

Recommendations for Improving Energy Efficiency in Quigley Hall

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Abstract

This project uses an ASHRAE level 1 and a partial level 2 energy audit to examine the energy use of Quigley Hall. The primary problem that this is addressing is inefficient energy use in buildings, which results in costs to building owners and can coincide with discomfort for users of the building. A walkthrough of the building was conducted in order to assess it and identify areas to look at more closely. An IR camera was used to identify areas of heat loss from the building and areas that are not sealed. Gas bills from the building in past years were examined to determine how much natural gas the building uses and at what times of the year it is used. It was found that replacing two sets of doors, which were found to allow heat to escape from the inside of the building in large amounts, would be the most beneficial improvement to the examined aspects of the building.

Introduction

Energy is used for many different things in buildings including heating, lighting, and electricity. This use of energy results in costs to the building owners and releasing greenhouse gasses into the atmosphere. Buildings account for as much as almost 40% of global energy related carbon dioxide emissions. The primary areas of energy consumption in buildings are heating, ventilation and air conditioning that account for 35% of total building energy, lighting that takes up 11% of energy, appliances such as refrigerators and dryers that account for 18%, and other miscellaneous things such as electronics that make up 36% of total energy use (DOE, 2015). Heating systems are one the largest users of energy. The heating process can be achieved in a number of ways including free convection with systems such as radiators and electric heaters, forced convection with systems such as fan coils, and radiation heat transfer with systems like radiators or electric radiative heaters (Dincer, 2021). Improvements can be made to building efficiency such as increasing the amount of natural daylight inside, ventilation, and insulation can help to greatly reduce the energy usage of these buildings (Stewart et al., 2019).

The main cause of this problem is that older buildings are often built and equipped with less efficient systems and appliances. Old electric heaters, oil boilers, coal boilers, HVAC systems use energy less efficiently than modern ones would. Older buildings also often have a less sealed building envelope, which results in more energy being required for temperature control (Ascione, 2017). A building's envelope is how airtight it is, and being less airtight can result in higher air leakage. Air leakage is the unintentional exchange of air between inside a building and outside. Leaks can occur at failed joints, flanges, or weld or material failures (Kent, 2018). Reducing air leakage can save 5-40% of the energy used for heating and cooling in buildings. Sealants, gaskets, and additional window panels can reduce air leakage (El-Darwish, 2017). Upgrading these takes money and time, which can prevent switching to newer and more energy efficient systems and structures.

In higher educational buildings, newer buildings are very likely to use less energy than older buildings of similar size and purpose. Heating requirements for these buildings tend to be much lower, most likely due to more efficient systems and more insulation and sealing. Electricity consumption tends to rise in newer buildings, possibly because of more electronic devices and systems being added into them. Higher educational buildings typically have less variation in heating and electricity consumption than other similar sized buildings (Sekki, 2015). Higher educational buildings of different uses have different average energy use intensities (EIU). One study found that buildings that are used for research have a benchmark EIU value of 216 kWh/m²/year, science buildings have a benchmark EIU of 164

kWh/m²/year, academic offices have a benchmark of 137 kWh/m²/year, and health building have a benchmark of 136 kWh/m²/year (Khoshbakht, 2018). These buildings use energy for different purposes and thus have different amounts of energy consumption. These benchmarks are lower than those found for some other types of educational buildings in another study, which found K-12 schools have a median EIU of 127 kWh/m²/year, elementary schools have a median EIU of 270 kWh/m²/year, and secondary schools have a median EIU of 264 kWh/m²/year (Ouf, 2017).

