Ice Dam Symptoms and Solutions for a Cold-Climate Roof

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ABSTRACT

Ice dams occur on cold climate roofs when warm zones on the roof melt snow, and cold spots simultaneously freeze the water into large ice formations, typically found on eaves. This is a result of improper air sealing and attic insulation, insufficient attic ventilation, and an assortment of design and construction flaws in new and old homes. Attic bypass in the winter relates to escaping heat from conditioned portions of the house into the attic as a result of an inadequate vapor and thermal barrier separating the two zones. Inadequate attic ventilation perpetuates ice dams by failing to cool the roof deck and venting moisture out. Non-vented warm and moist air can melt snow unevenly, and in extreme cases lead to frost in the attic. This fate causes a home durability issue, and can remain unfixed for years without proper diagnostics and solutions. This research will quantify and analyze attic bypass and air sealing effectiveness using zone pressure diagnostics and blower door testing on a South Minneapolis home. Contractors, homeowners, and diagnosticians to understand how ice dams occur and the relation to conditioned air infiltrating the attic zone will use this information.

INTRODUCTION

Ice dams occur on many homes annually and can incur major water damage repair costs to homeowners. This phenomenon is a result of melted snow on the roof that freezes over the eaves and blocks water from falling. Water will deteriorate shingles, sheathing, and wood rafters if it stands for long enough. Heat leakage from the house causes this snow to melt, but the moisture the heat leakage carries can be even more dangerous than the water from the melted snow. Heat leaks through penetrations in the pressure boundary separating the conditioned space of the house and its attic. The moisture from the house's conditioned air condenses and freezes on cold surfaces in the attic at temperatures less than 32 degrees Fahrenheit. Attic frost occurs on wood rafters, wood sheathing, and the insulation in an attic. Mold forms in the attic when this frost melts, which is a significant indoor air quality issue for the house and its occupants.

These problems are difficult to identify without adequate knowledge and resources to evaluate building performance. For the common homeowner, mold and ice dams may seem an annoyance brought upon by the extreme weather. However, these issues often point to areas of air leakage from the house. Homeowners should care about this because this points to significant energy loss as well as being harmful to the house. Energy loss on cold days increases energy bills. Older homes are more notorious for these leakages because of inadequate insulation and aging of materials, but penetrations in the air barrier between the attic and conditioned spaces occur in almost every home, old or new, in varying magnitudes.

The homeowner cannot quantify this problem alone, and very often the problems can be undetectable without adequate tools such as an infrared camera and blower door. For this reason, a home energy auditor is recommended to inspect a house with attic or ice dam issues. It is important to understand why ice dams occur to better realize how the energy auditor can resolve these issues. *The three core reasons for ice dams are: Inadequate insulation in attic, poor air sealing of the attic to house pressure boundary, and inadequate attic ventilation.* Image 1 below depicts a basic ice dam and how it forms on a roof.

Image 1: Formation of an Ice Dam on a Roof

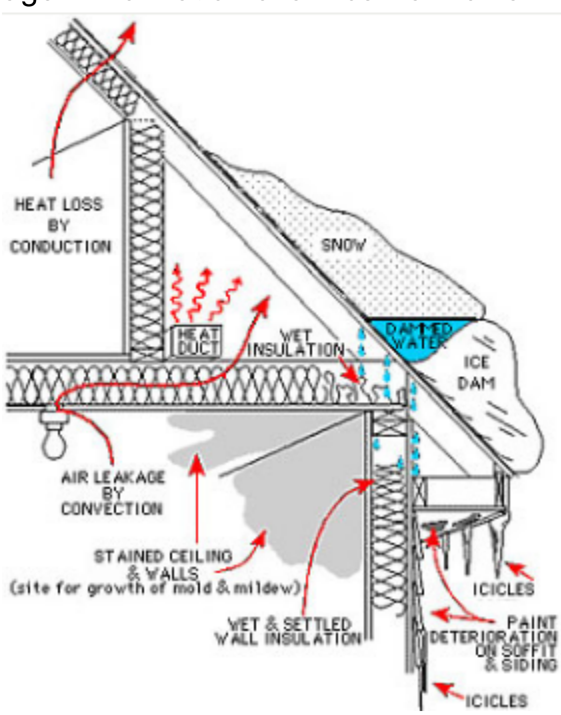

Image 1: Depicts how an ice dam is formed and the effects it can have on a house.

Inadequate insulation

Insulation prevents heat flow, but when the conditioned air inside the house is at a drastically warmer temperature than the air in the attic, then heat will leak faster. A proper amount of insulation must be added to the attic before other places because it can hold the most insulation and is the location of many harmful air leakage locations. Houses in MN built to the MN 2015 energy code are required to have R49 in the roof, so this would be a good goal for a homeowner to add. The current insulation value can be identified visually by determining the material and thickness of the layer of insulation in the house. The R-value can be determined with these measurements and by using the values given by Appendix 1. Ducts or other chase ways from the conditioned house must also be insulated to prevent heat leakage. Areas such as recessed lights may receive less insulation because of the space the box shaped fixture takes in the attic, so these areas must be well spray foamed. The end of an eave is also difficult to reach with insulation due to it being pinched between the rafter and joist. Attic hatches are another location where insulation is commonly neglected. Other areas commonly inadequately insulated are knee walls separating portions in an attic. Assessment of insulation levels should begin in these areas if ice dams are being investigated.

Poor Air Sealing

A pressure boundary in a house describes the theoretically airtight division between a conditioned and unconditioned space. This barrier should be aligned with the thermal boundary to negate the most heat leakage. Ducting in the attic greatly complicates the pressure boundary when placed outside of conditioned spaces. Commonly ducting and even HVAC equipment itself is placed in the attic. This is a problem when it is not properly air sealed and insulated because leaks in the ducts or equipment directly ejects warm, moist air into the attic. Bath fans and their ducts in the attic are another location where warm, moist air can leak into attic spaces. The pressure boundary is established at the attic by drywall or by a sheet of poly beneath the ceiling joists. Penetrations in the pressure boundary occur in gaps of the drywall, commonly for electrical or plumbing holes, recessed light boxes, and attic hatches. These areas are the culprit for air leakages, and some will be easier to identify and fix than others. An infrared camera used with a blower door test is the best way to identify air leakage. A process to measure the air sealing potential of the pressure boundary is discussed in the Methodology section. Air leakage in a house is measured and quantified using the blower door test, and the specific air leakage from the house to the attic is determined by applying zone pressure diagnostics to the blower door test.

Inadequate Attic Ventilation

Attic ventilation does not describe putting ducts and heating equipment in the attic, but refers to fans and vents placed along the roof deck, soffits, or gables. Attic ventilation combats the problems that be a result of improper insulation and inadequate attic air sealing. Cold air is naturally taken in from outside through the soffits and gables and released through openings towards the ridge of the roof. This keeps the roof deck cool, which prevents heat from the house from building up and melting snow on the house. Ventilation must be placed continuously among the soffits and must have sufficient openings towards the ridge. Opening up the house for outside air to flow seems to not make sense for energy efficiency, but it is necessary to prevent ice dams and attic frost. Intake should at least equal exhaust, but it is acceptable and sometimes favorable to have more openings by the soffit and less by the ridge. This will cause a positive pressure in the attic by allowing air to enter faster than exit. The theory behind this is that creating a positive pressure in the attic will reduce heat from escaping into the attic. If there is insufficient attic ventilation, than the roof deck will melt snow easier and will create a buildup of moisture in the attic. It is important to know that adding venting should take place after attic bypasses are sealed. Not doing this can lead to attic mold or frost. Baffles leading from the soffit to the ridge are very helpful in directing the air to flow passed layers of insulation and across the roof deck. Image 2 and 3 give simple depictions of recommended ventilation and baffles in an attic.

