The Economic Thickness of Thermal Insulation

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 guarded hotbox apparatus. This test procedure (ASTM C-518-02) measures the thermal conductivity of insulation material. In this test, one side of the specimen is heated to a specific temperature and after steady state heat flow has been reached, the temperature on the opposite side is measured. Through this temperature measurement the R-value is calculated. The outside surface of the test apparatus and the specimen is sealed and insulated to minimize the heat loss through the edge and eliminate the effects of any convection or radiant heat flow. This measurement solely defines the conductive heat flow resistance of the insulation material, the R-value.

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 = Temperature differential, ° F
R = Resistance to 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. Let us include 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 following heat flow rates as shown in Figure 1.1 & 1.2.

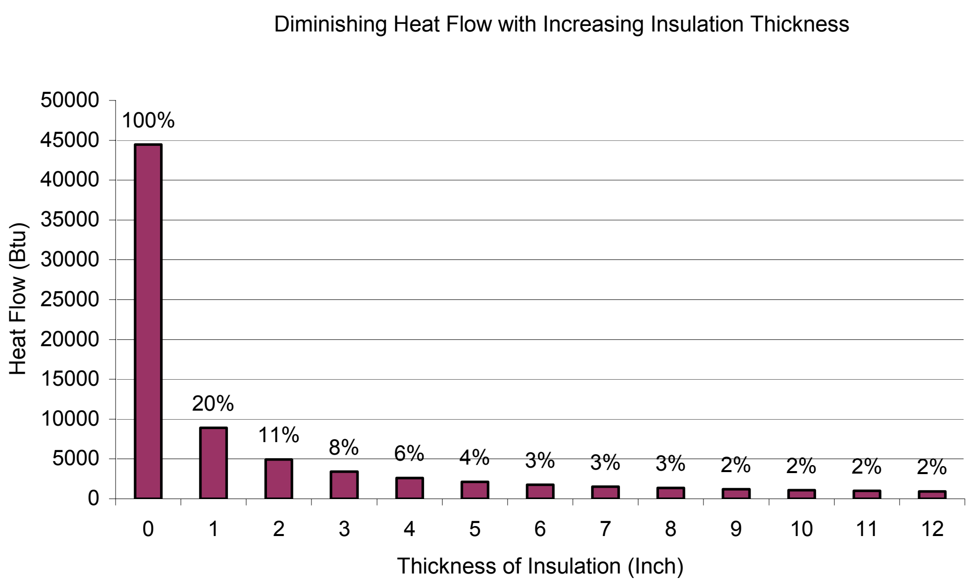


Figure 1.1: Percentage of total heat flow

Total Heat Flow Reduction with Increasing Insulation Thickness

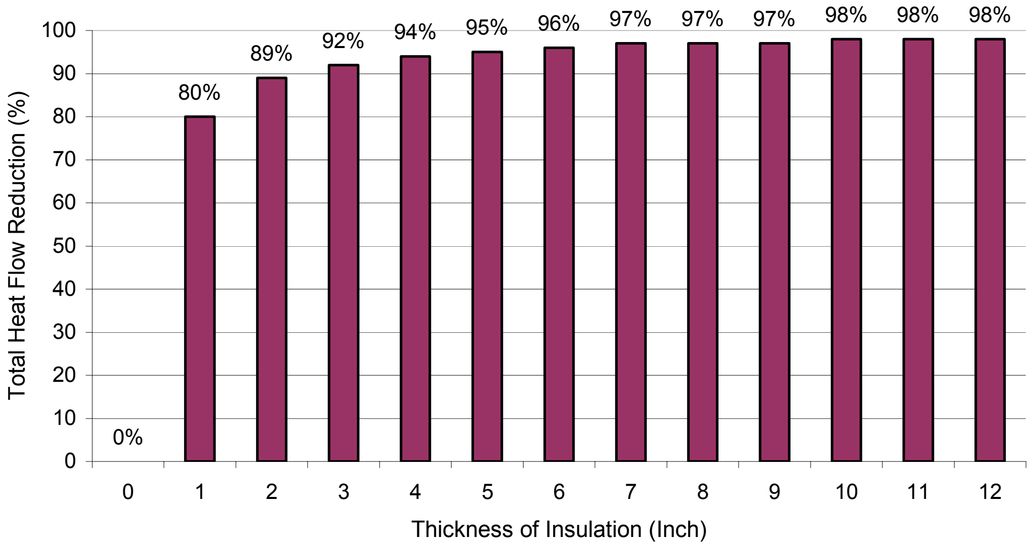


Figure 1.2: Percentage of total heat flow reduction

In Figure 1.1, we can see that the first 1” of insulation reduces the heat flow to 20% of the total and at 5” of thickness, the heat flow is reduced further, down to 5% of the total. In looking at Figure 1.2, we see that increasing the insulation thickness from 6” to 12” only provides an additional heat flow reduction of 2%. Doubling the insulation thickness (R-value); doubling the 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 5”.