The main consequence of this problem is that inefficient energy use causes unnecessary costs to the building owners in order to maintain the building's function and can affect the comfort of occupants. Lighting and heating are both major sources of energy use in buildings, and both have a significant impact on the comfort of people inside the building (Moazzen, 2021). Heating, ventilation, and air conditioning systems can greatly improve occupant thermal comfort, but this often comes at the cost of having higher energy use from running more intensive systems (Papadopoulos, 2019). This can conflict with attempts to reduce energy use by renovating and replacing. Ventilation can be important in preventing high amounts of indoor humidity, which can be uncomfortable (Zeiler, 2013). Improving thermal comfort in academic buildings can be particularly important because thermal discomfort can affect learning performance (Moazzen, 2021). It is usually best to search for cost-optimal solutions, which are when the energy performance level leads to the lowest possible cost during the entire estimated life cycle of something (Vilches, 2017). Retrofitting a similar educational building in another study found a net payback period of 1.95 years for lighting and 6.30 years for air-cooling and air-conditioning load (Latif, 2019). Energy use also contributes to climate change. The United Nations describes climate change as "long-term shifts in temperatures and weather patterns" (UN, n.d.). Climate change can occur both naturally by means such as variations in the solar cycle or as a result of human activities. Since the 1800s, human contributions to climate change have increased and may have become the main driver of it. The main way in which humans contribute to climate change is through emissions of greenhouse gasses from burning fossil fuels such as coal, oil, and gas for energy production (UN, n.d.). Greenhouse gasses such as carbon dioxide cause earth's atmosphere to retain more heat (Herbert, 2007). The burning of fossil fuels contributes to climate change by contributing to the greenhouse effect by releasing greenhouse gasses into the atmosphere. These greenhouse gasses trap heat in the lower atmosphere and keep the planet warm, but higher amounts increase this effect (Hardy, 2003). Powering buildings is one of the ways in which this energy is used (ACEE, n.d.). Energy also goes into creating buildings and everything inside them. (IEA, n.d.). The world has warmed by about 0.6°C since temperature records began in the 1850s, and much of this change has occurred in the last 3 decades (Haines, 2004). Climate change affects people's health, contributes to sea level rise, and can reduce agricultural yields (Schramek, 2001). Reducing energy use in buildings can be beneficial by lowering costs.

Energy use in educational buildings is primarily in the form of heating and electricity. In most educational buildings that use boilers for heating, the amount of energy used for heating is greater than the energy use for electricity (Jain, 2020). Heating can be done by a number of different heating systems such as boilers, furnaces, heat pumps, or electric heaters (Friedman, 2023). Energy use for heating can be decreased by using more efficient heating systems or by improving the building's envelope to decrease the exchange of air between inside the building and outside. Doors and windows are common areas for heat loss that can be improved by renovations and replacements. Having better insulation, a better seal, or double pane glass on doors and windows reduces the amount of heat loss through them (DOE, 2023). Quigley Hall is heated by a boiler in the basement of the building that uses natural gas. Electricity is used for powering appliances such as computers and projectors, powering lighting, and air conditioning. Quigley Hall is not air conditioned, however it does have many computers in its computer lab and most classrooms have a computer and projector, and all rooms have lighting.

A potential research tool that can be used to address the problem of inefficient energy use in buildings is an energy audit. Alajmi (2017) explains that an energy audit is a process that is used in order to detect operating issues, improve the comfort of occupants, and optimize the energy use of an already existing building. It also identifies possible opportunities to conserve energy. The process is periodic, and it assesses changes in building use, the condition of the current equipment, and the suitability of new energy efficient technology that could be implemented. There are 3 possible levels to this process that can be conducted, and the level that it is conducted at depends on the available time, budget, and the complexity of the building (Energy Advantage Team, 2017). The first level is a walk through assessment, the second level is an energy survey and analysis, and the third level is a detailed analysis of capital intensive modifications. The procedures of each of these levels are not provided in exact detail, which leaves room for the team conducting the energy audit to decide what data should be gathered and what specific improvements should be evaluated, however the result of any energy audit at any level should include a list of energy conservation opportunities (Alajmi, 2012). An energy audit can measure and characterize HVAC systems, temperature, lighting, humidity, and other indoor conditions. It can involve investigating the architecture and history of the building, an audit of the building envelope, characterizing technical systems and equipment, defining the building uses and thermal zones, and obtaining and examining the energy data of the building (Assimakopoulos, 2018).

There are many different ways to improve the energy efficiency of buildings, and an energy audit can be a useful tool to help identify them. One past study found that the best improvements to make to the building that it focused on was to increase the amount of natural light inside the building, clean the solar panels that had already been installed so that they could work more effectively, and replace some electrical regulators and conductors (Baskar, 2014). Another study found that changing the temperature

that parts of the building were kept at when in use was a worthwhile change (Merabtime, 2018). A different study supported changes to a building's ventilation and airflow systems (Allab, 2017). There are many past studies that have recommended heating system improvement and insulation improvements in the form of window retrofits and insulation, roof insulation, wall insulation, floor insulation, insulated shutters, envelope insulation, and air sealing (Pombo, 2016).

