The Economic Thickness of Thermal Insulation Design Note

The conventional method of evaluating the performance of insulation is to measure the R-value, the conductive heat flow resistance of the material.

The measurement of conductive heat flow resistance is made using the heat flow meter apparatus. This test procedure (ASTM C-518) measures the thermal conductivity of insulation material. This measurement solely defines the conductive heat flow resistance of the insulation material (the R-value) and it ignores the influence of convective and radiant heat flow.

Once the R-value of an insulation material is determined, the heat flow through it can be calculated using Fourier's steady-state heat flow equation.

$$Q = \frac{A \times \Delta T}{R}$$

Where:
Q = Rate of heat flow (BTU/hr)
A = Area (ft^2)
ΔT = Difference in Temperature (°F)
R = Resistance to conductive heat flow ($hr.ft^2$ °F/BTU)

This equation is used to calculate the benefit of increasing the thickness of any type of insulation as long as there is no air movement (convective heat transfer) through the insulation.

As an example, consider 1000 ft^2 of insulated area with a temperature differential of 40°F. Based on the assumption that the outside air film at R-0.2 and the inside air film at R-0.7, the total R-value before the application of any insulation is 0.9. Increasing the insulation thickness by 1" increments at R-3.6/inch provides the heat flow rates as shown in Figure 1.1 and 1.2.

Figure 1.1

Conductive Heat Flow

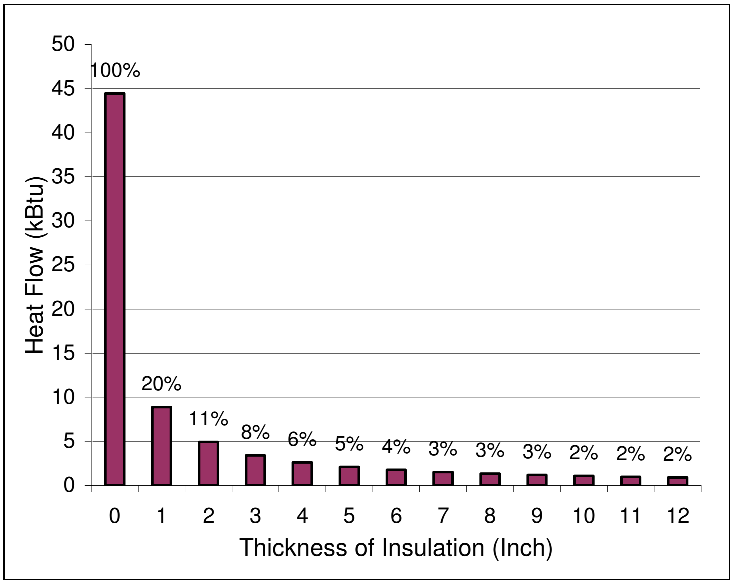
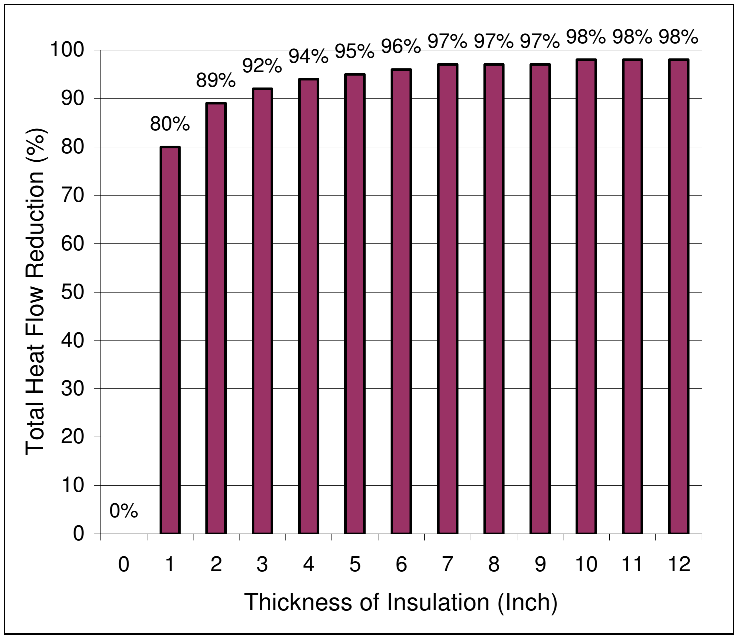


Figure 1.2

Conductive Heat Flow Reduction



In Figure 1.1, the first 1” of insulation reduces the heat flow to 20% of the total and at a 6” thickness, the heat flow is reduced further, down to 4% of the total. As indicated in Figure 1.2, increasing the insulation thickness from 6” to 12” provides an additional heat flow reduction of only 2%. Stated another way doubling the insulation thickness (R-value) and cost; only provides a modest 2% increase in heat flow reduction. Based on this observation, it is very difficult to justify the additional cost of adding insulation thickness beyond 6” in thickness.

