"R" Fairy Tale
The Myth of Insulation Values

by David B. South

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One of the fairy tales of our time is the "R-value." The "R-value" is touted to the American consumer to the point where it has taken a "chiseled in stone" status. The saddest part of the fairy tale is the R-value by itself is almost a worthless number.

It is impossible to define an insulation with a single number. It is imperative we know more than a single "R" number. So why do we allow the R-value fairy tale to be perpetuated? I don't know. I don't know if anybody knows. It obviously favors fiber insulation. Consider the R-value of an insulation after it has been submersed in water or with a 20 mile per hour wind blowing through it. Obviously the R-value of fiber insulations would go to zero. Under the same conditions, the solid insulations would be largely unaffected. Again R-value numbers are "funny" numbers. They are meaningless unless we know other characteristics.

None of us would ever buy a piece of property if we knew only one dimension. Suppose someone offered a property for $10,000 and told you it was a seven. You would instantly wonder if that meant seven acres, seven square feet, seven miles square, or what. You would want to know where it was -- in a swamp, on a mountain, in downtown Dallas. In other words, one number cannot accurately describe anything. The use of an R-value alone is absolutely ridiculous. Yet we have Code bodies mandating R-values of 20's or 30's or 40's. A fiber insulation having an R-value of 25 placed in a house not properly sealed will allow the wind to blow through it as if there were no insulation. Maybe the R-value is accurate in the tested material in the lab, but it is not even remotely part of the real world. We must start asking for some additional dimensions to our insulation. We need to know its resistance to air penetration, to free water, and to vapor drive. What is the R-value after it is subjected to real world conditions?

The R-value is a fictitious number supposed to indicate a material's ability to resist heat loss. It is derived by taking the "k" value of a product and dividing it into the number one. The "k" value is the actual measurement of heat transferred through a specific material.

Test to Determine the R-Value

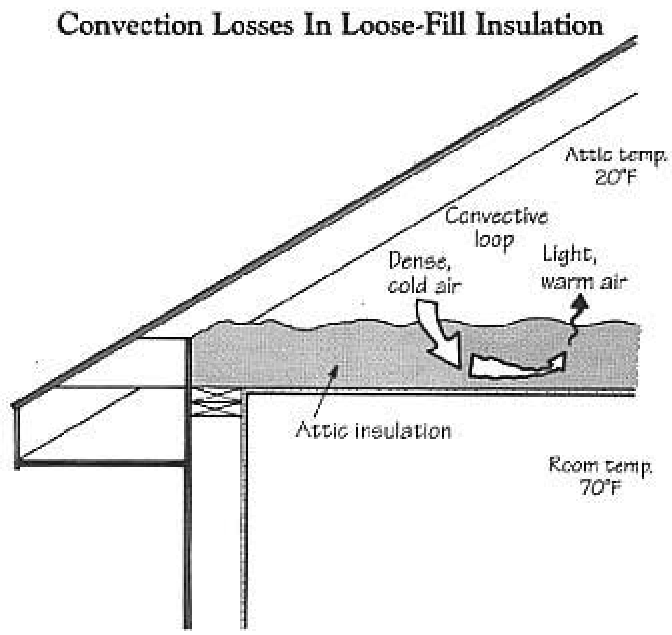
The test used to produce the "k" value is an ASTM test. This ASTM test was designed by a committee to give us measurement values that hopefully would be meaningful. A major part of the problem lies in the design of the test. The test favors the fiber insulations -- fiberglass, rock wool, and cellulose fiber. Very little input went into the test for the solid insulations, such as foam glass, cork, expanded polystyrene or urethane foam.

