2011

Keith Abbott - Energy Audits and Consulting

[ENERGY ANALYSIS - WARWICK ELEMENTARY SCHOOL]

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Understanding Building Science and the Role of Efficiency

"The U.S. has a renewable resource that is perfectly clean, remarkably cheap, surprisingly abundant and immediately available. It has astonishing potential to reduce the carbon emissions that threaten our planet, the dependence on foreign oil that threatens our security and the energy costs that threaten our wallets. Unlike coal and petroleum, it doesn't pollute; unlike solar and wind it doesn't depend on the weather; unlike ethanol, it doesn't accelerate deforestation or inflate food prices; unlike nuclear power plants it doesn't raise uncomfortable questions about meltdowns or terrorist attacks or radioactive-waste storage, and it doesn't take a decade to build. It isn't a what-if like hydrogen, clean coal and tidal power; it's already proven to be workable, scalable and cost-effective. And we don't need to import it.

This miracle goes by the distinctly boring name of ***energy efficiency****."*

Michael Grunwald, Time Magazine, "Wasting our Watts," January 12, 2009

Introduction

At the request of the Town of Warwick Energy Committee, Keith Abbott - Energy Audits and Consulting conducted an energy audit on the Warwick Elementary School in Warwick, Massachusetts. Since construction, the school's energy bills have been higher than anticipated, and numerous problems such as ice dam formation and comfort issues have resulted in a building that is performing far below expectations.

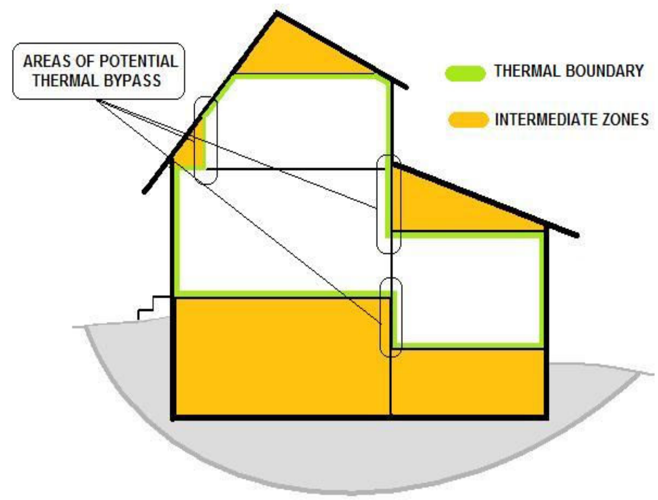
The building was audited using state-of-the-art diagnostic tools, energy modeling software, and building science principles. The physical audit was conducted on December 30th, 2010. An explanation of methods, results, solutions and recommendations follows:

In past experiences working on public buildings and private institutions I have recognized the importance of not only making physical improvements to existing structures, but addressing behavioral aspects of energy conservation as well. In order for significant quantifiable progress to be made in reducing the energy consumption of the school, student and faculty awareness must be a key component of any effort. Along with the specific efficiency improvements made in this report, I highly recommend that a school wide energy efficiency awareness campaign be a component of the overall effort.

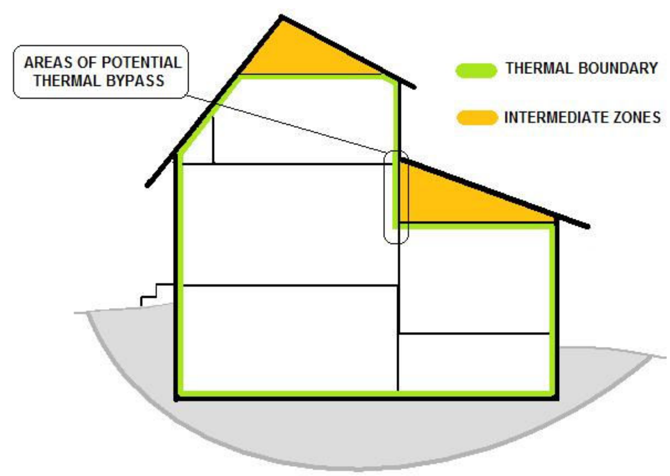
Although there are unique characteristics specific to the building audited, there are several basic building science concepts that pertain to all buildings. These factors have a significant influence on energy use and directly impact recommendations made in this report. Hopefully, an understanding of these basic ideas will lead to a more comprehensive understanding of my approach. Section I contains a basic building science primer that will help you better understand your building and this report. Section II contains the specific diagnostic results of the blower door test, infrared scans and combustion analysis. It includes details on your air exchange rate and the infrared images that were captured as a part of the audit. At the end of the report you will find solutions and recommendations to the building flaws identified during the audit.

DEFINING THE THERMAL BOUNDARY

Most notions of where we are in relation to the buildings we utilize fall into two distinct definitions – you are either inside or you are outside. However, building scientists and companies like Thermal House recognize that, in reality there are many areas in buildings that fall into other grey areas. This could be either by design or by accident. Therefore, in order to fully understand any building's thermal efficiency, the building scientist, energy auditor, and efficiency remediator need to first clearly define all the spaces in the home.



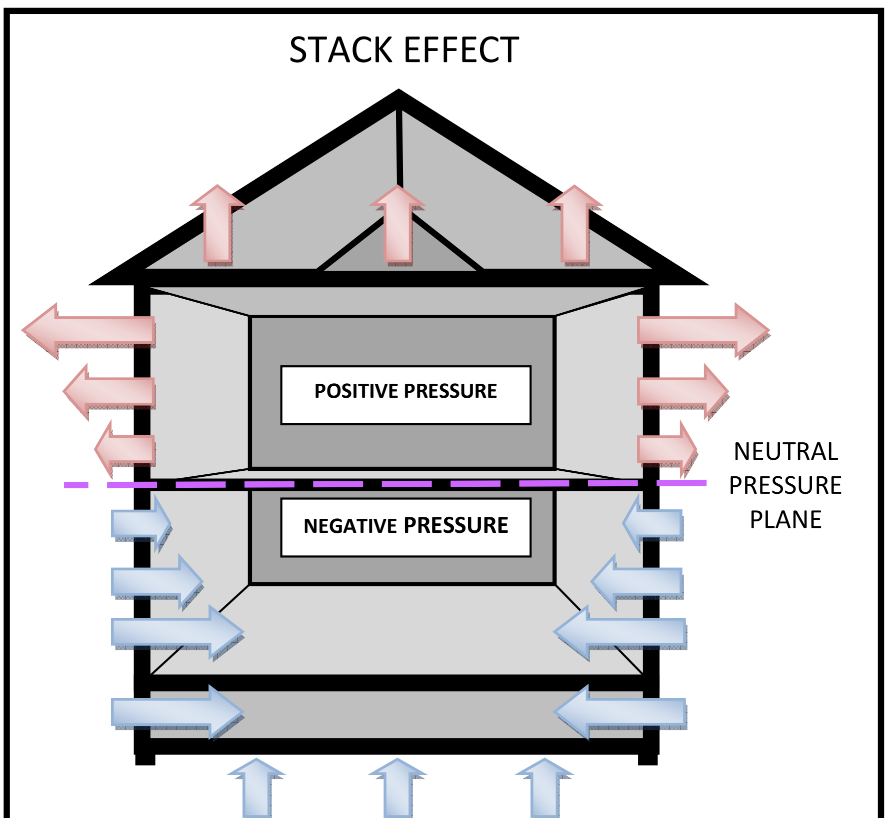
The thermal boundary (also called the thermal envelope) should completely enclose all of a buildings conditioned space. Conditioned space is the area in the home that is intentionally heated or cooled with some type of distribution system. A good thermal boundary ensures that conditioned air is distributed only to those areas where it is required, excluding areas that are unnecessary to condition. Critical to this boundary are insulation *and* an effective air barrier in direct contact with it. Many building's total enclosed space is also the conditioned space – however many more buildings have areas that are not intentionally heated or cooled. Common New England examples are knee-walls, crawlspaces, attics, and attached garages. Interior access to and through the thermal boundary are often problematic areas of heat and air loss. It is a common (and inefficient) practice to run a building's distribution system (duct work, hot water lines) through these unconditioned spaces (like kneewalls, crawlspaces, and attics). You would easily recognize this inefficiency if the duct work were running outside of your building –but fail to do so when the same ductwork appears "inside" but actually runs outside of the thermal boundary. Unfortunately, many people are unaware of where their thermal boundary actually is until an event like frozen pipes gets their attention. Some of these unconditioned spaces; like basements, are often unintentionally heated by waste heat from furnaces or boilers and others; like attics, are warmed by unregulated heat flow. These



spaces that fall outside the thermal boundary but still inside the enclosed space are referred to as *intermediate zones*.

Stack Effect Pressure

The **stack effect** is a natural phenomenon that occurs in all conditioned buildings to a greater or lesser degree. It is created by the differences in air density caused by differing temperatures and by the natural movement of air from areas of high pressure to areas of low pressure. The size (especially the height) and shape of a building is an added variable which has a direct influence on overall stack effect significance. Remediation work to your building's basement and attic not only adds R-value and slows heat loss but air sealing in these areas help stifle the engine that drives air movement (and the BTU's you've paid for) out of your building.



The stack effect is caused by the relative buoyancy of warmer air. Warmer air's upward force exerts an outward pressure. Airflow, through holes in the top of the building creates suction at lower levels, pulling air in. Arrows indicate direction of positive pressure.

Understanding Heat Movement and Debunking the "Heat Rises" Myth

"Heat rises," is a common misconception. Hot *air*, being more buoyant does in fact, rise. This is the catalyst that drives stack effect pressure. *Heat* however, always moves from warm to cold – it can move (through a variety of mechanisms) up, down, or around a corner. Cold areas are always robbing the school of heat in much the same way that sitting next to a cold window will chill you, even if there is no draft at all. Your body's heat moves toward that cold surface, causing you to feel chilled.

Heat can travel from areas of high temperature to areas of low temperature in 3 distinct ways: *conduction, convection*, and *radiation*.

Conduction is the primary mechanism that moves heat through solid objects. It is typically the most predictable and easy to understand. When you touch a hot frying pan the heat from the pan is transferred rapidly to the cooler surface, your hand. R-value relates specifically to how quickly or slowly heat moves through a particular material. A high R value indicates a material that is very slow to conduct heat. In your attics you want a high R value - though residential energy code only requires R 38, many homeowners are insulating for the future and insulating up to R 50 and R 60. Dense materials like concrete have low R value – in fact 12 inches of concrete, has an R value of only 1, essentially the same R value as a single pane of glass. Building scientists often refer to un-insulated concrete as "windows without a view"

Convection is the movement of heat via a fluid. Air, is considered a fluid so convection in a building science context generally relates to the movement of heat on air. A home with a forced hot air system is delivering warm air to the home, warming the surfaces and occupants via convection.

Radiation is the movement of heat through space from one object to another. The sun warms the earth via radiation. Standing next to a cold window pulls radiant heat away from your warm body and towards the cooler surface of the glass.

Moisture and Ventilation

Most everyone has heard the old saying "a house has to breathe." Although there is some wisdom in this idea, it is far from appropriate considering today's energy prices and the need to reduce green house gas emissions. The saying actually addresses moisture concerns and the acknowledgement that when we tighten up a building's ability to disperse moisture. This in part explains why so many older structures are still standing and are in relatively good shape regardless of the their drainage. An extremely drafty and inefficient building is likely to have few, if any moisture problems.

Effective moisture management must be a top priority whenever significant reductions in air exchange are incorporated into the work scope. This is especially true when working on historical structures. Point sources of moisture, such as bathrooms, cooking appliances, and clothes dryers should be exhausted directly to the outside. Basements should have effective drainage. If drainage is not possible water should be collected in an internal drainage system and removed from the building. Dirt floors should be covered with an appropriate vapor barrier that is sealed to the foundation perimeter.

The need for adequate ventilation cannot be overstated – whether the building is currently under construction or was built 200 years ago. Interior relative humidity must be controlled by exhausting moisture at its source. Over 90% of the moisture in a building is in vapor form and travels through the air. Air leakage pathways can provide a steady stream of moisture which once in contact with exterior building components can condense and cause significant problems such as mold growth and deterioration of the structure.

Figure 4 summarizes a study conducted by the Building Science Corporation and exemplifies the significance of air transported moisture.