Icynene® is able to fill irregular shaped cavities and adheres to most construction materials, thereby, forming an insulation layer with very low air permeance. Air flow is virtually eliminated and for this reason, conductive heat loss can be used as a sole criterion for establishing insulation thickness with Icynene®.

As shown in Figure 1.2, insulation material with R-value of 3.6 per inch blocks out 96% of conductive heat flow within the first 6 inches of the material. Thickness beyond this point would bring more reduction in heat flow but it would not be economically justified since the returns on additional R-value have greatly diminished.

Reduced Air Infiltration = Reduced Energy Use =Reduced Equipment Size

In the case of insulation material with significant air permeance, conductive heat loss should not be the only criterion used for assessing an insulations performance and establishing its thickness. Convective heat loss must be considered as well, particularly when a substantial latent load is involved.

Oak Ridge National Laboratory (ORNL) conducted an experiment[1] to determine the efficiency of a roof assembly insulated with low density, loose-fill fiberglass insulation and discovered that up to 50% of the heat loss occurred as a result of convection; air circulation through the insulation. This result showed that the air-permeable insulation had lost its anticipated thermal performance level by half and that convective heat transfer had a significant negative impact on insulation performance.

The importance of reducing air infiltration can be easily demonstrated by analyzing the energy consumption for heating and cooling houses that have different R-values and air infiltration rates. The following evaluation was generated using the REM/Design™ energy analysis software as reflected in the charts (2.1 – 2.4). This evaluation deals with three identical houses, located in different North American cities with three different levels of insulation and air-infiltration. The house design is fully detached, has approximately 3,500 ft^2 of conditioned area, with two stories and a conditioned basement.

The first house is the **Base Case** with R-19 air-permeable insulation installed in the walls and R-30 in the ceiling. The air infiltration rate used for this analysis is 0.55 ACH at natural pressure as determined by NAHB as an average value for newly constructed residential buildings in U.S.[2]

The second house has the same air-permeable insulation with a **Higher R-value,** R-43 in the ceiling and R-19 in the walls. The air infiltration rate is maintained at 0.55 ACH at natural pressure.

The third house is insulated with Icynene®, an air-impermeable insulation, with R-11 in the walls, R- 18 in the ceiling. An air infiltration rate of 0.1 ACH at natural pressure was used for Icynene® because of its air sealing capability.

Heating and cooling costs and the required heating and cooling equipment capacities for each house are plotted on the following graphs. The efficiencies of heating and cooling systems are 92

[1] ORNL’s Building Envelope Center: Fighting the Other Cold War
URL: http://www.ornl.gov/ORNLReview/rev26-2/text/usemain.html

AFUE for the furnace and 13 SEER for A/C unit respectively with utility rates set at $0.10 per kWh for electricity and $1.50 per Therm for natural gas.

[2] NAHBA Research Center, Novenber, 2007;
Air Infiltration Data Analysis for Newly Constructed Homes Insulated With Icynene® Spray Foam.

Figure 2.1

Annual Heating Cost by City

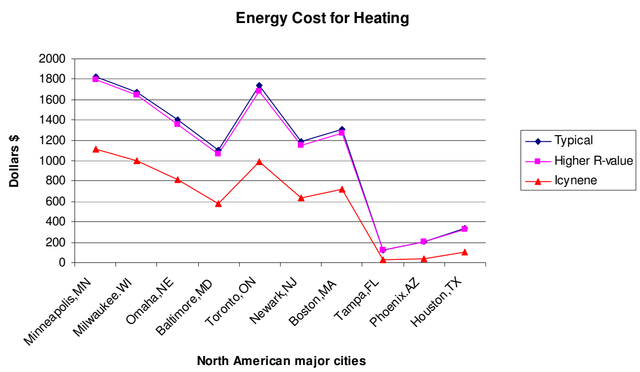


Figure 2.1 shows the energy costs for heating in several different cities throughout North America. The heating costs are compared for the three different insulation systems. It can be seen that savings on heating cost reached up to 30%-40% with Icynene® when compared to the **"Base Case"** and **"Higher R-Value"** insulation systems. Also, the graph indicates that the colder the climate, the greater the heating cost savings are with Icynene®.

