The Relationship Between the Inside and Outside Environments of the Shippensburg University Rife Alumni House: A Comprehensive Energy Analysis

Image By Michael D. Griesemer (2013)

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ABSTRACT

Ensuring a tight building envelope is necessary towards improving comfort while decreasing energy costs. When initial insulation and air sealing measures fail to mitigate the stack effect, it is beneficial to understand and analyze where the most cost-effective remediation can occur. The objective of this research was to determine where the most detrimental air sealing and insulation flaws were located within the Shippensburg University Richard D. Rife Alumni House. The results of a comprehensive energy analysis indicated significant deficiencies within the building envelope caused by major air sealing and insulation flaws. With an air infiltration rate of 8210 cfm @ 50 *pa*, a high rate of air reduction (~45%) can be achieved related to the area of conditioned space. The following report points to problem areas of the Rife Alumni House that should be addressed, and offers possible retrofit strategies to mitigate such issues. There are several cost-effective and practical remediation strategies that can be performed to significantly reduce energy usage, and in turn, increase building comfort. These include 1) Insulating and air sealing the third floor attic space, 2) Air sealing the basement rim and band in order to isolate air infiltration, 3) Insulating and air sealing accessible basement rim and band, 4) Fixing or replacing window and door seals and/or sills, 5) Replacing single pane wooden frame windows if it is found to be cost-effective. These alterations could potentially reduce air infiltration and decrease annual energy costs.

INTRODUCTION

Reducing energy consumption has become a main focus for those who worry about the health of our environment, as well as those who would like to see their utility bills decrease. One small scale approach towards mitigating these issues is to analyze the amount of energy being lost due to infrastructure flaws by performing a comprehensive energy audit. The primary objective of an energy audit is to examine particular features of a building, as well as its flaws, in order to establish an effective plan of remediation. There are a number of goals that must be accomplished in order to complete a successful energy audit. For instance, energy efficiency must be sustained or increased post remediation efforts. This, in turn, has the potential to lower utility costs while increasing comfort. It is interesting to note that, more often than not, the majority of building occupants desire to increase their comfort as opposed to saving money on heating and cooling costs.

Additionally, energy audits are performed to improve the safety, health, and well-being of residents by recording potential hazards and proposing possible solutions towards mitigating such problems. It is pertinent that problem areas be identified within a structure so that remediation strategies and possible energy-saving retrofits can be suggested. In addition, certain methods should be taken into account in order to prevent further pollution, decreasing harmful energy waste byproducts. Finally, it is important that each audit is performed in a meticulous manner while recording copious notes during examination to ensure accurate and useful data (Lstiburek 2011).

It is important to keep in mind that each building is a unique, and rather complex, system. There are a number of factors that need to be taken into account during an energy analysis. These include, but are not limited to: lighting and appliances, HVAC, the entire building envelope, climate and weather, and the lifestyle of occupants within. This research focuses on the building envelope integrity of the Richard D. Rife Alumni House with emphasis on specific areas that may possess air sealing and insulation deficiencies, causing a decrease in overall energy efficiency and personal comfort. This will be accomplished by performing a building walkthrough, an energy analysis utilizing a blower door test and thermal imagery, as well as a final energy audit review.

COMPREHENSIVE ENERGY ANALYSIS: A LITERATURE REVIEW

The Building Envelope

Buildings come in all shapes and forms. The construction of a building directly reflects its age. For example, the majority of residential structures built before 1940 have a balloon-type construction. This type of construction consists of supporting wall studs that reach two stories in height with no present top or bottom plates. This lack of sealing creates the presence of numerous open wall cavities. These cavities allow for increased unwanted air infiltration and exfiltration. Most of the surviving older structures are built from brick and mortar. These building materials possess a minimal to a non-significant resistance to heat value (R-value). The following section will touch on the importance of unwanted air movement, insulation issues, and a phenomenon known as the stack effect.

The most dramatic temperature differences between two areas within a building are typically located at the points where conditioned meets unconditioned space. For example, excessive and uncontrolled air movement has the potential to create undesirable living conditions. The larger the temperature differences between these two environments, the greater potential there is for heat to be transferred to the cooler side of a wall. By preventing air transfer at its source, it is possible to maintain warmth during the winter months while sustaining cooler conditions during the summer months. This modification may provide for less use of heating fuel, maintained comfort levels, and reduced utility bills. Fortunately, air infiltration is one of the easiest forms of energy loss to correct. Inadequate insulation must be addressed to keep heat in and cold air out. Similarly, proper insulation aids in keeping heat out during the warmer months, keeping the interior cool air at a satisfactory level.

Air Infiltration, Insulation, and the Stack Effect

While it may be the most challenging aspect of building improvement, preventing unwanted air infiltration and exfiltration is an extremely important factor. In fact, nearly 40% of heating and cooling costs can be attributed to improper weatherization resulting from excessive air movement. The benefits of mitigating air leakage, as well as improving insulation, include saving energy, preventing excessive moisture issues, and improving overall comfort (Wilson and Morrill 2003). Not only do these improvements increase comfort and reduce costs, they also have the potential to maintain health, safety, and welfare of the people within.

In order for air movement to occur, there must be two points present that have a difference in pressure, as well as a continuous open cavity. There are numerous locations within a residence that may feel a bit “drafty.” It is commonplace to assume that fenestrations (windows and doors) are to blame. In older residences, this may be the case. However, there is a more pressing phenomenon to take into account. When the “hat and socks” (attic and basement) of a building allow air exfiltration and infiltration uncontrollably, one may experience undesirable air movement known as the stack effect (Figure 1).

According to the Environmental Protection Agency, the stack effect is defined as "the overall upward movement of air inside a building that results from heated air rising and escaping through openings in the building super structure, thus causing an indoor pressure level lower than that in the soil gas beneath or surrounding the building foundation" (EPA 2013). The movement of air within a building envelope is created by differences in pressure and the quality of mechanical equipment, such as exhaust fans and furnace-like heating sources (Building Science 2008). In order to determine which building features contribute to the stack effect, it is important to take a whole house approach (Kautz 2013). A few areas of interest include the following: crawlspaces, basement rim and band, attic space, fenestrations (windows and doors), and mechanical equipment.

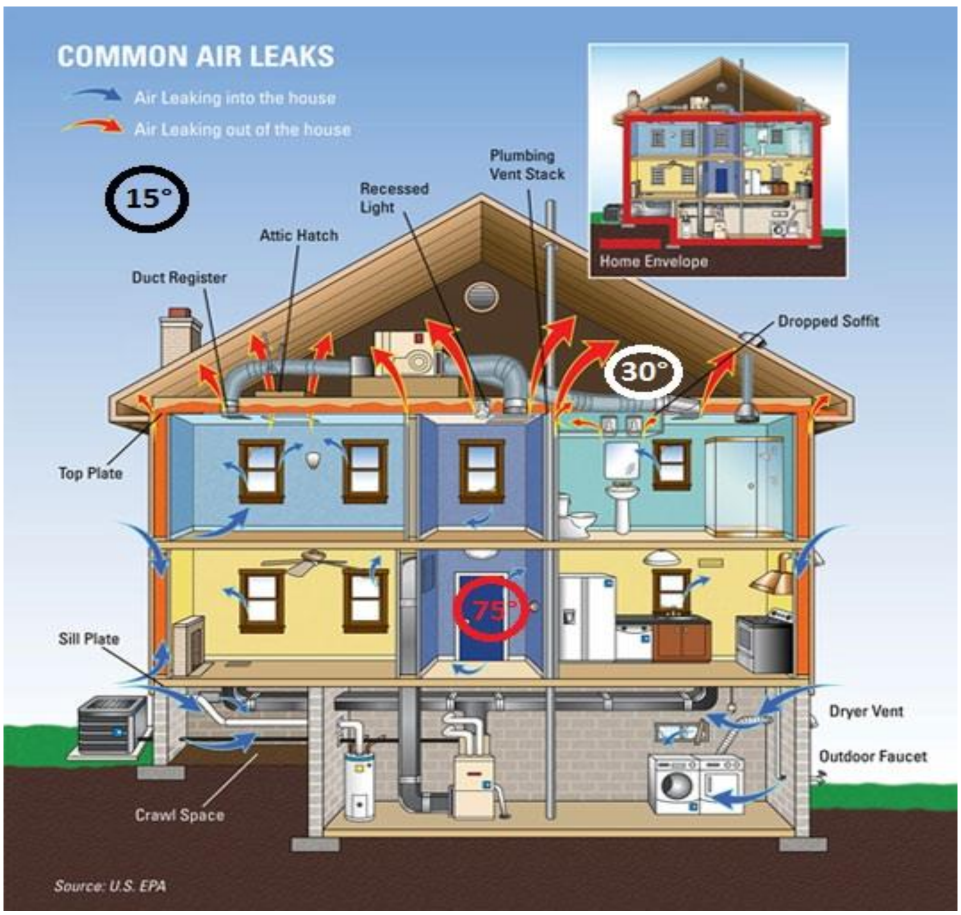

Figure 1: The Stack Effect (U.S. EPA 2013).

Crawlspaces and Basements

One of the main areas of a building where air can easily infiltrate is through improperly sealed and insulated crawlspaces and basements. An improperly sealed rim and band of a basement or crawlspace has the potential to cause gross amounts of top plate air movement (Figure 2). This movement of air has the potential to increase the presence of the stack effect (Kautz 2013).

Figure 2: Basement Rim and Band

Attics

Acting as the "hat" of a building, the attic is responsible for keeping warm air from escaping during cold exterior conditions during winter months. However, when air is excessively permitted to enter, due to construction flaws, at the lower foundation of a building (such as basements and crawlspaces), it has the potential to force warm air out through gaps in the upper foundation, or attic. There are a few features that should be taken into account when considering attic analysis and remediation. First, one should note the construction and shape of the space in question. However, it may be difficult and nearly impossible to access certain areas, such as knee walls (Figure 3), in order to determine the area's composite R-value.

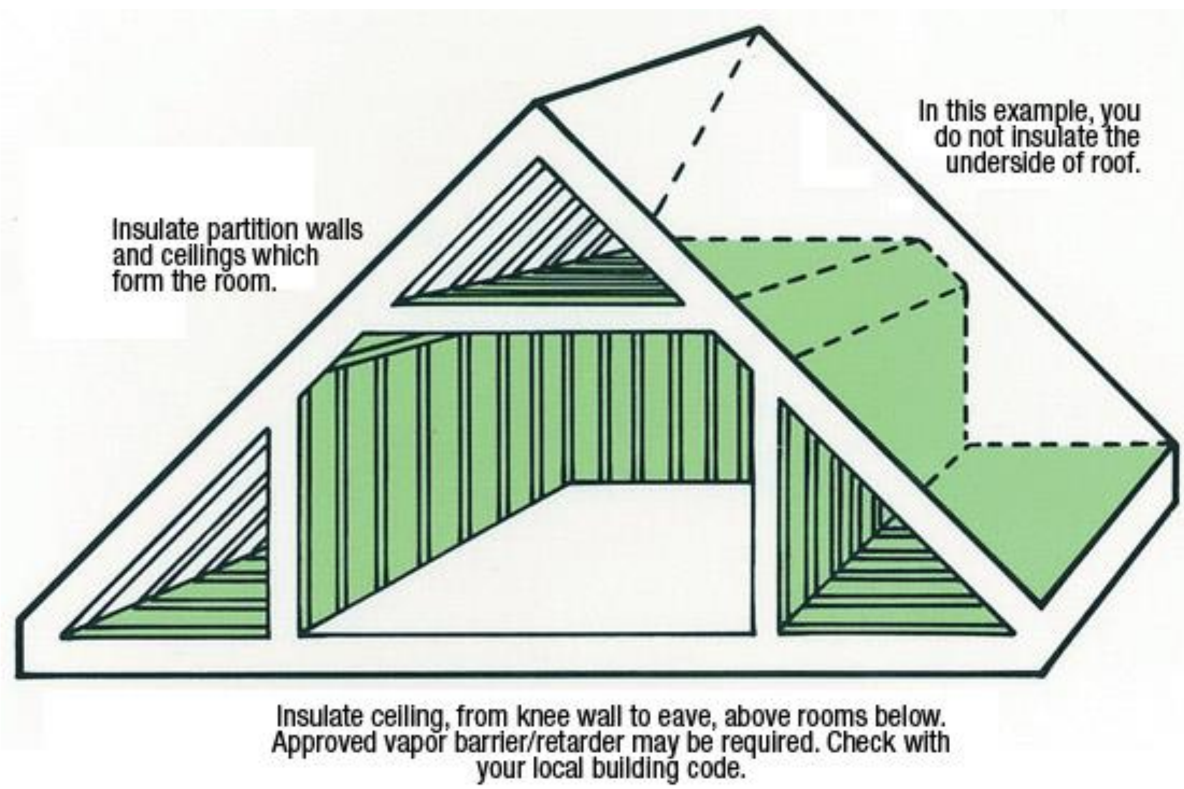

Figure 3: Knee wall diagram (www.Roxul.com).

In Figure 3 above, it is evident that only certain surfaces are required to be insulated and air sealed in order to maintain an effective building envelope. Knowing this important skill in building science will ultimately save on installation time and cost. When these areas are inaccessible, new access ways may be necessary. A second feature of the attic that allows gross amounts of air movement is an attic hatch or entryway. Figure 4 below depicts an acceptable attic hatch construction. More often than not, this feature is poorly insulated and inadequately air sealed (Dorsi and Krigger 2009).

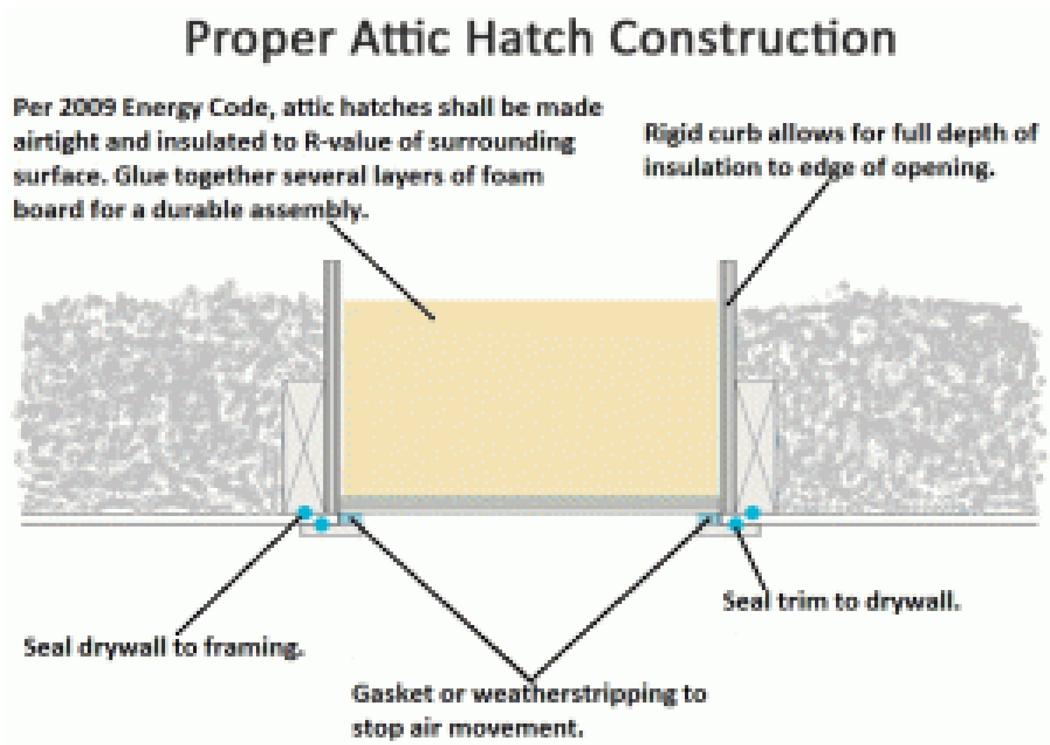

Figure 4: Proper attic hatch construction (commonwealthsustainability.com).