The test does not account for air movement (wind) or any amount of moisture (water vapor). In other words, the test used to create the R-value is a test in non-real-world conditions. For instance, fiberglass is generally assigned an R-value of approximately 3.5. It will only achieve that R-value if tested in an absolute zero wind and zero moisture environment. **Zero wind and zero moisture are not real-world.** Our houses leak air, all our buildings leak air, and they often leak water. Water vapor from the atmosphere, showers, cooking, breathing, etc. constantly moves back and forth through the walls and ceilings. If an attic is not properly ventilated, the water vapor from inside a house will very quickly semi-saturate the insulation above the ceiling. Even small amounts of moisture will cause a dramatic drop in fiber insulation's R-value -- as much as 50 percent or more.

Vapor Barriers

We are told, with very good reason, that insulation should have a vapor barrier on the warm side. Which is the warm side of the wall of a house? Obviously, it changes from summer to winter -- even from day to night. If it is 20 F below zero outside, the inside of an occupied house is certainly the warm side. During the summer months, when the sun is shining, very obviously the warm side is the outside. Sometimes the novice will try to put vapor barriers on both sides of the insulation. Vapor barriers on both sides of fiber insulation generally prove to be disastrous. It seems the vapor barriers will stop most of the moisture but not all. Small amounts of moisture will move into the fiber insulation between the two vapor barriers and be trapped. It will accumulate as the temperature swings back and forth. This accumulation can become a huge problem. We have re-insulated a number of potato storages which originally were insulated with fiberglass having a vapor barrier on both sides. Within a year or two the insulation would completely fail to insulate. The moisture would get trapped between the vapor barriers and saturate the fiberglass insulation to the point of holding buckets of water. Fiber insulation needs ventilation on one side; therefore, the vapor barrier should go on the side where it will do the most good.

We understand air penetration through the wall of the house. In some homes when the wind blows, we often can feel it. But what most people, including many engineers, do not realize is that there are very serious convection currents that occur within the fiber insulations. These convection currents rotate vast amounts of air. The air currents are not fast enough to feel or even measure with any but the most sensitive instruments. Nevertheless, the air is constantly carrying heat from the underside of the pile of fibers to the top side, letting it escape. If we seal off the air movement, we generally seal in water vapor. The additional water often will condense (this now becomes a source of water for rotting of the structure). The water, as a vapor or condensation, will seriously decrease the insulation value -- the R-value. The only way to deal with a fiber insulation is to ventilate. But to ventilate means moving air which also decreases the R-value.



At very cold temperatures, when the temperature difference across the attic insulation reaches a certain critical point, convection within the insulation can reduce R-value.

Nisson, J.D. Ned, JLC, "Attic Insulation Problems In Cold Climates" March 1992, pp. 42-43

Air Penetration

The filter medium for most furnace filters is fiberglass -- the same spun fiberglass used as insulation. Fiberglass is used for an air filter because it has less impedance to the air flow, and it is cheap. In other words, the air flows through it very readily. It is ironic how we wrap our house in a furnace filter that will strain the bugs out of the wind as it blows through the house. There are tremendous air currents that blow through the walls of a typical home. As a demonstration, hold a lit candle near an electrical outlet on an outside wall when the wind is blowing. The average home with all its doors and windows closed has a combination of air leaks equal to the size of an open door. Even if we do a perfect job of installing the fiber insulation in our house and bring the air infiltration very close to zero from one side of the wall to the other, we still do not stop the air from moving through the insulation itself vertically both in the ceiling and the walls.

The best known solid insulation is expanded polystyrene. Other solid insulations include cork, foam glass and polyisocyanate or polyisocyanurate board stock. The latter two being variations of urethane foam. Each of these insulations are ideally suited for many uses. Foam glass has been used for years on hot and cold tanks, especially in places where vapor drive is a problem. Cork is of course a very old standby often used in freezer applications. EPS or expanded polystyrene is seemingly used everywhere from throw away drinking cups and food containers to perimeter foundation insulation, masonry insulations, and more. Urethane board stock is becoming the standard for roof insulation, especially for hot mopped roofs. It is also widely used for exterior sheathing on many of the new houses. The R-value of the urethane board stock is of course better than any of the other solid insulations. All of the solid insulations will perform far better than fiber insulations whenever there is wind or moisture involved.