Allegheny College is a liberal arts college in Meadville, Pennsylvania. The college has a dedication to being as sustainable as possible, which includes trying to conserve energy as much as possible. Because of this, identifying areas for potential energy conservation by using an energy audit in a building would help with working towards the college's goals. Energy efficiency on the campus has been improved by 22.5% over the past decade and a half. Improvements that have been made include adding insulation, retrofitting boilers, installing controls, and optimizing the density of use in buildings. New construction projects are LEED certified, and renovations have been made to existing buildings to make them certified. Sources of renewable energy including solar and geothermal heat pumps are used on campus, and energy is purchased from renewable sources like wind. Programs are in place to manage and maintain the efficiency of buildings on campus (Allegheny College, n.d.).

Quigley Hall is a two story academic building on campus. It is used mostly for teaching economics and political science. The building holds one auditorium, multiple classrooms, and multiple offices. It primarily uses LED and T5 lighting. The building is primarily made out of brick and is heated by a boiler in its basement. The building was built in 1953, and has not received any major renovations since, so it most likely is not optimally energy efficient.

This research project addresses the issue of inefficient energy use in buildings. The goal of this energy audit is to be able to recommend a number of specific improvements that can be made to the building, primarily to its envelope, to improve its energy efficiency in a cost effective manner. Through this energy audit, I hope to discover what areas have the most potential for improving energy efficiency and what measures could be taken to improve the energy efficiency in Quigley Hall of Allegheny College. I would like to recommend at least 3 specific improvements, including what can be done and the cost and energy savings of doing so. To do this, an ASHRAE level 1 and 2 energy audit was conducted in this building, which looked most closely at the envelope of the building. One way in which my research proposal is distinct from the past research examples provided is that the goal of this project is primarily focused on reducing energy consumption to reduce costs and improve the conditions for occupants inside the building by looking primarily at the envelope and other specific areas, and it does not include airflow tests or surveys.

Process/Approach

The data that was collected was mostly experimental data. The project includes a level 1 and a partial level 2 energy audit that will each produce deliverables. The level 1 audit was done primarily to uncover and identify major problems and potential improvements. The data that was collected for this project in order to find this is visually obvious areas for improvement, which will include things such as outdated heating systems or appliances, lighting, poorly insulated walls and structures, cracks under or around doors or windows, types of doors and windows, signs of moisture or damage, holes and ventilation losses, and other possible inefficiencies or problems. The level 2 audit will involve a more in depth analysis of the building, aspects of it, and appliances in it in order to find where energy conservation measures may be possible to implement and a detailed financial analysis of each. This will require finding major areas of energy loss and researching energy conservation measures. (Energy Advantage, 2017)

The process that the study will use in order to collect the data was primarily through an American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) level 1 and level 2 energy audits. A level 1 energy audit, also known as a screening audit or walk-through audit, involves a walk-through of the building in order to visually identify areas for possible improvement or future consideration. The main purpose of it is to assess the need for a future audit. The materials and tools required for this will only be access to the building's utility bills and information as well as access to the building itself. The work that was done included walking through the building, inspecting different parts of it, and filling out a checklist based on what is found. The checklist that was filled out is included below. This work was carried out by me, and this step does not need to be repeated.

Date:

OUTSIDE:

- ☐ Check number of exterior doors :
- ☐ Check number of exterior windows + Note approximate size :
- ☐ Check + Note number of south facing window panes :
- ☐ Outside temperature :

FIRST FLOOR:

- ☐ Check for cracks under exterior doors :
- ☐ Note types of exterior doors and anything noteworthy :
- ☐ Check for cracks under interior doors :
- ☐ Note types of interior doors and anything noteworthy :
- ☐ Feel for drafts that indicate openings/cracks around windows :

- ☐ Window frame material :
- ☐ Note approximate temperature :
- ☐ Do any rooms feel different temperature than rest of building :
- ☐ Check around vents for leaks or gaps :
- ☐ Check for outlets for leaks or gaps :
- ☐ Check other areas where leaks or gaps are likely :
- ☐ Heat distribution damage :
- ☐ Type of light fixtures :
- ☐ Check for stains or other evidence of moisture :
- ☐ Check for mold :
- ☐ Old or seemingly inefficient appliances :

SECOND FLOOR:

- ☐ Check for cracks under interior doors :
- ☐ Note types of interior doors and anything noteworthy :
- ☐ Feel for drafts that indicate openings/cracks around windows :
- ☐ Window frame material :
- ☐ Do any rooms feel different temperature than rest of building :
- ☐ Check around vents for leaks or gaps :
- ☐ Check for outlets for leaks or gaps :
- ☐ Check other areas where leaks or gaps are likely :
- ☐ Heat distribution damage :
- ☐ Type of light fixtures :
- ☐ Check for stains or other evidence of moisture :
- ☐ Check for mold :
- ☐ Old or seemingly inefficient appliances :

BASEMENT:

- ☐ Basement wall material :
- ☐ Check for cracks under doors :
- ☐ Check for mold :
- ☐ Old or seemingly inefficient appliances :
- ☐ Type of light fixtures :
- ☐ Check around vents for leaks or gaps :

- [] Check for outlets for leaks or gaps :
- [] Check other areas where leaks or gaps are likely :
- [] Note approximate temperature :

The second stage of the project that will follow this is a level 2 energy audit. This was done similar to an audit by Alajmi (2012). Due to the limited time frame, large size of the building, and impracticality of taking many types of measurements by means such as blower door tests, this level of the audit is limited in scope compared to most past energy audits. This step involved first collecting information on the building including information on the heating system. Before beginning measurements, strategic measuring points must be identified. This was done by examining the results of the level 1 audit to see what in the building appears to be worth examining closer. This includes doors, windows, cracks, and other areas of importance or likely potential problems. Measurement taking includes examining the temperature of objects which requires an IR camera. To do this, the building was examined with an IR camera making sure to examine important spots such as doors and windows, and pictures were taken of important areas or potential places for improvement. While using the IR camera, areas inside along the outer walls of the building, including doors and windows, were examined looking for colder temperatures that could indicate leaks. The outside of the building was examined similarly, looking for warm areas that could indicate heat escaping from the building. Pictures were taken of the most important areas, primarily doors, and anything that stood out while investigating the building with the IR camera. The other important part of this was examining the natural gas use of the building. This involved using records of the gas use of the building for each month in 2017 and 2018. These years were chosen because they were before the covid 19 pandemic that could have altered the building's energy use. This step of data collection was done by me. (Energy Advantage, 2017)

The data analysis in this project follows a similar method as Alajmi (2012). In order to analyze the data that is collected in this project through the level 1 energy audit, the walk-through analysis will be analyzed to identify possible visually identifiable areas for improvement, which will also help determine the exact method of the level 2 energy audit that will follow. The results of the level 2 energy audit will need to be extensively analyzed and will involve using past research projects and other literature review in order to be able to make recommendations for improvements to energy efficiency. The results of this energy audit will be compared to the other projects in order to identify which areas are most in need for improvement and how to improve them. Each specific potential energy saving area will be examined using information from past studies to find out which ones are in need of improvement. Next, possible measures that can be taken to improve energy efficiency will be found by looking at the past studies. The

costs and savings of each of these was calculated using data from past research. The only materials and tools needed for this analysis were access to a computer and other research. (Alajmi, 2012)

Results

The data that was gathered has identified a number of aspects of the building that have the potential to be improved in order to improve the building's energy efficiency. The most important possible renovation that was identified was the doors in the building. There are a total of five exterior doors in the building, four of which are pictured below. Two of these doors are glass with metal frames, two are thin metal, and one is metal boarded up with wood and leads to the basement.

The checklist below shows the results of the level 1 energy audit and what was looked for during it.

Date: 10/17/2022

OUTSIDE:

- [✓] Check number of exterior doors : 4
- [✓] Check number of exterior windows + Note approximate size : 33 mid sized, 6 large
- [✓] Check + Note number of south facing window panes : 5 normal sized, 6 large
- [✓] Outside temperature : 42 degrees F

FIRST FLOOR:

- [✓] Check for cracks under exterior doors : Auditorium metal door has cracks under and between doors
- [✓] Note types of exterior doors and anything noteworthy : 2 glass with metal frame, 2 metal
- [✓] Check for cracks under interior doors : not sealed
- [✓] Note types of interior doors and anything noteworthy : wood
- [✓] Feel for drafts that indicate openings/cracks around windows : n/a
- [✓] Window frame material : metal
- [✓] Note approximate temperature : normal room temperature (about 70 degrees F)
- [✓] Do any rooms feel different temperature than rest of building : n/a
- [✓] Check around vents for leaks or gaps : n/a
- [✓] Check for outlets for leaks or gaps : n/a
- [✓] Check other areas where leaks or gaps are likely : n/a
- [✓] Heat distribution damage : n/a
- [✓] Type of light fixtures : T5 and LED
- [✓] Check for stains or other evidence of moisture : Small spot on edge of auditorium

