted ceilings separate
        - Vaulted ceilings are just triangle shaped ceilings
        - There is a vaulted ceiling box in 3D mode??? - not actually sure about this

        - Pink = overlapping
        - Rooms that are not square
            - Place in a triangle shaped room to fill voids left by squares
                - Tab to rotate (I think)
            - <u>Shift + click to group the "rooms" created when filling voids</u>
            - Check to make sure they are grouped by clicking and dragging
        - Do garages (even though typically unconditioned)
        - Ignore fireplaces
- Data tab gets rid of separation line
- Doors and windows tab
    - Alt + click places a window
    - Can type in the size box the dimensions (bottom/middle left of the screen)
        - Can copy windows by control + c
        - Then control + alt + click
    - Size is the "rough opening" this includes the frame + ½ an inch approx
- Systems house has: HVAC Tab
- Data tab
    - Keeps track of dimensions and items placed and what not
    - Each tab on the left will pull up a table of what you've drawn
- Be sure not to make rooms too small
    - Check alignment button
    - If they aren't attached the program will assume that space is open to an unconditioned space
- Can change window, wall type, etc. type in libraries tab
- To show that something is underground put a box next to it called "Earth"
    - Must put box next to each wall that is underground
    - Basement = 1st floor and work your way up
- Name rooms in data tab then room table - also put room type
- # of occupants
    - # of bedrooms + 1 is the general rule of thumb
- Energy gauge loads button
    - Pick State + city
    - Resist the temptation to change temperatures manually, will cause inaccurate results
- HVAC Draw
    - Place registers in rooms
    - Add start collars
    - Highlight start collar and highlight register then hit enter to make a duct
    - Manual D will do later

Clint Noack & Kartik Ganjoo
Date: 2/7
Location: Teams

Attendees: Clinton Noack, Kartik Ganjoo, Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Lucas Ritz

Absentees: Ethan Rihn

Topics to Discuss:
- Brief overview of our project

Notes:
- Kartik
    - Associate at the innovation center for a year and a half
    - Works with electrification accessibility
- Clint
    - New member of the team
    - Environmental engineer
    - Both engineers
    - Want to boost electricity usage in the area (company interest but also help carbon emissions)
    - Want to boost whole home electrification
- Home is probably wired for 200 Amps of service
- Have a program that will support electrifying old homes
- Amp diet more than Watt diet
- https://homes.rewiringamerica.org/personal-electrification-planner
- Electricity on duq light grid is majority nuclear → low carbon
    - Energy mix is 77.2% nuke, 20.1% nat gas, 0.2% hydro, 2% solar, 0.02% wind, 0.01 fuel cell, and 0.41 CH&P (combined heating & power, usually natural gas)
        - (Fuel cell is likely natural gas)
        - Calculated by Kartik
- Battery power vs. connect to the grid for solar
- Incentives available
    - https://www.dlc-ira.com/
    - IRA credits + DLC rebates
        - IRA: 2 parts (income qualified vs. not income qualified) when you apply for your taxes you present a receipt of your project and you will receive a rebate- most likely credited

                - They are looking into ways to pay these rebates up front
                - Air source heat pumps are not necessarily a good deal for all people
                - Water heater heat pumps are a good deal for most people
                - Offered help with rewiring america website
- Offering to give us a home energy audit- ~$500 but potentially covered by DLC
    - $275 rebate
- Start to finish electrifying
    - Start with energy audit
    - Use applications for solar, meters, etc. (notify DLC)
    - Find electrician to rewire house in preparation for equipment (checking amps)
    - Find vendor to install equipment (currently do not have anyone to recommend)
- An old type of wiring that may not be able to handle some equipment: Knob and tube wiring
- Moduly Company is building module homes in Pittsburgh that are fully electrified.
- DLC and Rewiring America is working together to support 100 low income households to be electrified before 2025 (may be good to mention at end of presentation to show practicality of project)
- Considerations for reliability–snowstorm taking out electricity can lead to no heat
- DLC has a small discount (1 penny less per kilowatt hour) for electric homes with heat pumps

Tasks:

- Try and find a seller's disclosure for anything wrong with the electric (Bilec is kinda doing this)
- Should think about reliability / start to look into how we will address concerns of power outage
- Ask Bill at next meeting if it is okay to introduce him to DLC (it seems like a customer discovery thing for DLC, not for our project)
- Send them project reports

Weekly Management Reports
Project Management Report for the week of 1/28/2024

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Bill Spohn: 1/29 @ 10 am
2. Dr. Bilec: 1/29 @ 11:30 am
3. Dr. Wang: 2/2 @ 1:00 pm