The Icynene Insulation System® fills any shaped cavity and adheres to almost all materials, thereby, forming an insulation layer with very low air permeance. Air flow is 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 95% of conductive heat flow within the first 5 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.

REDUCE AIR INFILTRATION - REDUCE ENERGY USE REDUCE EQUIPMENT SIZE

In the case of insulation material with significant air permeance, conductive heat loss should not be the only criterion used for establishing insulation 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.

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

The importance of reducing air infiltration can be easily demonstrated by analyzing the energy consumption for heating and cooling houses that have different air infiltration rates. The following evaluation was generated using the REM/Design energy analysis software. 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 2000 sq.ft of floor area with two stories and a double car garage.

The first is a **Typical** house designed according to the general building code requirements; with fiberglass insulation, R-30 in the attic, R-19 in the walls and an air infiltration rate of 0.7 ACH at natural pressure.

The second is a **Better** version of this house with fiberglass insulation, R-43 in the attic and R-19 in the walls and 0.6 ACH at natural pressure.

The third is an **Icynene®** house with an insulation level of R-20 in the walls, R-20 in the ceiling and an air infiltration rate of 0.1 ACH at natural pressure.

Heating and cooling costs and the required heating and cooling equipment capacities for each house are plotted on the following graphs. The utility rates are set at $0.15 per kWh for electricity and $0.90 per Therm for natural gas.

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 40%~50% with Icynene® when compared to the **Typical** insulation system. Also, the graph indicates that the colder the climate, the greater the heating cost savings are with Icynene.