Most of the solid insulations are placed as sheets or board stock. They suffer from one very common problem. They generally don't fit tight enough to prevent air infiltration. It does not matters how thick these board stocks are if the wind gets behind it. We see this often in masonry construction where board stock is used between a brick and a block wall. Unless the board stock is actually physically glued to the block wall air will infiltrate behind it. In this case as the air flows through the weep holes in the brick and around the insulation it is rendered virtually useless. Great care must be exercised in placing the solid insulations. The brick ties need to be fitted at the joints and then sealed to prevent air flow behind the insulation.

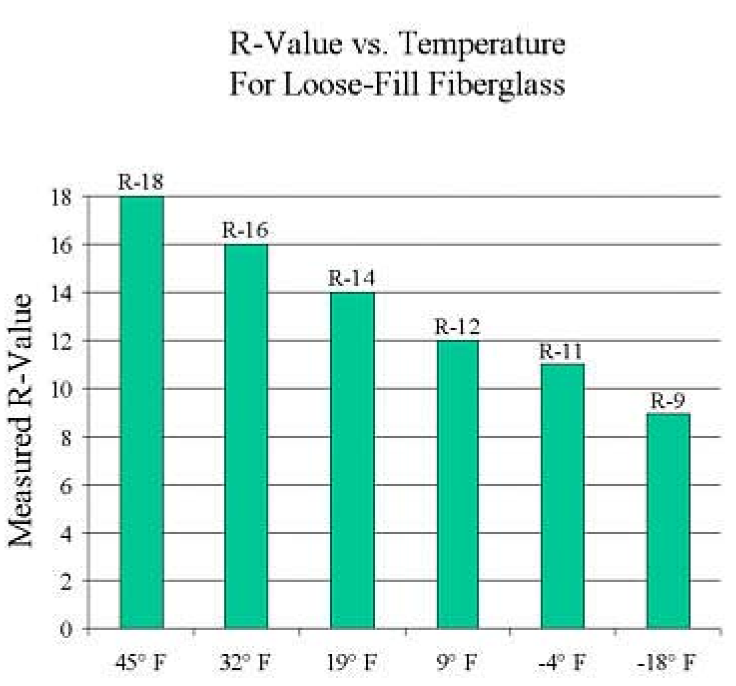
The only commonly used solid insulation that absolutely protects itself from air infiltration is the spray-in-place polyurethane. When it is properly placed between two studs or against the concrete block wall or wherever, the bonding of the spray plus the expansion of the material in place will effect a total seal. This total seal is almost impossible to overestimate. In my opinion most of the heat loss in the walls of the home have to do with the seal rather than the insulation.

For physical reasons, heat does not conduct horizontally nearly as well as it does vertically. Therefore, if there were no insulation in the walls of the homes, but an absolute airtight seal, there would not necessarily be a huge difference in the heat loss. This would not be the case if the insulation was missing from the ceiling. Air infiltration can most effectively be stopped with spray-in-place polyurethane. It is the only material (properly applied) that will fill in the corners, the cripples, the double studs, bottom plates, top plates, etc. The R-value of a material is of no interest or consequence if air can get past it.

Anecdotes

During the 1970s my firm insulated a bunch of new homes in the Snake River Valley of Idaho with 1.25 inches of spray-in-place polyurethane foam in the walls. In 1970 the popular number for the R-value of one inch of urethane foam was 9.09 per inch. Using this value, we were putting an R of 1.25 x 9.09 = 11.36 in the walls. This was much less than the R = 16 claimed by the fiberglass insulators. Today, using the charts from an ASHRAE book, we would only be able to claim an R-value for the 1.25 inches of 7.5 to 9. Neither of these numbers make for a very big R-value. The reality is that the people for whom we insulated their homes invariably would thank us for the savings in their heat bills. They would tell us their heating bill was half of their neighbor's. They felt as if they saved the cost of the polyurethane in one, or at most two, years. This is anecdotal evidence, I know, but anecdotal evidence is also compelling and very real in our world. Most of these customers were savvy people. They would not have paid the extra to get the urethane insulation if it had not been better.