Windows

Windows typically possess the following characteristics: glass configuration, rough opening, fixed or movable sashes, and a frame. Table 1 describes the R-values of window types (Carmody, Selkowitz, and Heschong 1996). While it is beneficial to understand how R-values are contrived, insulating values (U-values) prove to be more beneficial when dealing with possible window retrofit strategies (Kautz 2013). While it may appear to a homeowner that the majority of their discomfort and energy costs can be attributed to improperly installed fenestrations, it is typically not cost-effective to address these issues.

Table 1: Window type with R-values.

Window Type	R-Value
Single Pane	**1**
Double Pane	**4**
Double Pane Low-e and Argon	**5**

However, the most common issues pertaining to window air infiltration is the failure of their sills, their construction, and their installation. Faulty seals can lead to unwanted drafty conditions. When this barrier is breached, air can easily transfer between the interior and exterior environments (Window and Door Efficiency 1986).

Doors

There are a number of door types available at the consumer level. Table 2, below, provides a number of these along with their R- and U-values (Brennan et al. 2007). Insulated doors are becoming increasingly useful due to their high resistance to heat.

Table 2: Door Types with R & U-values.

Door Type	R-Value	U-Value
Solid Wood	**2.5**	**0.40**
Wood Panel	**1.75**	**0.57**
Insulated Panel	**5 - 7**	**0.20 – 0.14**

Doors have similar components as windows. With that in mind, replacing exterior doors is not a cost-effective way to cut energy costs. Alternatively, there are a variety of weather stripping types available that can be used to prevent unwanted air movement (Figure 5).

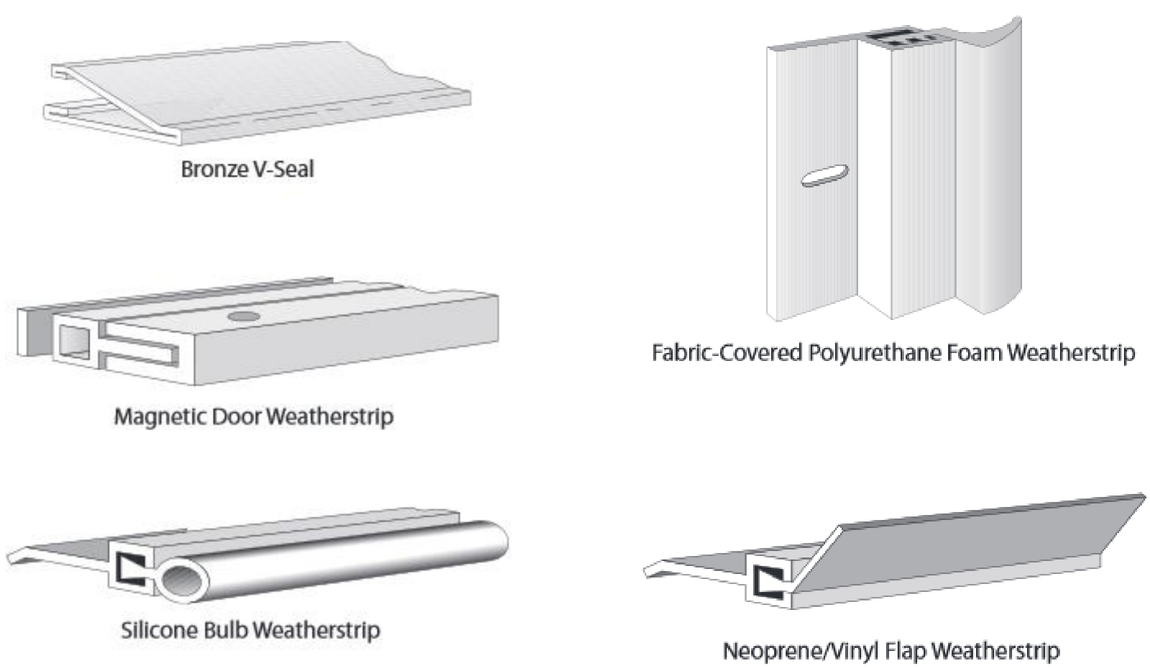

Figure 5: Examples of door weather stripping (Dorsi and Krigger 2009).

PURPOSE AND SCOPE

Maintaining a tight building envelope is essential towards increasing comfort and decreasing energy costs within a residence. The purpose of this study is to determine the current state of the Richard D. Rife Alumni House's weather resistance and building envelope, including the quality of air sealing and insulation, in order to improve and/or mitigate future issues. This data analysis will focus on the top and bottom floors, as well as a number of outstanding problem areas, to establish a possible building retrofit strategy. In doing so, proper data analysis will conclude if:

1) *…there is an excess of air infiltration and exfiltration through the Shippensburg University Richard D. Rife Alumni House.*

2) *…there are any possible retrofit strategies available that can be performed in order to increase personal comfort while decreasing energy costs in the Shippensburg University Richard D. Rife Alumni House.*

In order to answer these questions, a comprehensive energy audit will be performed to investigate problem areas within the Shippensburg University Richard D. Rife Alumni House. It is anticipated that, due to the building's construction and age, the main issues will be located in the attic and the basement areas. It is also proposed that the stack effect is likely present, causing cool air to easily enter through the lowest level, forcing warmer air out through the upper layers.

STUDY AREA

The area of interest for this study is located on the Shippensburg University Campus at 315 Prince Street, Shippensburg Pennsylvania 17257. The building audited was the Shippensburg University Richard D. Rife Alumni House (Figure 6). This structure has an area of approximately 6,821 square feet, divided between three stories, as well as a basement containing a number of crawlspaces. Originally, this building was used for residential occupation. Later, it was transformed into the Alumni House with rented living spaces located on the third floor. Currently it is solely used for alumni and communication purposes.

Figure 6: Study Site – Shippensburg University Richard D. Rife Alumni House. Image by Michael D. Griesemer.

Floor plans for the Rife Alumni House can be found below in Figures 7 through 10.

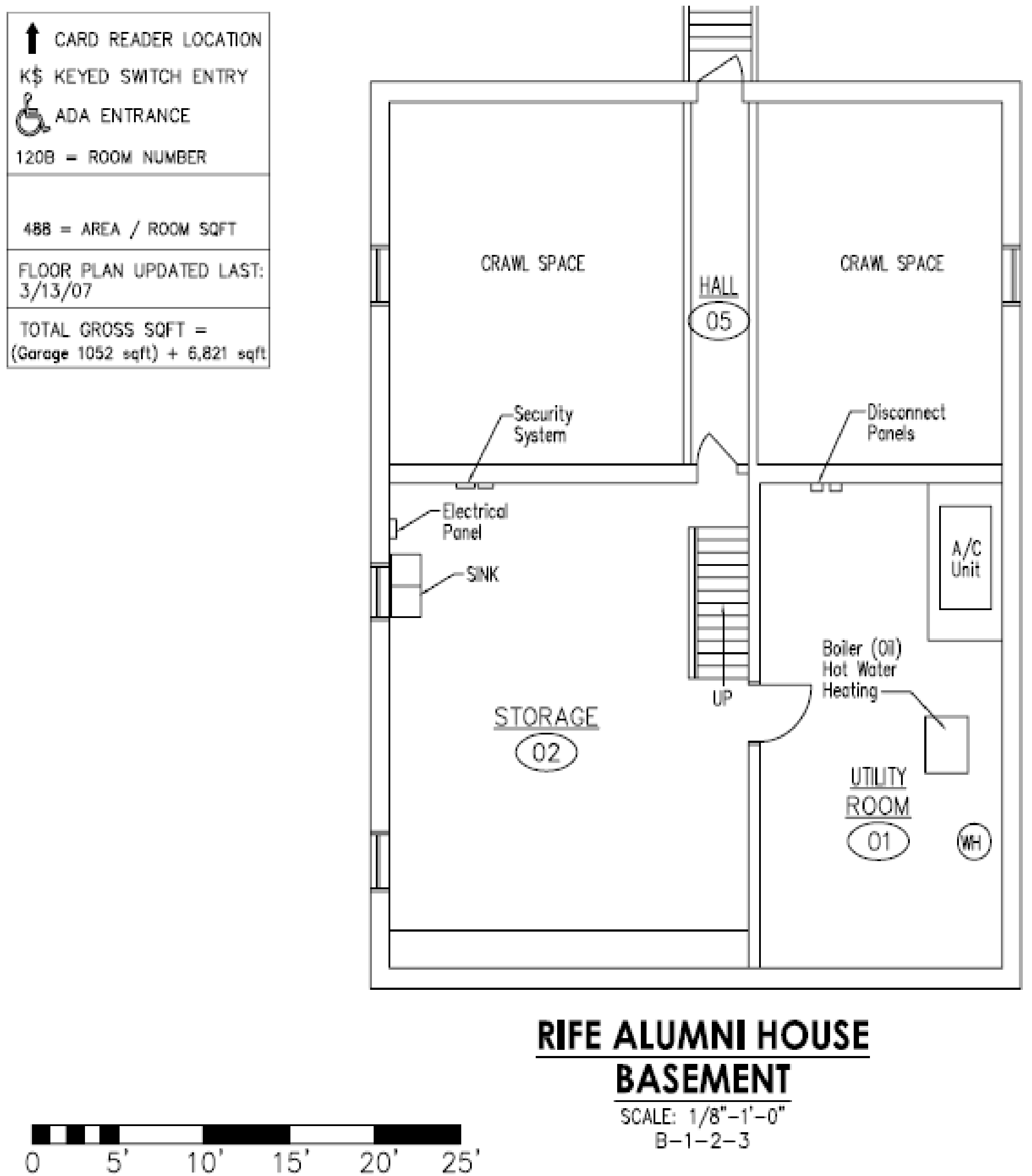

Figure 7: Study Site – Shippensburg University Richard D. Rife Alumni House basement floor plan.

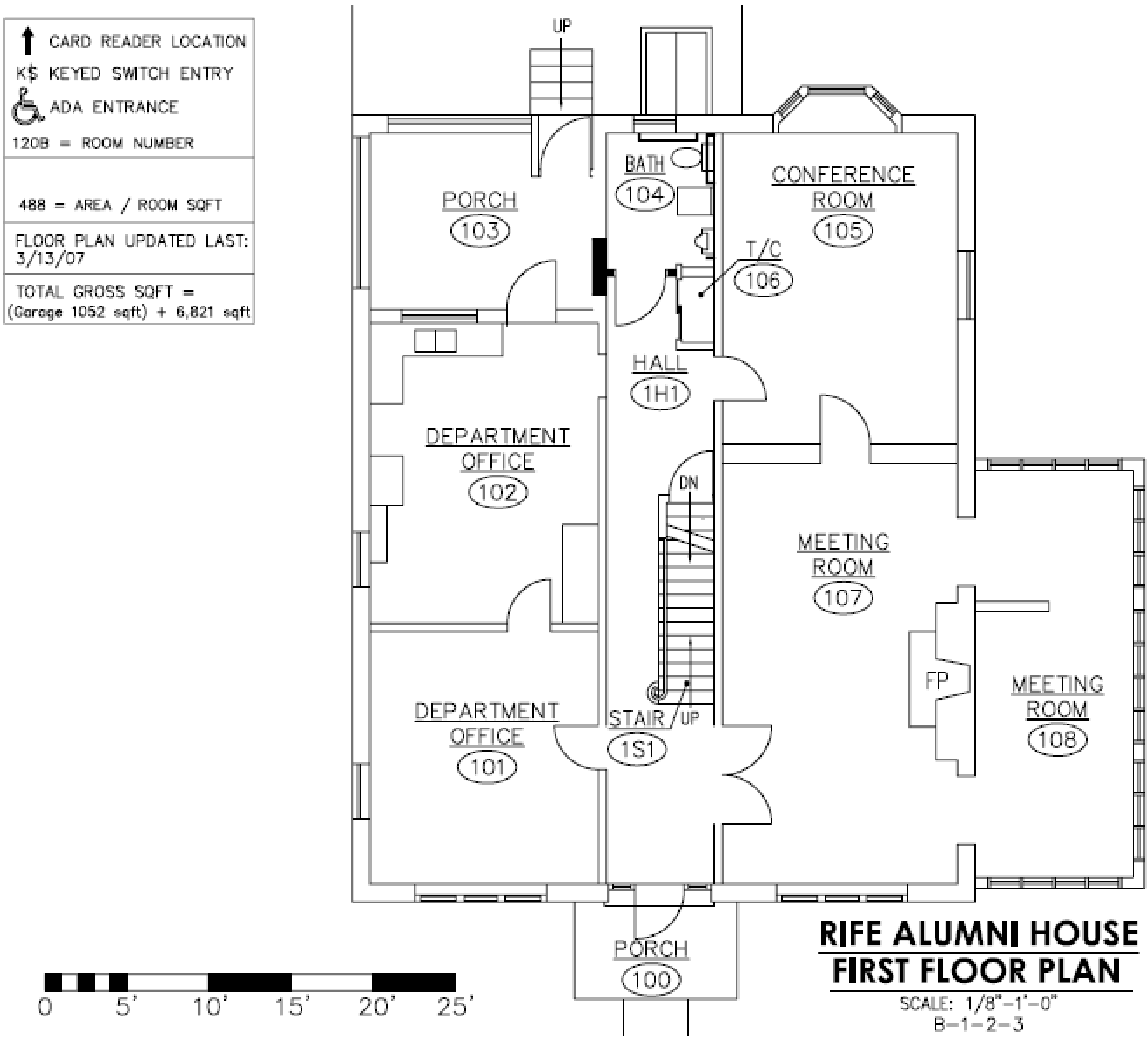

Figure 8: Study Site – Shippensburg University Richard D. Rife Alumni House first floor plan.