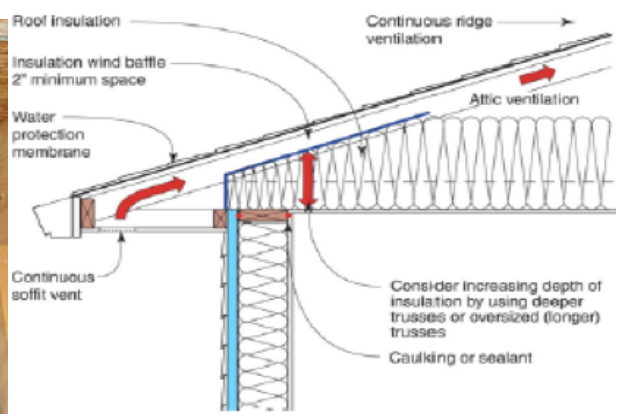

Image 2: Example of a baffle in an attic to allow air ventilation passed insulation.
http://www.diychatroom.com/attachments/f9/42924d1324578013-proper-vent-baffles-continuous-not-dsc04220.jpg
Image 3: Pathway attic ventilation takes in a typical wall to eave assembly. Baffle is shown in this description as well.

PURPOSE

Ice dams are a complex phenomenon and often difficult to identify the underlying cause. Because the house acts as a system, there are many different possibilities for conditioned air to travel through the house and into the attic. The path of air leakage is often not straightforward and is constantly affected by the HVAC and other appliances that affect the pressure in different areas in the house.

A snowmelt pattern was noticed among houses of the same house design. Dr. Robert Seavey owns one of such houses and wanted to understand what was causing this to happen, as a snow melt pattern such as this can indicate possible ice dam formation. A chase way was discovered to be underneath this part of the attic, but was thought to be sealed to the attic. Image 4 gives the snowmelt pattern that inspired the research. The three reasons for ice dams were interpreted in relation to the tested house to determine how this managed to cause such a snow melt pattern.

Image 4: Snowmelt pattern in middle of roof indicates uneven heating of the roof deck. This was theorized to be an area where heat leakage was rather high from the house.

METHODOLOGY

To determine the cause of this snowmelt, and to consider possible solutions, it is important to determine where the excess heat is coming from and how drastic a difference there is. It is also important to consider the effects of attic ventilation and how it affects the airflow in the roof.

Temperature and Relative Humidity of Zones

Four HOBO data loggers were placed in the roof in places of interest. The temperature and relative humidity of zone above the chase way was compared to that of three other different zones. The locations of these data loggers, along with the chase way and attic hatch, can be seen in appendix 2.The data loggers recorded a temperature and relative humidity every 10 minutes beginning October 2015- Late April 2016. Trends within these points were interpreted in relation to the zones of the house the data loggers were placed above. Higher temperatures and relative humidity were indicative of higher heat leakage from the house.

Blower Door Test

A blower door test works to determine the air leakage from the house to the outside by creating a pressure difference from 25 Pa- 55 Pa and determining the airflow at 50 pa. The blower door screen covers an entryway and a powerful fan move air into or outside the house. Blowing air out through the fan depressurizes the house so air from the outside will attempt to flow into the house. Blowing air into the house pressurizes the house and forces air to blow from the outside to the inside. A baseline test measuring the natural pressure differences preempts the actual measuring. To get an accurate reading, all windows and combustion appliances must be closed or turned off. Measurement is taken on a DG-700, and cfm (cubic feet per meter) values are recorded for 25 Pa, 30 Pa, 35 Pa, 40 Pa, 50 Pa, and 55 Pa. CFM measures airflow, and the number given by a blower door indicates the amount of airflow through the thermal envelope of the house. A linear trend indicates a successful test, and the interpolated value at 50 Pa is considered the standard air leakage rate measurement for homes. Code requires the house to have 3 ACH (Air changes per hour). Since the DG-700 measures in cfm, 3 ACH must be converted to cfm to understand the standard for the local MN residential energy code in terms of the blower door test. Equation 1 indicates this conversion.

$$3\ ACH = \frac{60 * cfm}{Vol}$$

$$CFM = \frac{3\ ACH * Vol}{60}$$

The volume of the tested house was found to be 21344 ft^3. Therefore the target blower door cfm, which equates to the 2015 code of 3 ACH is found to be 1067.8

cfm. This is not expected, but represents the maximum air leakage for houses built today.

Infrared Camera Analysis

A blower door test measurement is a good and simple indication of the energy efficiency and effectiveness of the pressure barrier of the house. A simple number can be compared to other houses with similar volumes and floor space. This test alone will not diagnose any specific issues in the house without the use of an infrared camera to find where heat is leaking from the house. The IR camera will show where conditioned air is escaping and thus indicate a penetration or hole in the pressure boundary. It also indicates areas where there is insulation lacking relative to other areas of the house. The IR camera is very useful in both finding and eventually diagnosing heat leakage to the attic.

Zone Pressure Diagnostics

“Zones” in a house are usually distinguished by whether they are conditioned or not. Attics, garages, and crawl spaces are rarely conditioned and therefore must be sealed from the conditioned zones. Zone Pressure Diagnostics (ZPD) uses relative pressures between zones that are sealed off and introduces holes to determine the air leakage through the pressure boundary. Airflow is a function of pressure differences and the size and shape of the hole, so changing these variables will change the airflow. ZPD uses a blower door to depressurize the house and then measures the pressure in the attic and conditioned space, which are the two zones that impact ice dams the most.

Running a tube through the closed attic hatch and measuring the pressure of each zone take a baseline. The pressure in the attic is compared to the pressure in the conditioned zone as a ratio, thus providing information on the relative leaks between the attic space and the conditioned space. For instance, pressures in the attic and house of 25 Pa each indicate that it is essentially shared space. Air does not face resistance as it passes through the pressure boundary. During depressurization of the house, an attic with a pressure closer to 50 Pa indicates greater resistance to airflow between the house and attic. A common target is set at 45 Pa in the attic and 5 Pa in the house. These numbers found in the baseline test would show an acceptable amount of air tightness between the zones. Appendix 4 can be used to understand how pressure differences can indicate relative size of holes between each zone.

Theoretically, a pressure of 50 Pa in the attic and 0 Pa in the house represents complete airtightness. Therefore this test will show that there is room for improvement for many houses by finding a less than ideal pressure distribution. Advanced ZPD can actually quantify the amount of airflow that can be reduced with proper air sealing. This is done by adding holes of known shape and size to the pressure boundary and comparing the airflow and pressure ratio of each trial. The only variable is the hole size, which will be used as to determine the amount of leakage between zones that can be sealed. Appendix 5 shows the chart that is used to find the data and gives insight into more of the mathematical procedure. The chart produces a multiplier that indicates the range of cfm of airflow that an air-sealing job could successfully reduce.