"There is a problem with loose-fill fiberglass attic insulation is cold climates. It appears that, as attic temperature drops below a certain point, air begins to circulate into and within the insulation, forming "convective loops" that increase heat loss and decrease the effective R-value. At very cold temperatures (-20F), the R-value may decrease by up to 50%."



In full-scale attic tests at Oak Ridge national Laboratory, the R-value of 6 inches of cubed loose-fill attic insulation progressively fell as the attic air temperature dropped. At -18 F, the R-value measured only R-9. The problem seems to occur with any low-density, loose-fill fibrous insulation.

Nisson, J.D. Ned, JLC, "Attic Insulation Problems In Cold Climates" March 1992, pp 42-43

About mid 1975 I received a call from a division manager of one of the major fiberglass insulation manufacturers. The caller asked, "I understand that you are spraying polyurethane in the walls of homes?" I told him that was true. He was calling because we were cutting into the fiberglass insulation sales in our area. He asked, "How can you do it?"

I knew what he meant. He wanted to know how I could look somebody in the eye and sell them a more expensive insulation than the cheap old fiberglass. I told him the way I did it is with a spray gun. Of course, that wasn't the answer he wanted. He wanted to know how I could not feel guilty. I told him of insulating one of two nearly identical houses built side by side. We insulated the walls of one with 1.25 inches of urethane. The other house was insulated with full thick fiberglass batts put in place by a reputable installer. Not only did we use only 1.25 inches of urethane as the total wall insulation, but we had the builder leave off the insulated sheathing. At the end of the first winter, the urethane insulated home had a heating bill half of their neighbor's. I know that is not terribly scientific, but it is very real. I am not sure he was convinced, but it should be noted that same company jumped into the urethane foam supply business the next year.

One and a quarter inch of polyurethane sprayed properly in the wall of a house will prevent more heat loss than all the fiber insulation that can be crammed in the walls

-- even up to an eight inch thickness. Not only does it provide better insulation, but it provides significant additional strength to the house.

One of my early clients was Brent. I had insulated several potato storages for Brent. He knew what spray-in-place urethane insulation could do. When he decided to build his new, very large, very fancy new home, he asked me to come insulate it. I told him I would be delighted. The builder pitched a fit. He "didn't need any of that spray-in-place urethane in his buildings. He made his buildings tight, and fiberglass was just as good."

Brent explained to the builder, "I know who is going to insulate the building. It is not as definite as to who is going to be the contractor. You can make up your mind. We are going to have the urethane insulation and you build the building, or we are going to have the urethane insulation, and I will have someone else build the building." It didn't take the contractor long to decide he wanted to use urethane insulation.