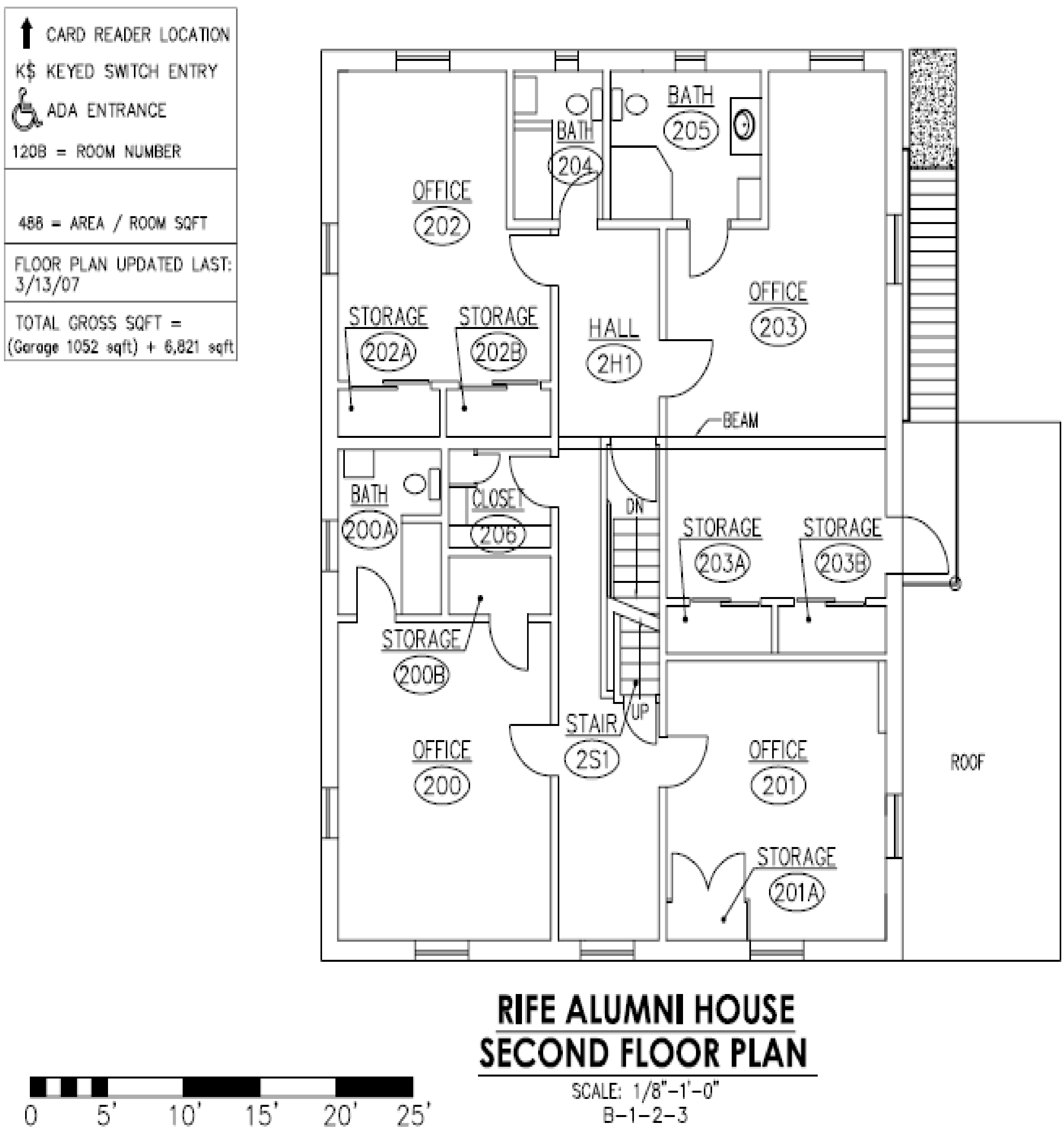

Figure 9: Study Site – Shippensburg University Richard D. Rife Alumni House second floor plan.

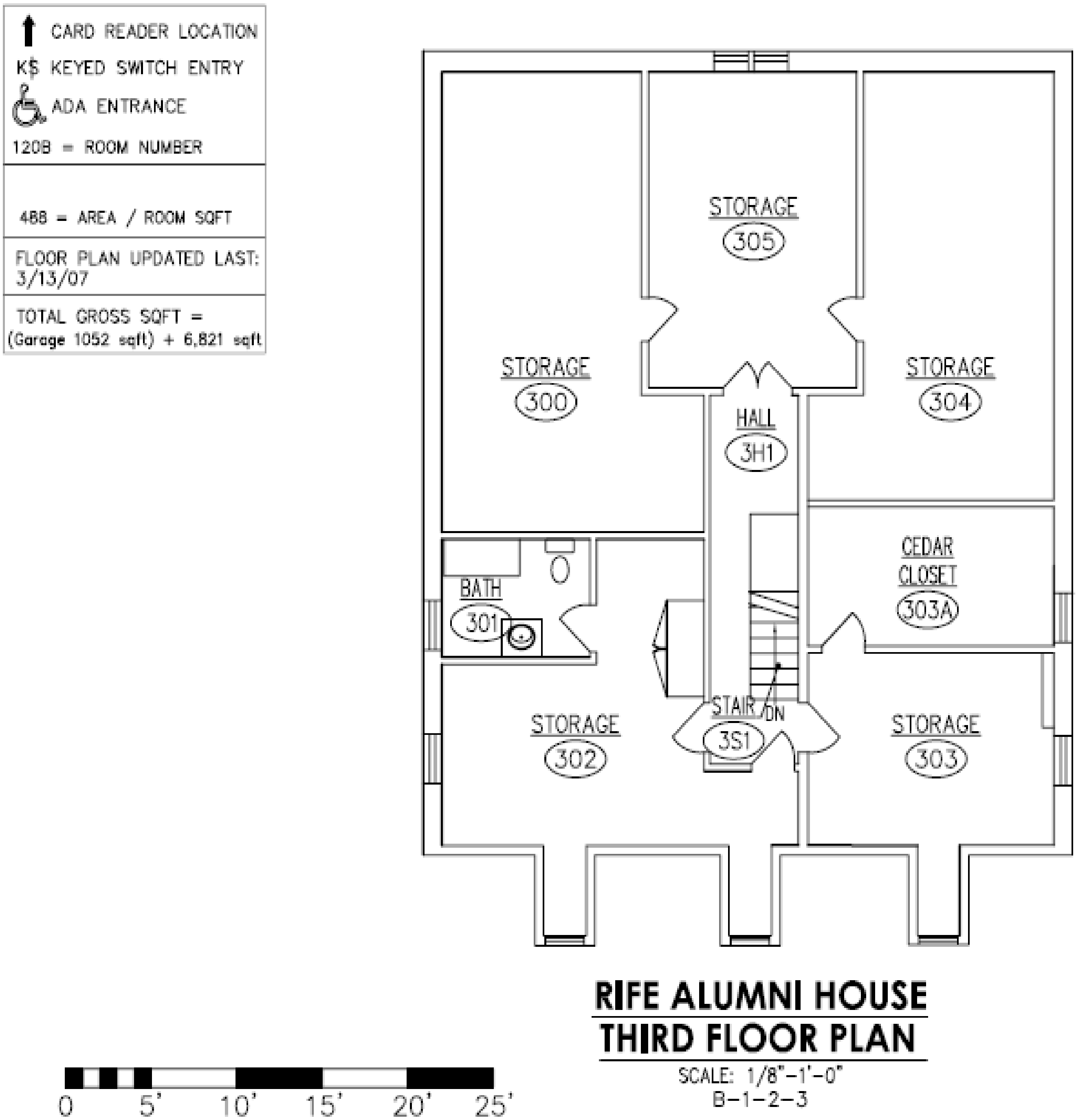

Figure 10: Study Site – Shippensburg University Richard D. Rife Alumni House third floor plan.

MATERIALS AND METHODS

A comprehensive energy audit is a challenging and rather variable analysis. A number of instruments and procedures are necessary to ensure accurate results. This research was completed in four primary stages in order to establish a viable analysis of the building to determine specific problem areas. These stages included a logistical preparation, an initial walkthrough of the building's exterior and interior, an energy audit (consisting of thermal imagery and a blower door test), and a final energy audit review (Guiterman and Krarti 2011).

Preparation

Before analysis could commence, it was necessary to acquire permission from the Shippensburg Universities Facility Management in order to perform an audit on university property. These parties included Mr. Don Blakelock and Mr. Lance Bryson, facilities manager. Once approved, a three stage approach was set into motion. The following sections describe the methodology performed during the investigation of the Rife Alumni House building envelope quality.

Residential Walkthrough: November 2013

When performing any stage of a residential energy analysis, it is important to be meticulous and redundant. This means that each step of every analysis should be performed in the same order every time to maintain accuracy. The first step of the walkthrough was to assess the overall design and characteristics of the exterior. Visible light images of the front elevation, right-front elevation, right elevation, right-rear elevation, rear elevation, left-rear elevation, left elevation, and left-front elevation (APPENDIX I) were taken with the use of a digital camera. These images were used to evaluate the buildings dimensions, areas of probable air exchange, and to determine areas of focus for subsequent analysis. In addition, a front-facing direction of northeast was recorded in order to assess the potential for future passive solar heating/cooling opportunities. These methods have been utilized for centuries by past cultures to avoid excessive costs and increase indoor comfort (Fairey 1981). Finally, while exploring the interior of the Rife Alumni House, the positions of windows and doors, building dimensions, and the location of mechanical equipment, including HVAC units, water heaters, and furnaces were recorded and compared to the blueprints previously obtained. These data were gathered during the month of November 2013.

Energy Audit- Infrared Imagery and Blower Door Test: December 9, 2013

In order to determine temperature reference points for comparison, specific areas of the Rife Alumni House were chosen, from the data obtained from the initial walkthrough, for thermal imagery under natural and depressurized conditions. The first step was to prepare the building by closing all exterior doors and windows, turning off all heating and cooling equipment, and shutting down all combustion appliances. This was done to ensure a safe study environment. The second step was to take thermal images of potential problem areas within the Rife Alumni House using a Fluke Ti125 thermal imaging camera (Figure 11) under natural conditions (APPENDIX II).

Figure 11: Fluke Ti125 Thermal Imaging Camera (Fluke.com).

These areas included windows, doors, basement, attic, crawlspaces, and other locations of interest that may possess infrastructure flaws (Balaras and Argiriou 2001). During this stage, readings were taken to detect and quantify the presence of excessive carbon monoxide and hazardous combustible gas. One of the most dangerous and deadly gases found in residential dwellings is carbon monoxide (CO). CO hinders the blood's ability to carry oxygen throughout the body. High-level exposure has the potential to cause severe brain damage and possible death (Dorsi and Krigger 2009). Exposure to CO is a serious problem in the United States, causing a mortality rate of approximately 400 people annually (McDonald et. al 2013). It is important that each home be tested for CO levels before beginning any stage of an energy audit. When levels of CO in a residence exceed 32ppm, the conditions of indoor air quality are no longer fit for safe human occupation (Stevens and Siegel 2012). If the quantities of these gases are above acceptable limits for human health and safety, the audit would end immediately. Since there was no presence of CO or combustible gases, the final stages of the audit were able to commence.

Each thermal image taken under natural conditions was paired with a visible light image in order to highlight the location more distinctly (Dall'O', Sarto, and Panza 2013). These images were used as an initial baseline to later be compared with thermal imagery under depressurized conditions. For these images to be viable for analysis, measuring of an overall temperature differential was necessary. To establish a temperature differential, interior and exterior temperatures were taken into account. An indoor temperature of 72ºF was recorded from the indoor first floor thermostat within the Rife Alumni House, while an outside temperature of 47ºF was recorded from the Shippensburg University Weather Page (webspace.ship.edu/weather). Having a temperature difference of at least 20°F between the interior and exterior of a building produces the most precise and accurate thermal images (Kautz 2013).

After taking thermal images of the structure under natural conditions, additional thermal images were needed for comparison. In order to do so, the Rife Alumni House needed to be placed under depressurization through the process of a blower door test. This test was set up according to the guidelines in the Retrotec blower door setup manual provided. Great care was needed in the initial setup to prevent false data. This test utilized the analytic capabilities of a Retrotec Series 1000 Blower Door (Figure 12) and a Retrotec M-32 Manometer (Figure 13).

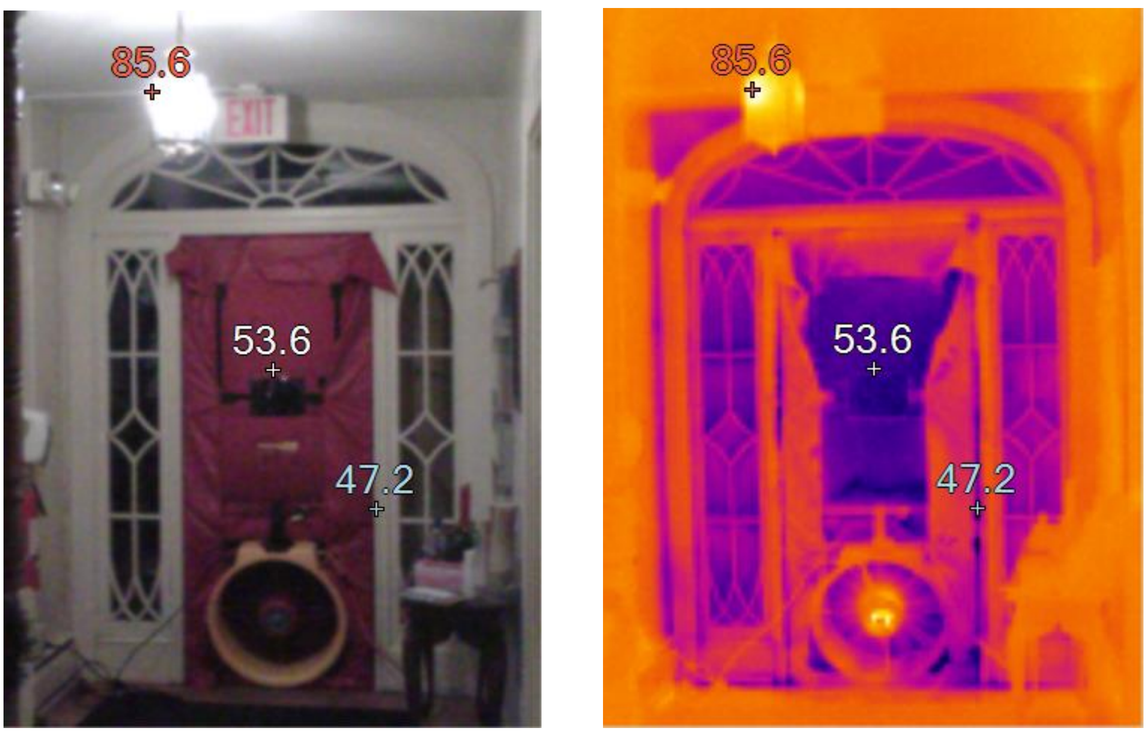

Figure 12: Visible and thermal imagery of a Retrotec Series 1000 Blower Door under natural conditions (Image by Michael D. Griesemer 2013).

Figure 13: Retrotec M-32 Manometer (www.aikencolon.com).