RESULTS

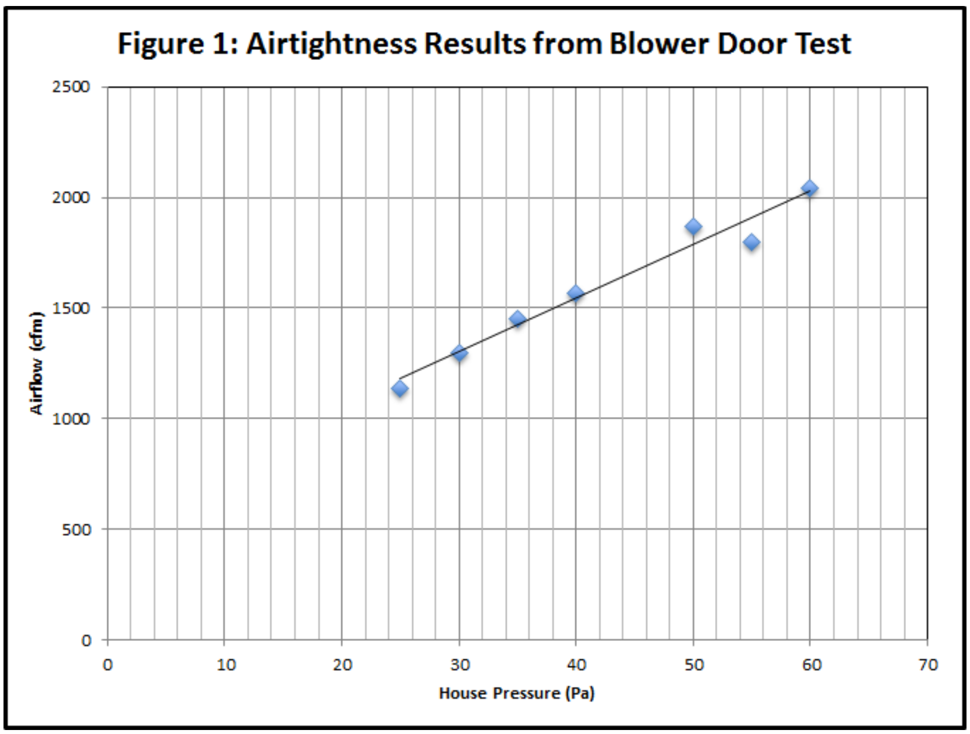

Figure 1: Blower door results for the tested house. A multi point test reduces the error that a single point test at 50 pa will have. **The air leakage for this house is found to be 1870 cfm at 50 Pa.** New homes are expected to have less than 1,500 cfm in MN, so this is a very good rate for an older home.

Image 5

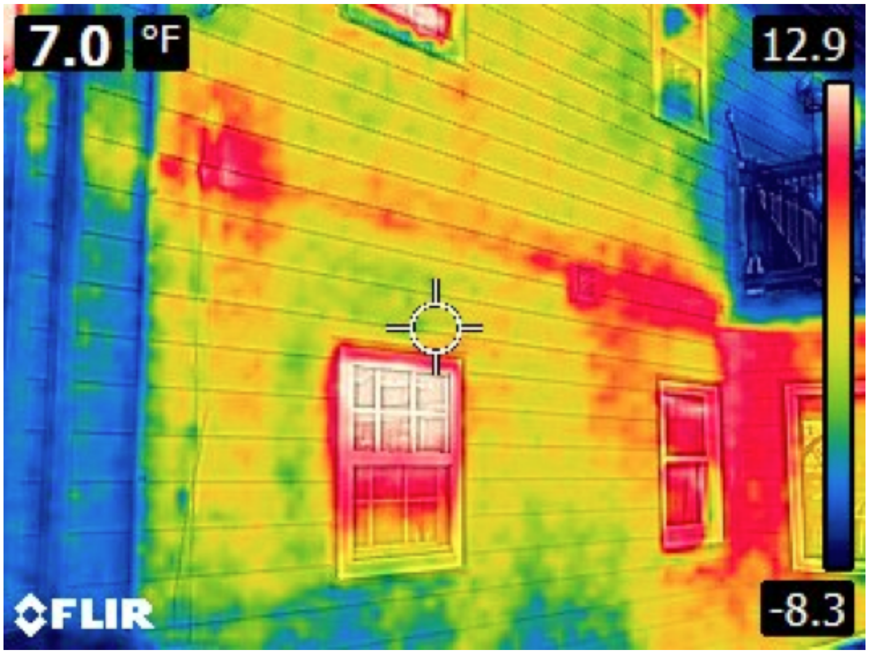

Image 5: Backside of the tested house through IR camera lens.

Image 6

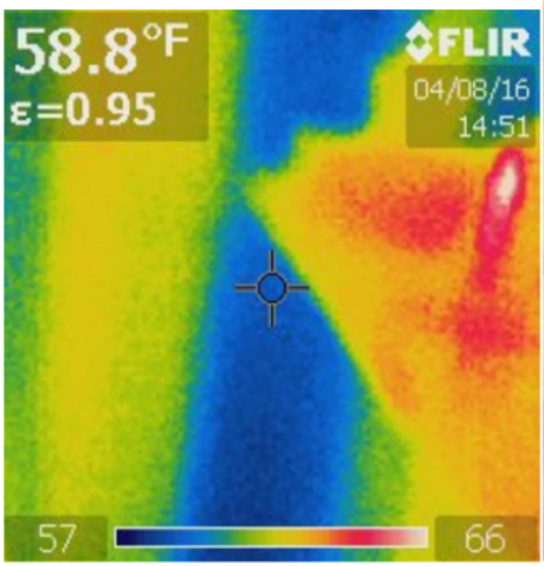

Image 7

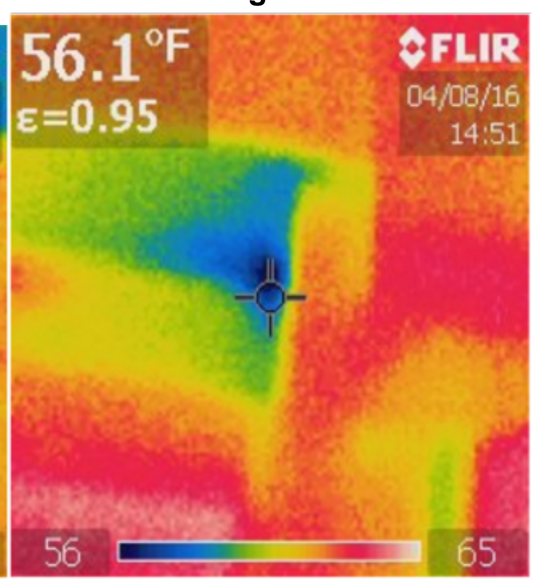

Image 5: Depicts chase way emerging from basement and flowing up towards the second floor, and eventually the attic.

Image 6: Depicts kitchen drop soffit. Air leakage is occurring here and actually connects to the chase way in image 5.