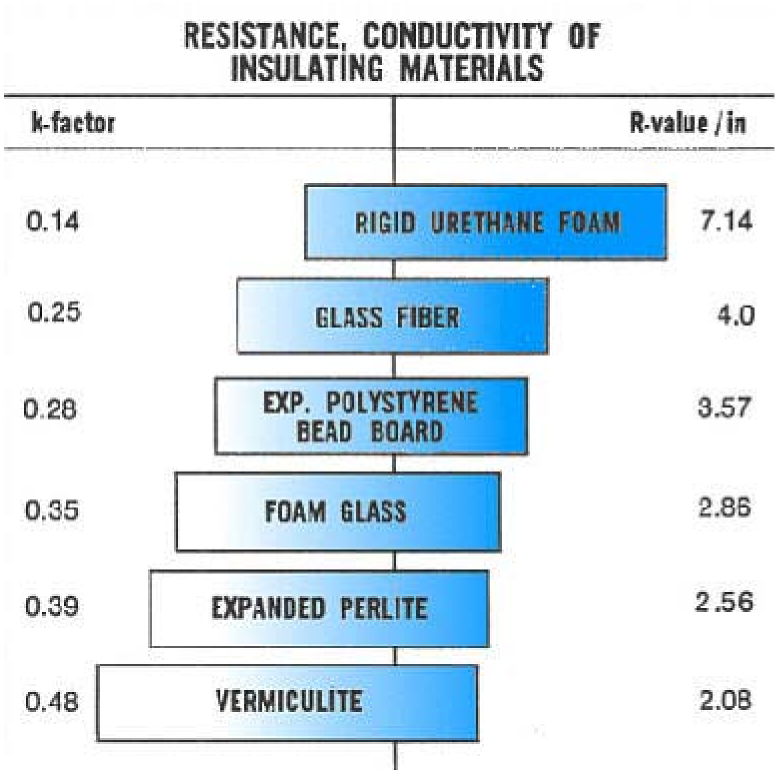
It was amazing to me how it worked out. We sprayed a lot of foam in Brent's house, and it cost him quite a bit of money because it was such a large home. Always after when I would meet him, he would tell me his heat bill was less than any of his rent houses or homes of anybody else he knew. And his home was two or three times larger. Also, the builder started having me insulate most of his new custom built houses. He told me he would explain to his clients the best insulation was the spray-in-place urethane. It would cost a little more, but it was by far the best. Most of the owners opted for the urethane. Never have I had a customer tell me that he did not save money by using the urethane spray-in-place insulation. You can spend all the time you want with R-values and "k" factors, and "prove" on paper there is no way the urethane can do the insulation job that the fiberglass will. In the real world, I can assure anyone there is no way fiber insulation can be as effective as spray-in-place urethane -- not even close.

R-value tables are truly part of the "Fairy Tale." They show the solid and the fiber insulations side by side, implying they can be compared. The fact is, without taking installation conditions into account, comparisons are meaningless. Spray-in-place urethane foam provides its own vapor barrier, water barrier, and wind barrier. None of the other insulations are as effective without special care taken at installation. The fiber insulations must be protected from wind, water and water vapor. Again the tables need a second table to state installation conditions.

Consider the following anecdotes:

Meadow Gold Company was going to build a freezer in Idaho Falls, Idaho. Chet, the plant manager was a good friend of the local Butler dealer. The local Butler dealer and I had become good friends. A Butler building does not lend itself very well to a freezer if you are going to insulate the freezer with expanded polystyrene. So the three of us got together and planned a freezer that would accommodate the needs of Meadow Gold yet be built of a Butler building and be properly insulated. This was in my first year of spraying polyurethane foam, and at that time I believed all the literature and knew what we were doing was going to be just right. It turned out even better. The then current R-value table showed one inch of urethane equal to 2.5 inches of expanded polystyrene. So, I suggested we spray the metal building with four inches of urethane to replace the 10 inches of expanded polystyrene normally used by Meadow Gold for freezers.

I sprayed under the slab with four inches, the walls with four inches, and the underside of the roof with five inches of urethane (the fifth inch was added as a safety margin). Chet, the plant manager, was pretty worried, because he stuck his neck out going with this non-traditional insulation and the non-traditional building for Meadow Gold Company. Well, the building progressed on schedule, but the equipment to cool the building did not arrive on time. By summer only one of the two refrigeration compressors had arrived. Two compressors were needed (per the Meadow Gold engineers) to handle needs of the building based on using 10 inches of expanded polystyrene.



With the lowest k-factor and the highest R-value, urethane foam can provide more thermal resistance with less material than any other insulation.