When conditions inside the Rife House were deemed safe and acceptable, the next stage of depressurization was initiated. During this test, air infiltration was recorded in cubic feet per minute (cfm) at natural and depressurized conditions. In addition, a minimum ventilation requirement (MVR) of 70% was used for both conditions based on the size of the building and updated building code standards (Kautz 2013). Careful steps were taken prior to initiating the blower door test. First, all outside doors and windows were left closed. Second, all interior doors leading to conditioned space were left ajar. These steps were extremely important for accurately testing the tightness of the building envelope by eliminating unwanted circulation hindrances. In addition, all fireplaces and stoves were turned off, with their doors shut to avoid any backdraft of particulate matter or ash. Lastly, it was important to turn off all mechanical equipment, including HVAC, exhaust fans, furnaces, air conditioners, and combustion appliances. While running mechanical equipment can lead to false surface and air temperature readings, shutting these appliances off will also prevent the backdraft of hazardous natural gas and carbon monoxide. Thermal images under depressurized conditions (APPENDIX III) were then taken for comparison.

Energy Audit Analysis Report

For this study, the energy audit analysis was comprised of a number of integral parts. First there is a summary of the initial observations recorded during the residential walkthrough. It is important to provide a summary of the target areas that will need to be addressed, as well as all possible cost-effective recommendations for potential retrofit strategies. The second part includes the initial inspection of mechanical equipment for safety and energy efficiency. Last, recommended improvements are suggested in order to establish a new and improved pressure boundary and building envelope of the Rife Alumni House.

RESULTS

The results of the blower door test indicated an air infiltration rate of 8210 cfm @ 50 pa. Taking into account the 6,281 sq. ft. of living space, four floors, and the amount of air infiltrating at the time of depressurization, a potential 45% reduction in air infiltration is possible with future remediation in upgrading insulation and additional air sealing. For instance, this could include sealing the attic and basement rim and bands, equaling an area of approximately 3140 sq. ft. Thermal images with commentary were recorded and can be found in APPENDIX I and APPENDIX II. Example thermal imagery of problem areas pertaining to the attic (Figures 14a-14c) and basement (Figures 15a-15c) infrastructure can be found below.

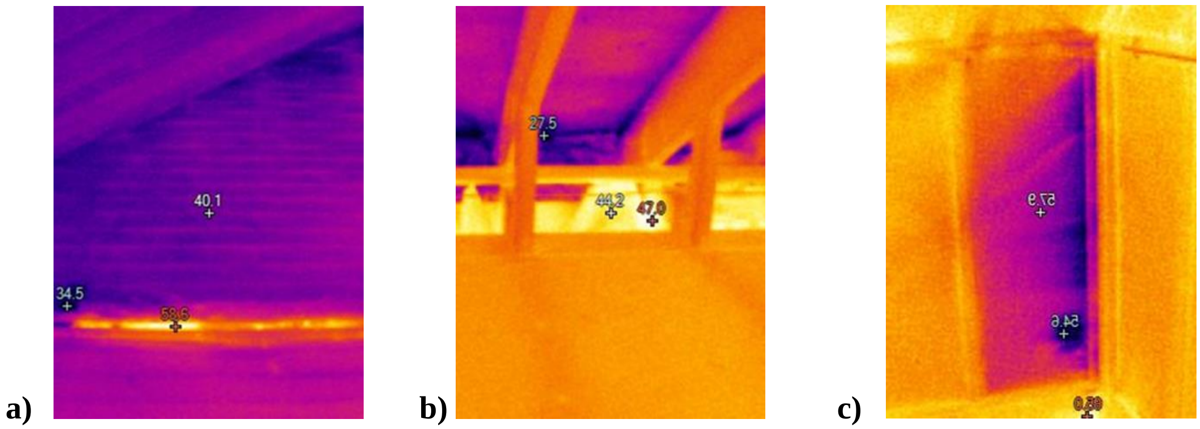

Figure 14: Examples of attic air sealing and insulation flaws (Michael D. Griesemer 2013).

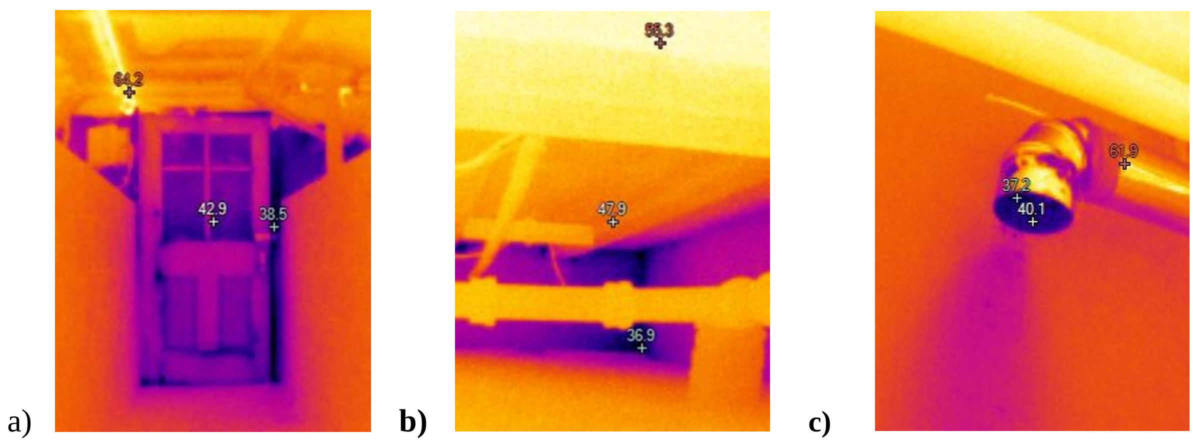

Figure 15: Examples of basement air sealing and insulation flaws (Michael D. Griesemer 2013).

The thermal images in Figure 14 provide a good indication of the present stack effect while displaying evidence of heat exfiltration through the buildings framework. Similarly, in Figure 15, it can be seen that cooler air is infiltrating at the lowest level of the building envelope, causing heat to escape through the upper levels.

ANALYSIS AND DISCUSSION OF RESULTS

Throughout the duration of this study, it was expected that a number of building flaws leading to unwanted air infiltration would be present. Following analysis of the data, it appears beneficial to improve the current insulation to a higher overall R-value while reducing the amount of air infiltration through the process of air sealing the building envelope, particularly the basement and attic areas. Upon completion of the initial walkthrough and subsequent energy audit, the data gathered provided valuable insight towards the current heating and cooling conditions of the Rife Alumni House. It is expected that the following problems will need to be addressed in the near future to reduce energy costs and increase building comfort performed through a variety of retrofit strategies. These include but are not limited to:

1) Insulating and air sealing the third floor attic space
2) Air sealing the basement rim and band in order to isolate air infiltration
3) Insulating and air sealing accessible basement rim and band
4) Fixing or replacing window and door seals and/or sills
5) Replacing single pane wooden frame windows if it is found to be cost-effective

In addition, this documentation provides useful information for study. The most current energy usage data collected (Table 3) may provide useful to determine potential return on investment if remediation were to occur in the near future. This can be done by determining the amount of heating and cooling days for the particular area of study in order to extrapolate future energy consumption in kilowatt hours, which is dependent on the overall reduction in air infiltration as well as the total increase in building R-value.

Table 3: Energy Usage Data as of October 16, 2013 (Penelec: A FirstEnergy Company 2013).

Date	Total Cost ($)	Energy Usage (KWH)
10/16/2013	NA	2114
9/17/2013	NA	2332
8/16/2013	NA	2186
7/17/2013	249.38	2683
6/17/2013	249.25	2470
5/16/2013	150.56	1342
4/16/2013	177.26	1578
3/18/2013	267.15	1520
2/14/2013	51.98	1331
1/16/2013	NA	1560
12/13/2012	130.19	1368
11/14/2012	NA	1414
10/15/2012	162.98	1547

The table above shows the energy usage trend of the Rife Alumni House between October 2012 and October 2013. Currently, it appears that consumption of energy increases by approximately 600 KWH between the early summer and late fall. These data indicate an increase in cooling and/or heating costs during that period. It would be beneficial to, in the near future, perform additional audits, remediation, and calculate the energy saved based on the previous energy usage data.

Do It Yourself (DIY) Remedies

There are a number of additional measures that can be performed in order to reduce building energy costs. For example, the price of heating water can be decreased by maintaining a constant temperature of 120°F and insulating all exposed copper pipes. This simple procedure has the ability to raise the overall water temperature a few degrees, ultimately increasing savings by reducing waste over time. An average reduction of 4% in energy costs can be saved by reducing water temperature 10°F (U.S. EPA 2013). In addition, a constant temperature of 120°F will ultimately slow the process of mineral accumulation and prevent corrosion of the system. Programmable thermostats allow homeowners to reduce heating and cooling processes by regulating temperatures and, in turn, reducing energy costs (Kautz 2013).

Being vigilant about regularly replacing filters in an HVAC system can reduce the accumulation of particulate matter in the inner environment. This accumulation of material in the filters can restrict airflow, consequently increasing energy costs. In addition, replacing existing light fixtures with compact fluorescent lighting (CFL) can also cut utility costs dramatically. According to EnergyStar, their products reduce energy consumption by 75% and last tenfold longer (EnergyStar 2013).

Last, but not least, a vast amount of energy waste leading to increased energy costs can be attributed to what is called the "phantom load." Phantom loads are defined as the wasted energy of electronic devices that are plugged in, yet not being used at the moment (U.S. EPA 2014). A swift visual inspection of electronics with standby lights illuminated can indicate the extent of the current phantom load. To test this quantitatively, a kilowatt meter can be utilized. This device gives exact measurements of wattage used for an appliance that is disengaged, yet still plugged in. Keeping high-energy consuming appliances unplugged could significantly reduce one's annual wattage consumption.

CONCLUSION

Ensuring a tight building envelope is necessary towards improving home comfort while decreasing energy costs. When initial insulation and air sealing measures fail to mitigate the stack effect, it is beneficial to analyze where the most cost-effective remediation can occur. During this study, it appeared that the initial insulation and air sealing failed to mitigate the stack effect. The objective of this research was to determine where the most detrimental air sealing and insulation flaws were located within the Shippensburg University Richard D. Rife Alumni House. The results of this comprehensive energy analysis indicated significant deficiencies within the building envelope caused by major air sealing and insulation flaws. With an air infiltration rate of 8210 cfm @ 50 *pa*, a decrease in air infiltration (45%) can be achieved related to the area of conditioned space. Several cost-effective and practical remediation strategies are able to be applied to significantly reduce energy usage and increase building comfort. These alterations include insulating and air sealing the third floor attic space, air sealing the basement rim and band in order to isolate air infiltration, insulating and air sealing accessible basement rim and band, fixing or replacing window and door seals and/or sills, and replacing single pane wooden frame windows. These alterations could potentially reduce air infiltration and decrease annual energy costs.

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APPENDIX I: Exterior Images of the Richard D. Rife Alumni House

Shippensburg University Rife Alumni House; front elevation. (Image by Michael D. Griesemer)

Shippensburg University Rife Alumni House; right-front elevation. (Image by Michael D. Griesemer)

Shippensburg University Rife Alumni House; right elevation. (Image by Michael D. Griesemer)

Shippensburg University Rife Alumni House; right-rear elevation. (Image by Michael D. Griesemer)

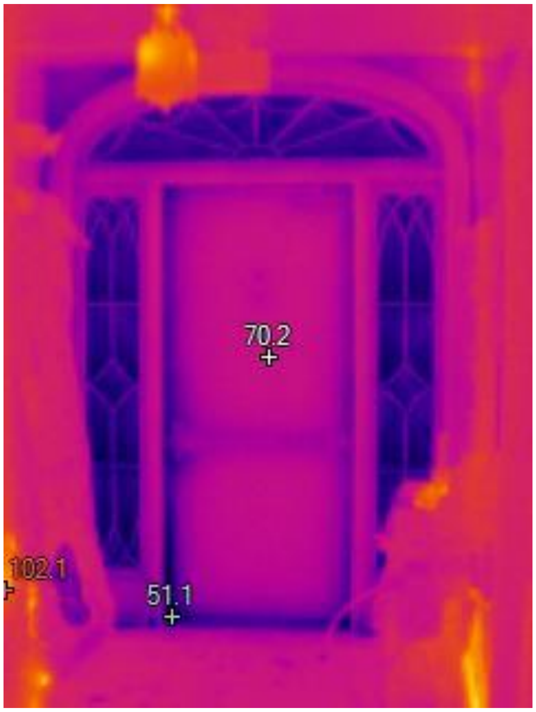
Shippensburg University Rife Alumni House; rear elevation. (Image by Michael D. Griesemer)

Shippensburg University Rife Alumni House; left-rear elevation. (Image by Michael D. Griesemer)

Shippensburg University Rife Alumni House; left elevation. (Image by Michael D. Griesemer)

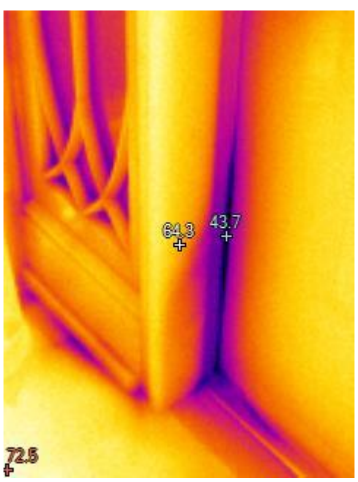
Shippensburg University Rife Alumni House; left-front elevation. (Image by Michael D. Griesemer).

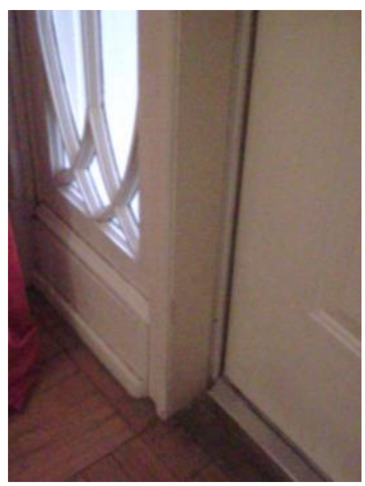
APPENDIX I: Thermal Imagery Natural Conditions



First Floor Front Door
12/9/2013 5:21:23 PM

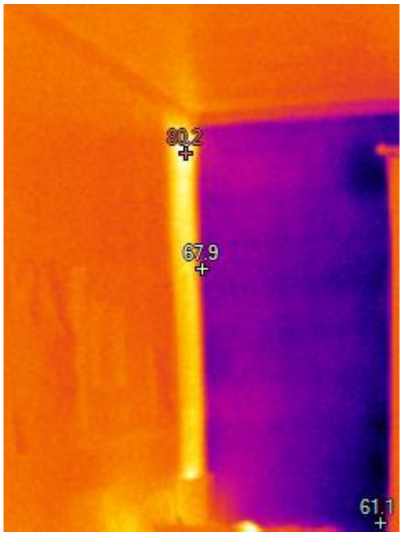
Single pane side/top lights. One inch insulated steel.