Figure 4

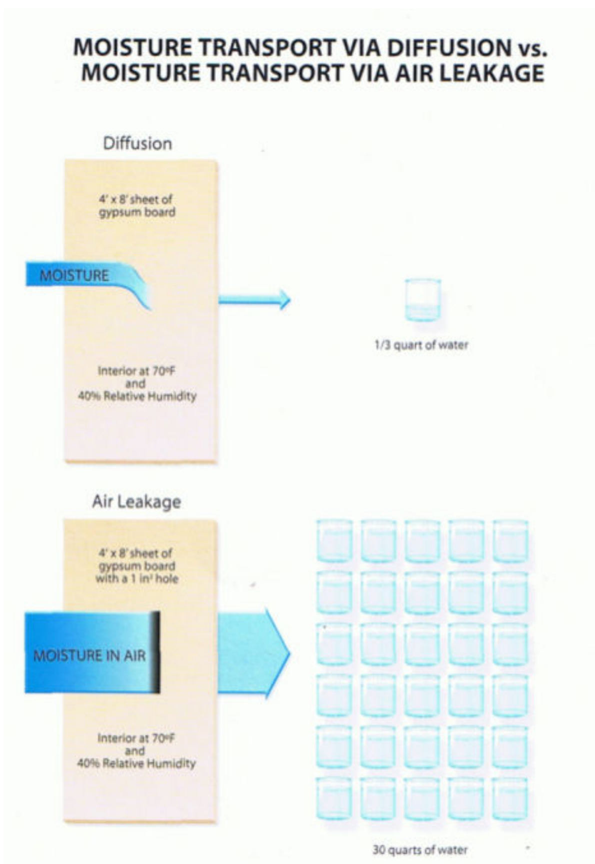
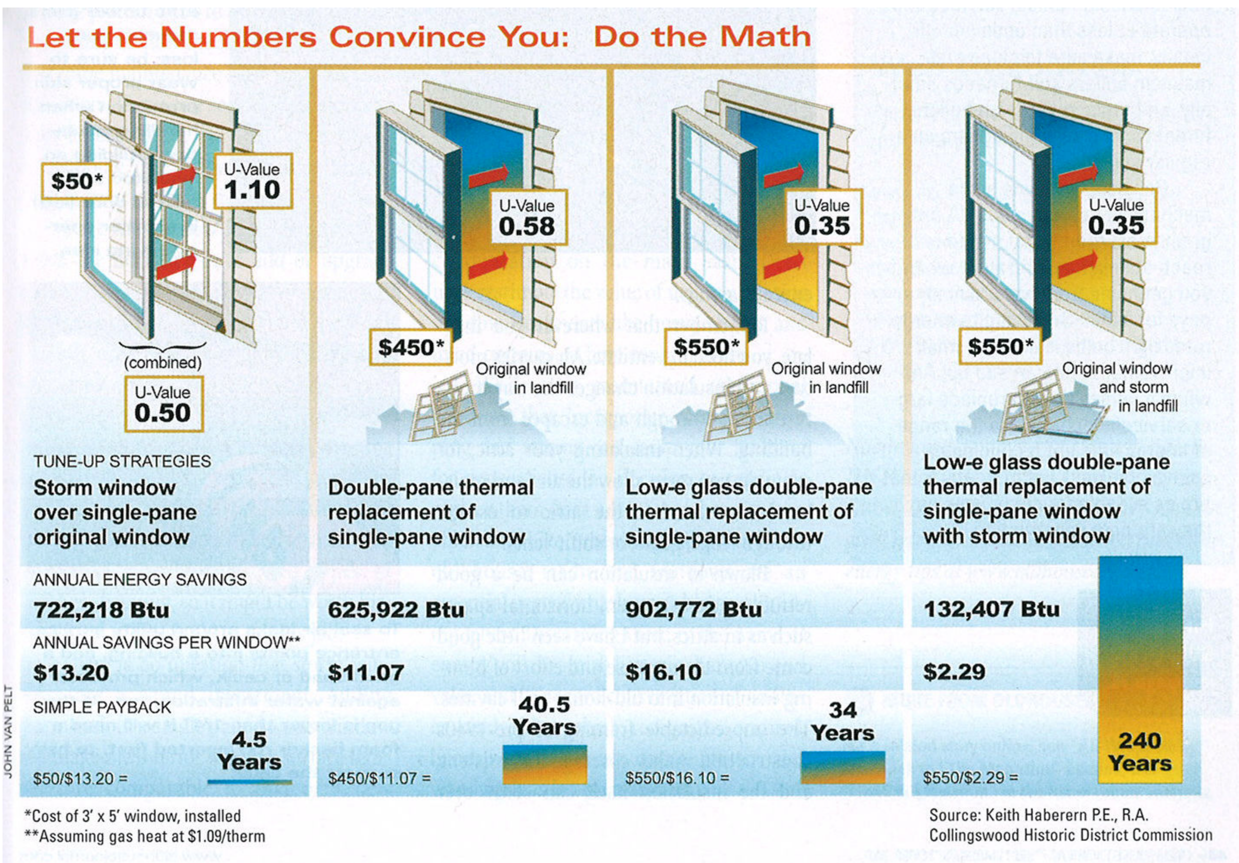


Figure 1: Almost 99% of moisture travels through the air, while diffusion represents only 1% of the total moisture flow. Diffused moisture travels through the sheathing and the insulation to the interior space where it is easily removed from the air by the A/C system.

Windows

Generally window improvements are low on the list with respect to cost/benefit savings associated with energy efficiency improvements (see figure below). A single pane double hung window has an R value of 1, and a double pane window R 2. A gas filled energy star has an R value of 3. Windows are actually rated in U Values, which is an inverse of R value. Therefore the smaller the U-value, the higher the insulating value. Windows are an important part of historical structures, and every attempt should be made to utilize existing windows while improving energy efficiency.



Although not displayed in the figure on the previous page, Advanced Energy Panels®, an interior storm window constructed of cross-laminated poly-olefin, can increase the R value of a single pane window to R4. The internal storms are much easier to install and un-install and their cost is only slightly higher than the less effective exterior storm windows. Window quilts and insulating shades offer the greatest return on investment, are relatively inexpensive and can increase the performance of a single pane window to R 7. The one drawback of the window shades and quilts is that they require a person to close them when light from the window is not needed.

Energy Models, TREAT and QLoss

Two energy modeling software programs were used to analyze the use of energy and evaluate the cost effectiveness of the recommendations made in this report. Before discussing each program, it is important to understand what energy models are, how they work, and what their limitations are. Energy modeling is in many ways an art as much as it is a science.

Energy modeling programs use quantitative analysis tools used to evaluate a building's energy consumption. Weather data from the national weather service is used to determine the heating and cooling days where the building is located. Building data such as r-values of exterior walls, u-values of windows, heating and cooling system efficiency, lighting and major appliance electrical consumption, and many other building characteristics are entered into the model to determine the overall btu load of the building analyzed. More sophisticated programs such as TREAT calculate variables such as solar heat gain, and internal gains from occupants, lighting, and appliances into the model. Once all of the building data is entered, the program calculates a model that determines the overall energy use of the building. If available historical energy use data can be compared to the model to determine how accurate the model has calculated the building's energy use. If the model and historical data are relatively close, the model can be "trued up" to more precisely reflect actual energy consumption.

A major limitation of today's energy models is the inability to predict the impact of human behavior on energy consumption. The models can only use measurable data. Variables in how one person uses energy can be markedly different from how another person uses energy. Recent studies have been conducted on identical buildings where the only major difference is occupant behavior. These studies have shown that differences of as much as 50% can be attributed to the behavior of the buildings occupants.

Benefits are difficult to quantify and often vary from one person to another. For instance, one person may assign high value to reducing their carbon footprint, while another is not the least interested. There are several important benefits that cannot be quantified by energy models, but are important to consider. A well ventilated and energy efficient building requires less maintenance. Both the physical structure and mechanical systems will benefit from reduced energy consumption and proper ventilation. A heating system that does not run as often will have a longer service life than one that runs constantly and is over worked. The same can be said for other mechanicals such as circulator pumps, the energy recovery ventilators and even light bulbs. Structural benefits such as roof longevity due to a reduction in freeze thaw cycling, overheating, and condensation should also be considered when determining the overall benefit of implementing energy efficiency improvements.

Quite possibly the most difficult benefit to quantify, but one that may rank high on the list for the students, faculty and staff is comfort. Increased comfort in the school could increase productivity of students and staff, and even reduce the number of sick days traditionally experienced in during the school year.

Although all models have their limitations, they are the best analysis tools we have at present. The primary energy model used to analyze the Warwick school is TREAT. It is a DOE approved energy modeling software program developed by Performance Systems Development of New York, and is widely regarded as one of the most accurate programs to evaluate existing structures. Q-Loss, developed by Efficiency Vermont is a much simpler program that was used primarily to ensure the primary program was accurately modeling the school.

Understanding Infrared Images

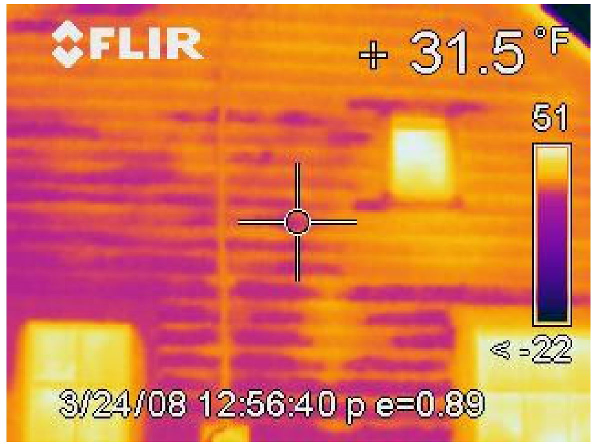
When viewing the infrared images contained in this report, you will notice that each picture contains a temperature scale, temperature reading in degrees Fahrenheit, and the date and time the image was taken. The temperature scale represents the range of temperatures measured by the camera at the time the photo was taken. This range is displayed by different colors and shades; lighter, yellower shades represent warm temperatures and darker, blue shades, colder temperatures. This graduated scale changes from image to image based on the highest and lowest temperatures recorded on each image. Therefore it is important to keep in mind that each infrared images and the colors therein cannot compared to one another on color alone since each photograph has its own individual color scale. The greater the temperature differential between inside and outside temperatures, the greater the dramatic color scale. When some buildings were tested, the difference between inside and outside temperatures was as much as 60 degrees. On other testing days, that differential was as little as 20 degrees, leading to less dramatic, but still valuable imagery.

In the interior images darker shades represent cold air infiltrating the conditioned space. Keep in mind the interior images were taken while the blower door was operating. This means that many of the areas where cold air is entering the building are places where under natural conditions heat would actually be escaping. This is especially true in the images taken along the upper portions of the thermal boundary. Exterior images, like those of foundations are telling in how hot the foundation is and therefore loosing heat to the environment.

The temperature reading is an exact temperature of the area within the center crosshairs of the image, and in most cases is not significant.

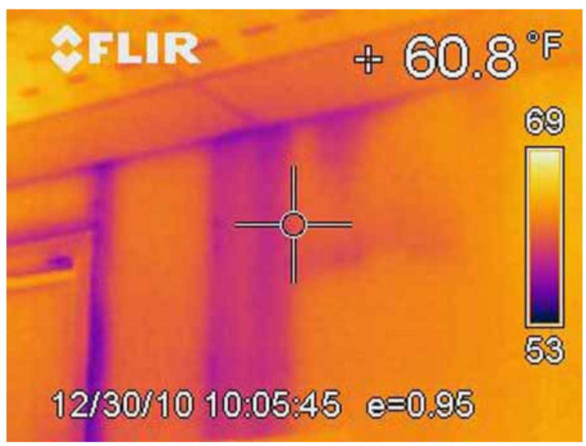
Sample Images and Explanations

Exterior Images - Depicting poor performing insulation (heat loss via conduction) and a poor performing air barrier (heat loss via convection)



The above infrared and digital images were taken during the exterior inspection of the Dalrymple building at Marlboro College. The most significant thermal problem identified in the infrared image is the excessive amount of heat coming through the vent. The wall area surrounding the vent is also significantly warm and is losing heat to the outside. Further investigation of this area during the interior inspection revealed serious problems with the insulation and air barrier along the third floor knee wall of the building.

Interior Images - Depicting air infiltration through an interior wall.



The above images were in one of the classrooms at the Warwick School. Note the cold/dark area along the interior wall. The top wall plate is open to the above cold attic space.

Interior Images - Depicting air leaks/connections to the exterior

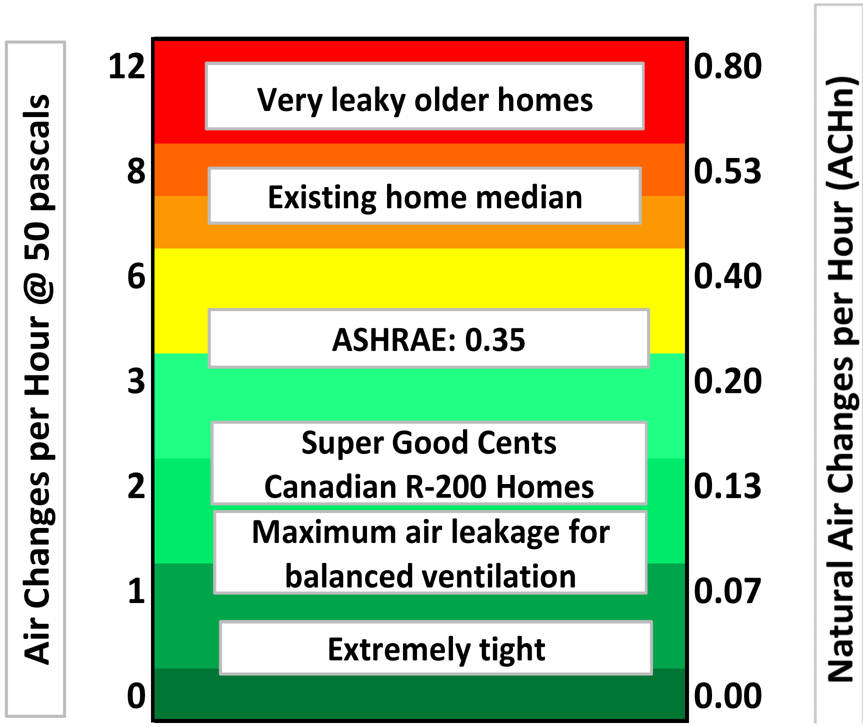
A poorly sealed exterior door provides a perfect example of how air leaks to the interior appear in an infrared image. Note the dark wispy pattern around the door perimeter. These images were taken while the blower door was operating. Cold air drawn into the building during depressurization can be easily detected by the infrared camera.