Chet considered one alternative to his predicament was to turn one of the older freezers that had been used as a cooler back into a freezer. Then maybe he could make a cooler out of the new building with the just the one compressor. It was not a satisfactory arrangement, but it maybe could work. The other thing Chet kept telling us was that he would know as soon as he turned on the freezer equipment whether or not the building would work. When I pressed him, he said that normally it takes five days to bring a freezer down to 10 F below zero -- needed for ice cream. When he turned on the new freezer, with only the one compressor, the temperature dropped to 18F degrees below zero by the second morning. They had their freezer. It ran the entire summer using only the single compressor.

Urethane Conserves Energy

Excellent thermal resistance is the primary performance benefit of urethane foam insulation, but it is not the only one. Urethane also has these advantages as a construction material:

Its closed cell structure makes urethane most effective initially and in the long run.
When protected by skins or other covering, urethane will not absorb water. Consequently the x-factor (thermal conductivity) is virtually constant.
Sprayed-on foam has the advantage of no seams or joints.
Urethane's thermal resistance means that only one thickness of material is need for most jobs.
It has a low moisture permeability (1-3 perms).

Where circumstances demand thinner walls or roofs, urethane -- with its superior insulating capability -- makes it possible to reduce the thickness of the insulation component with no loss of thermal resistance. Or the thermal resistance of an assembly can be increased without enlarging the size of the member. Urethane helps to offset the design restrictions imposed by the fact that most building materials are constant in thickness and weight.

"Urethane Foam as an Energy Conserver", How to Conserve Energy: in commercial, institutional and industrial construction, Mobay Chemical Corp. Pittsburgh, PA: 1975, p 3

A few weeks after start up of the freezer, I was visited by a Meadow Gold engineer from Chicago. He wanted to know exactly what we had done to insulate the freezer. One compressor should not be able to hold the temperature as it was doing. I explained to him exactly what we had done. He seemed satisfied and he left. A few weeks later he showed up again with his boss. We went to the plant and verified with an ice pick the thickness of the foam. It was indeed four inches in the walls and five inches in the ceiling. Here again they reiterated that the building should not be operating as it was. What they were telling me was that even though I had used one inch of urethane to replace 2.5 inches of expanded polystyrene, the building was still requiring only 50 percent of the normal compressor power for cooling. As you can imagine, the experience made me a lot more bold, and I used the information to sell more freezer insulation jobs.

One of our largest freezer insulation projects was a sixty thousand square foot freezer at Clearfield, Utah. I was able to talk the general contractor into letting us insulate with spray-in-place polyurethane foam the brand-new all-concrete freezer he was building. This building was the 12th in a chain of freezers. My friend Bob, the contractor, had taken it upon himself to make the switch from the ten inches of expanded polystyrene to four inches of urethane with a fifth inch on the roof. The building was built with tilt up concrete insulated on the interior side of the concrete with spray-in-place urethane. We then sprayed on a three-fourths of an inch thick layer of plaster as the thermal barrier. Over the pre-stressed concrete roof panels, we put five inches of spray-in-place urethane and then covered it with hot tar and rock. (This is an old CPR-specification).

I was on the job the last day. As we finished up the owner showed up. He had expected to see ten inches of expanded polystyrene, and here was four inches of urethane. I told him he would like the four inches of urethane as it would be even better than the expanded polystyrene, based on my previous experience. He told me he was sicker than a dog because he felt like there was no way that could be true. It was too late for him to do anything about it. If he could have, he would have changed the contract instantly, but he was stuck and felt stuck.

They had 12 other similar size freezers, except the others were insulated with expanded polystyrene. The normal way of operating them was to use three large compressor assemblies. Two of the compressors would be needed all summer to keep the building cold, and the third one would be a standby unit, in case one of the other two had problems.

About a year later, I received a phone call from one of the managers. He asked me if I had time to insulate another sixty thousand square foot freezer in Clearfield, Utah. I assured him we had the time, the inclination, and the excitement to do it, but I thought the owner wanted nothing to do with urethane foam insulation. The manager explained to me that not only had the Clearfield freezer operated better than any other freezer in their line, it had operated for less than half the costs of any others. They were adding another sixty thousand square feet without adding more compressors. The compressor power available to them because of the urethane insulation efficiency allowed them to do it. The building had run very nicely through the hot part of the summer with just one compressor. Now they would be able to run two buildings off of two compressors and still have a spare.