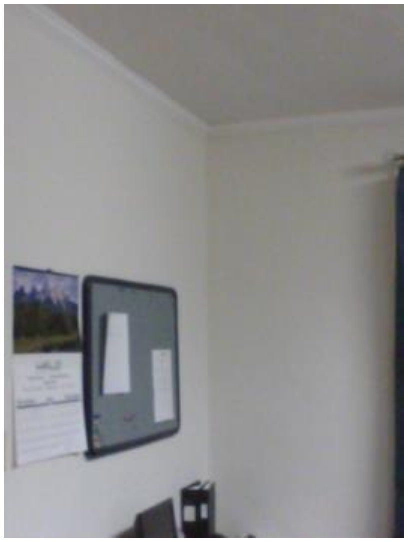




First Floor Front Door
12/9/2013 5:21:45 PM

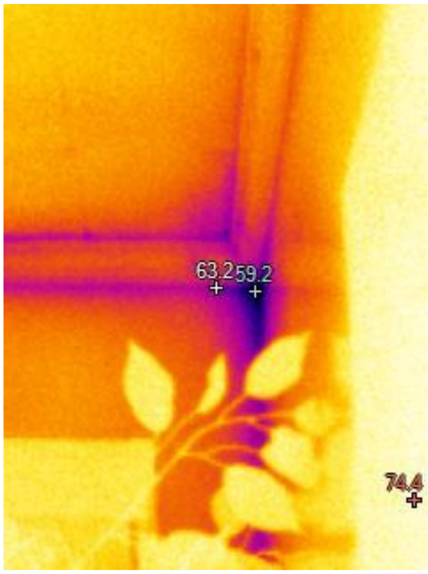
Evidence of air movement
through handed side of door.





First Floor Front Elevation Wall
12/9/2013 5:30:44 PM

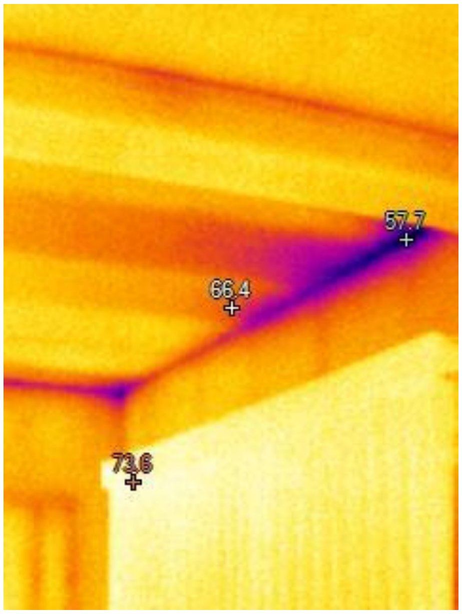
Here it can be seen that there is a lack of insulation in the front elevation wall. This should be obvious due the nature of the plaster and brick construction.



First Floor Front Elevation Wall
12/9/2013 5:31:44 PM

Visible Light Image

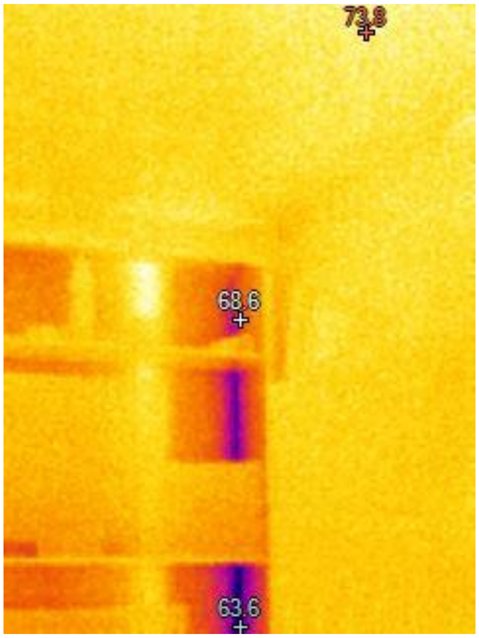
Top plate air movement.



First Floor Meeting Room
12/9/2013 5:32:00 PM

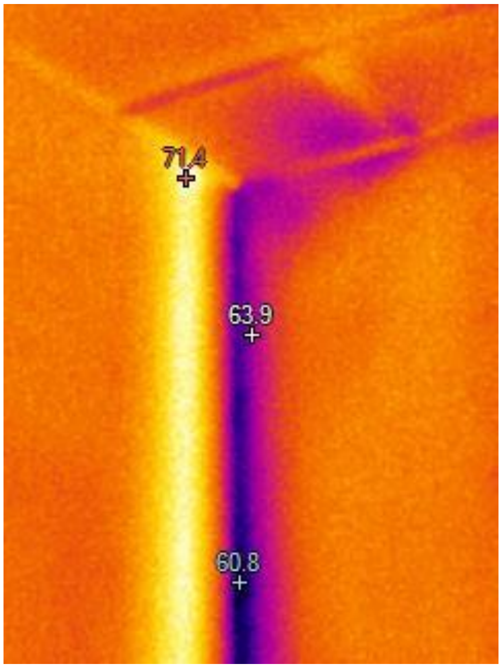
Visible Light Image

Figure shows evidence of top place air movement due to improper sealing.



First Floor Office
12/9/2013 5:32:24 PM

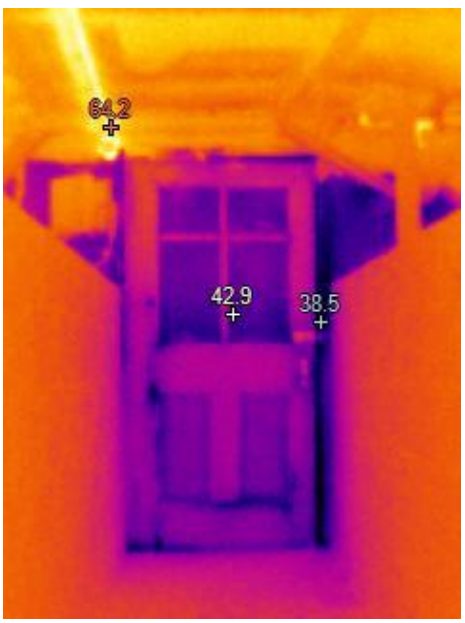
Air movement along the wall seam.



Kitchen
12/9/2013 5:36:55 PM

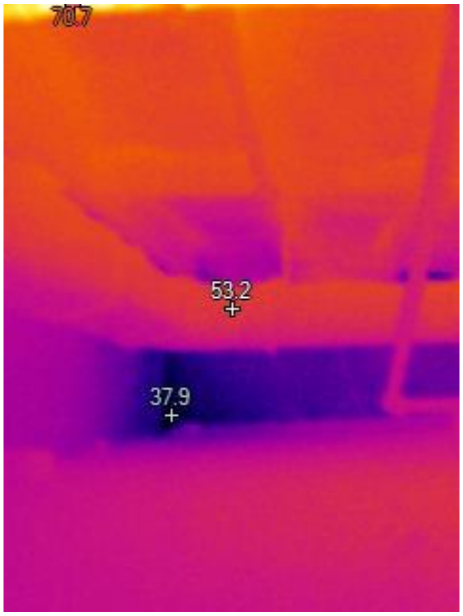
Visible Light Image

Air movement along the air seam.



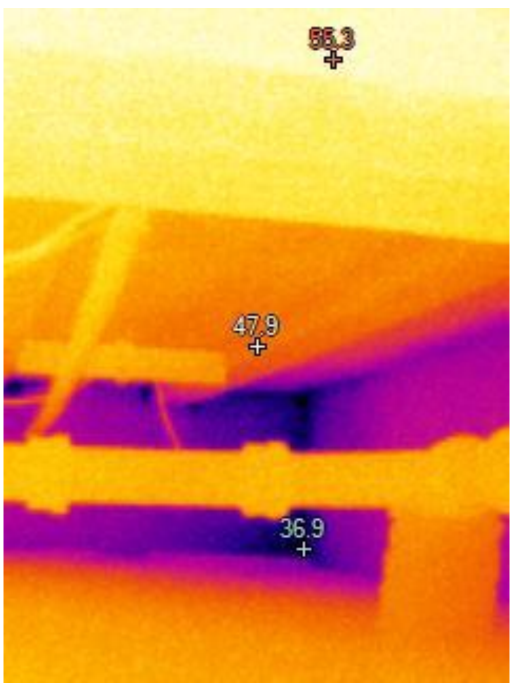
Rear Elevation Basement Door
12/9/2013 5:39:25 PM

Lack of air sealing.



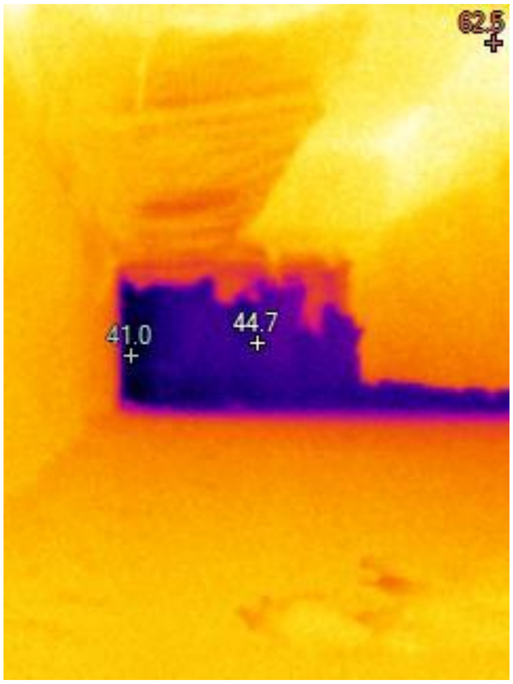
Left-Rear Elevation Basement Crawlspace
12/9/2013 5:40:15 PM

Air infiltration through the basement rim and band.



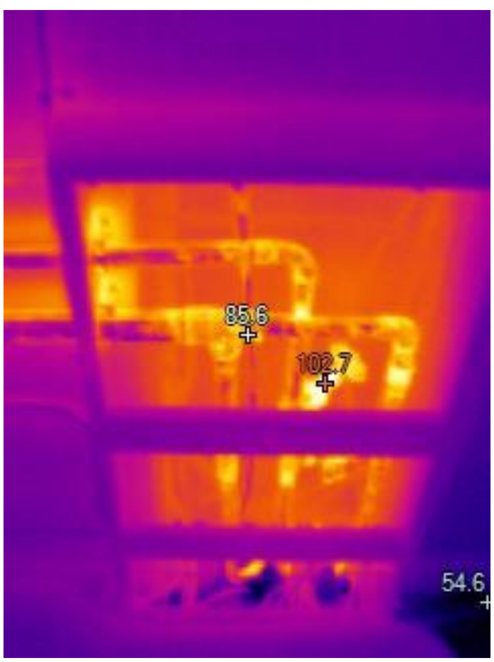
Left-Rear Elevation Basement Crawlspace
12/9/2013 5:41:02 PM

Air infiltration through the basement rim and band.



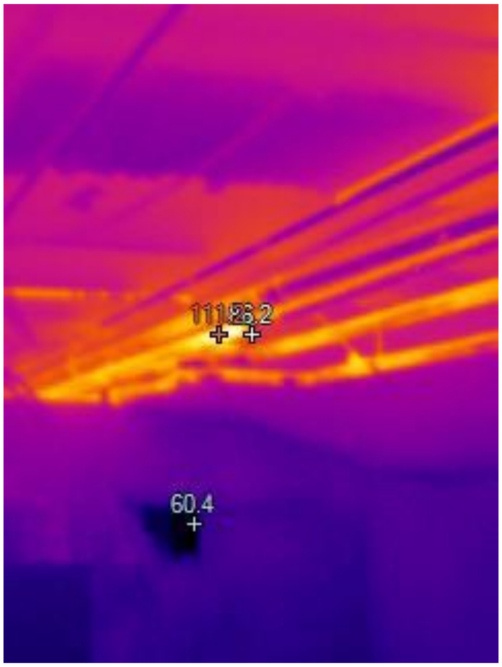
Left-Elevation Basement Crawlspace
12/9/2013 5:41:56 PM

Air infiltration through the basement rim and band.



Basement- Water Pipes in Ceiling
12/9/2013 5:42:48 PM

Lack of insulation.

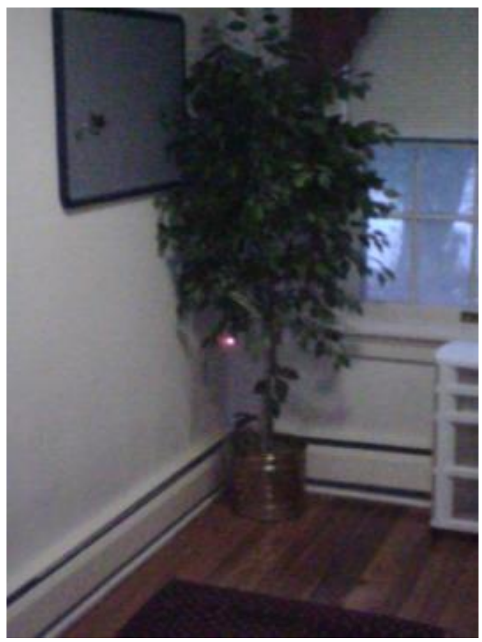


Basement Ceiling – Water Pipes
12/9/2013 5:44:05 PM

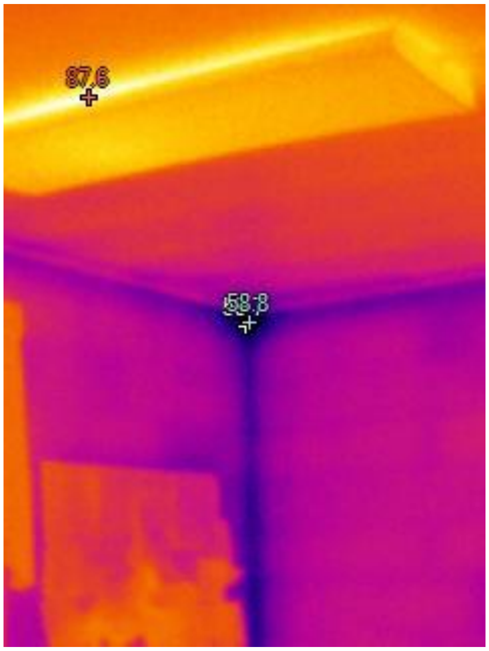
Visible Light Image

Lack of insulation

Second Floor – Right-Front Elevation Wall
12/9/2013 5:45:31 PM

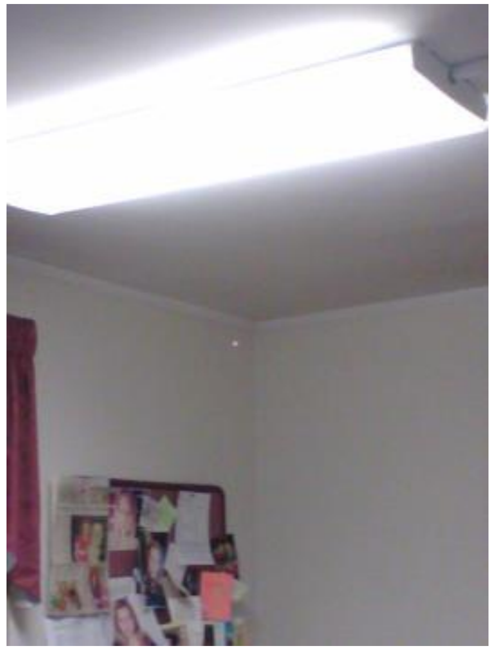


Visible Light Image

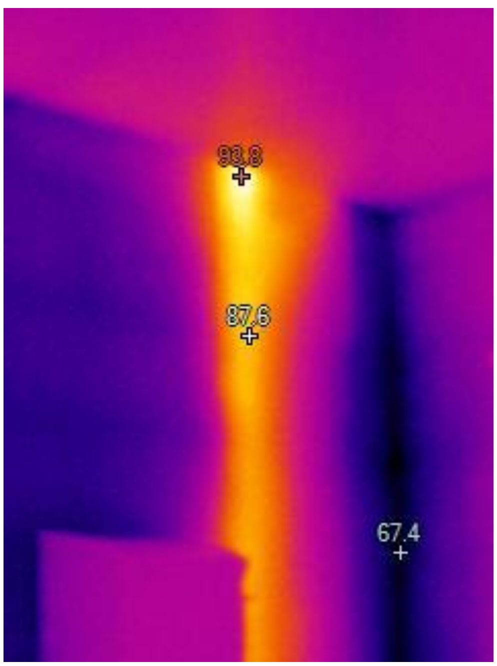


Second Floor Front Elevation
12/9/2013 5:46:08 PM

Air movement through wall seam.