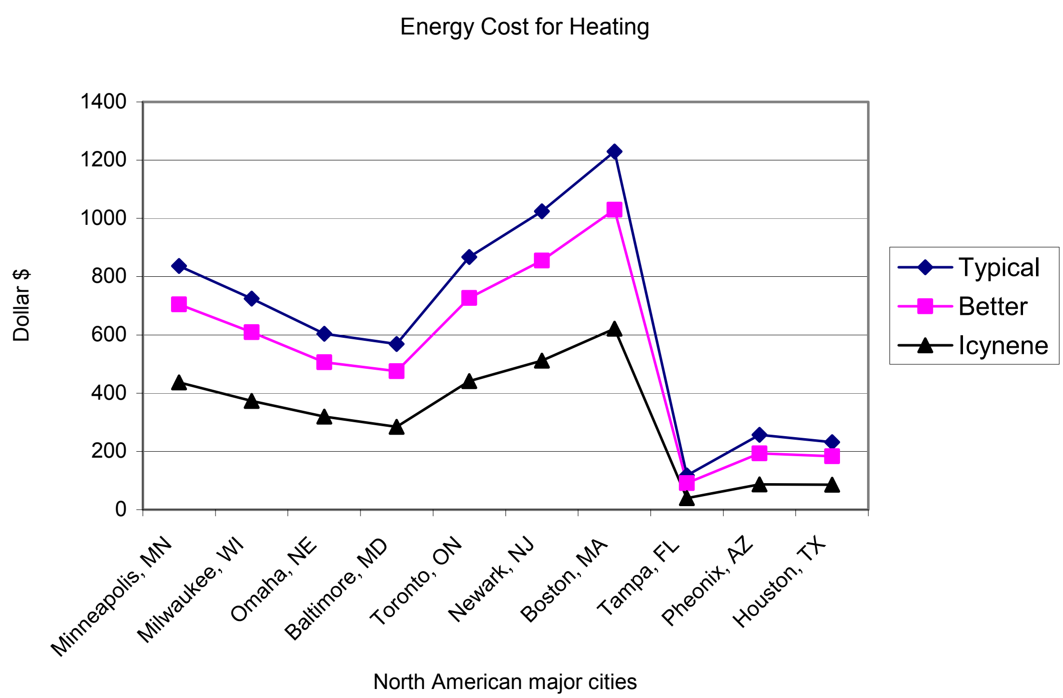
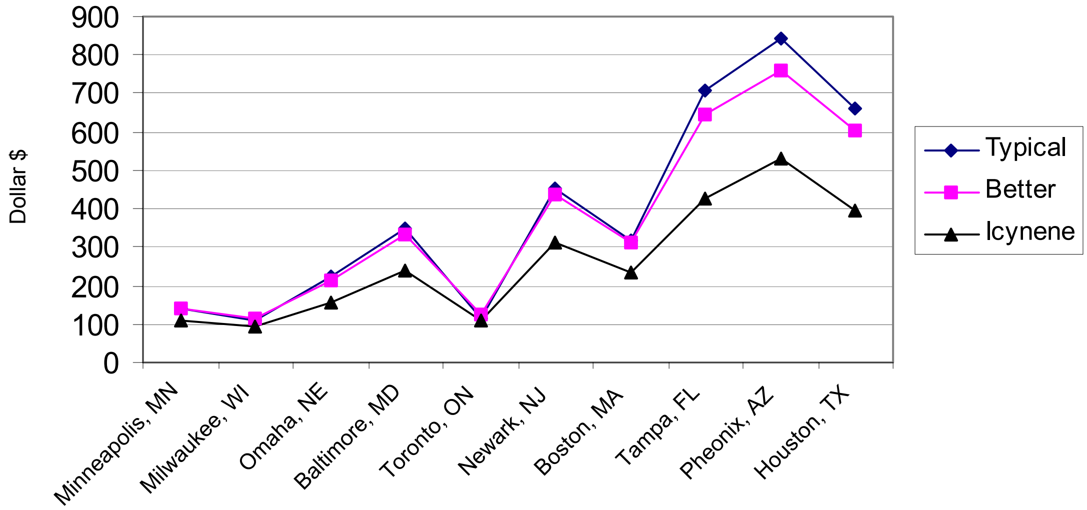


Figure 2.1

Figure 2.2 shows savings on cooling costs with Icynene. They provide savings of 25%~40% over the **typical** insulation system. The cities in a hot & humid climate show greater savings due to the higher cooling demand.