Blower Door Basics

The blower door is a valuable tool to the energy auditor and is used to quantify air leakage in buildings. The process is quite simple and involves sealing a large fan into an exterior doorway. The fan is connected to a digital monometer that reads pressure and airflow. The pressure gauge is set up to read building pressure relative to outside air pressure, and the flow is measured by connecting an air hose between the fan and an input tap on the monometer that measures airflow in cubic feet/minute @ 50 Pascals (cfm50).

Once the blower door is set up, the building can either be pressurized by blowing air into the structure, or depressurized by pulling air out of the structure. The most common method used by an auditor is to depressurize a building 50 Pascals relative to outside air pressure. After pressure is stabilized by either reaching 50 Pascals, or by maximizing the exhaust capability of the fan, the air flow is recorded. This air flow measurement is exactly equal to the amount of air coming into the building through air leaks in the building envelope. The Warwick school is a large building that required three blower doors to be used in order to depressurize the building to determine the air leakage rate. Separate measurements were taken from each fan, they were then simply added together to quantify the air leakage.

The blower door set up and operating (left photo), and the digital manometer recording building pressure relative to the outside, and air flow in cfm through the fan.



The above chart shows the correlation between natural air changes per hour and pressure induced air changes per hour during blower door operation.

Glossary of Terms

AEP's	Advanced Energy Panels – cross-laminated poly-olefin aluminum framed interior inserts for windows. Converts single pane window to Energy Star rated window.
Air Barrier	Any part of the building shell that offers resistance to air leakage. The air barrier is effective if it stops most air leakage.
Blower Door	A device that consists of a fan, a removable panel, and gauges used to measure and locate air leaks.
BTU	A British Thermal Unit is the industry standard for measuring heat. One BTU is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit. 1 wooden kitchen match is roughly equivalent t o a single BTU.
CFM	cubic feet/minute
CFM 50	The number of cubic feet/minute of air, flowing through the fan housing of a blower door when the house pressure is 50 pascals. This figure is the most common and accurate way of comparing the air-tightness of buildings that are tested using a blower door.
Cellulose	A higher performing and environmentally sound insulating material made of recycled newsprint that can be applied in a variety of ways. Loose fill cellulose can be installed in flat attic spaces, its R value comes from it depth. Dense-packed cellulose is ideal for filling enclosed cavities, but must be installed greater than its settled density (3½ pounds per ft^2) to prevent settling. Damp spray cellulose can be installed into open vertical cavities and shaved smooth for later drywall

	installation. Thermal House utilizes borate treated cellulose that is fire retardant and an irritant to pests and rodents
Closed-cell Foam	All poly-urethane foam come in a variety of densities. Open cell foam are generally in the ½ pound density range and serve as an air barrier and excellent insulator. Closed-cell foams come in a variety of higher densities from 1 ½ pound to 3 pound foams. Closed cell foam act as a complete air and vapor barrier.
Conditioned	Intentionally heated or cooled areas of a building are conditioned.
Depressurize	To create a lower pressure as compared to a standard of high pressure.
Envelope	The building shell. This consists of the exterior walls, floor, and roof assembly of a building.
Infiltration	The inflow of outdoor air into the indoors, which is accompanied by an equal outflow of air from indoors to the outdoors.
Pascal	Unit of measurement of air pressure – abbreviated Pa
R-value	Used to measure the thermal resistance of building components in numbers ranging from 1 to 60. Higher numbers equal better heat retention. R values (unlike U-values) can be added together.
Retrofit	An energy conservation measure that is applied to an existing building. Also means the action of improving the thermal performance or maintenance of a building.

Stack effect	The draft established in a building from air infiltrating low and exfiltrating high.
U-value	The inverse of R-value. Meaning U=1/R. Commonly used for rating windows and heat load calculations.

Section II

Building Analysis

Blower Door Test Results,

Fan #1 (Single Fan located in Library exterior door)

Depressurization: -28.5 Pascals Fan Flow: 8,350 cfm50

Fan #2 (Double Fan located in East side Gymnasium ext. door)

Fan A)

Depressurization: -29.5 Pascals Fan Flow: 8,925 cfm50

Fan B)

Depressurization: -29.0 Pascals Fan Flow: 8,425 cfm50

Total Fan Flow: 25,700 cfm50

Volume of Conditioned Space 312,360 cft.

312,360 cft.x 0.35ACH = 109,326/60min. = 1822 ACH

1822 x 17(n) = 30,974 cfm50

Air Exchange Required for 200 occupants converted to cfm 50

200 x 15 = 300 cfm x 17 (n) = 5100 cfm 50

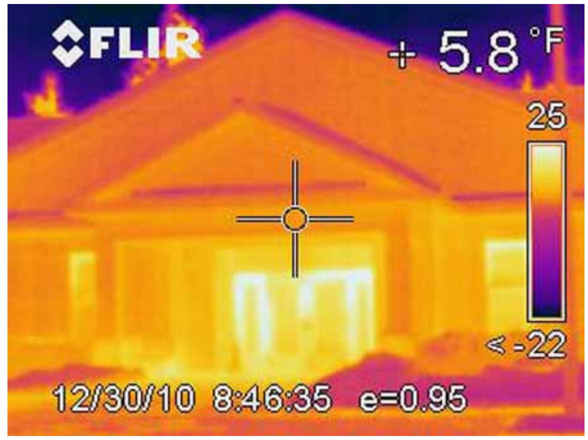
*Air Exchange Provided by ERV's @ 50% volume of capacity

6000 cfm x 17 (n) = 102,000 cfm50

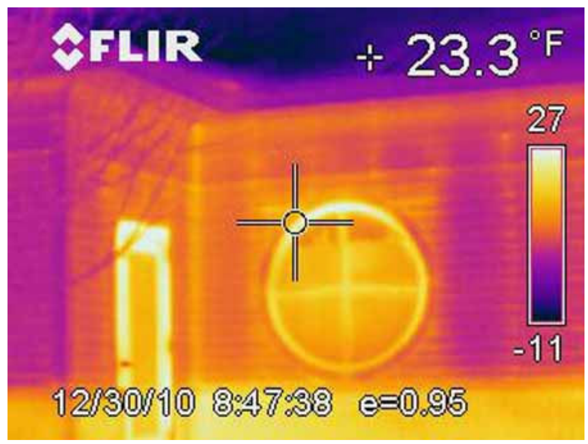
* Each ERV supplies 4000 cfm (maximum air volume) directly from outside.

The fresh air supplied by the three Venmar CES 3000i ERV's is more than adequate to supply the ventilation required for the building's occupants. As a result, all fresh air leaks through the building's envelope measured by the blower door are not only unnecessary from a ventilation standpoint, but are wasting a significant amount of energy. Although it is not economically feasible to reduce natural air infiltration to zero, any meaningful reduction will result in significant savings on heating expenses.

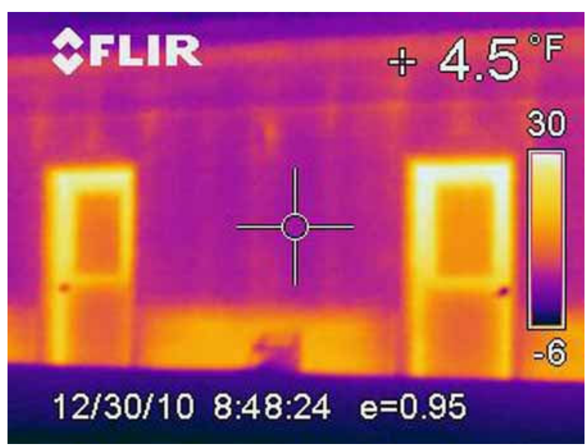
Exterior Thermal Images:



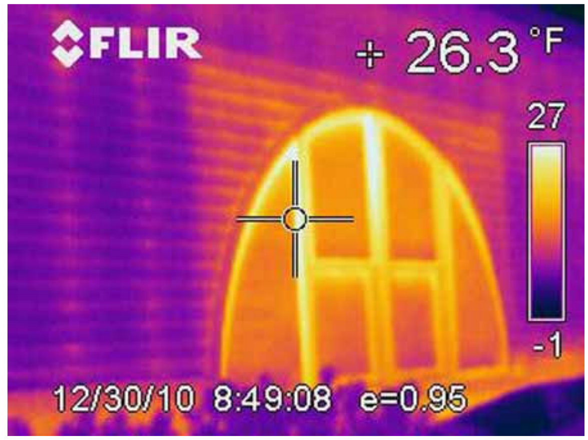
Minor heat loss around doors and windows is all but impossible to stop completely. The exterior walls of the building are performing well in this image.

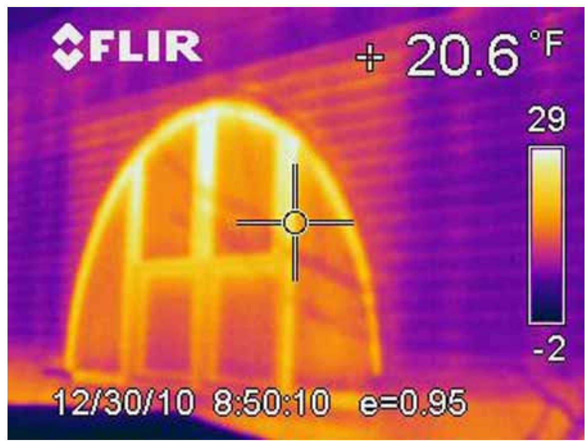


Due to framing differences, the wall adjacent to the round window is not as thermally efficient as other portions of the wall

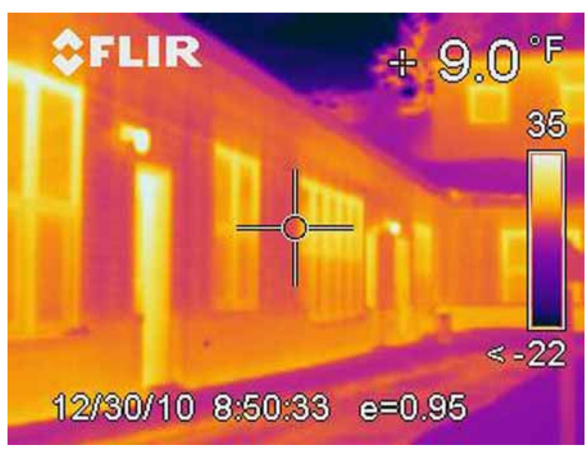


The IR image of the wall area is fine, but notice the snow melting on the roof even at temperatures well below freezing

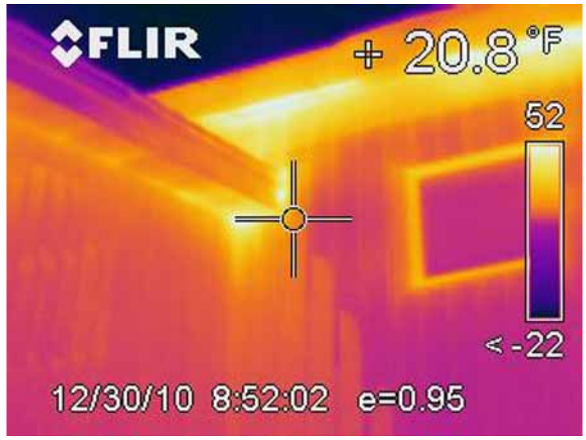



Again, differences in framing explain the difference in thermal performance around the half round window. Note the difference between the wood siding and the brick. The brick is more conductive and is transferring more heat to the outside.

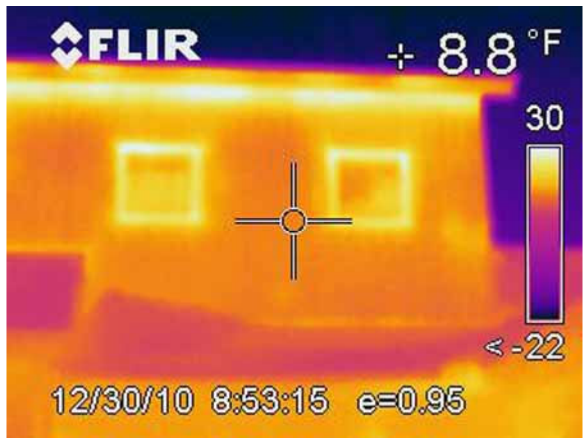



The entire length of this wall looks good and is well within its designed thermal performance.

In both the digital image, and the infrared image, the transfer of heat through the gymnasium rafters is evident. Note also the significant heat emanating from the area between the stage areas roof, and the gym.

Heat loss at the soffit area of the gym, and at the junction of the stage area's roof and gym wall.

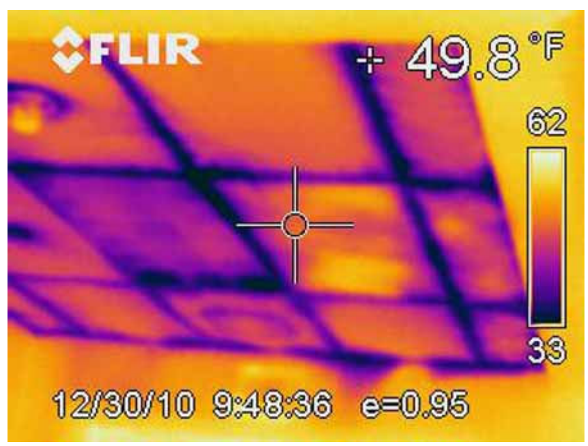



The west side of the gym, the roof and soffit area are transferring or losing a significant amount of heat to the outside.