- [✓] Check for mold : n/a
- [✓] Old or seemingly inefficient appliances : old electronics

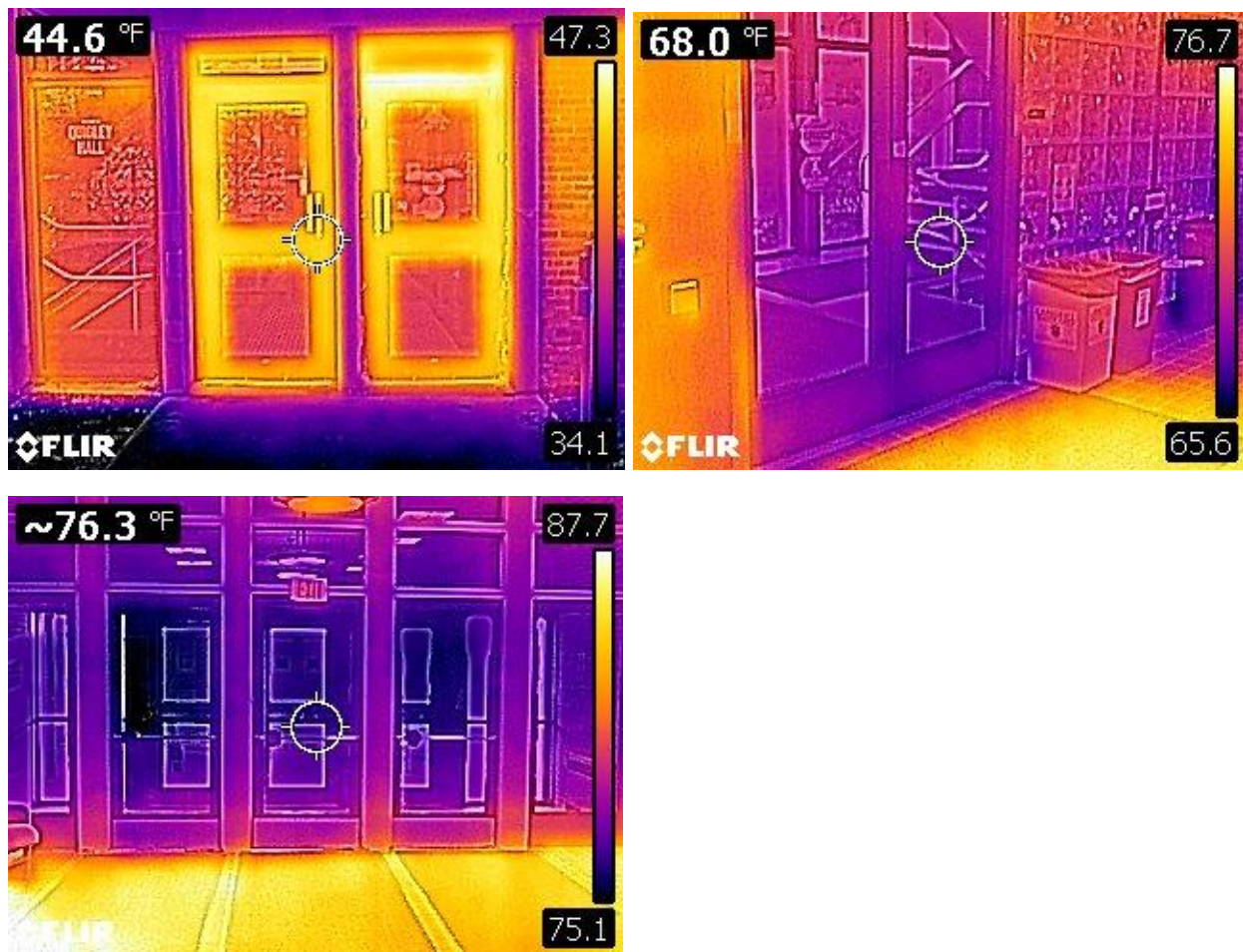
SECOND FLOOR:

- [✓] Check for cracks under interior doors : not sealed
- [✓] Note types of interior doors and anything noteworthy : wood
- [✓] Feel for drafts that indicate openings/cracks around windows : n/a
- [✓] Window frame material : metal
- [✓] Do any rooms feel different temperature than rest of building : n/a
- [✓] Check around vents for leaks or gaps : n/a
- [✓] Check for outlets for leaks or gaps : n/a
- [✓] Check other areas where leaks or gaps are likely : n/a
- [✓] Heat distribution damage : n/a
- [✓] Type of light fixtures : T5 and LED
- [✓] Check for stains or other evidence of moisture : n/a
- [✓] Check for mold : n/a
- [✓] Old or seemingly inefficient appliances : old electronics

BASEMENT:

- [✓] Basement wall material : Concrete and Brick
- [✓] Check for cracks under doors : exterior door has large crack, board with holes drilled into it covering up most of area, water flowing in beneath it
- [✓] Check for mold : N/A but lots of moisture, water flowing in from pipes near door
- [✓] Old or seemingly inefficient appliances : N/A
- [✓] Type of light fixtures : LED
- [✓] Check around vents for leaks or gaps : Multiple gaps present between interior spaces but not directly to outside
- [✓] Check for outlets for leaks or gaps : N/A (some gaps but only on interior outlets)
- [✓] Check other areas where leaks or gaps are likely : Many gaps/holes between interior spaces mostly around pipes/wires, insulation foam around gaps that lead to exterior
- [✓] Note approximate temperature : same as outside or a bit warmer/ about room temperature

The two main entrances to the building are shown in the three pictures that were taken with an IR camera. These doors are made out of thick metal and glass. Both of the entrances also have a second set of doors behind the first doors, with only a small empty space between them in the front entrance and a staircase leading up to the second floor and down to the basement between the back doors. The first image shows the back entrance from the outside, the second image shows the back entrance inner door from the inside, and the third image shows the front entrance doors from the inside. These doors were not found to have any significant gaps around them, however the glass and metal are not the best for insulation. This is shown by the IR camera by the doors being much cooler than their surroundings on the inside and much warmer on the outside. This applies to both the inside and outside sets of doors in both entrances.



There is one door on the building that leads from the outside to the basement, which is pictured below. This door is very poorly insulated and the IR camera shows a large amount of heat escaping from it and heating the surrounding area. There are small holes in this door intentionally.



There are two other doors on the building's exterior on the east and west sides of it. These doors are both made out of metal and are poorly insulated. There are visible cracks both around and between the doors that are large enough to see through, and heat can be seen escaping from them in the picture below.



The interior doors in the building other than the inner entrances are all made out of wood and have visible cracks around them. These doors are not very well insulated.

The building has many windows on all sides of it that make up a large amount of the building's surface area. These windows are single pane and have metal around them. The IR picture below shows a classroom window, which is colder than the rest of the classroom and indicates that it does not have great insulation.



Another possible improvement that could be made to the building is replacing some of the lights and electronics. The lights are mostly LED, but there are still some T5 lights that could be changed to LED to reduce their energy consumption. Some electronics and devices such as computers are older and could potentially be replaced. The image below shows a large amount of heat around a projector, which indicates that it is using a large amount of energy.



Tables and Figures

Table 1 : Quigley Hall Natural Gas Use in CCF During 2017-2018

Year	2018	2017
Jan	2362	2101
Feb	1621	1610
Mar	1819	1728
Apr	1281	605
May	72	410
Jun	5	5
Jul	4	5
Aug	26	19
Sep	53	52
Oct	765	350
Nov	1849	1443
Dec	1599	2153
total	11456	10481

This table shows natural gas meter readings for Quigley Hall each month in 2017 and 2018 in CCF.