Energy Cost for Cooling

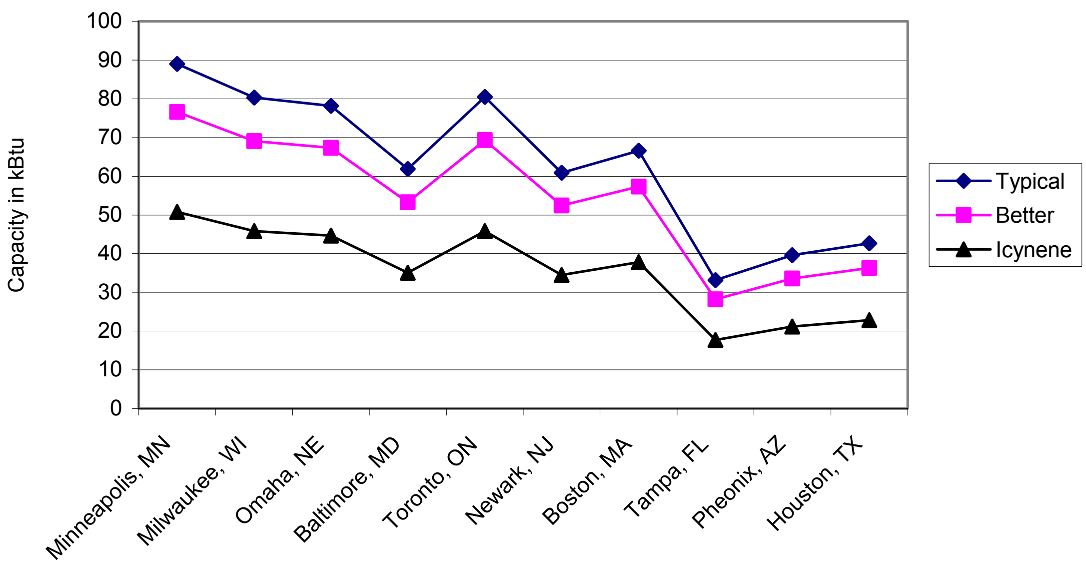


North American major cities

Figure 2.2

As far as sizing heating and cooling equipment is concerned, Icynene provides a significant reduction in both heating & 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 **Typica**l & **Better** systems. Often with Icynene, size reduction for heating equipment can reach up to 50% and for cooling, it can be up to 40%.

Equipment size required for heating



North American major cities

Figure 2.3

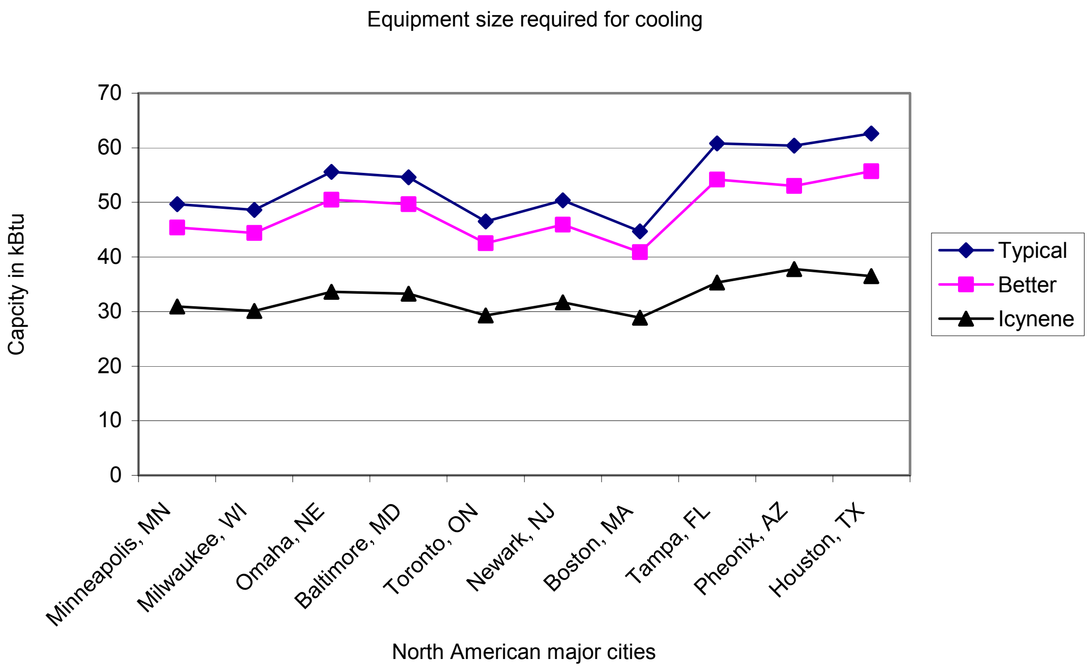


Figure 2.4

Icynene's air seal capability 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 provides an excellent air seal that ensures 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.