The lack of snow on the roof, and the fact that the walls and roof appear to be performing about the same thermally is a concern. Typically, ceilings or rooves are insulated a minimum of two times greater than walls.

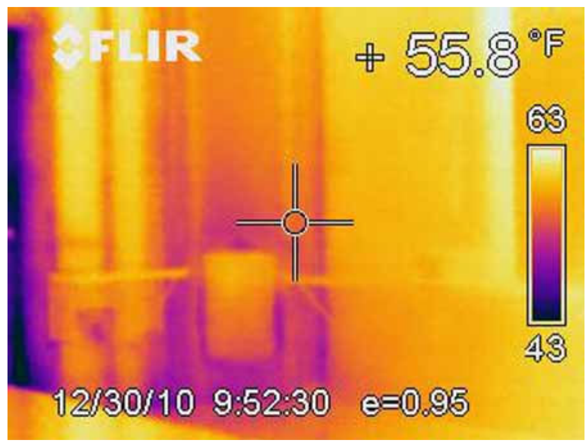
The western side of the gym roof shows an identical heat loss pattern to the East side. There is significant conductive heat transfer through the rafters, and convective heat loss along the eve/soffit area.

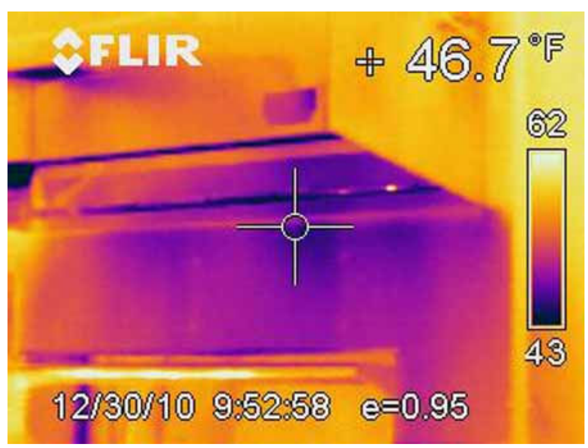
Interior Images:



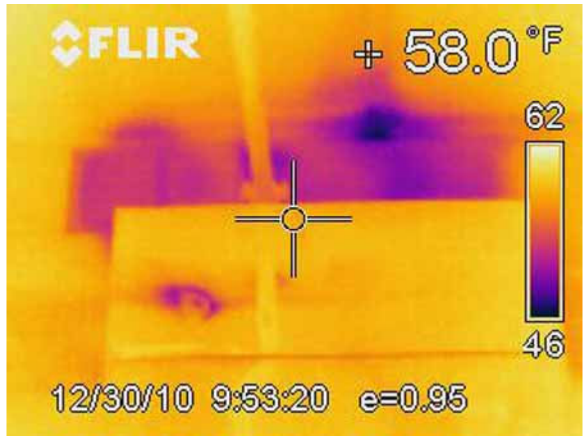
This ceiling area just in front of the west side entry is connected to the outside through the attic. The blower door is pulling cold air from the attic area into the building through the gaps and cracks around the ceiling tiles and light.

Although the windows have a special coating that reflects some of the heat back into the room, drawing the shades in the evening will conserve more energy.

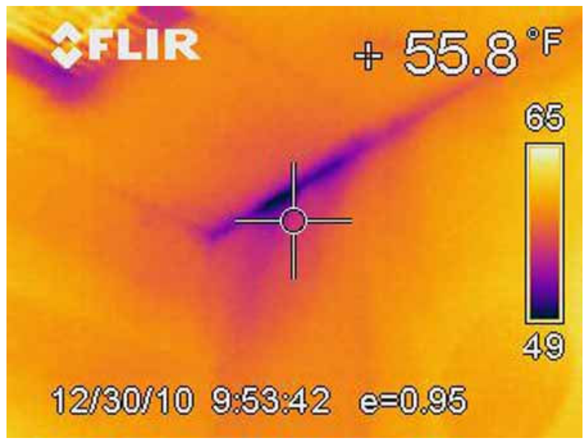




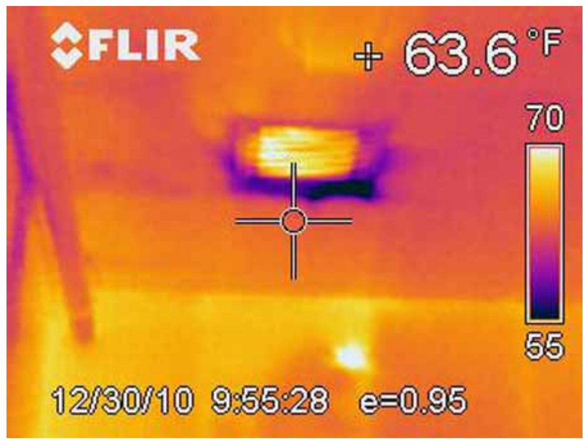
The range hood is connected to the outside via the ductwork that exhausts the fumes and moisture from cooking to the outside. A simple vent baffle can be installed to reduce heat loss through the range hood.



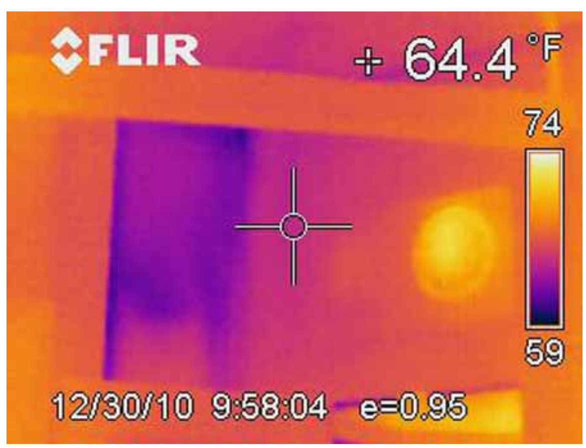
There is a significant air leak in this soffit behind the dishwasher.



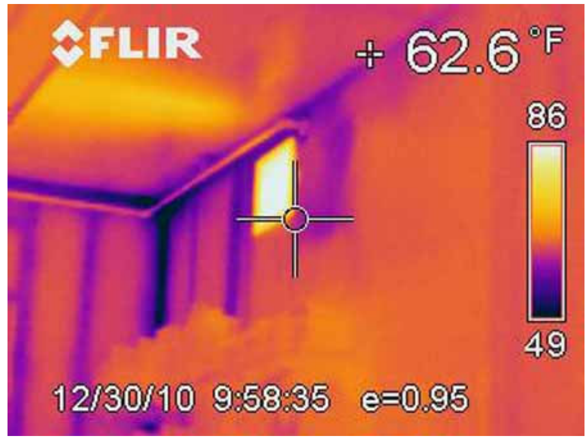
The stud bay between the exterior door and the door that enters the gym through the kitchen is missing insulation. The gym wall meets the main building at this point. Such junction points are common air leak passageways.

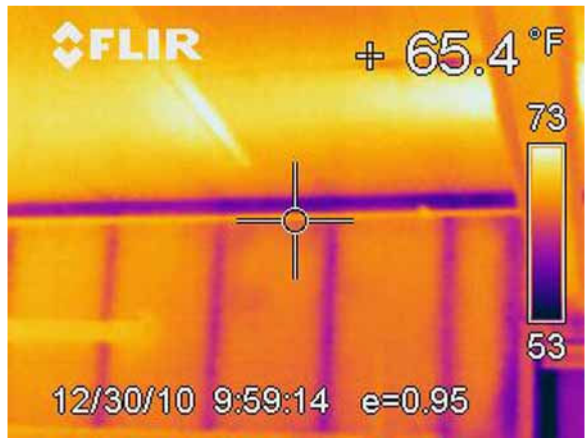



This supply duct and other holes in the ceiling like it need to be sealed with either caulking and/or expandable foam when installed to ensure an airtight seal.

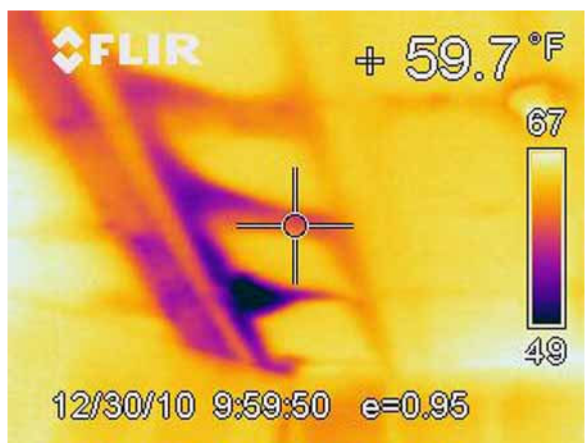



There are numerous cold spots along interior wall cavities. Note how the cold air is coming down from the ceiling/attic and gradually warming up as it contacts the interior sheetrock

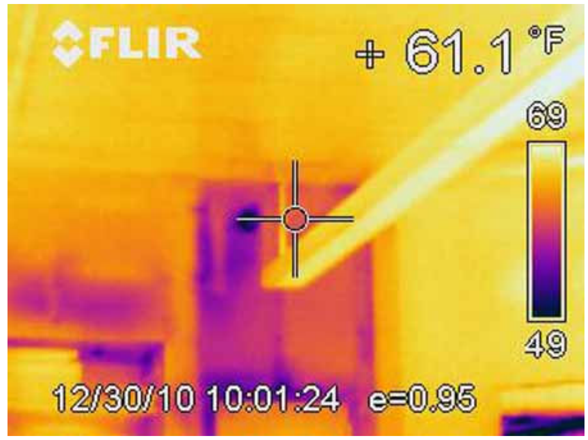



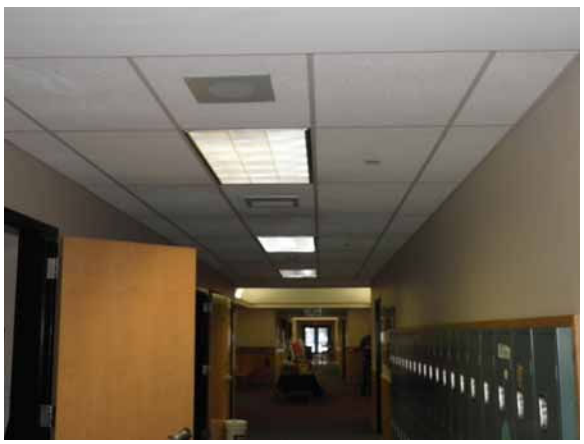
This image of an exterior wall is an example of an area that is well insulated.

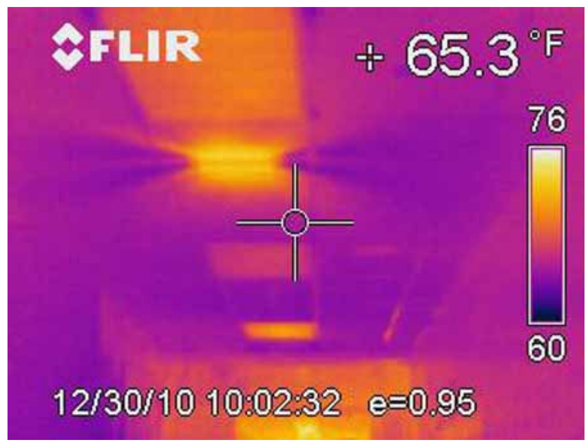



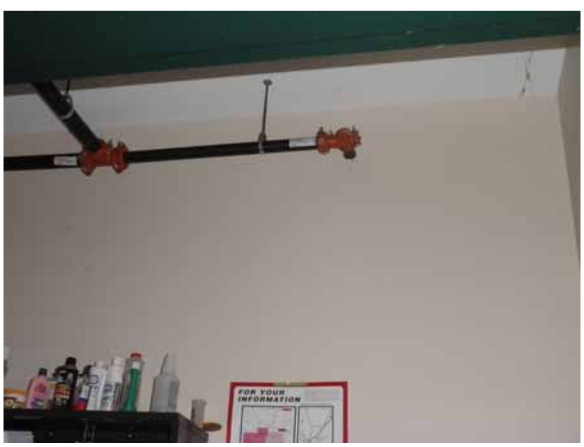
When viewed with the infrared camera, there are obvious thermal air leaks and insulation problems in the sections of raised ceiling in the main hallway.