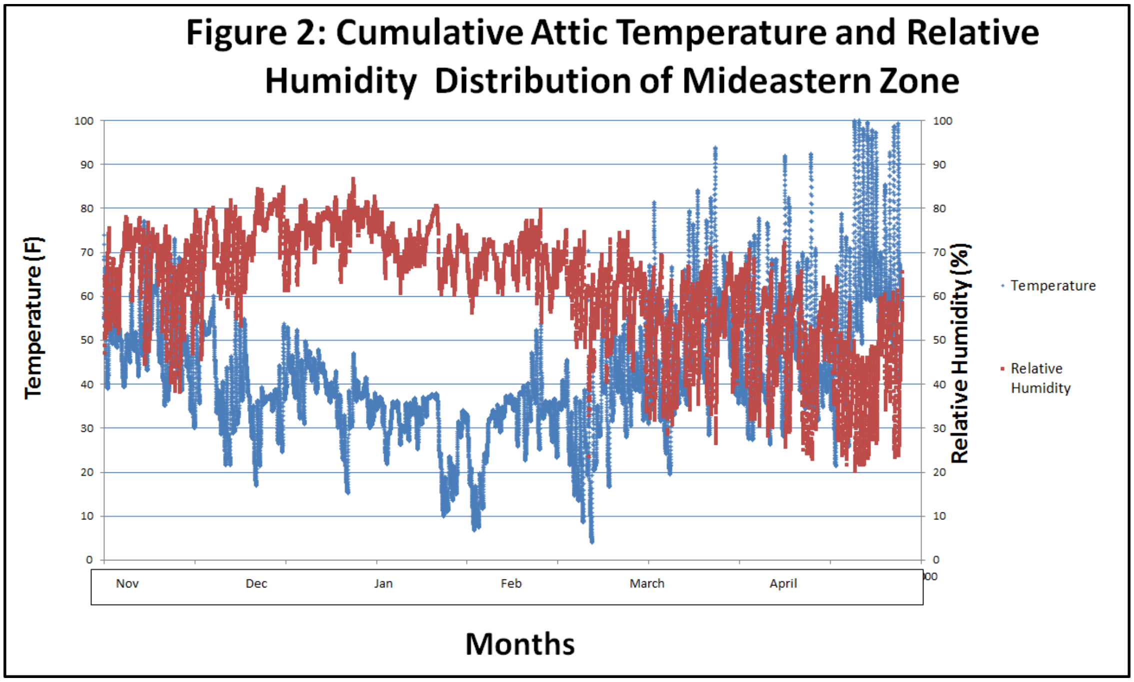

Figure 2: Depicts the attic temperature and relative humidity trends from November 2015- April 2016 in the Mideastern zone. Data for all three zones were collected, but the Mideastern zone contains the chase way that is hypothesized to be causing much of the snow melt pattern on the roof. This data is only for the Mideastern, or "chase way zone".

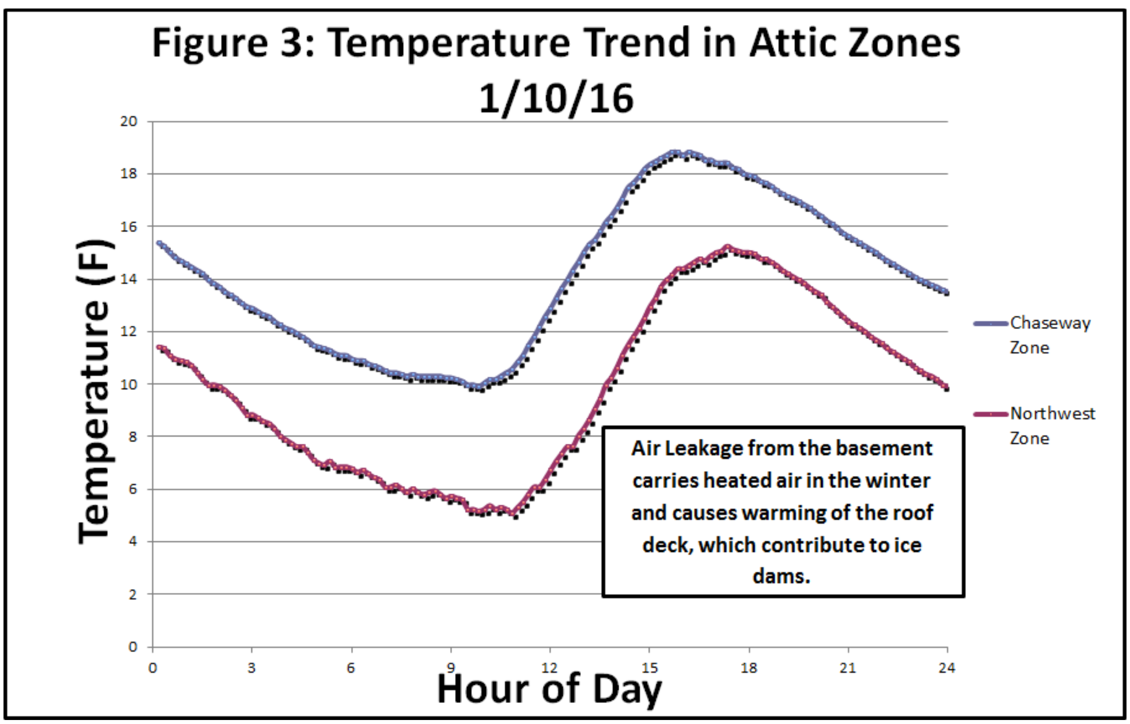

Figure 3: Temperature data from 1/10/2016. This was one of the coldest days of the year, and was selected for interpretation because of the amount of energy

that would disproportionately leak in less insulated or leakier areas. Compared to the Northwest zone, the Chase way zone is found to consistently be 4 degrees warmer. This is a significant difference and was common on many different days of the year.

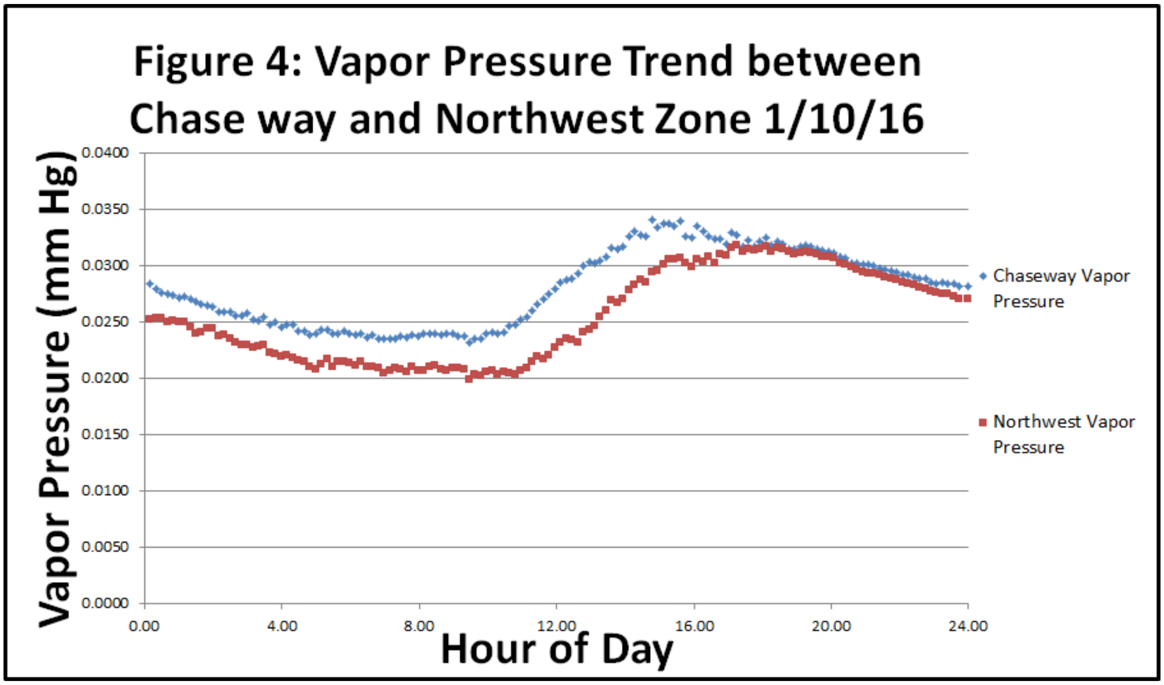

Figure 4: Vapor pressure numbers were calculated using relative humidity data and represent the amount of vapor in the air. More vapor is indicative of more conditioned air being released into the air. Data from 1/10/2016 was interpreted due to it being a very cold day. An increase in vapor to a certain point may create frost in the attic unless properly vented out.