Weekly Accomplishments:
1. Percy Curtis
    a. Began research on thermal envelopes, mean radiant temperature, and window design
2. Emily D'Angelo
    a. Began research on carbon emissions of household appliances and looked into passive house design
3. Alex Demko
    a. Gantt chart created
    b. Began research on residential building energy models, Rewiring America (funding for the project), and HVAC systems.
4. Abigail Gerhart
    a. Met with Bill Spohn for the first time
    b. Began research on the environmental impacts of natural gas and electric BTUs and the Watt Diet
5. Ethan Rihn
    a. Met with Bill Spohn for the first time
    b. Began research on solar panel systems, heat pumps, and heat sumps
6. Lucas Ritz
    a. Began research on solar panel systems, heat pumps, and heat sumps
7. Everyone
    a. Divided into teams (supply and demand sides)
    b. Beginning preliminary research
    c. Created a project management report

Next Week Tasks:
1. Hopefully a site visit to HHL & approval from them

2. Continuing research and share results with team

Open Issues:

1. Contacting HHL
2. Blower test coordination

Project Management Report for the week of 2/4/2024

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Dr. Bilec: 2/5 @ 9:30 am
2. Bill Spohn: 2/5 @ 10 am
3. Duquesne Light: 2/7 @ 1 pm

Weekly Accomplishments:
1. Percy Curtis
    a. Presented research on thermal envelopes, mean radiant temperature, and window design
    b. Began looking into electric appliances to replace existing gas
2. Emily D'Angelo
    a. Presented research on carbon emissions of household appliances and looked into passive house design
    b. Began research on greywater systems
3. Alex Demko
    a. Presented research on residential building energy models and Rewiring America (funding for the project).
    b. Scheduled site visit at HHL, 2/12 @ 10:00 am
4. Abigail Gerhart
    a. Presented research on the environmental impacts of natural gas and electric BTUs and the Watt Diet
    b. Began research on greywater systems
5. Ethan Rihn
    a. Presented research on solar panel systems, heat pumps, and heat sumps
    b. Began research on rainwater harvesting system & internal plumbing networks
    c. Looked into general electric home design
6. Lucas Ritz
    a. Presented research on solar panel systems, heat pumps, and heat sumps
    b. Began research on rainwater harvesting system & internal plumbing networks
7. Everyone
    a. Redivided into teams (supply - Ethan/Lucas, demand - Percy/Alex, and water - Emily/Abbie)
    b. Continued additional research

c. Created a project management report
d. Created site visit plan

Next Week Tasks:

1. Site visit to HHL on Monday
2. Continuing research and share results with team

Open Issues:

1. Blower test coordination
2. Coordinate meeting with Rebuilding Together Pittsburgh

Project Management Report for the Week of 2/11/2024

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. HHL Site Visit: 2/12 @ 10:00 am
2. Russ King: 2/13 @ 2:30 pm
3. Dr. Bilec: 2/15 @ 2:00 pm

Weekly Accomplishments:
1. Percy Curtis
    a. Used Amply to make a 3D model of the HHL
    b. Practiced modeling a basic house using Kwik Model
    c. Began looking into existing and appliances and investigating alternatives researching forced air HVAC
2. Emily D'Angelo
    a. Used Amply to make a 3D model of the HHL
    b. Continued researching greywater/ rainwater systems
3. Alex Demko
    a. Coordinated with multiple sources within our group
    b. Began looking into HHL appliances and possible replacements
4. Abbie Gerhart
    a. Completed the first-floor AutoCAD Model
    b. Continued researching greywater/rainwater systems
5. Ethan Rihn
    a. Began looking into solar panel system design
    b. Investigating air-to-water heat pump (AWHP) design
    c. Researched rain barrel construction and application to gray water systems & gardening
    d. Reviewed standard plumbing design practices
6. Lucas Ritz
    a. Continued research on heat pumps and water heaters
    b. Began research on rain barrels/rain collections
    c. Calculated roof rain runoff
7. Everyone
    a. HHL site visit
        i. Took pictures of the HHL

ii. Got room dimensions to make floorplan
iii. List of appliances and power sources
iv. Began looking into design plans

b. Learned how to use Kwik Model with Russ
c. Started progress report 1

Next Week Tasks:

1. Make building model in Kwik Model
2. Make floorplans for basement/second floor
3. Begin system designs (greywater/rainwater, solar panels, duct networks(?))
4. Finish Progress Report 1

Open Issues:

1. Blower test coordination
2. Coordinate meeting with Rebuilding Together Pittsburgh

Project Management Report for the Week of 2/18/2024

Project Scope: Retrofitting the University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Dr. Bilec & Dr. Wang 2/19 @ 9:30 am
2. Bill 2/21 @ 10:00 am
3. Dr. Kerzmann 2/21 @ 10:00am

Weekly Accomplishments:
1. Percy Curtis
    a. Researched ENERGY STAR program and current appliance standards
    b. Preliminary research on average PA demand + rebates & incentives for green upgrades
2. Emily D'Angelo
    a. Researched treatment options for combined rainwater-greywater systems as well as the process of how these systems work
    b. Conducted preliminary research on the legality and permitting of rainwater collection and combined systems
3. Alex Demko
    a. Finished energy model in KwikModel
    b. Researched the importance of windows for energy efficiency and thermal bridging
4. Abbie Gerhart
    a. Conducted preliminary research on the legality and permitting of rainwater collection and combined systems
5. Ethan Rihn
    a. Continued research into Air-to-Water Heat Pump selection and design
    b. Researched and decided to use average PA electricity usage as a baseline for solar design calculations
    c. Met with Dr. Kerzmann to discuss solar and heat pump options
6. Lucas Ritz
    a. Preliminary solar design on house
    b. Continued research on heat pumps and water heating
    c. Met with Dr. Kerzmann to discuss solar and heat pump options
7. Everyone

    a. Finished and presented progress report 1

Next Week Tasks:
1. Finalize criteria to evaluate design components
2. Start working on designs from information on our research
3. Meet with Evan from Rebuilding Together Pittsburgh

Open Issues:
1. Getting information on the energy usage of the house
    a. Should be complete with Duquesne Light energy audit and Bill's blower door test in the future

Project Management Report for the Week of 2/25/2024

Project Scope: Retrofitting the University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Dr. Bilec 2/29 @ 2:00

Weekly Accomplishments:
1. Percy Curtis
    a. Found multiple estimations for heating and cooling loads to use while waiting for the model
2. Emily D'Angelo
    a. Created a plan of action for designing Greywater System in compliance with PA DEP Resources and Regulations
    b. Began capacity, dose, and pump calculations
3. Alex Demko
    a. Attempted to finish KwikModel (having issues with HVAC system for modeling heating and cooling loads)
    b. Organized Energy Audit of the HHL, Monday, 3/4 @ 10 am
4. Abbie Gerhart
    a. Created a plan of action for designing Greywater System in compliance with PA DEP Resources and Regulations
    b. Began capacity, dose, and pump calculations
5. Ethan Rihn
    a. Collaborated with the demand team to investigate energy (heating & electricity) usage & load information
    b. Reviewed & updated research on AWHP from prior meetings with Bill Spohn and Dr. Kerzmann
6. Lucas Ritz
    a. Continued research on heat pumps - waiting for energy audit numbers in order to properly size pumps

Next Week Tasks:
1. Blower Door test
2. Duquesne Energy audit

Open Issues:
1. Trouble shooting KwikModel issues

Project Management Report for the Week of 3/3/2024

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. N/A

Weekly Accomplishments:
1. Percy Curtis
    a. Worked with Alex to determine heating load of HHL as is through Manual J and other research from multiple sources (~210-230k btu)
    b. Researched air sealing and insulation companies and prices
    c. Began looking into window types and installation companies/costs
2. Emily D'Angelo
    a. Began sizing the greywater/ rainwater system
    b. Finalized research on the permitting/ rules of a greywater system in PA
3. Alex Demko
    a. Worked with Percy to determine the heating load of HHL as is through Manual J and other research from multiple sources (~210-230k btu)
    b. Researched air sealing and insulation companies and prices
    c. Began writing up a preliminary project schedule and cost estimate
4. Abbie Gerhart
    a. Began sizing the greywater/ rainwater system
    b. Finalized research on the permitting/ rules of a greywater system in PA
5. Ethan Rihn
    a. Worked with the demand team to determine heat load calculations based on information learned from the energy audit and two blower door tests
    b. Looked into solar panel design options and formulated an action plan emphasizing the maximization of meeting net annual energy consumption needs
6. Lucas Ritz
    a. Began sizing heat pump based on estimated heating load for HHL
    b. Developed plan for solar panel design/layout with Ethan
7. Everyone
    a. Blower door test at HHL
    b. Energy audit at HHL

Next Week Tasks:

1. To enjoy spring break :)

Open Issues:

1. Waiting for utility bills from the University
2. Determining the influence of air sealing and improved insulation on the manual J heat load calculation
    a. Blower door tests revealed a leakage rate of ~9000 CFM and an estimate of ~15 Air Exchanges per hour, so need to determine how much that can be reduced by air sealing/insulation/window changes for a final Manual J heating load calculation.