Quigley Hall Natural Gas Use in CCF During 2017-2018

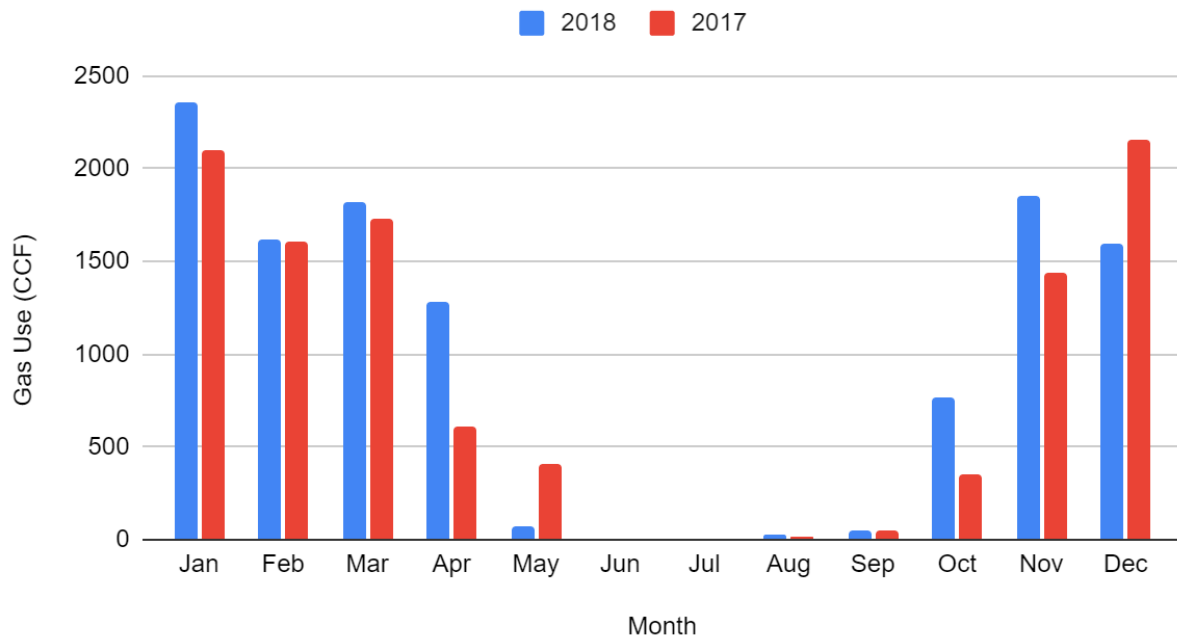


Figure 1 : Quigley Hall Natural Gas Use in CCF During 2017-2018

Table 2 : Quigley Hall Natural Gas Cost in Dollars feet During 2017-2018

Year	2018	2017
Jan	1582.54	1407.67
Feb	1086.07	1078.7
Mar	1218.73	1157.76
Apr	858.27	405.35
May	48.24	274.7
Jun	3.35	3.35
Jul	2.68	3.35
Aug	17.42	12.73
Sep	35.51	34.84
Oct	512.55	234.5
Nov	1238.83	966.81

Dec	1071.33	1442.51
total	7675.52	7022.27

This table shows natural gas costs for Quigley Hall each month in 2017 and 2018 in U.S. dollars. This was calculated using a price of \$0.67 per CCF of natural gas (AFDC, 2022).



The total floor area of Quigley is approximately 20,600 ft². The average amount of annual natural gas use for US higher education buildings is about 17 to 50 cubic feet of natural gas per square foot of floor space (BEA, 2020). Based on this, the building would be expected to use between 350,200 and 1,030,000 cubic feet of natural gas, or about 3,502 to 10,300 CCF, per year. The building used an average of about 10,968.5 CCF in 2017 and 2018. This means that Quigley Hall uses more natural gas than what would be expected for a building of its size.

Based on the results of this research, it is recommended to replace the 2 external metal double doors on the first floor, since these doors are not sealed and allow heat and air to escape and lead to interior areas that need to have their temperature maintained. The price of a new metal double door would range from \$707.00 to \$1,274.20 from CDF Distributors, and the cost of installation ranges from \$478.00 to \$1,798.00 (CDF, n.d.). This means that the total cost of replacing both doors would be between \$2,370.00 and \$6,144.40.

Discussion

Making a few upgrades to Quigley Hall could be beneficial for Allegheny college and for students because it could help to reduce the costs of running the building and improve the comfort of people who use it and spend time inside of it. The main improvements that can be made are things that reduce the loss of heat from the building, which improves the building's envelope and can help to reduce the amount of energy that is needed to produce the heat to maintain its temperature. Upgrading the doors and windows on the building would help to do this. Based on what was found by this research, it would be most recommended to replace the 2 external metal double doors on the first floor. These doors are not sealed or insulated, and allow a large amount of heat to escape through the gaps in them. Unlike the external door that leads down to the basement, these doors lead to interior areas that need to have their temperature maintained at a level that is comfortable for occupants. While the exact amount of energy that would be saved cannot be calculated based on what is known, replacing these doors with doors that do not have gaps and are more insulated would help to reduce the loss of heat and would save on energy costs for the building, especially in colder temperatures in the winter when heat loss would matter the most. The replacement doors could be purchased and installed through a large number of contractors or distributors, such as CDF Distributors. Installing new doors would have to occur either when the building is not in use or when outdoor temperatures are higher, or both optimally. The doors would be unusable while being replaced, however these are not the main doors to access the building through so this would not be too large of a concern. The building would be temporarily opened up where the doors were and snow could make the installation of new doors somewhat more difficult, so doing the installation would be best during less cold temperatures. Installing the new doors would produce noise, so it would be best to do when classes are not in session. For these reasons the summer months when there are no classes would be the best time to do replacements. Upgrading some or all of the windows on the building could potentially be worth doing, but doing this would be relatively very expensive and the windows currently do not release an abnormally high amount of heat from the building for windows. Installing these would have the same concerns and factors as with doors, but would be far more disruptive to classes since classrooms would not be usable during the process. It also would most likely take more time. This would