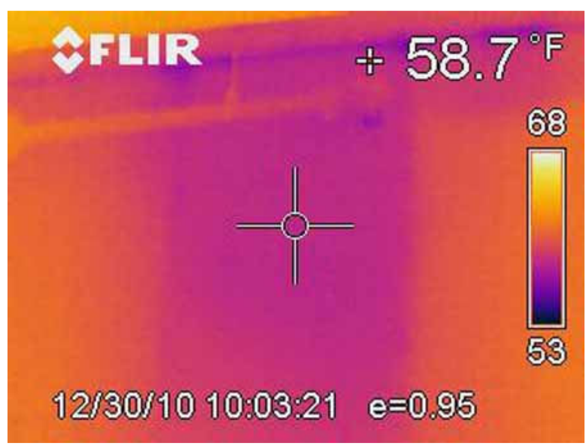


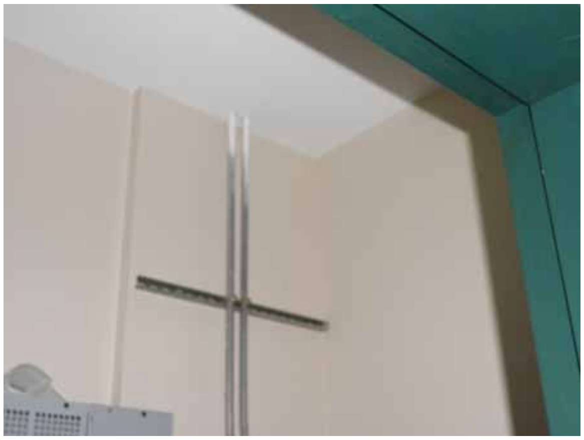
Another interior wall connected to the above attic space. There is most likely plumbing or wiring penetration in the top wall plate that is connecting the interior to the attic.

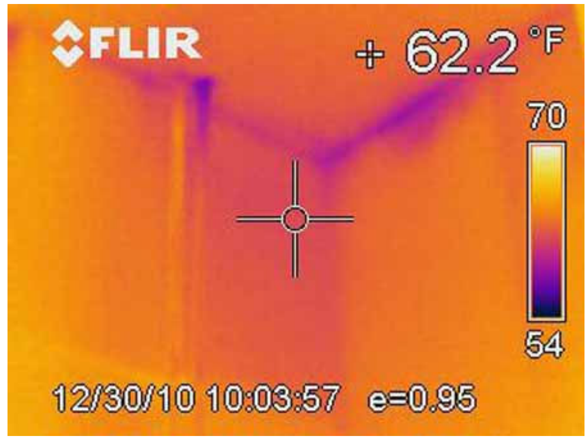


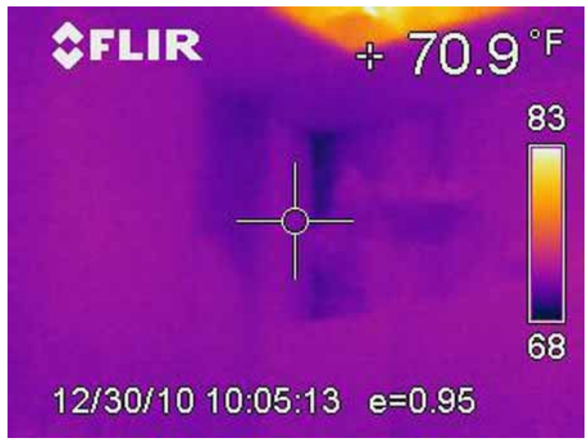




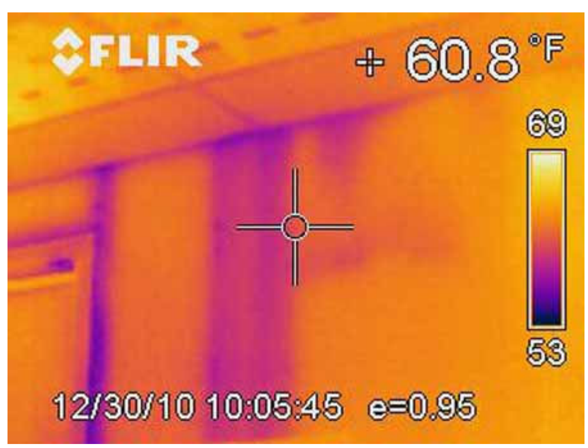


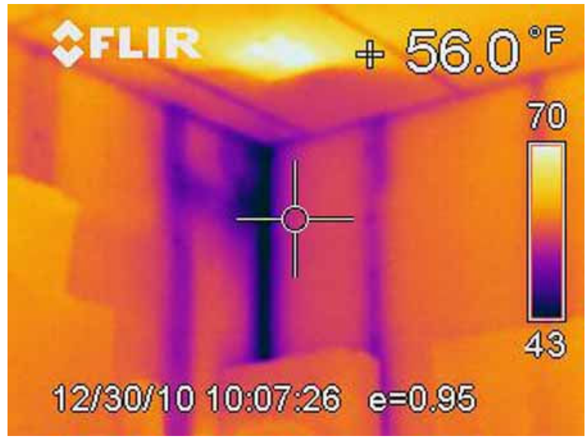




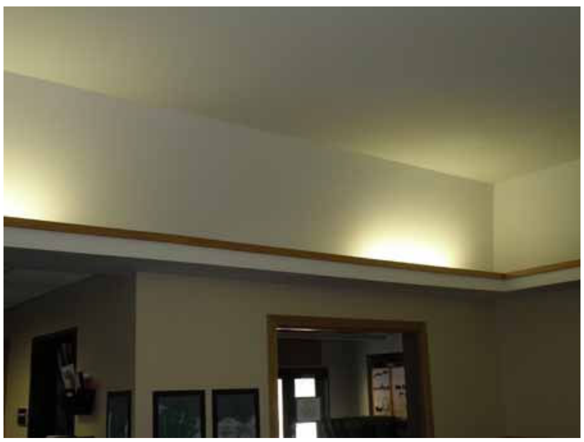


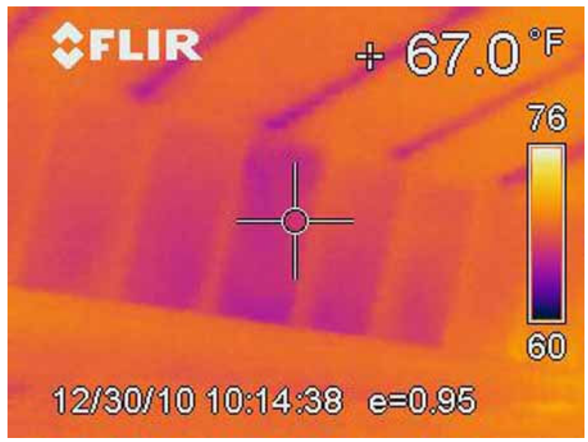
More interior walls connected to the attic. Students and faculty who sit directly adjacent to these cold areas will be colder than others sitting next to warm walls. The body heat of those next to walls will flow toward the cold areas, making them feel chilled; much in the same way sitting on a cold rock will make you feel cold.



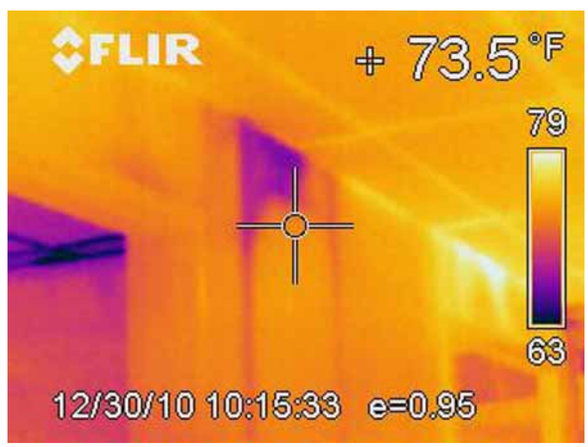


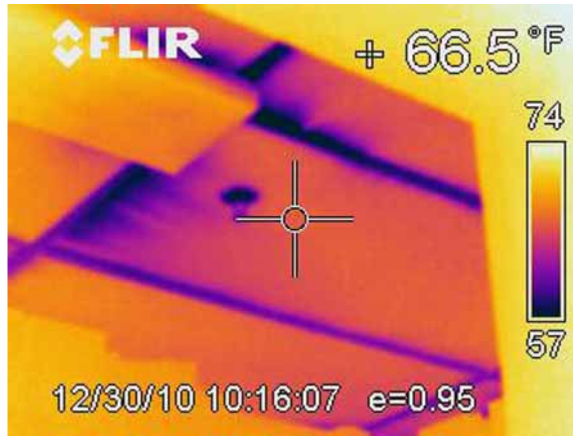
Clearly the bulk of thermal flaws captured by the infrared camera during the interior inspection, document walls that are connected to the attic area. During the blower door test, cold air is being pulled through the air leaks and into the wall cavities. Under normal circumstances, warm air rises up through these areas in much the same way that smoke travels up through a chimney. It is also important to remember that any amount of air that is lost through convection must be replaced. If the building only lost air, it would eventually implode. These air leaks do not lose a constant amount of air, but actually will lose more air when the temperature difference between inside and outside is at its greatest.



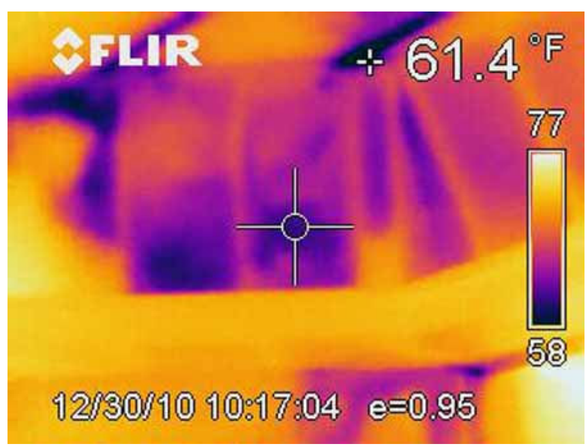


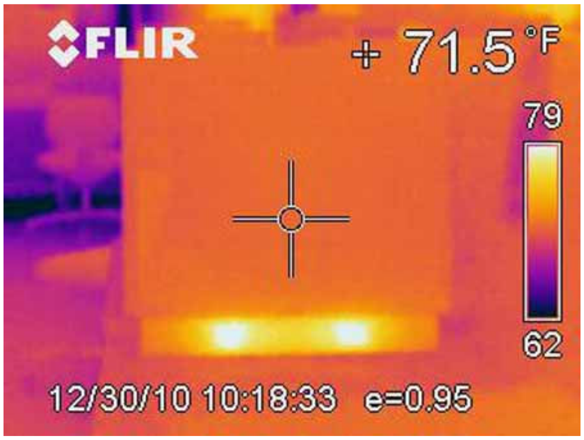
The soffit area is not well insulated and is connected to the above attic space.



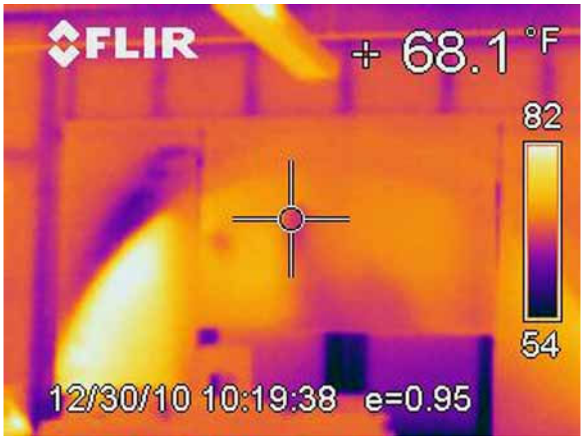

FLIR
+ 66.5 °F
74
57
12/30/10 10:16:07 e=0.95


FLIR
+ 65.5 °F
75
59
12/30/10 10:16:26 e=0.95

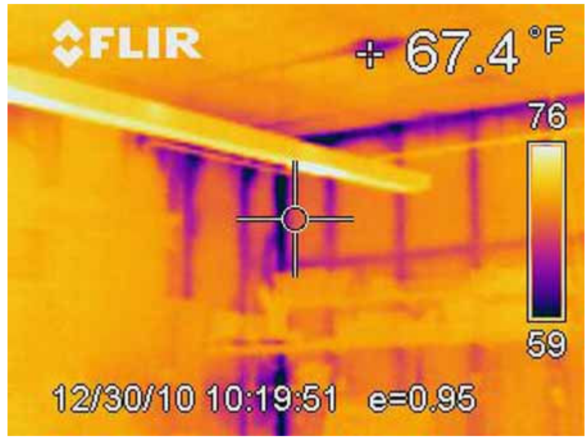

FLIR
+ 61.4 °F
77
58
12/30/10 10:17:04 e=0.95

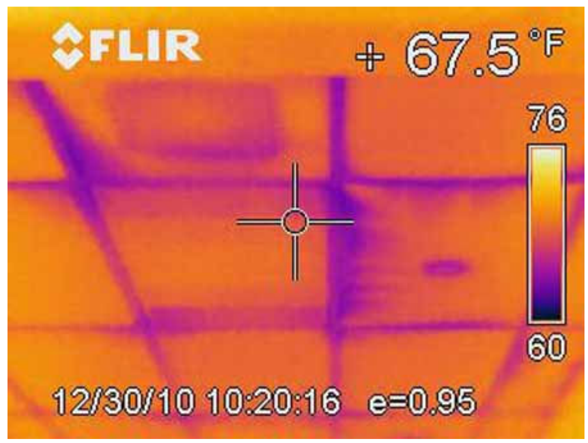


Standby losses (more commonly referred to as phantom loads) can add up especially when there is a significant amount of electrical equipment in a building. All computers, copiers, fax machines, TV's and other devises that consume power even when shut off should be manually shutdown, or should be plugged into smart strips that detect phantom loads and automatically stop sending power to the device.