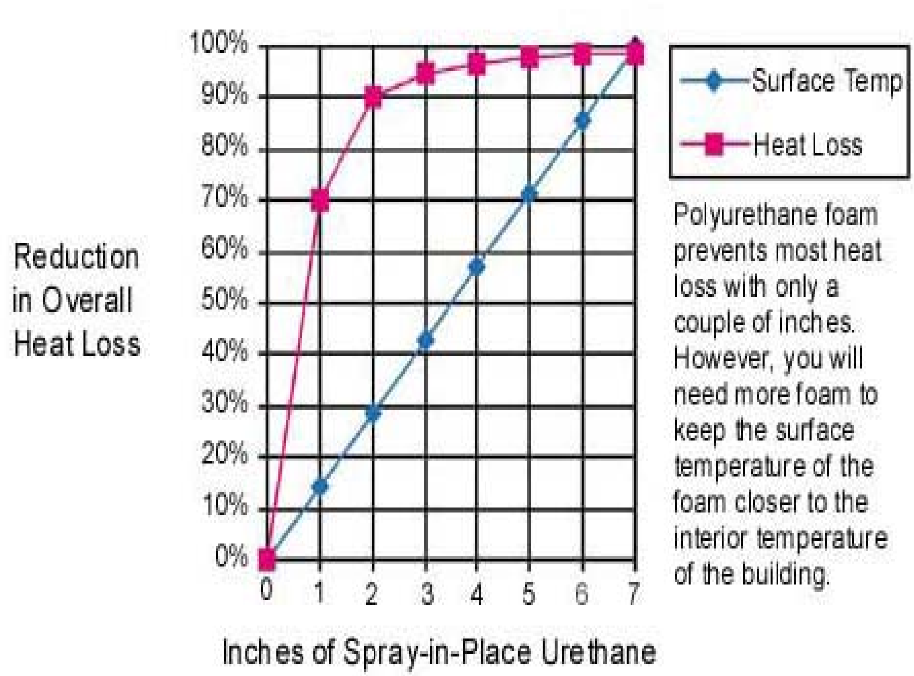
Again, this is anecdotal evidence, but let me assure you that you will get the same results if you do the same thing as we have. I have insulated too many buildings now to know that this will happen in every case. Never can you use an R-value from a fiber insulation and compare it to the R-value of a foam insulation. Nor can you use the R-value of a foam insulation if it is in sheet form and compare it to the R-value of the foam insulation if it is spray-in-place. Spray-in-place polyurethane is an absolute minimum of three to ten times as effective as any other insulation available today.

During the late 1970s, the FTC went after the urethane foam suppliers for misleading advertising especially with regard to fire claims. A consent decree followed. It destroyed a tremendous amount of confidence in the use of urethane. Up to that point, Commonwealth Edison would give Gold Medallion approval for homes insulated with 1.25 inches of spray-in-place urethane in the side walls of masonry constructed homes. True, that was anecdotal evidence, but also true, it worked. Much work was done in the early 1970s using a 1.25 inches urethane as a replacement for wall insulation in a home. Not only did it replace the wall insulation, it also replaced the exterior sheathing. The buildings are stronger and better insulated when sprayed with the 1.25 inches of urethane.

Understanding the two purposes of insulation gives a standard to measure the insulations:

I. Heat loss

There is a little understood part about insulation that needs to be covered. There is a substantial difference between insulation for temperature control and insulation for heat loss control. For instance, the graph (*below*) shows the heat loss control of the spray-in-place urethane foam insulation. Any insulation will have a similar graph but with thicker amounts of insulation. This graph points out that more insulation is not necessarily cost effective. There is a point where more insulation is pointless from a total heat loss perspective.