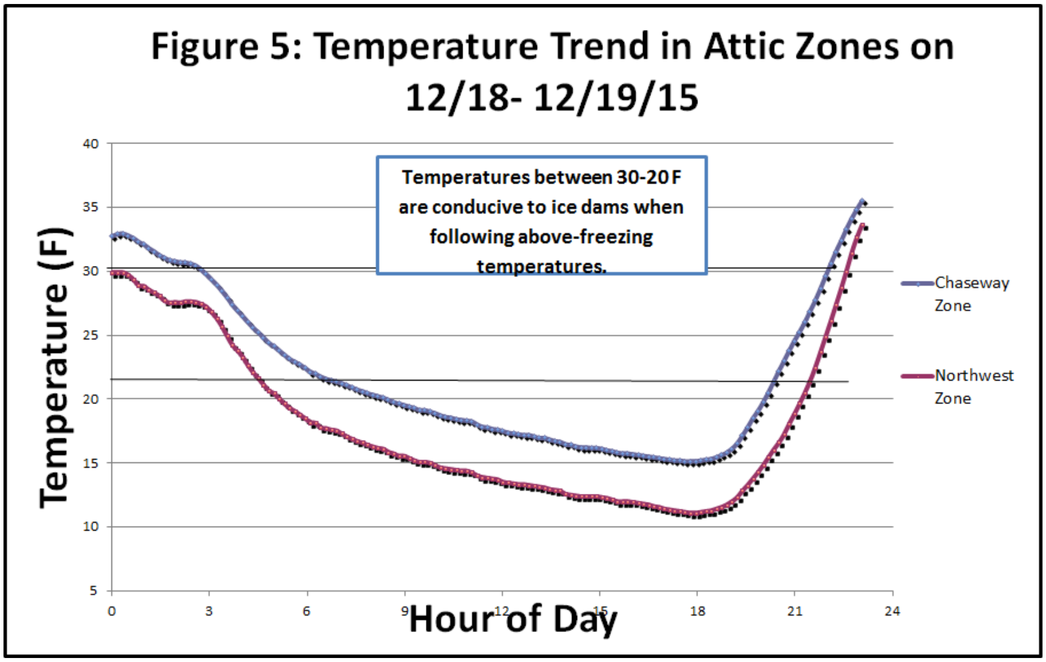

Figure 5: Temperature data from 12/18 and 12/19/2015. This data represents fluctuations in attic temperature above and below freezing. When this happens constantly, snow will melt and freeze and possibly cause ice dams. If one zone is above 32 degrees while another zone is below 32, the snow will melt and freeze disproportionately and can cause visible patterns in the snow on the roof.

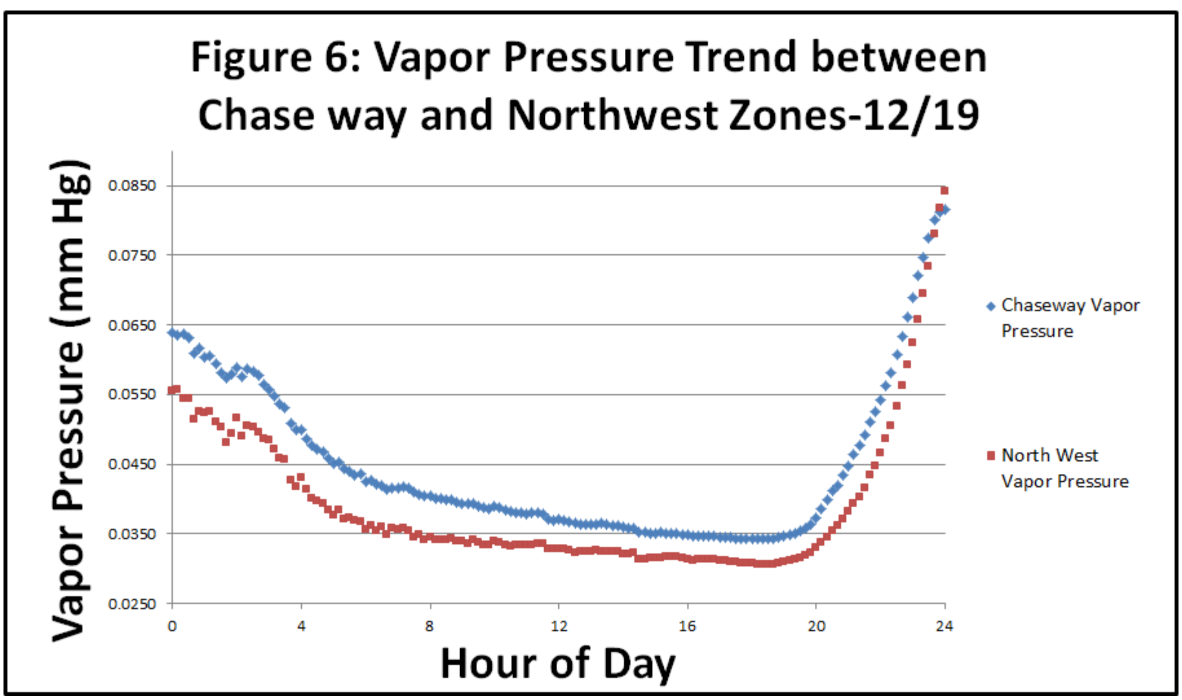

Figure 6: Vapor Pressure data from 12/18-12/19. An increase in vapor pressure can be dangerous when temperatures fluctuate above and below 32 degrees

because the vapor can freeze and thaw producing liquid water. This will create mold unless it is dried out.

	Hatch A	Hatch C	Airflow Difference	Air Sealing Effectiveness	Reduction (+/- 25%)
Airflow (cfm@50 Pa)	2155	3247			
House to Zone Pressure	44.8	31.2	1092 cfm	0.73	600-1000 cfm
Zone to Outside Pressure	5.2	18.8			
Hole Area (Sq Ft)	0	1.04			

Table 1: Zone Pressure Diagnostics Result. Hatch A represents the baseline measurements, with the attic hatch completely sealed as it would be normally. Hatch C opened a hole of 1.04 square feet and the new pressures were recorded. The chart in Appendix 5 was used to find the air sealing effectiveness that could reduce the airflow through the pressure boundary. The amount of reduction that air sealing could have, with 25% uncertainty, was 800 cfm. Therefore 600cfm-1000cfm could be reduced by sealing holes in the attic to house zone alone.

DISCUSSION

Blower Door and IR camera

Table 1 gives the blower door results for the tested house. An airflow of 1870 cfm at 50 Pa is higher than houses currently being built, but is an average number compared to existing houses of similar age and size. A new home of the same volume built to the 2015 MN energy codes would require a air leakage rate of the 1068 cfm, which is not common for many houses built before 2000. Since this house was built in the 1960s, it was not expected to achieve a similar air leakage rate. It performed well with 1870 cfm, but can be significantly reduced. This particular blower door test may have been +/- 5% inaccurate due to heavy winds outside, but regardless finds that the house has considerable leaks to the outside.