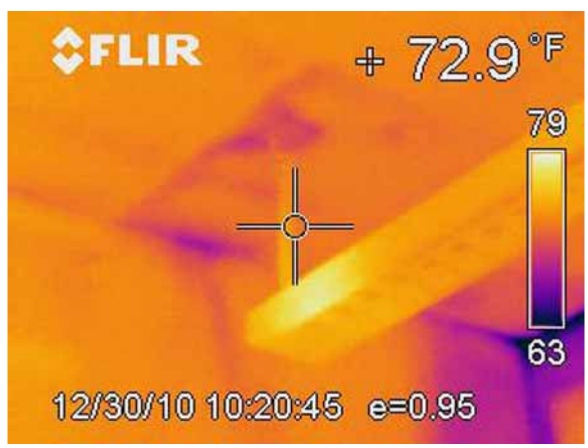


Fully draw the shades each evening and pull them up during the school day. This would be a good activity to get the students involved in saving energy.

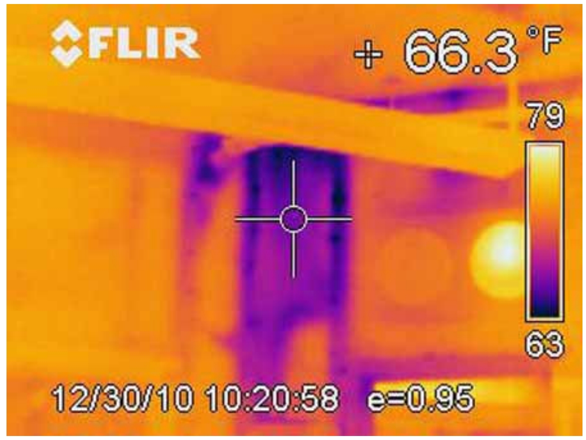


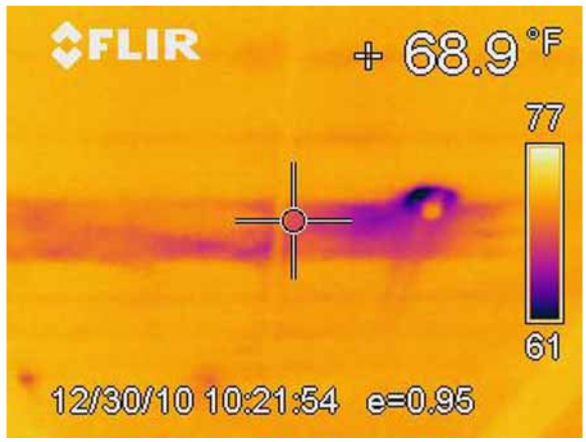


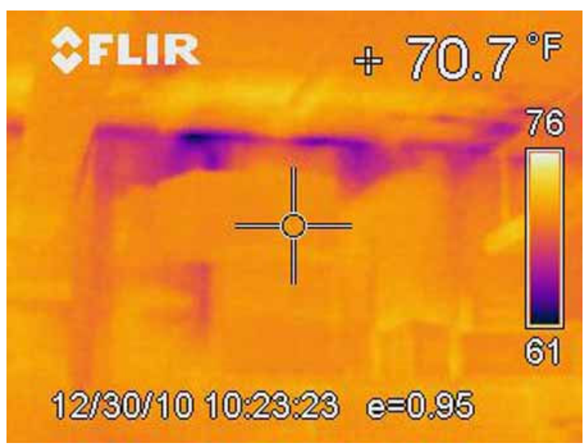
More air leakage through the ceiling tile. This is at the eastern entryway to the school.

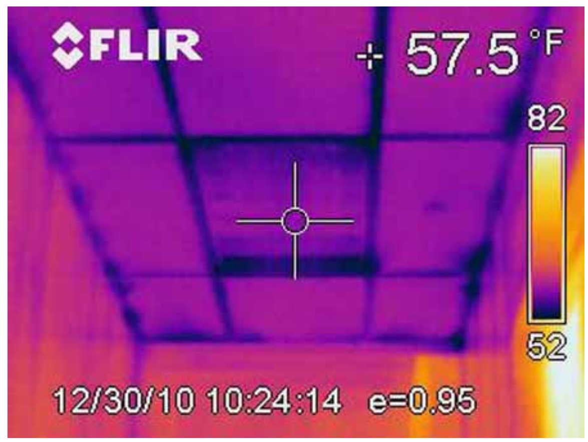


Although it may be difficult to notice the difference, the area above the suspended light appears wet in the image. Also note the cold wall section in the corner of the room.

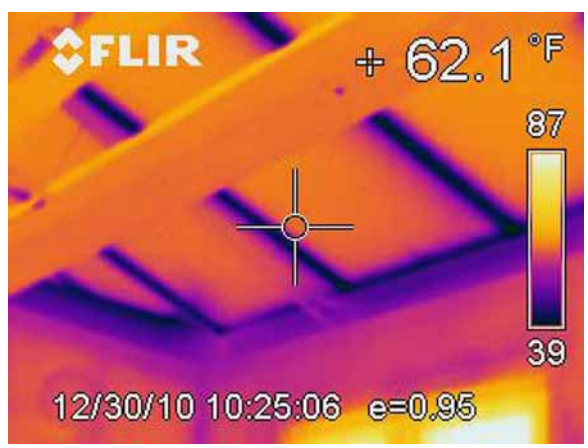

FLIR
+ 66.3 °F
79
63
12/30/10 10:20:58 e=0.95


FLIR
+ 68.9 °F
77
61
12/30/10 10:21:54 e=0.95

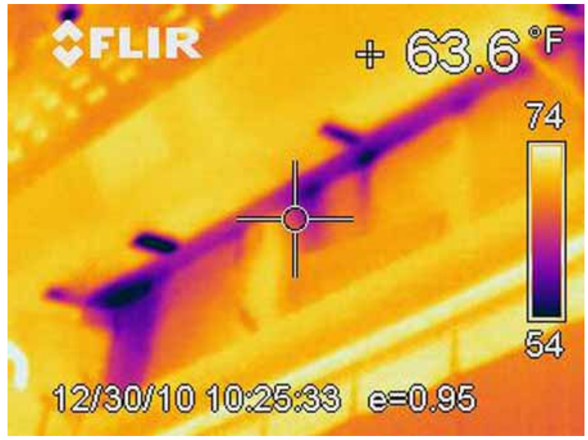

FLIR
+ 70.7 °F
76
61
12/30/10 10:23:23 e=0.95

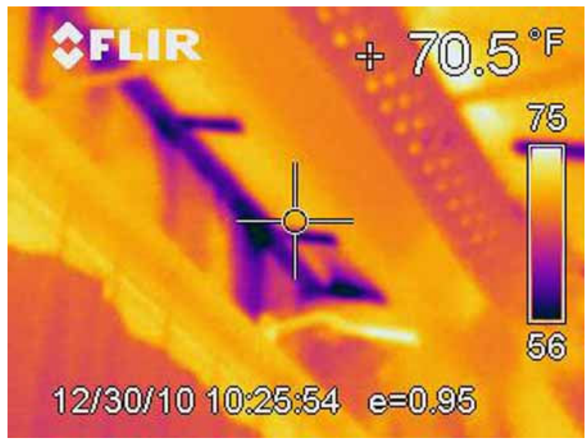


The hallway leading to the stage area is cold and quite leaky. This small roof area is separated from both the gymnasium and school and can easily be accessed by removing several of the ceiling tiles.

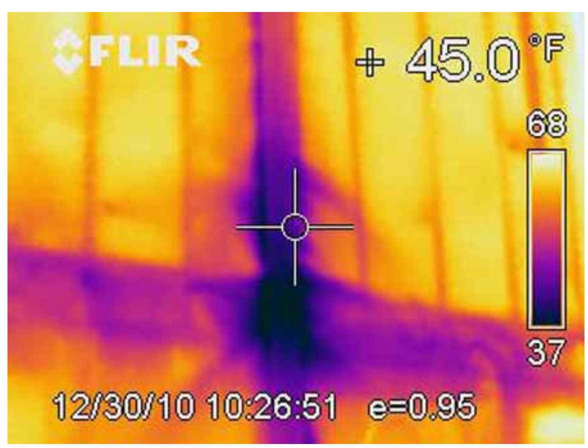


You can see the steel rafters underneath the finished ceiling. These framing members are large and extremely conductive and were easily detected in the exterior images.

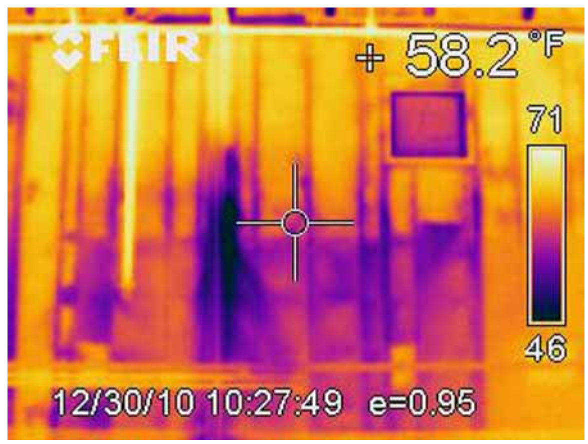


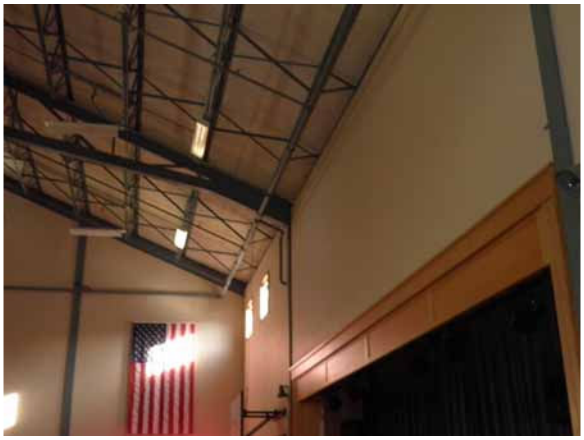


The above two images clearly show the support beam that connects the stage area to the gym wall. This beam is not well sealed, is leaking air, and is also extremely conductive.

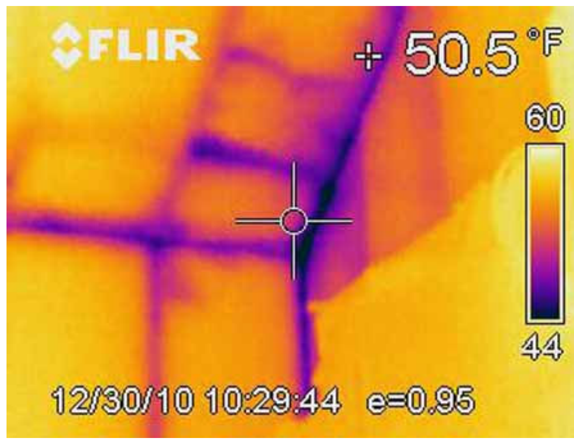


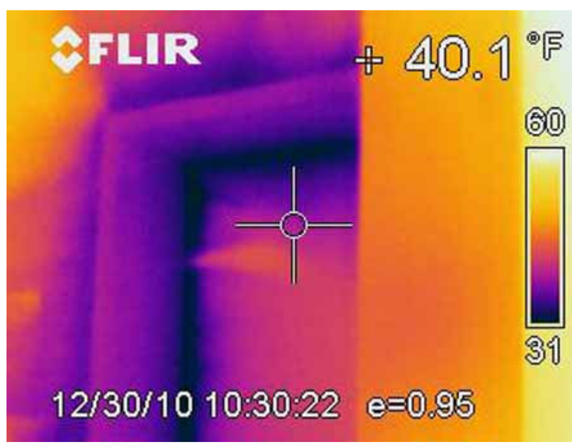
The steel framing in the gym is far more conductive than the framing members in the exterior walls of the school. The large beams and posts that support the building are highly conductive and in many areas are not well air sealed. The air leakage is likely due to minor settling or shifting of the building after it was constructed.



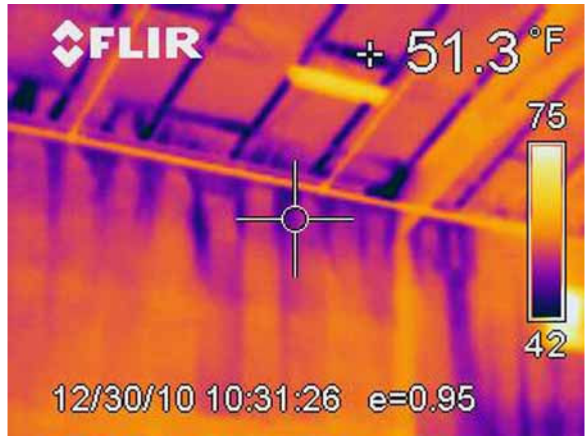


The air leakage along the top of the exterior wall and ceiling junction reinforces the information from the exterior images. This area is not well air sealed and is contributing to heat loss and to uncomfortable conditions in the gym and stage areas.





This door leads to the generator room, which is essentially outside the thermal envelope. For both safety and thermal efficiency reasons, door and wall should be well insulated and air sealed.



This shot of the east side gym wall clearly shows the air leakage at the top of the wall where the steel strut joins the wall and roof assembly.

Other Digital Images:

This section of the attic is connected to the mechanical room and was designed to be inside the conditioned space. The holes, un-insulated and poorly sealed doors, and gaps and cracks in the sheetrock all connect this area to the outside.