This graph illustrates the reduction in heat loss from a building when it is insulated with various thicknesses of spray-in-place urethane foam. Note: the insulation benefit tops off very quickly above three inches. The graph is not exact, but it shows in general what happens as additional insulation is added to the surface temperature. In other words, by super-insulating , the surface temperature of the inside of the exterior walls comes very close to the room temperature. This prevents condensation, which prevents the growth of mold.

The graph shows that 70% of heat loss from conductance is stopped by a one inch thickness of spray-in-place urethane foam. Remember we are going to stop nearly 100% of the heat loss from air infiltration with the first one-fourth of an inch of urethane foam. The second inch of spray-in-place urethane stops about 90% of the heat loss and the third inch 95% and so forth.

Thermal diffusivity and Heat Sinks

It should be noted that when the urethane is used on the exterior of a heat sink, such as concrete, the actual effective R-value is approximately doubled. This is why with the Monolithic Dome, we are able to calculate effective R-values in excess of 60. A heat sink is any substance capable of storing large amounts of heat. Most commonly we think of concrete, brick, water, adobe and earth as heat sink materials used in building. The property of a heat sink to act as an insulation is called thermal diffusivity.

The simple explanation for the way it works is: As the temperature of the atmosphere cycles from cold to hot to cold to hot the heat sink absorbs or gives up heat. But because the heat sink can absorb so much heat it never catches up with the full range of the cycle. Therefore, the temperature of the heat sink tends to average. Large heat sinks will average over many days, weeks or even months.

An example is the adobe hacienda with its 2 to 6 foot thick walls. By the time the adobe walls begin to absorb the daytime heat it is night time and the same heat then escapes into the cooler night. Therefore the temperature would average. Because the mass of the adobe is so large the temperature averages over periods of months. Adobe acts as an insulation even though adobe has a minimal "R" value.

You can see from the graph that urethane thicknesses beyond four or five inches is practically immaterial. We use three inches for most of our construction. Two inches will do a very superior job. We have insulated many metal buildings with one inch of urethane and the drop in heat loss is absolutely dramatic. Obviously the first quarter inch takes care of the wind blowing through the cracks. (It usually takes an inch to be sure the cracks are all filled.) The balance of the inch adds the thermal protection.

II. Surface temperature control

Surface temperature control is the second reason for insulation. In many cases it is the most important reason for the insulation. I noticed this phenomena first while insulating potato storages.

We had various customers ask us to insulate the buildings anywhere from two to five inches of urethane. The buildings insulated with two inches would hold the temperatures of the potatoes properly, just as well as the buildings insulated with five inches. The difference came in the condensation. Potato storages are kept up at very high humidity levels. The buildings with the two inches of urethane would have far more condensation than those with the five inches.

An engineer from the Upjohn company explained this to me. He stated that thicker insulation is absolutely necessary to maintain higher interior surface temperatures. One and a half inches of urethane on the walls and ceiling of a potato storage would control the heat loss from the building, but it took a minimum of three inches of urethane to control the interior surface temperature. Four inches was even better. With five inches the difference is practically negligible. The only place where we have felt the need for five inches of urethane was insulating the roof or ceiling of a sub-zero freezer.

Underground housing — surface temperature control vs. heat loss control.

Most underground housing is in trouble from mold and mildew growth. The cause is not enough insulation to control interior surface temperatures. Rarely is there a problem with total heat loss. Water vapor condenses on the surface allowing mold to grow. Mold makes people sick. The only solution is lots of insulation for temperature control and ignore total heat loss.

My experience is that R-value tables can be used as indicators. They need modifications to make them equal to real world conditions. There needs to be allowances made. They must show equivalents. These equivalents will be more like one inch of spray-in-place urethane equal to four inches of fiberglass in a normal installation. Footnotes to the table will need to define degradation of insulations in real world conditions. Only then will the "R-value" Fairy Tale become a real world success story.