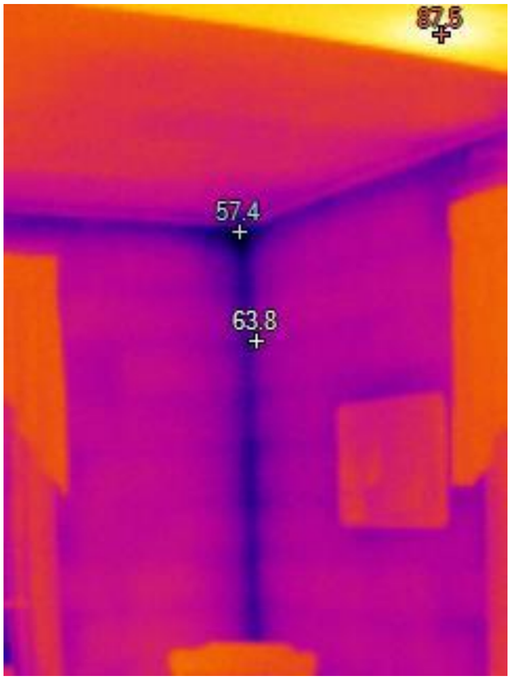
Visible Light Image

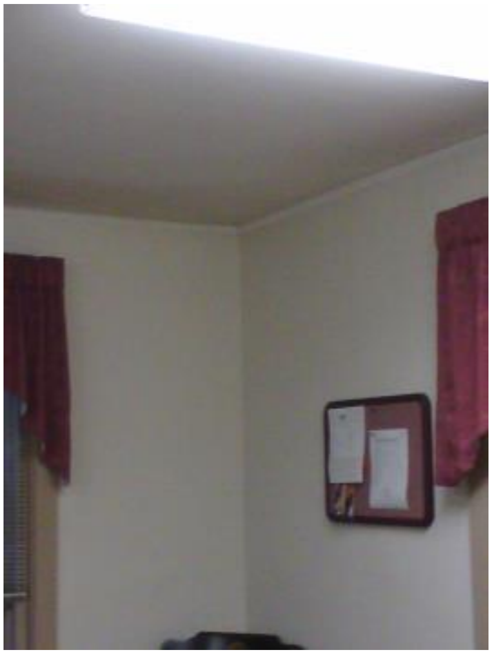


Second Floor Front Elevation
12/9/2013 5:46:55 PM

Air movement through wall seam.

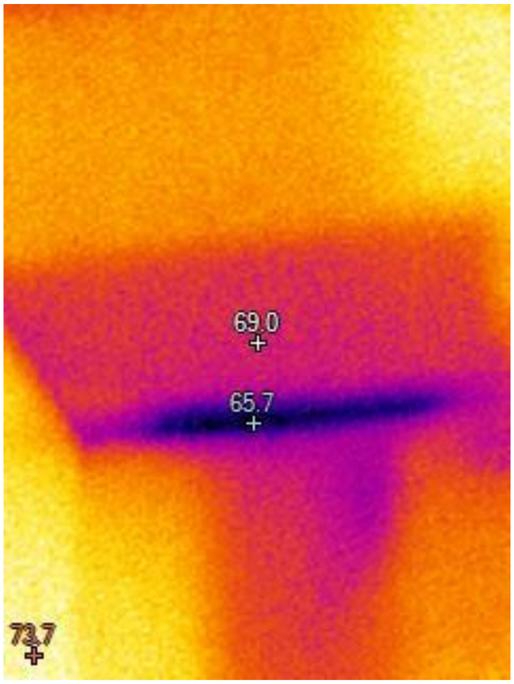
Visible Light Image





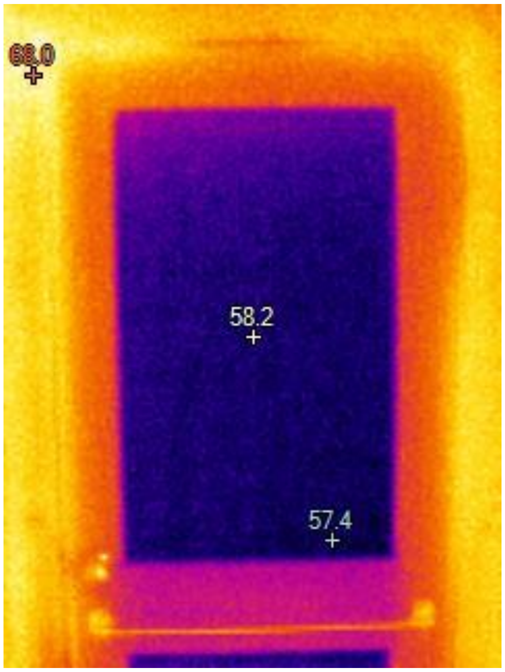
Second Floor Front Elevation
12/9/2013 5:48:00 PM

Air movement through wall seam.



Second Floor Office; Right Elevation
12/9/2013 5:49:02 PM

Top plate air movement.

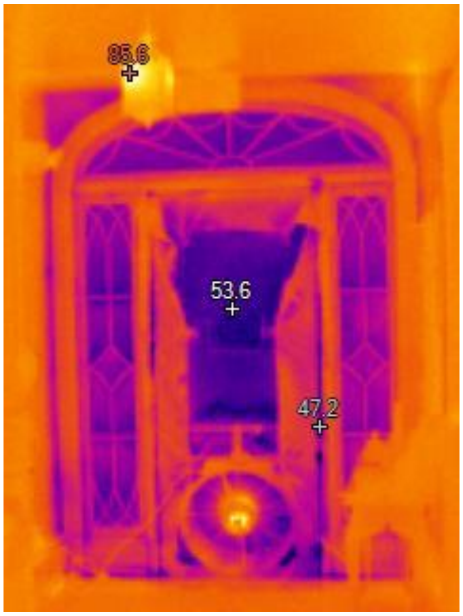


Attic Door
12/9/2013 6:09:23 PM

Visible Light Image

Lack of insulation.

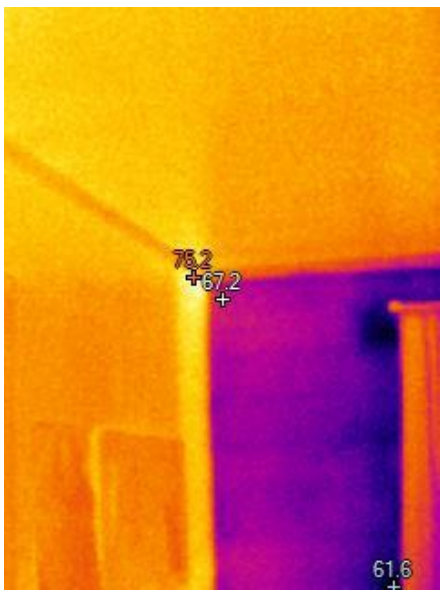
APPENDIX II: Thermal Imagery Under Depressurized Conditions



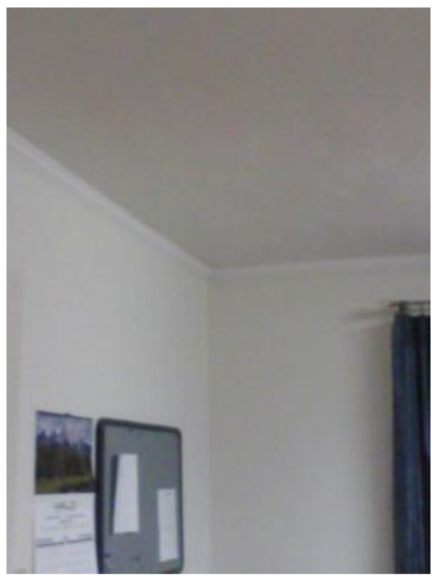
First Floor Front Door
12/9/2013 6:33:36 PM

Visible Light Image

Blower door setup.

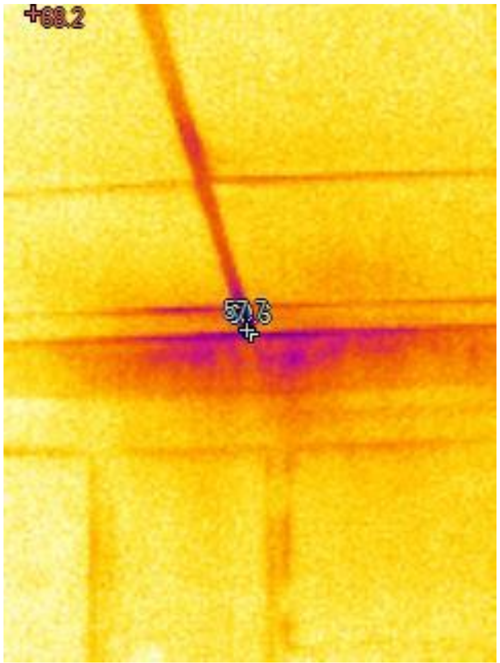


First Floor Front Elevation Wall
12/9/2013 6:34:33 PM



Visible Light Image

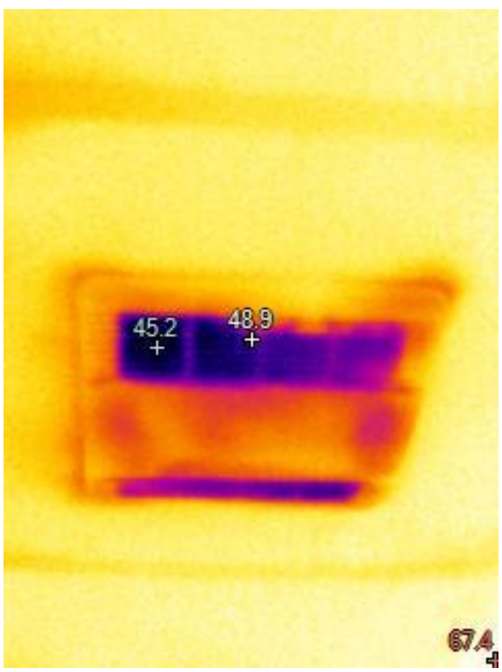
Lack of insulation.



Kitchen
12/9/2013 6:35:14 PM

Top plate air movement.

Visible Light Image



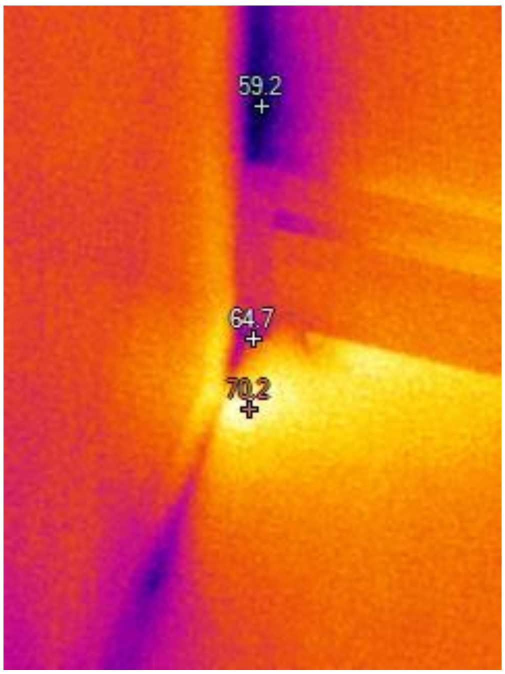
First Floor Bathroom Fan
12/9/2013 6:36:07 PM

Lack of air sealing.

Visible Light Image

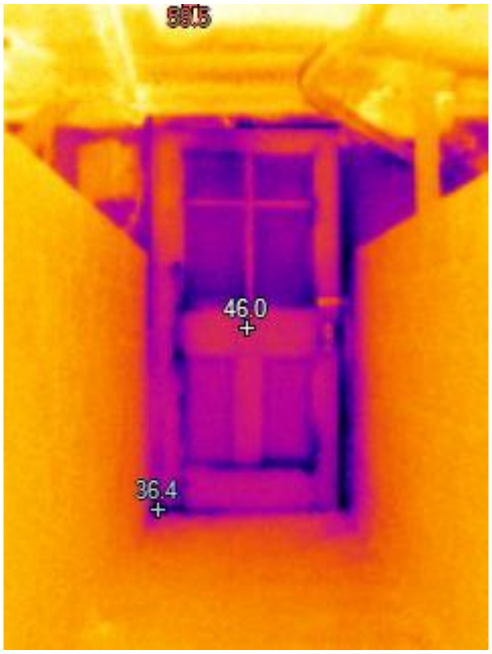
First Floor Kitchen Window
12/9/2013 6:36:41 PM

Lack of air sealing.