These images were taken from the backside of the mechanical room hallway. All vertically installed fiberglass must be covered on all six sides with an effective air barrier in order to attain its stated/intended thermal performance.


This duct has been stepped on and flattened (left). It goes to an interior fan which is leaking air around its perimeter. The right photo shows a problem that is common in many schools, hospitals and other public buildings. Access through the thermal boundary is attained by a trades person, wires, plumbing, or fire suppression equipment is installed, and the insulation is left to the side, and the hole is left wide open.

There are numerous holes in the attic floor which connect the outside to the building's interior conditioned space. The cellulose insulation is uneven in its distribution and depth. The average depth of the cellulose is 8 inches which at best (if it were in direct contact with an effective air barrier) would be an R-value of 29.6

The thermal flaws in the conditioned attic/mechanical room area do not end with the uncovered vertically installed fiberglass and the numerous holes linking the space to the outside. The left side picture shows that the bottom floor of the area is not blocked off, allowing a connection to the outside underneath the entire length of the floor.

Several of the Heat Exchangers are outside the thermal envelope and are not insulated. The result is that heat from the water pipes is being lost to the cold outside air before it warms the air that is delivered to the classrooms and other areas of the building. This in part helps to explain the differences in temperatures between various parts of the building, and represents a significant flaw in the distribution system.

The portion of the gym wall that adjoins the attic has uncovered, vertically installed fiberglass and exposed steel framing.

The above two images show the exterior side of the hallway connecting the boiler room to the conditioned/insulated section of the attic. Again, all vertically installed fiberglass must be covered with an effective air barrier on all six sides. Significant gaps and holes in this "thermal blanket" add to heat loss and decrease the performance of the insulation.

The above photographs are of the metal chimney for the boilers. According to manufacturer specifications, this 14"diameter pipe should have a minimum clearance to combustibles of 6". This code violation represents a health and safety concern which under BPI (Building Performance Institute) protocol receives top priority.

On the other side of this wall is a space between the flat hallway ceiling of the back stage access, and the roof. This gap in the thermal boundary helps to explain the poor thermal performance of the hallway ceiling.




More photographs of the numerous problems with the heating distribution system. All exposed joints should be sealed with mastic if they are not already, and missing insulation should be repaired or replaced.

As with most problems, there is usually more than one answer, or many different approaches one can take to accomplish similar results. In this section, I attempt to solve heating problems in the most sensible way given the particular situation. The fixes may not always be practical or economical for the building, depending on plans for the future, available resources, etc...Further discussion at that point can lead to the best solution.

Recommendations are prioritized in accordance with Building Performance Institute Standards. Health and Safety concerns always receive top priority when remediation measures are prescribed.

1) Air seal upper thermal boundary and effectively insulate to R-50 minimum.

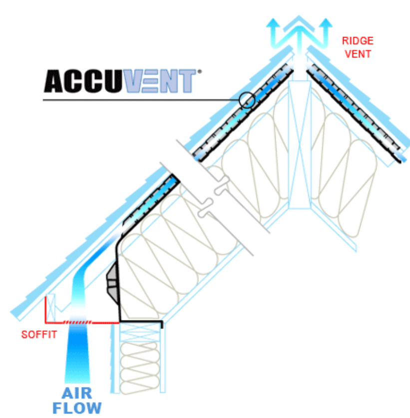
The upper thermal boundary (the area between the classrooms, offices, kitchen, library and dining room) and the attic needs significant air sealing work. There is an average of 8" of loose fill cellulose over the attic floor, which if properly air sealed would only provide R-30 thermal performance. Complicating the issue is the fact that the majority of the heating distribution system and a number of heat exchangers are outside the thermal envelope. Given this fact the best way to treat the area would be to enclose the entire area under the roof within the thermal boundary. The "second best" option is to seal the air leaks, seal the ductwork and insulate it better, and insulate around the heat exchangers. Both options are discussed below.

Option A - Realign thermal boundary at interior side of roof sheathing - Vented Assembly Method

There is far more to realigning the upper thermal boundary than spraying insulation to the back side of the roof decking. First, baffles and vent chutes should be installed at the exterior side of the top wall plate extending to the roof sheathing and then to the peak at all hip and gable ridges between all truss bays (See Fig 1 - 2)

Figure 1

Figure 2



The baffle vent (left) attaches to straight vents which extend to the ridge vents. The accuvents pictured above can be covered with spray applied polyurethane foam, or can be dense-packed against with cellulose.

After the vent baffles and chutes are installed, spray-applied polyurethane foam should be installed at a sufficient depth to attain an R-value of 40+. Any contract to install foam insulation should specify that the **minimum** insulation depth should be an equivalent of R-40. All exterior gable walls below the roof deck would need insulating, all roof and gable wall vents and penetrations connecting the roof and the attic to the outside will require sealing with proper materials such as caulking, spray applied foam insulation and/or rigid foam insulation.

Once complete, the entire attic area above the classroom and offices would be part of the thermal envelope. The benefits would include incorporating the entire distribution system within the thermal envelope, and would virtually eliminate heating system distribution losses. Any maintenance in the area could be conducted without worry of disturbing the insulation and air barrier. The actual thermal envelope would have less surface area exposed to the outside, which in turn would reduce conductive heat transfer through the building shell.

Total Cost of Improvement: $212,000.00 Estimated Savings = $8,096.00/yr.

Estimate Payback Years = 26.18 yrs.

Option 2) Maintain Existing thermal boundary by installing an adequate air barrier, more insulation and properly insulating all walls exposed to the outside in the attic.

There are so many penetrations connecting the conditioned space to the attic, that in order to properly/effectively air seal the area, the existing insulation should be removed. A commercial insulation vacuum can be used to remove the insulation effectively without creating dust and debris problems within the interior of the building. Several dumpsters could be strategically positioned around the perimeter of the building and the vacuum hose could be inserted into the attic area through any number of vents. Once cleaned, all holes connecting the attic to the interior should be sealed using appropriate material. These holes include, but are not limited to: wiring and plumbing penetrations, top wall plates, soffit penetrations, exhaust fan openings, and chimney and stack vent penetrations.

Wind baffles such as those shown in figure 1 should be installed at the top wall plates in all areas where the soffit vents connect the area to the outside. Figure 3 & 4 shows properly installed wind baffles after insulation is installed.

All vertical walls within the attic space must be covered on all six sides with an effective air barrier. This means that the south gable wall of the gym, and the walls surrounding the mechanical area need to be covered on the exterior. One inch rigid roam board insulation is the best material to cover the fiberglass. It will not only create an effective air barrier, but will reduce conductive heat transfer through the wood and metal framing members. The rigid foam should be installed all the way to the attic floor, and all joints should be sealed with either caulking, or an appropriate tape that adheres to the type of rigid foam used. Figure 3 shows a completed vertical attic wall covered with one inch polyisocyanurate rigid insulation.

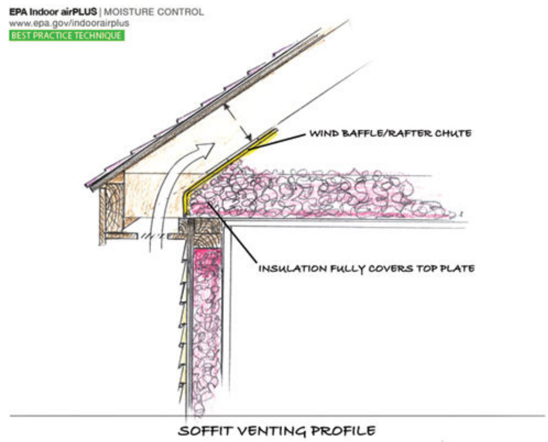
Figure 3

Vertical walls sealed and insulated with polyisocyanurate rigid foam board and sealed at the Grand Summit Lodge Mt. Snow. The attic floor is receiving final clean up prior to insulating with 2" of spray applied foam and cellulose.

In order to effectively seal the upper thermal boundary, after baffle vents are installed, and all large holes are sealed, I recommend spraying the attic floor with 2" of closed cell polyurethane foam. This step is the last to complete an effective air barrier to the vented attic space. To ensure the barrier is effective I recommend a blower door test be conducted, and a smoke machine be placed in the attic at the time of the test to ensure all air communication between the conditioned space and attic has been effectively sealed. Once completed, loose fill cellulose can be applied over the foam insulation at a minimum depth to attain R-50 thermal performance. (See figures 4-5)

Figure 4

Figure 5



Wind baffles ensure proper ventilation of the roof and attic without compromising the thermal performance of loose blown or other low density insulation materials.

Estimated Cost of Improvements = $68,000 Estimated Savings = $4,449.00/yr.

Estimate Payback = 15.28 yrs.

2) **Distribution System Efficiency Improvements**

The recommendations for distribution system improvements should be made regardless of which option is used to treat the upper thermal boundary. Although option one includes incorporating the entire attic system within the thermal boundary, it does not call for incorporating the attic within the area of intentionally conditioned space. Under option one, the attic space would be part of the thermal boundary, incorporating the distribution system within the insulated envelope, but the area would not have a thermostat, nor would it have ducts supplying heat to it. The attic would receive only heat through standby losses, and waste heat generated by the two boilers. The main intention of increasing distribution system efficiency is to ensure that a high percentage of heat generated by the two boilers reaches the occupied areas of the building without being lost to the outside.

The distribution system is more complex than what is typically found in a residential home, and in many commercial or public buildings. Within the distribution system there are two major components. First is the distribution of hot water generated in the two oil fired boilers. The most common way in which hot water systems deliver heat is through baseboard radiators, or in floor radiant heat systems which are becoming increasingly popular today.

Many people are familiar with heating system efficiency ratings. All newer furnaces and boilers come with AFUE (Annual Fuel Utilization Efficiency) ratings. When a furnace or boiler technician works on a heating system they also often test for efficiency. In both cases the efficiency percentage relates to how efficient the heating appliance is converting its fuel to heat. Efficient oil fired boilers and furnaces run in the mid to upper eighties in efficiency, while gas fired units run in the low nineties.

When discussing distribution system efficiency we are talking about how efficient the heat generated by the heating unit is delivered to the conditioned space within the building envelope. Distribution efficiency issues can greatly impact a building's energy consumption even when the heating unit is operating at maximum efficiency. Imagine a furnace running at 85% efficiency that has a major supply trunk line that is disconnected and is spilling all of its heat into an unconditioned space such as an attic. Although the furnace itself is converting fuel to heat at a high efficiency, the heat is never reaching the conditioned space where the thermostat is located. As a result the thermostat continues to call for heat and more energy is consumed. This is to some extent what is happening with the distribution system at the Warwick school.

The hot water generated through the boilers at the school is circulated through pipes which deliver the hot water to heat exchangers. The heat exchanger works similarly to the way a radiator in a car works. The heat exchanger consists of coils connected to small fins, that distribute the heat over a larger area. At this point, the other major component of the distribution system takes control of delivering the heat to its intended areas. Outside air is pulled into one of the three ERV's (Energy Recovery Ventilators) and is ducted directly to one of the heat exchangers. The air passes over the heat exchanger's fins and is further warmed, it is then delivered via the duct system to supply vents in the classrooms, offices, cafeteria etc.. The air takes most of the energy (heat) from the hot water and the water is redirected or circulated back to the boiler to be re-heated.

Many of the heat exchangers are located outside the thermal envelope. They can be insulated by making a box around them using heat resistant rigid foam board and mineral wool insulation. The duct work carrying the hot air to the classrooms needs significant work, all joints that are not currently sealed, should be sealed with duct mastic, and areas where the insulation has either come apart or fallen off should be re-insulated. If option 2 is used to increase the thermal efficiency of the attic, I would recommend that more insulation be added to the supply side ductwork that is located outside the thermal boundary.

The current condition of the distribution system helps to explain the uneven temperature distribution within various areas of the building. Areas supplied by the heat exchangers that are located outside the thermal envelope will deliver cooler air than the ones that are located within the thermal boundary. In most cases, the heat exchangers located outside have longer duct runs which further contributes to the problem.

There is still another issue with respect to the distribution system which impacts energy consumption at the school. As previously explained, the ERV's pull 100% of the supply air for heating distribution from the outside. Each ERV moves 4000 cfm of air through the ductwork and into the building. The system was set up to provide adequate ventilation to the occupied areas of the building, while at the same time providing enough fan power to run the force air portion of the heating distribution system. Because of the thermal inefficiencies documented in this report, the ERV's are required to run almost 100% of the time to supply heat to the building. The result is premature failure of the ERV's moving components, higher energy consumption (both heating oil and electricity) and an over ventilated building. The ERV's run at approximately 70% efficiency, meaning that that if it were 100 degrees Fahrenheit inside, and 0 outside, the air coming out of the ERV and to the heat exchangers would be about 70 degrees. The colder it is outside, the colder the air is coming out of the ERV's, making heating more energy intensive.

Even with the recommended improvements to the distribution system and thermal envelope, it is very possible that the ERV's will continue to operate more than required to provide the ventilation for the building's students and faculty. I would recommend hiring a professional ventilation company to investigate options that would decrease energy consumption and not over-ventilate the school. This should be done only after envelope improvements are made to the building. One possibility would be to reduce the amount of fresh air coming into the system and balance that by re-circulating some of the return air into the system. Although this idea may sound like a simple fix, it is very complex and will require a ventilation expert.

Estimated Cost of Improvements = $30,000.00 Estimated Savings = $7,976.00/yr.