also be best to do during the summer when there are no classes that would need to be taught in this building. It also could be worth considering making lighting schedule or improving the heating schedule for the building to have these turned off when not in use, however the lights are usually turned off already in classrooms when not in use and the building sees frequent enough use during most of the year that it may not make too much of a difference if a heating schedule were implemented.

There are a number of problems that exist with the current building that can cause energy inefficiency and lack of comfort for occupants. The building was built in 1953 and has not received any significant renovations since that time, and it is now getting to be very old for a large educational building. The building does not have air conditioning, does not have very good air circulation, and varies in temperature. These problems can make it less than ideal for people who use it. The building is made of multiple different materials that vary in the amount of insulation they provide. While most of the building uses ok materials, the metal and single pane glass found on the windows and some doors could potentially be improved to reduce the building's loss of heat. Some of the building's problems most likely are caused as a result of the building being built a long time ago when air conditioning was less common and less consideration was given to circulation and energy use.

This study has a number of similarities and differences compared to past studies that have been conducted. Many past energy audit projects have examined far more aspects of the buildings that are looked at and in more detail. These studies had teams that consisted of multiple people, more funding, and more time to conduct the energy audit than this study. Unlike this study, one study included measuring the air exchange efficiency with different forms of ventilation and had questionnaires for building occupants about comfort in the building (Allab, 2017). Another study focused on indoor air quality and also included questionnaires for building occupants about thermal comfort in the building (Merabtine, 2018). These studies sometimes were conducted with the intention of finding improvements that can be made to buildings, similar to this one, or sometimes for other reasons such as finding out more about the building's energy use without intention for immediate renovation or to seek certifications (Allab, 2017). This study had a more limited focus on the envelope and some aspects of the heating of the building.

Many other studies have made similar changes to the ones that were recommended or noted as worth considering here. One study found that a building's annual energy consumption could be reduced 6.5% by non-retrofitting changes including lighting schedules, equipment schedules, and keeping doors closed, and that the building's energy consumption could be reduced by 49.3% by retrofitting measures with HVAC, lighting, and insulation (Alajmi, 2012). That study shows the amount of impact that different measures, especially retrofits, can have on reducing a building's energy use.

This study had a number of limitations and weaknesses. This project was conducted within a very limited time frame, which limited the amount of work that could be completed in order to gather relevant

information. Information gathering was also limited by building access and access to some information that would be helpful to the study. The observation parts of the study were conducted by only a single person, which limited the amount of observation that could be completed and may have resulted in some notable features being missed in the building. Some parts of the building such as classrooms were not open or available for use for this study at times, which made it difficult to examine every room in the building and prevented this from happening. Access to rooms like the basement was only available at limited and certain times, which led to problems such as not being able to use the IR camera to examine the basement from inside. This study also only examined a limited number of aspects of the buildings, with a focus primarily on the building's envelope. Many other features of the building and its efficiency were not included, some of which could have included significant areas for possible improvement of energy use.

There are many different ways that further research could be conducted in order to gather more information related to this topic. Some further testing that could be done on Quigley hall would be to examine aspects of the building other than envelope and heating in more detail. This could include testing the electricity use of individual electronics and devices in the building or finding the electricity use of the lighting in the building specifically. The envelope of the building could also be tested at different times throughout the year to see if there is change in different temperatures. A blower door test could potentially be used to better test the building's envelope, although this would be difficult to do especially since the building sees frequent use throughout most of the year. More research could be done on how lighting or heating schedules could impact energy use in the building. Interviews or surveys of occupants and frequent users of the building could potentially be conducted in order to better understand how the performance of the current building affects them and what they think of it. It may also be worthwhile to research if it would be worth replacing this building, or any other buildings on the campus.

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