These leaks were identified by IR camera analysis in various places such as the rim joists and various places along the backside of the house near a connection to a sunroom. Image 5 provides the IR image of the backside of the house. These areas represent both lack of insulation and also heat/ air leakage. Heavy red spots on this image near the kitchen point to leaks occurring in a drop soffit. This area is often missed in insulating and air sealing and it is often simply a drywall barrier. Image 6 and 7 show this soffit from the inside. In image 6, the long blue column is the chase way that leads from the basement to the second floor and attic. It is funneling conditioned air from the basement and traveling to the attic. Image 7 shows that the kitchen soffit is taking in air from the outside when the house is depressurized. The chase way image is far more interesting because it travels and leaks all the way up to the attic, which the HOBO data loggers could pick up on.

HOBO Data Logger Results

The Data Loggers were retrieved and data was downloaded twice throughout their lifetime for interpretation. Both retrievals were combined to make Figure 2. This graph does not reveal much vital information, but it is interesting to note that temperatures in the attic by the chase way was below freezing for almost the entire month of January. Relative Humidity levels during this time were around 50%. This amount of time spent in freezing temperatures can quickly build frost in an attic if there were to be more heat leakage into the attic. R44 Insulation and a good pressure boundary prevented moisture build up and frost. The chase way is found to be leaking heat at higher temperatures than other zones as found by Figure 3. A four-degree temperature difference was consistent for a large period of the time. Figure 3 specifically shows a cold day in January, where attic temperatures dropped below 10 degrees. The chase way leaking four extra degrees may seem minimal, but it is a very significant amount of heat leakage on a cold day. This would be a priority to properly seal if lower energy bills are desired. The top of the chase way would have to be sealed inside the conditioned space and insulated with spray foam to prevent this leakage.

Vapor pressure is a specific indication of the amount of water vapor in the air. Relative humidity does not alone quantify the amount of water in the air, but vapor pressure does. Figure 4 show that the chase way also increases the vapor pressure in the air. This is a result of extra moisture coming from conditioned air from the chase way and other areas compared to the Northwest zone. The Data logger was placed very near this chase way to maximize the probability that there would be more air originating from this area. An average increase of .006 mm Hg of vapor pressure compared to other zones represents about a 25% increase compared to the Northeast zone.

This is significant at low temperatures in regards to frost in the attic. More water vapor raises the frost point, which is a function of the dew point. Vapor will turn into frost at a level between the dew point and the temperature. An increase of 25% in vapor pressure equates to a significant increase in dew point, and thus an increase in the frost point. An increase in frost point obviously points to a higher potential for frost in the attic given there is enough water in the air. No frost was found in the attic because there still was not enough vapor in the air to freeze, and the temperatures did not quite reach the frost point. Attic ventilation may also play a part in ventilating the moisture out of the roof. Temperatures and moisture by the roof would be different based on attic ventilation, but this was not experimentally explored in this research.

Figure 5 shows the temperature data for the same zones on a different day. This day was found to be an example where ice dams may be found given enough snow on the roof. The temperature in the attic space under the roof deck fluctuates between 35 and 15 degrees Fahrenheit. Snow can both melt and freeze on the same day. The chase way's zone again exhibits temperatures of about 4 degrees warmer than the Northwest zone. This will undoubtedly melt snow faster than other zones when it is over 35 degrees. This finding explains the snowmelt pattern depicted on the roof in Image 4. Using this knowledge, the IR camera photos from the inside also show that conditioned air of around 60 degrees from the basement is traveling from the basement into the Mideast zone of the attic via the chase way shown in Appendix 3.

Figure 6 shows the vapor pressure data for the day in December that produced ideal temperatures for ice dams. In this case, there is much more moisture in the air due to the temperature rise. The chase way produces 12% more vapor pressure than the northwest zone on average for this day. This is not enough to cause significant damage, but still indicates conditioned air leakage through this zone.

Zone Pressure Diagnostics

Conducting zone pressure diagnostics (ZPD) allows an airflow value between the conditioned house and the unconditioned attic to be determined. Table 1 gives the data for this test. Using Appendix 4, it is found that the attic has four times the amount of leaks relative to the house. Since the attic is unconditioned and connected through the outside by attic ventilation, this is expected. This says more about the pressure boundary that separates these zones and how much leakage there is. This test does not specifically relate to any certain area for leakage, but identifies the ceiling as a pressure boundary that is incompletely air sealed. Insulation does slow air movement along with reducing convective heat flow, but does not do well enough to prevent the flow of air completely. The chase way is a perfect example of how penetrations in the pressure boundary can cause conditioned air to flow into the attic.

Table 1 also shows advanced ZPD being used to understand how much of the air leakage can be sealed at the ceiling air barrier. When a hole of 1.04 sq. ft. is introduced to the attic hatch, an airflow increase of 1094 cfm occurs. The attic holes are a little less than twice as big as the ceiling holes based on the pressure differential. Improving the air sealing could reduce the airflow through the house by 600-1000 cfm. This may improve the blower door test by 20-30% depending on the effectiveness. It is very likely that sealing the chase way will be able to provide much of this reduction.

CONCLUSION

There are considerable leaks emanating from areas hypothesized as having prevalence to leaking conditioned air into the attic. The heat shown flowing through the chase way in Image 3 and 4 is causing a temperature and vapor pressure increase in the Mideastern zone of the attic. Attic bypass from the chase way melts the snow on the mideastern portion of the roof seen in Image 2. Air sealing the ceiling to attic pressure zone can significantly reduce the air leakage to the attic. Air sealing the attic to ceiling zone will prevent conditioned space from escaping into the attic, which will allow for snow to safely melt off the roof in an even fashion.

FUTURE RESEARCH

Ice dams and their symptoms were tested in terms of attic bypass and air sealing, but not attic ventilation. Attic Ventilation will be tested for at a later date using a duct blaster fan to depressurize the attic and then measuring rates of ventilation for soffit, ridge, gable, and fan vents. With these tests and associated analysis, it is possible to identify areas susceptible to damaging ice dams by identifying heat leakages, and how insulation and attic ventilation affects this.