Figure 2.2 shows savings on cooling costs with Icynene®. They provide savings of 20%-35% over the **"Base Case"** and **"Higher R-Value"** insulation system. The cities in a hot and humid climate show greater savings due to the higher cooling demand and latent load.
As far as the sizing of heating and cooling equipment is concerned, Icynene® provides a significant reduction in both heating and cooling load due to its air-sealing property. Figures 2.3 & 2.4 show the equipment size required in these houses for heating and cooling. The graphs show that there is a significant reduction in required capacity for both heating and cooling relative to **"Base Case"** and **"Higher R-Value"** systems. Often with Icynene®, size reduction for both heating & cooling equipments can reach up to 35%.

Icynene®'s air-seal capability virtually eliminates convective heat transfer within the insulation and reduces unwanted air leakage through the building envelope. This feature improves the efficiency of the building envelope thereby reducing the heating and cooling costs and reducing the size of HVAC equipment as outlined in figures 2.1 through 2.4. As a result, lower operating costs are realized and the cost of the operating equipment is reduced.

Often, air-permeable insulation at twice the R-value gets used and still comes short of the desired energy savings as shown in Figures 2.1 and 2.2.

The on-site spray applied application of Icynene® creates an excellent air seal that provides a low air infiltration rate for the building envelope. This quality improves energy efficiency of the building as demonstrated through the graphs above and in addition, the overall performance of the building resulting in better sound attenuation, healthier indoor environment and enhanced thermal comfort.

Figure 2.2

Annual Cooling Cost by City

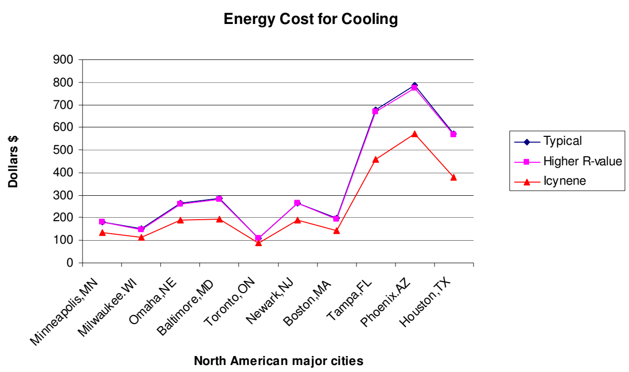


Figure 2.4

Cooling Equipment Size by City

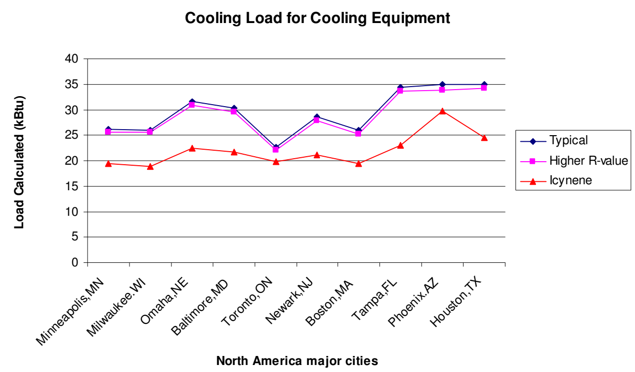
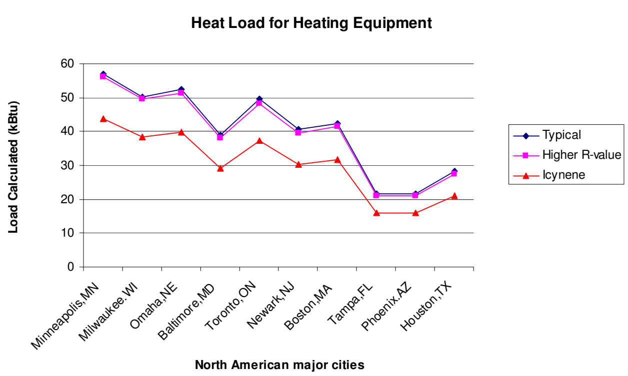


Figure 2.3

Heating Equipment Size by City



Icynene® is a low-density soft foam insulation, which is sprayed into/onto walls, crawlspaces, underside of roofs, attics and ceilings by Icynene Licensed Dealers. Sprayed as a liquid, it expands to 100 times its volume in seconds to create a superior insulation and air barrier. Every crevice, crack, electrical box, duct and exterior penetration is effortlessly sealed to reduce energy-robbing random air leakage. Icynene® adheres to the construction material and remains flexible so that the integrity of the building envelope seal remains intact over time. Icynene® is ideal for residential, commercial, industrial and institutional indoor applications. **Information about Icynene® can be obtained by visiting Icynene.com or contacting your local Icynene Licensed Dealer.**