First Floor Baseboard
12/9/2013 6:37:06 PM

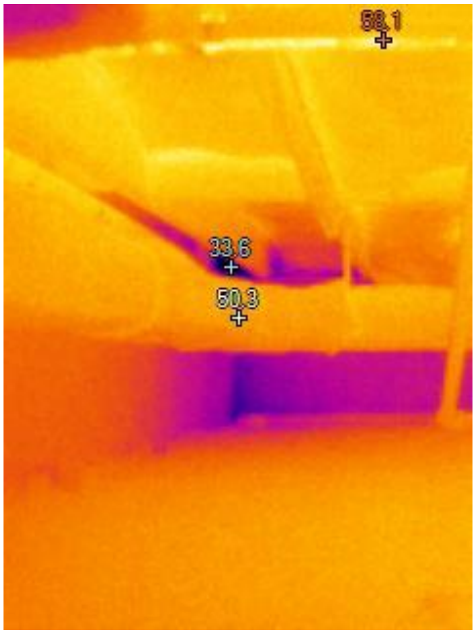
Visible Light Image



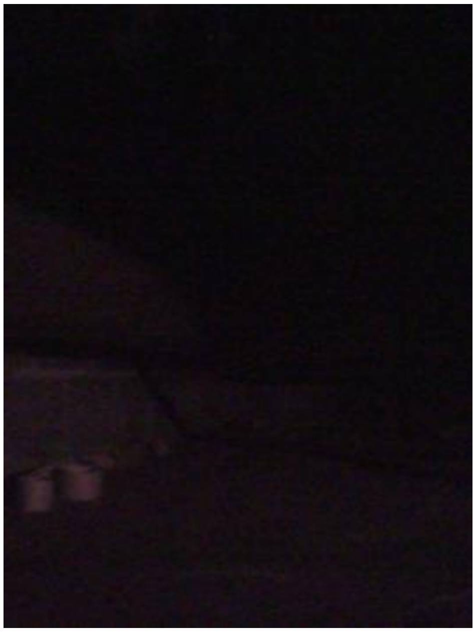
Rear Elevation Basement Door
12/9/2013 6:39:14 PM

Visible Light Image

Lack of air sealing.

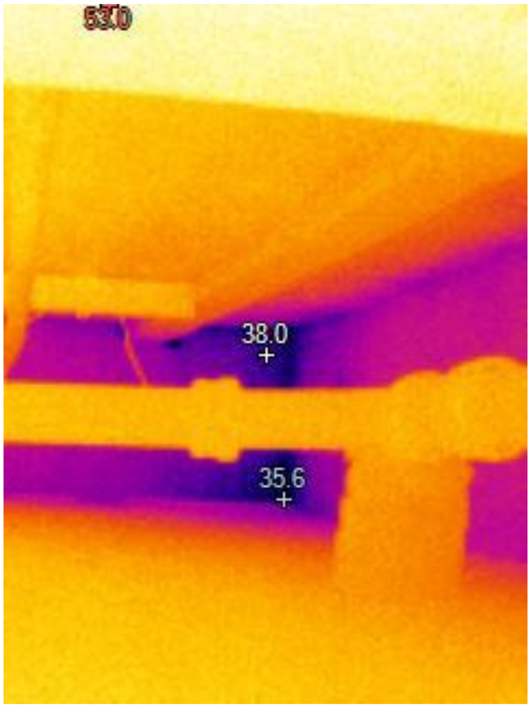


Basement Crawlspace
12/9/2013 6:39:25 PM



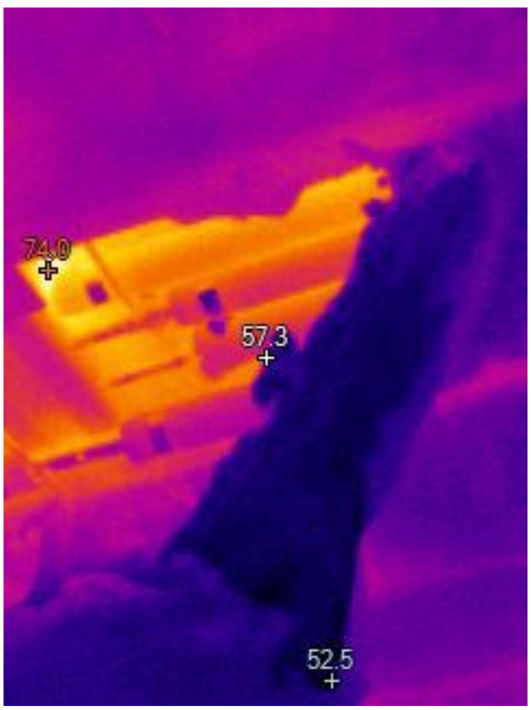
Visible Light Image

Rim and band air movement.



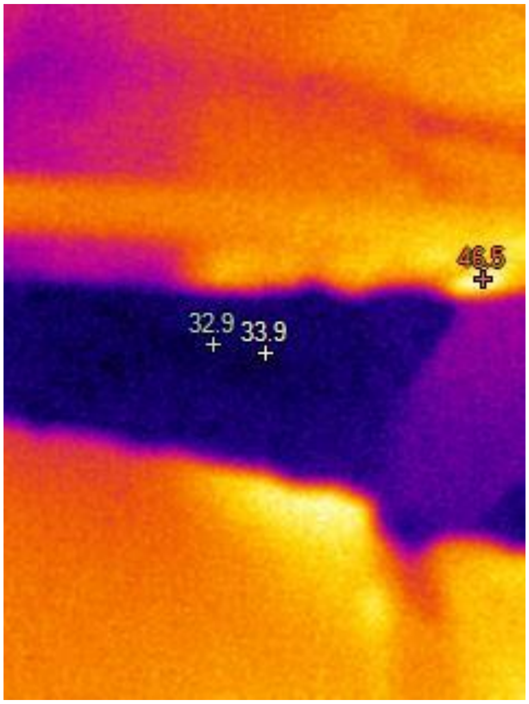
Basement Crawl Space
12/9/2013 6:39:42 PM

Visible Light Image



Basement Water Pipes
12/9/2013 6:40:27 PM

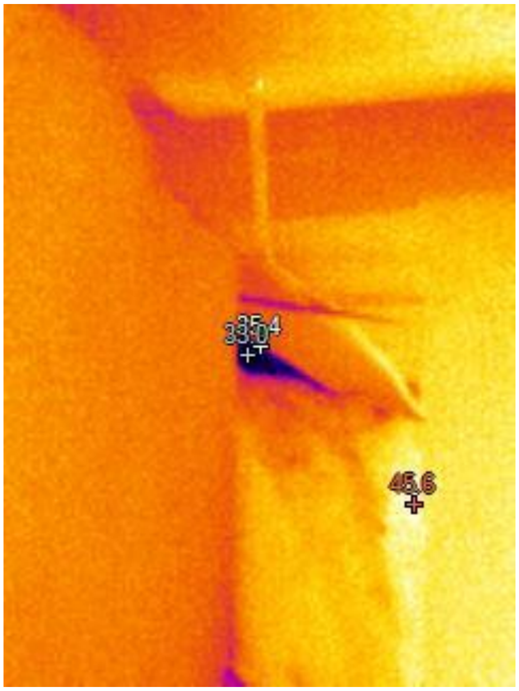
Visible Light Image



Basement Ceiling
12/9/2013 6:42:18 PM

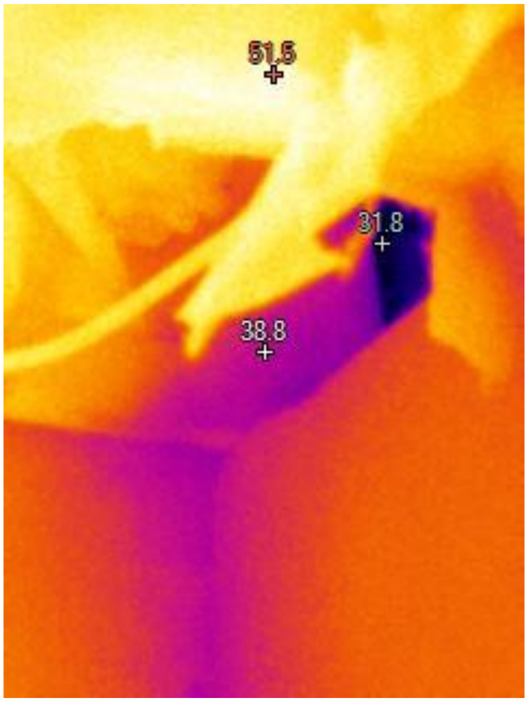
Visible Light Image

Top plate air movement.



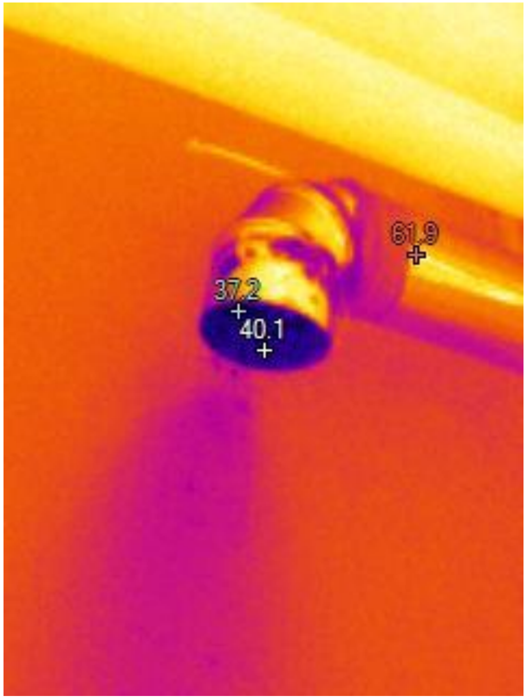
Basement
12/9/2013 6:42:30 PM

Visible Light Image



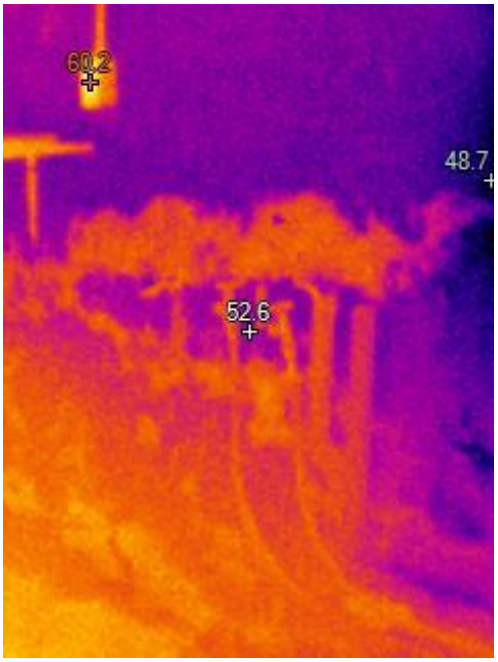
Basement
12/9/2013 6:42:57 PM

Visible Light Image



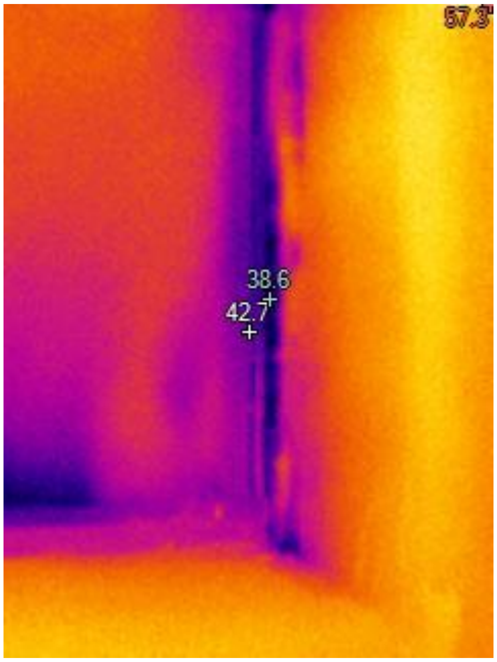
Basement Dryer Vent
12/9/2013 6:44:37 PM