ACKNOWLEDGEMENTS

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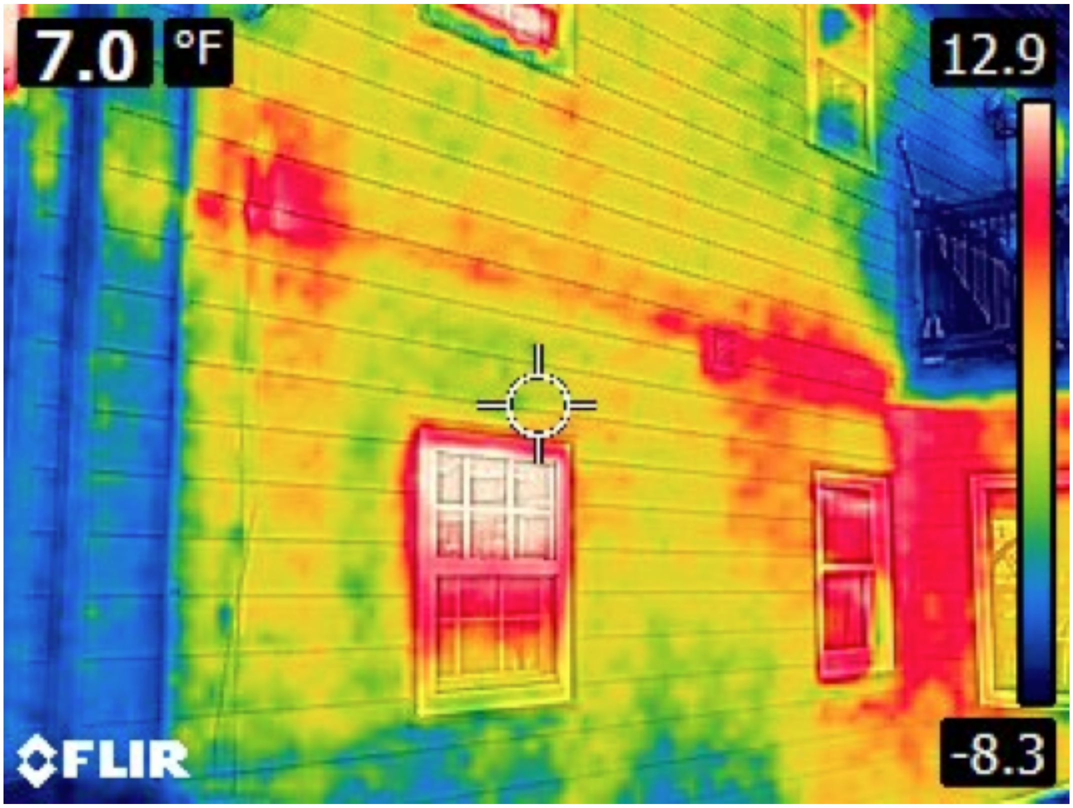
APPENDIX

Appendix 1

IR camera photo of the backside of the tested house. Heat leakage is seen in red. Areas of leakage are the rim joists, windows, kitchen drop soffits and others.



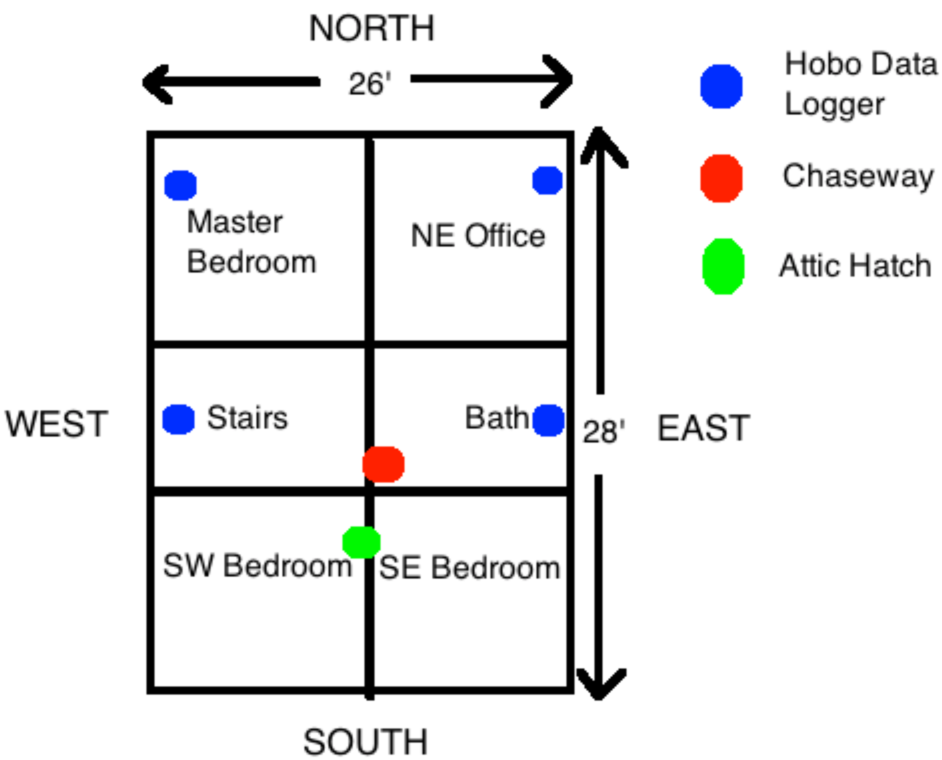
Appendix 2

Insulation values per inch used to determine the R value insulation and wood can provide for an attic.

Material	R-value Per inch	R-value for thickness listed
Batt and blanket insulation		
Glass or mineral wool, fiberglass	3.00-3.80+	
Loose fill		
Cellulose	3.13-3.70	
Glass or mineral wool	2.50-3.00	
Vermiculite	2.20	
Rigid insulation		
Expanded polystyrene		
Extruded, plain	5.00	
Molded beads, 1 pound/cubic foot	5.00	
Molded beads, over 1 pound/cubic foot	4.20	
Expanded rubber	4.55	
Expanded polyurethane, aged	6.25	
Glass fiber	4.00	
Wood or cane fiberboard	2.50	
Polyisocyanurate	7.04	
Foamed-in-place insulation		
Polyurethane	6.00	
Building materials		
Concrete, solid	0.08	
Concrete block, three hole, 8 inch		1.11
Lightweight aggregate, 8 inch		2.00
Lightweight, cores insulated		5.03
Brick, common	0.20	
Metal siding		
Hollow-backed		0.61
Insulated-backed, 3/8 inch		1.82
Softwoods, fir and pine	1.25	
Hardwoods, maple and oak	0.91	
Plywood, 3/8 inch	1.25	0.47
Plywood, 1/2 inch	1.25	0.62
Particleboard, medium density	1.06	
Hardboard, tempered, 1/4 inch	1.00	0.25
Insulating sheathing, 25/32 inch		2.06
Gypsum or plasterboard, 1/2 inch		0.45
Wood siding, lapped, 1/2 x 8 inch		0.81
Asphalt shingles		0.44
Wood shingles		0.94
Windows (includes air films)		
Single glazed		0.91
with storm windows		2.00
Insulating glass, 1/4 inch air space		
Double pane		2.85
Triple pane		3.70
Doors (exterior, includes air films)		
Wood, solid core, 1-3/4 inch		3.03
Metal, urethane core, 1-3/4 inch		2.50
Metal, polystyrene core, 1-3/4 inch		2.13
Air space (3/4 to 4 inches)		0.90
Air films		
Inside surface		0.68
Outside surface		0.17
Floor perimeter (per foot of exterior wall length)		
Concrete		1.23
Concrete, with 2x24 inch or rigid insulation around perimeter		2.22

Appendix 3

Orientation of the second floor of the tested house. Locations of data loggers, chaseway, and the attic hatch to enter the attic is indicated.



Appendix 4

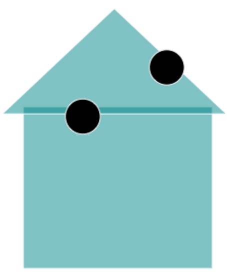
The image on the left shows the chase that leads from the basement to the second floor. The image on the right shows the very top of the chase, which is showed to be blocked by wood. Conditioned air from the basement is theorized to be bypassing this and

leaking into the attic

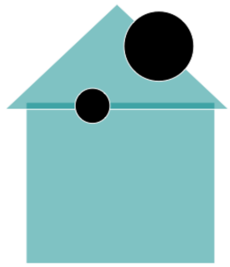
Appendix 5

Zone Pressures		Relative Size of Leaks	
Zone-House	Zone-Out	Zone-House	Zone-Out
12	38	2	1
25	25	1	1
37	13	½	1
41	9	1/3	1
45	5	¼	1
48	2	1/8	1
49	1	1/13	1

Attic Reading of 25 Pa



Attic Reading of 48pa



Appendix 6

Advanced ZPD uses this chart which calculates the multiplier of airflow reduction based on a change in pressure and airflow given a known sized hole. The colors indicate uncertainty. Our multiplier was .73 and thus fell in the 15 percent uncertainty range.