Estimated Payback = 3.76 yrs.

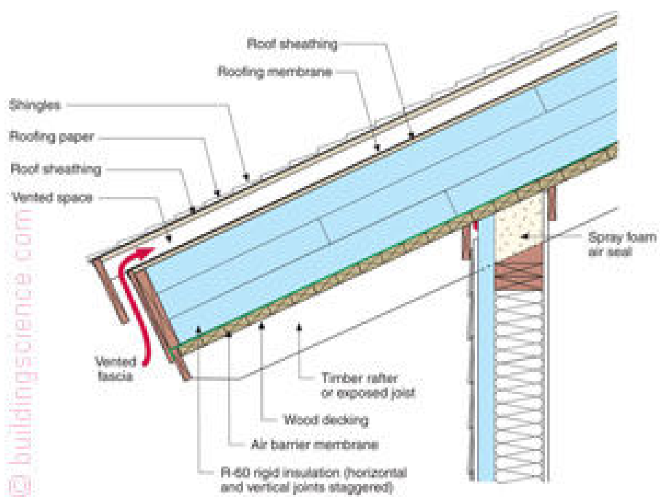
3) Air seal and increase the insulation level of the Gymnasium and Stage Ceilings.

The infrared images, and digital photos of the gym roof and ceiling show two distinct problems. There is significant conductive heat loss taking place through the gyms rafters, and there is air leakage along the steel strut at the soffit/wall junction. Reducing the air leakage may be difficult without taking off the upper row of siding along the exterior side of the walls. The optimal time to conduct any repairs to these areas upper thermal boundaries is when the roofs are re-shingled. It is important to mention that it is not common for a roof to need re-shingling after only six years. The premature failure of the asphalt shingles is likely due in part to inadequate thermal performance (freeze/thaw cycles) and a lack of ventilation (overheating of the asphalt shingles).

To address the heat loss, and maintenance issues, I recommend stripping the roof down to the roof deck (this should take place during re-shingling anyway) and installing a minimum of 2 inches of rigid foam insulation directly to the exposed decking. It is important that proper sealing of all seams and joints takes place when the insulation is installed. Once in place, strapping can be fastened over the rigid foam board. The strapping must be fastened with the run of the rafters, perpendicular to the eves. A new roof deck can be installed to the strapping and over the foam. The strapping will provide nailing for the roof deck, and will also create an air gap to provide ventilation for the roof.

This remediation will increase the depth of the roof and as a result will require that the top 1"x 4" fascia be replaced with a larger piece of trim. Rather than replacing the soffit, 3/4" blocking can be used to "hold off" the new piece of fascia from the lower fascia board. The new fascia will extend up to the new roof deck creating a vent pathway between it and the lower fascia. (See Figure 5)

Figure 5



The technique above can be used to create a vent pathway to the new roof deck. The new fascia board installed over the blocking does not have to extend all the way down and over the lower/older fascia board. When completed the fascia will match the original trim detail.

While the roof work is being conducted, the upper struts connecting the roof to the exterior walls should be air sealed. The old soffit vents need to be air sealed to ensure that the ventilation pathway is between the old and new decking as depicted in figure 5. This work will require some dismantling of the eve areas, and once access is attained, the joint between the strut, and roof should be sealed with spray applied closed cell foam insulation. During this phase of work it is very important, that the roofing company and insulation company communicate to determine that access is sufficient to air seal the area with spray applied foam.

Estimated Cost of Improvements = $18,000.00 Estimated Savings = $1,547.00/yr.

Estimated Payback = $11.6 yrs.

4) Air seal gymnasium exterior walls.

Air sealing the gymnasium's exterior walls must be done in the interior to be cost effective. The infrared images captured significant air leakage through the walls, especially around the large steel posts. Caulking all the joints between the exposed steel framing members and the interior walls will help to reduce the unwanted air infiltration. In areas where gaps are more than 1/8", backer rod can be used to fill the voids and then caulking can be used to complete the air seal and provide a finished look. The type of caulking used should be approved for air sealing, adhering to metal, and be elastic in order to move and shift with the building.

Figure 6

Accessing and spray foaming the metal struts at the Putney Schools new performing arts building.

For the purpose of simplifying the energy model, the cost of this recommendation has been included in the total cost for reducing air infiltration. The total for all air infiltration reduction was estimated at $30,000.00. The actual cost of this recommendation is approximately $8,000.00.

5) Reducing the consumption of electricity

Lighting constitutes the school's largest single use of electricity. The majority of the school's lighting fixtures are high efficiency T-8 fluorescent units that would not be cost effective to replace at this time. The metal halide lights in the gym are 400 watt fixtures which should only be used when necessary. The bathroom fans and lights are equipped with motion sensors which turn on and off automatically when the rooms are occupied. The most effective method the school can employ to reduce lighting demand is to conduct an energy conservation campaign involving both students and faculty. Everyone should be reminded to turn lights off when not needed, to take advantage of day lighting whenever possible, and to become proactive in conserving energy.

The energy model (TREAT) estimated the school's consumption of electricity to be well below the actual consumption reflected in the billing data. This discrepancy is likely due to the significant use of electricity by the heating and distribution system. With the three ERV's running almost constantly during the heating season, and the circulators constantly moving water through the system, the schools use of electricity is increased. To determine the exact amount of electricity attributable to the heating and distribution system, on/off data loggers would need to be placed on the equipment and long term data would need to be recorded and analyzed. For the purpose of this report, I have attributed the difference between modeled and actual electricity consumption to the heating and distribution system. It is my belief that once improvements to the thermal boundary are made, the electrical use will drop much closer to what is predicted in the energy model.

Meaningful reductions in electric use can also be made by reducing phantom loads consumed by devices such as computers, monitors, copiers, and televisions. The computers and monitors in the computer lab should be wired to a main switch that shuts down power to these devices in the evening, weekends and holidays. Other devices in classrooms and offices should be plugged in to "smart strips" that detect when the device is drawing low amounts of electricity and all power is shut off to the device.

The school's average annual use of electricity totals 93,644.2 kWh/year. The energy model calculated an annual use of 72,645.3 kWh/year, a 29% difference in actual to model. It is reasonable to predict that once heating distribution and envelope improvements are made, the school's use of electricity will be much closer to the modeled use. Another 5-10% reduction can be realized by implementing the recommendations to install smart strips, wire the computer room to shut all devices off during non-school hours, and implement an energy conservation program.

Actual use = 93,644.2 kWh/year - 72,645.3 kWh/year = 20,998.9 kWh/yr.

20,989.9 kWh/yr + 7.5% = **22,573.82 kWh/year** = ~ **$1,220.00 savings annually**

6) Implement and maintain a school wide Energy Conservation Campaign

It is unlikely that the majority of students and faculty are aware of how much energy the school consumes, how energy consumption impacts the annual budget, and what effect the school's energy consumption has on the environment. One gallon of #2 heating oil releases 16 pounds of carbon into the atmosphere. Consuming an average of 844 gallons of fuel oil per month releases 13,504 pounds of carbon into the atmosphere/month, or approximately 162,048 pounds annually.

Math and science classes can incorporate the school's effort into their learning programs. They can determine the school's total carbon footprint by investigating all activities that release carbon into the environment from fuel oil and electrical consumption to diesel fuel consumption by buses, gasoline consumption by faculty commuting and student pick off and drop off, waste disposal etc. While studying the school's energy use, students may come up with activities and programs that will further lead to energy conservation and a greener environment.

Students can become involved in drawing the shades at the end of the school day, and opening them first thing in the morning. Lighting use can be limited to what is needed, taking advantage of natural light whenever possible. Incorporating a public awareness campaign can be a positive step in reducing the school's energy consumption while at the same time increasing pride in the school and its accomplishments.

Estimated Cost of Improvement = $ 1,000.00 Estimated Savings = $285.00

Estimated payback = 3.5 years

Funding Energy Efficiency Projects:

Under the economic stimulus bill of 2009, a significant amount of money was allocated to each state to conduct energy efficiency improvement work to public buildings. Funding is available under the EECBG (Energy Efficiency and Conservation Block Grants). The following contacts were listed on the Massachusetts state web site.

Lisa Capone (617) 626-1119 lisa.capone@state.ma.us

Robert Keough (617) 626-1109 robert.keough@state.ma.us

Other than the EECBG grants, there are numerous other programs offered by both the state, and federal government. The environment for funding energy efficiency projects is very dynamic, with new programs available on a regular basis. For further information on programs and grants visit the following web sites: www.mass.gov, www.epa.gov, and U.S. Department of Energy @ www.energy.gov.

Interpreting Energy Models and Cost/Benefit data

As previously explained, energy modeling is not an exact science, and as such the figures should be used as a guide to understand the costs and benefits of improvements and to help prioritize work. Breaking down each improvement according to cost/benefit alone can sometimes be misleading. Air sealing work is often the most cost effective improvement one can make to reduce energy consumption. When air sealing is part of an overall package to increase insulation levels and thermal performance the figures often favor the air sealing as opposed to the benefits of adding insulation. A good example of this is the air sealing that needs to take place in the attic area above the classrooms and offices. Applying two inches of closed cell foam will effectively air seal the boundary between the conditioned space and the attic, but will only add R-12 in insulation value. The cost of applying foam to the entire attic floor vs. the benefit of R-12 does not look like a good decision from a cost/benefit standpoint. However, when you consider that it is an essential step to air seal the porous barrier between the conditioned space and the attic, the recommendation makes sense.

Fuel Cost data was determined using the current price/gallon. Any change in pricing will and project cost will affect the cost/benefit information provided in this report.

I have run two separate remediation packages through the TREAT energy model for the building.

The first package contains remediation recommendation 1 A, and recommendations 2-6.

Total Cost Package 1 = $ 230,000.00 Estimated Savings = $17,353.00

Estimated Payback = 13.25 yrs.

The Second package includes remediation recommendation 1 B, and recommendation 2-6.

Total Cost of Package 2 = $ 126,000.00 Estimated Savings = $13,184.00

Estimated Payback = 9.6 yrs.

Conclusion:

An energy audit in and of itself does not save energy. In order for meaningful reductions in energy consumption to become a reality, the recommendations in this report must be implemented. Due to budget constraints, it may not be feasible to implement all of the recommendations in one year, or even over several years. This report should be used as a guide to implement a long term energy reduction strategy for the school.

Any work conducted as a result of this report should be done by an experienced and certified building performance company. I recommend that Building Performance Institute Accreditation be a pre-requisite to bid on the project. Any company contracted to conduct the recommended energy efficiency improvements should have the capacity to conduct testing during each phase of the work. The results of the tests should be presented to the town's energy committee or a representative of the committee before the next phase of the project is implemented.

The return on investment figures were generated by estimating the cost of each recommendation listed. Once a contractor is selected, the cost of the project can be changed in the energy models to determine likely payback time.

Any questions pertaining to this report, and/or questions related to improving the energy efficiency of the Warwick School can be sent via email to Kaaudits@gmail.com.

Glossary of Terms

AEP's	Advanced Energy Panels – cross-laminated poly-olefin aluminum framed interior inserts for windows. Converts single pane window to Energy Star rated window.
Air Barrier	Any part of the building shell that offers resistance to air leakage. The air barrier is effective if it stops most air leakage.

Blower Door	A device that consists of a fan, a removable panel, and gauges used to measure and locate air leaks.
BTU	A British Thermal Unit is the industry standard for measuring heat. One BTU is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit. 1 wooden kitchen match is roughly equivalent t o a single BTU.
CFM	cubic feet/minute
CFM 50	The number of cubic feet/minute of air, flowing through the fan housing of a blower door when the house pressure is 50 pascals. This figure is the most common and accurate way of comparing the air-tightness of buildings that are tested using a blower door.
Cellulose	A higher performing and environmentally sound insulating material made of recycled newsprint that can be applied in a variety of ways. Loose fill cellulose can be installed in flat attic spaces, its R value comes from it depth. Dense-packed cellulose is ideal for filling enclosed cavities, but must be installed greater than its settled density (3½ pounds per ft^2) to prevent settling. Damp spray cellulose can be installed into open vertical cavities and shaved smooth for later drywall installation. Thermal House utilizes borate treated cellulose that is fire retardant and an irritant to pests and rodents
Closed-cell Foam	All poly-urethane foam come in a variety of densities. Open cell foam are generally in the ½ pound density range and serve as an air barrier and excellent insulator. Closed-cell foams come in a variety of higher densities from 1 ½ pound to 3 pound foams. Closed cell foam act as a complete air and vapor barrier.

Conditioned	Intentionally heated or cooled areas of a building are conditioned.
Depressurize	To create a lower pressure as compared to a standard of high pressure.
Envelope	The building shell. This consists of the exterior walls, floor, and roof assembly of a building.
Infiltration	The inflow of outdoor air into the indoors, which is accompanied by an equal outflow of air from indoors to the outdoors.
Pascal	Unit of measurement of air pressure – abbreviated Pa
R-value	Used to measure the thermal resistance of building components in numbers ranging from 1 to 60. Higher numbers equal better heat retention. R values (unlike U-values) can be added together.
Retrofit	An energy conservation measure that is applied to an existing building. Also means the action of improving the thermal performance or maintenance of a building.
Stack effect	The draft established in a building from air infiltrating low and exfiltrating high.
U-value	The inverse of R-value. Meaning U=1/R. Commonly used for rating windows and heat load calculations.