Visible Light Image



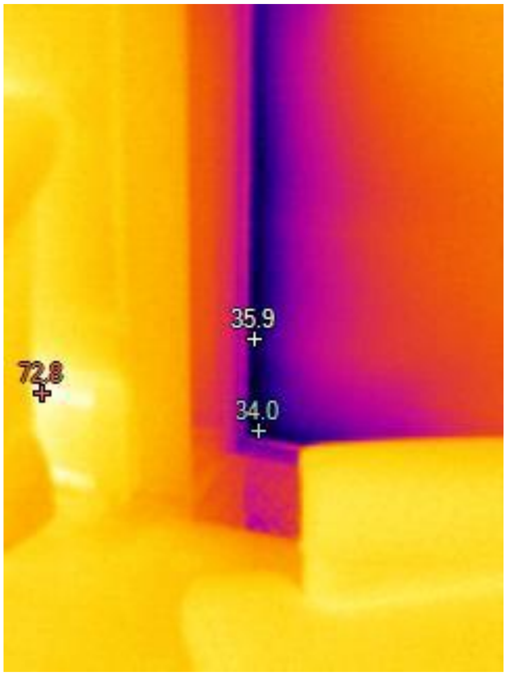
Basement
12/9/2013 6:45:04 PM

Visible Light Image

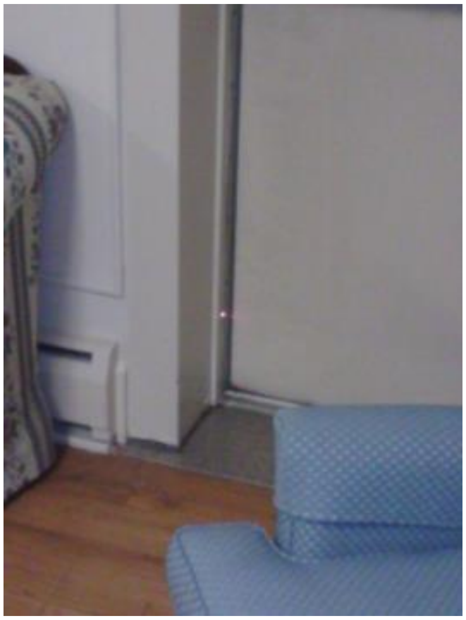


Basement Window
12/9/2013 6:45:28 PM

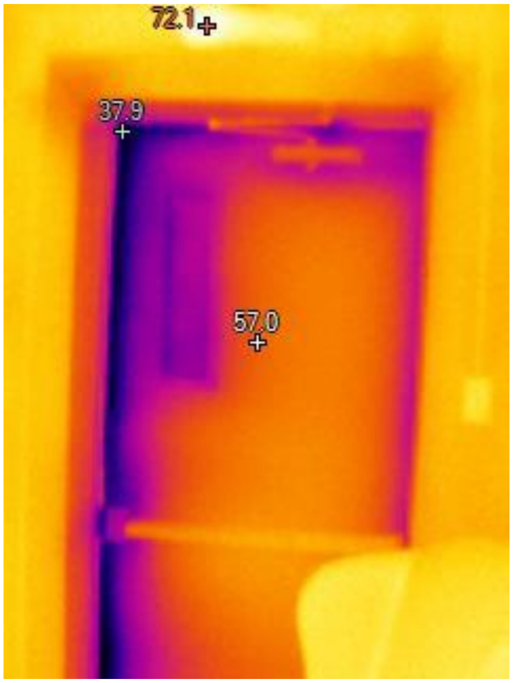
Visible Light Image



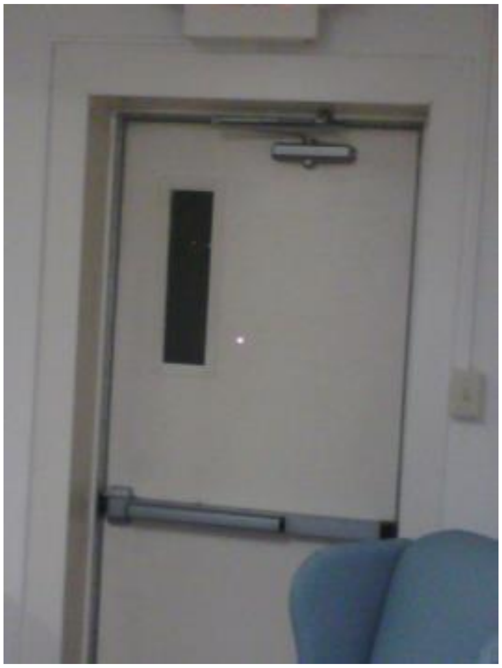
Basement Door
12/9/2013 6:47:01 PM



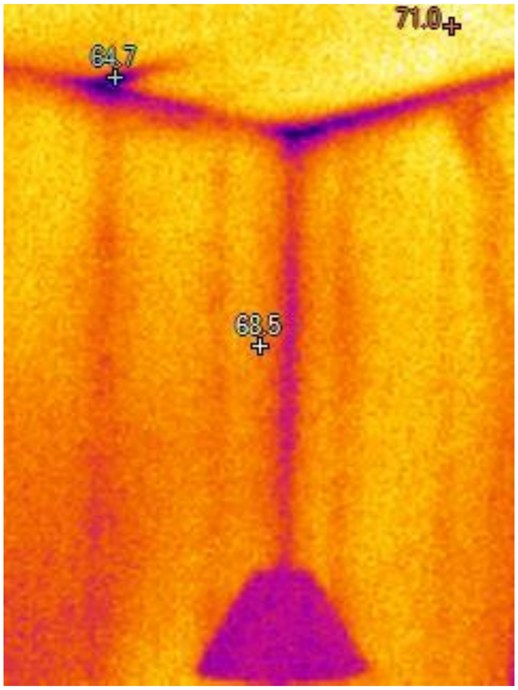
Visible Light Image



Second Floor Balcony Door
12/9/2013 6:47:18 PM

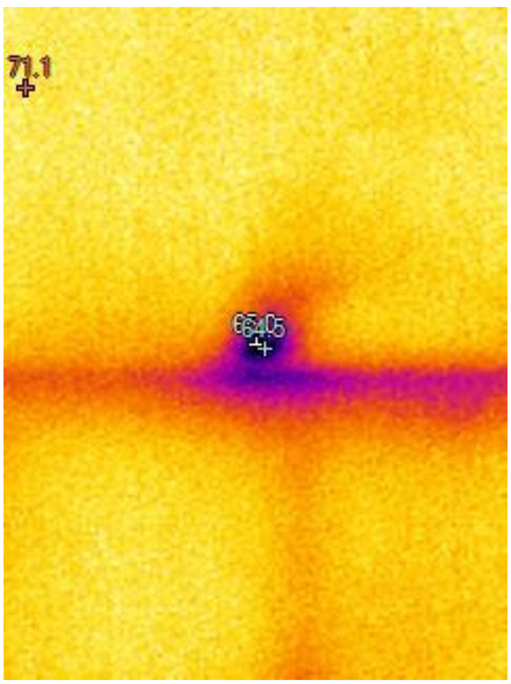


Visible Light Image



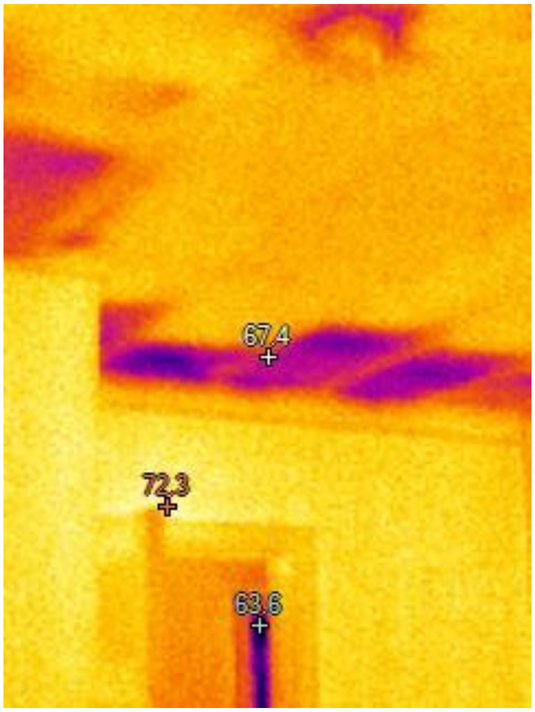
Second Floor Office
12/9/2013 6:48:46 PM

Visible Light Image



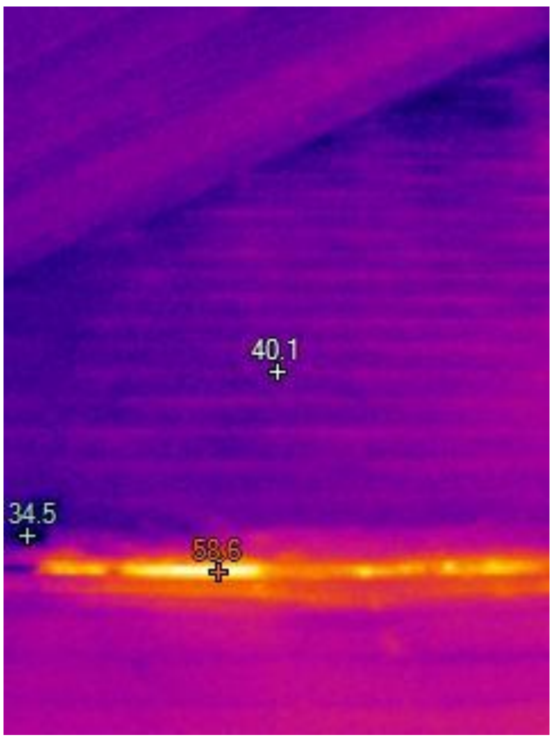
Second Floor Office
12/9/2013 6:49:06 PM

Visible Light Image



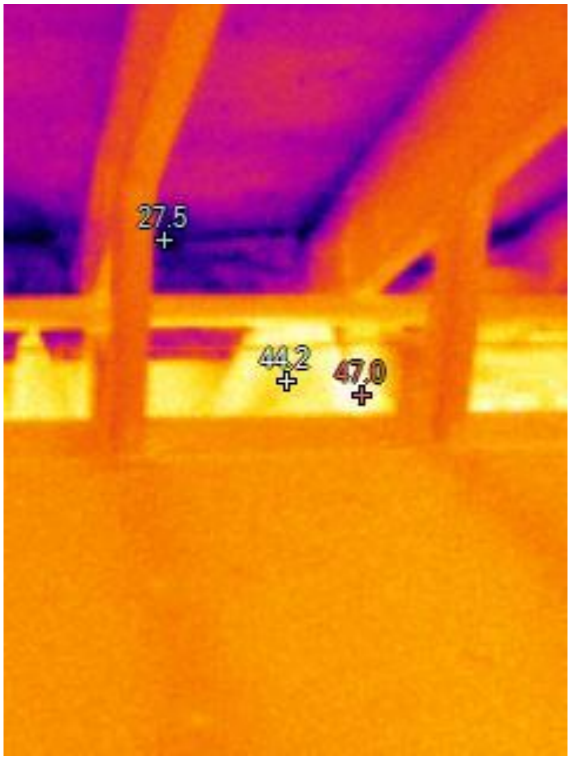
Second Floor Office
12/9/2013 6:50:53 PM

Visible Light Image



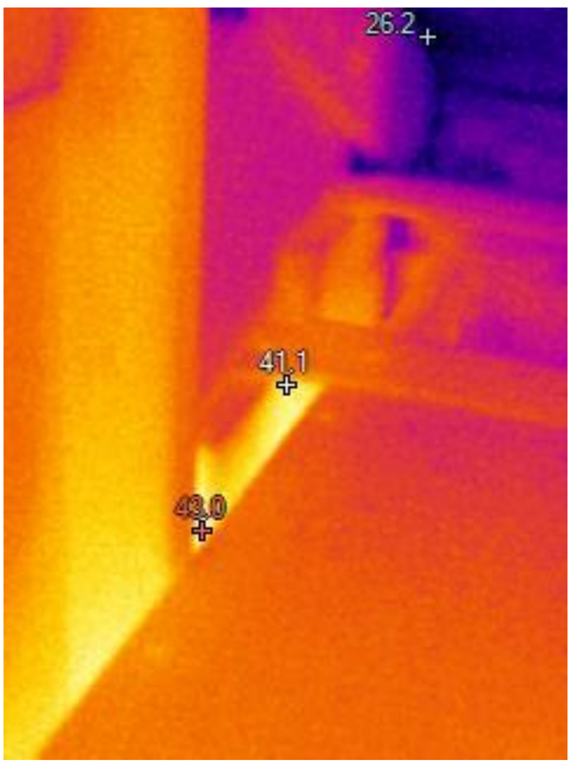
Third Floor Attic
12/9/2013 6:53:23 PM

Visible Light Image



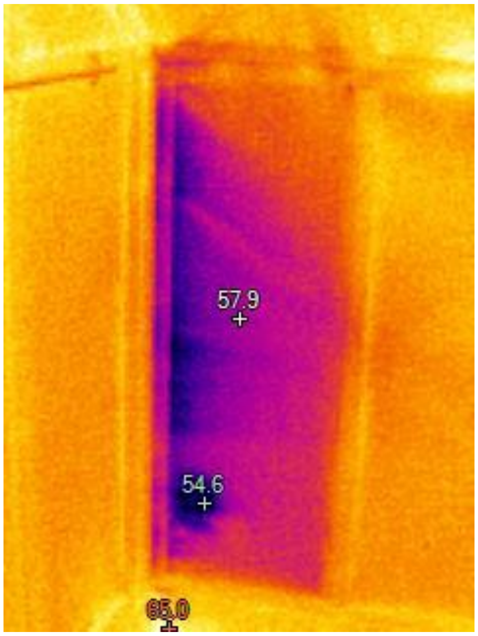
Third Floor Attic
12/9/2013 6:53:40 PM

Visible Light Image



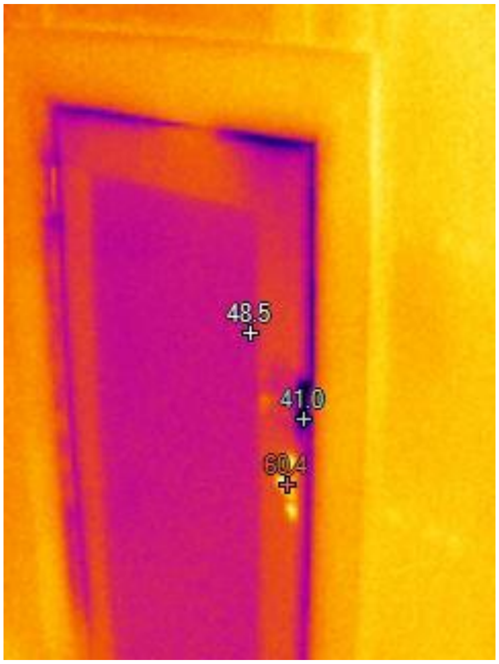
Third Floor Attic
12/9/2013 6:54:04 PM

Visible Light Image



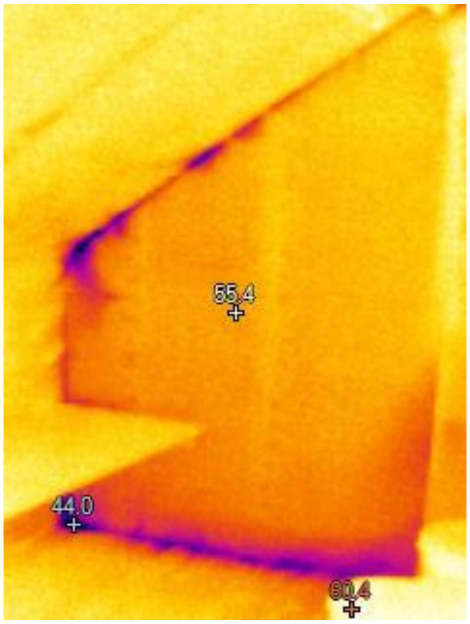
Third Floor Attic Side Wall Panel
12/9/2013 6:55:07 PM
Lack of air sealing and insulation.

Visible Light Image



Third Floor Attic Kneewall Access
12/9/2013 6:55:42 PM
Lack of air sealing and insulation.

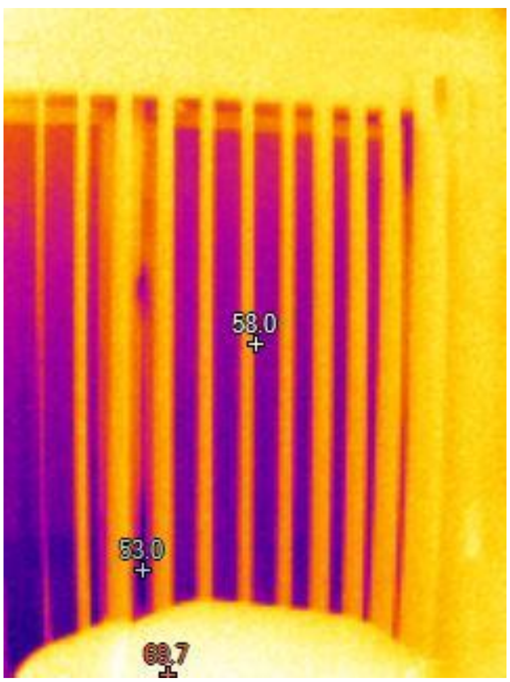
Visible Light Image



Third Floor Attic Cedar Room
12/9/2013 6:56:50 PM

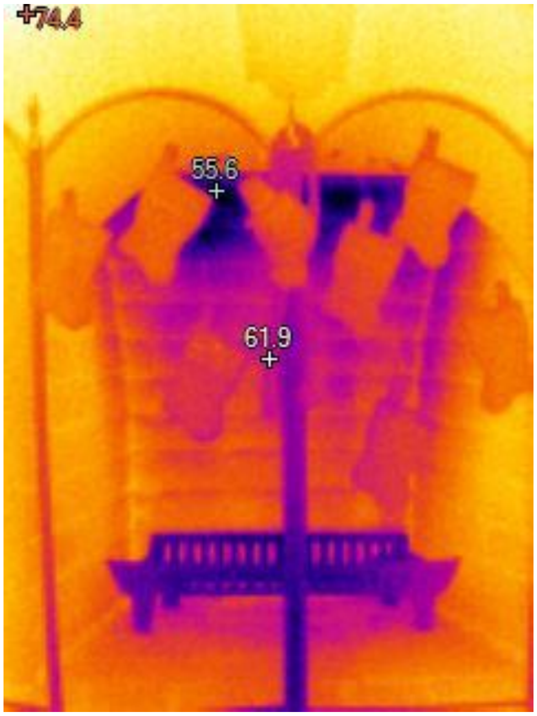
Visible Light Image

Air infiltration through the perimeter.



First Floor Sun Room
12/9/2013 7:00:33 PM

Visible Light Image



First Floor Fire Place
12/9/2013 7:01:41 PM

Visible Light Image

Presence of air infiltration through the top of the flu.