Project Management Report for the Week of 03/18/2024

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:

1. Dr. Bilec @ 9:30 3/18
2. Bill Spohn @ 10:00 3/18

Weekly Accomplishments:

1. Percy Curtis
    a. Calculated reduced heating demand with air sealing, insulation, and new windows with Manual J to be about 120k btu's
    b. Researched and selected insulation design for roof and basement
2. Emily D'Angelo
    a. Collected water samples from HHL
    b. Researched and designed a filtration tank for the greywater system
    c. Researched alternative design components for greywater systems
3. Alex Demko
    a. Contacted several air sealing and window installation companies to get cost and installation time estimates
    b. Researched different window types (going with casement windows)
    c. Calculated reduced heating demand with air sealing, insulation, and new windows with Manual J to be about 120k btu's
4. Abbie Gerhart
    a. Collected water samples from HHL
    b. Did flow and capacity calculations for holding tank
    c. Researched alternative design components for greywater systems
5. Ethan Rihn
    a. Met with Ryan from Palmetto Solar to discuss solar design
    b. Researched and cataloged a daily watt demand for a single-family home with the existing HHL conditions
    c. Assisted in refining Manual J calculations for heat pump load capacity
    d. Researched and analyzed appropriate air-to-water heat pumps (AWHPs) to meet the determined heat load requirements
6. Lucas Ritz
    a. Met with Ryan from Palmetto Solar to discuss solar design
    b. Researched Energy Star products to estimate the watt demand for the HHL

c. Began calculations on alternatives for solar design
d. Researched and analyzed appropriate air-to-water heat pumps (AWHPs) to meet the determined heat load requirements

7. Everyone
    a. Worked on creating our progress report 2

Next Week Tasks:
1. Work on finalizng last steps of our designs
2. Finalize project schedule and cost estimate

Open Issues:
1. Still trying to get utility bills from the university

Project Management Report for the Week of 3/24/24

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Dr. Bilec & Dr. Wang @ 9:30, 3/25
2. Bill @ 10:30, 3/25

Weekly Accomplishments:
1. Percy Curtis
    a. Initial research on rebates, tax deductions, credits, and other financial incentivess
2. Emily D'Angelo
    a. Collected waste water samples from Healthy Home Lab
    b. Began pipe routing model
3. Alex Demko
    a. Looked into appliance costs
    b. Started payback period calculations on both solar panels and appliance upgrades
4. Abbie Gerhart
    a. Collected waste water samples from Healthy Home Lab
    b. Began pipe routing model
5. Ethan Rihn
    a. Reviewed presentation feedback & formulated a plan for final design alternatives and alterations
    b. Initial research on solar panel rebate & cost reduction policies/grants
    c. Reviewed analysis on the payback period for solar and appliances
6. Lucas Ritz
    a. Finished solar panel & heat pump preliminary design
    b. Continued research on the final solar panel & heat pump design
7. Everyone
    a. Finalized and presented progress report 2

Next Week Tasks:
1. Finalize both water and energy designs (including cost estimate, payback period, schedule)
2. Run lab tests on water samples
3. Begin working on Final Presentation (due 4/11)

Project Management Report for the Week of 3/31/24

Project Scope: Retrofitting University of Pittsburgh's Healthy Home Lab to be All-Electric
Company Name: RetroFix
Team 9 Members: Percy Curtis, Emily D'Angelo, Alex Demko, Abigail Gerhart, Ethan Rihn, Lucas Ritz

Weekly Meetings:
1. Dr. Bilec & Dr. Wang 4/1 @ 9:30
2. Bill 4/1 @ 10:30

Weekly Accomplishments:
1. Percy & Alex
    a. Finalizing rebates and discounts for project cost
    b. Finalizing project schedule
    c. Making final edits to presentation
2. Emily & Abbie
    a. Tested water samples for water quality
    b. Making final edits to water design
    c. Making CAD drawings for pipe network
3. Ethan & Lucas
    a. Gathered weather data and made bin model to estimate energy consumption with heating degree days
    b. Finalizing heat pump and solar alternatives
4. Everyone
    a. Worked on final presentation
    b. Presented to environmental faculty

Next Week Tasks:
1. Practice final presentation
2. Record final presentation