Flow Method: Hole Added from House to Zone

Start Press		Ending Pressure After Making Hole to from House to Zone																							Uncertainty based on 1 Pa Errors
H/Z		44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4	2	0	
	Z/O	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	
50	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10%
49	1		0.35	0.29	0.25	0.22	0.20	0.18	0.17	0.15	0.15	0.14	0.13	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09	15%
48	2		0.60	0.54	0.45	0.39	0.35	0.32	0.29	0.27	0.25	0.23	0.22	0.21	0.20	0.19	0.18	0.17	0.17	0.16	0.15	0.15	0.15	0.14	20%
47	3			0.84	0.68	0.58	0.51	0.45	0.41	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	25%
46	4			1.23	0.96	0.80	0.68	0.60	0.54	0.49	0.45	0.42	0.39	0.37	0.35	0.33	0.32	0.30	0.29	0.28	0.27	0.26	0.25	0.24	>25%
45	5				1.30	1.05	0.89	0.77	0.68	0.62	0.56	0.52	0.48	0.45	0.43	0.40	0.38	0.37	0.35	0.33	0.32	0.31	0.30	0.29	
44	6				1.76	1.36	1.12	0.96	0.84	0.75	0.68	0.63	0.58	0.54	0.51	0.48	0.45	0.43	0.41	0.39	0.38	0.36	0.35	0.34	
43	7					1.76	1.41	1.18	1.02	0.90	0.81	0.74	0.68	0.63	0.59	0.56	0.53	0.50	0.48	0.45	0.43	0.42	0.40	0.39	
42	8					2.28	1.76	1.44	1.23	1.08	0.96	0.87	0.80	0.73	0.68	0.64	0.60	0.57	0.54	0.52	0.49	0.47	0.45	0.44	
41	9						2.20	1.78	1.47	1.27	1.12	1.01	0.92	0.84	0.78	0.73	0.68	0.65	0.61	0.58	0.55	0.53	0.51	0.49	
40	10						2.80	2.15	1.78	1.49	1.30	1.16	1.05	0.96	0.89	0.82	0.77	0.72	0.68	0.65	0.62	0.59	0.56	0.54	
39	11							2.65	2.11	1.76	1.51	1.33	1.20	1.09	1.00	0.92	0.86	0.81	0.76	0.72	0.68	0.65	0.62	0.60	
38	12							3.32	2.54	2.07	1.76	1.53	1.36	1.23	1.12	1.03	0.96	0.90	0.84	0.80	0.75	0.72	0.68	0.65	
37	13								3.09	2.45	2.04	1.76	1.55	1.38	1.26	1.15	1.07	0.99	0.93	0.87	0.83	0.79	0.75	0.71	
36	14								3.83	2.93	2.36	2.02	1.76	1.56	1.41	1.28	1.18	1.09	1.02	0.96	0.90	0.86	0.81	0.78	
35	15									3.54	2.80	2.33	2.00	1.76	1.57	1.42	1.30	1.21	1.12	1.05	0.99	0.93	0.89	0.84	
34	16									4.35	3.32	2.70	2.28	1.98	1.76	1.58	1.44	1.33	1.23	1.15	1.08	1.01	0.96	0.91	
33	17										3.96	3.14	2.61	2.24	1.97	1.76	1.59	1.46	1.34	1.25	1.17	1.10	1.04	0.98	
32	18										4.86	3.70	3.01	2.54	2.20	1.95	1.76	1.60	1.47	1.36	1.27	1.19	1.12	1.06	
31	19											4.42	3.49	2.89	2.46	2.16	1.94	1.76	1.61	1.48	1.38	1.29	1.21	1.14	
30	20											5.36	4.09	3.32	2.80	2.43	2.15	1.93	1.76	1.61	1.49	1.39	1.30	1.23	
29	21												4.06	3.83	3.18	2.72	2.38	2.13	1.92	1.76	1.62	1.50	1.41	1.32	
28	22												5.09	4.46	3.63	3.06	2.65	2.34	2.11	1.91	1.76	1.63	1.51	1.42	
27	23	**Attic Example (House in Winter Mode)**												5.30	4.18	3.48	2.96	2.59	2.31	2.09	1.91	1.76	1.63	1.52	
26	24	Attic Access Closed with Hose Running to Blower Door												6.41	4.86	3.94	3.32	2.87	2.54	2.28	2.07	1.90	1.76	1.64	
25	25	Measure House CFM 50 (example: 2400 CFM50)													5.75	4.52	3.74	3.20	2.80	2.49	2.25	2.06	1.89	1.76	
24	26	Measure House to Attic Pressure (Verify with Attic to Outside)													6.92	5.25	4.25	3.57	3.09	2.73	2.45	2.23	2.04	1.89	
23	27	(example: 36 PA House to Attic)														6.19	4.86	4.02	3.44	3.01	2.68	2.42	2.20	2.03	
22	28															7.43	5.84	4.55	3.83	3.32	2.93	2.63	2.38	2.18	
21	29	**Make Opening From House to Attic**															6.83	5.21	4.30	3.67	3.21	2.86	2.58	2.35	
20	30	(enough for at least 6 PA Change)															7.95	6.02	4.86	4.09	3.54	3.12	2.80	2.54	
19	31	Measure House CFM 50 (example: 3000 CFM50)																7.07	5.55	4.58	3.91	3.42	3.04	2.74	
18	32	Measure House to Attic Pressure (Verify with Attic to Outside)																8.46	6.41	5.17	4.35	3.78	3.32	2.97	
17	33	(example: 20PA House to Attic)																	7.51	5.89	4.86	4.15	3.63	3.23	
16	34																		8.96	6.79	5.48	4.61	3.96	3.51	
15	35																			7.96	6.24	5.14	4.39	3.83	
14	36	Take 2nd Blower Door Reading (3000) - First Blower Reading (2400) = 600																		9.49	7.18	5.79	4.86	4.20	
13	37	Look in Row with 36 H/Z and move over to Column with 20 H/Z to Find Multiplier =1.56																			8.39	6.58	5.42	4.63	
12	38																				10.00	7.58	6.10	5.12	
11	39	Take 600 X 1.56 = 936																				8.83	6.90	5.71	
10	40	(This is Maximum CFM50 REDUCTION AVAILABLE by sealing all holes to Attic)																				10.52	7.95	6.41	
9	41																						9.27	7.26	
8	42	To Determine Uncertainty Range multiply Answer by percentage in Uncertainty Table																					11.03	8.33	
7	43	To Determine Approximate Hole Size Divide Answer by 10 (936 / 10= 94 sq in)																						9.71	
6	44																							11.54	

Anthony Cox and Collin Olson, 2006

Before Hole

CFM50

H/Z

After Hole

CFM50

H/Z

ANSWER

CFM50 Diff

Multiplier

Maximum Reduction

(total path CFM50)

ext exponent =0.65

May 25, 2006