Thermal Resistance of Loose-Fill Fiberglass Insulation in Spaces Heated from Below

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ABSTRACT

In this investigation a laboratory model of a house attic was used to experimentally determine the thermal resistance of blown fiberglass insulation. The attic model test cell was 12 ft. (3.66 m) square. Several types of fiberglass insulation were tested, namely cubed type, nodulated type, and batts.

Cubed type insulation resembles batt insulation which has been cut up or 'cubed' into cubes with sides 3/4 to 1 1/4 in. (20 to 30 mm). Nodulated type insulation is very unlike the cubed type insulation in that it resembles wool-like fibers which are randomly orientated and which have a tendency to clump together in nodules.

Energy was input at the bottom side of the insulation in the test cell by means of an electric heating element. A resistance was calculated for the insulation by determining the amount of heat flowing upward through the insulation over a measured temperature difference.

The test results showed that the batts had a thermal resistance equal to the manufacturer's claim, but the loose-fill insulations had a somewhat lower thermal resistance, especially at larger temperature differences across the insulation. The thermal resistance of the insulation appeared to depend on insulation density, fiber orientation and temperature difference.

INTRODUCTION

Until recently 2 to 8 in. (50 to 200 mm) of insulation was typical in attics. Recent interest in energy conservation has seen this amount increase up to 31.5 in. (800 mm.) Low-density loose-fill insulation of such a depth may not only show some density variation with depth, but the thermal resistance may not be constant for all temperature differences across the insulation.

Most previous work on fibrous insulation materials was performed on specimens less than 6 in. (152 mm) thick. Mumaw[1] stated that Rowley noticed that convective heat transfer increased with specimen thickness. Pratt[2] and others found that thermal conductivities caused by radiative and convective heat transfer increased considerably below insulation densities of 6.14 lb/ft^2 (30 $kg/^2$) while heat conduction of air within the insulation is essentially the same for all insulation densities (see Fig. 1).

It is the purpose of this study to investigate the thermal resistance of large thicknesses of fiberglass insulation because it may be installed commercially in the attics of houses. Three different types of fiberglass insulation were tested: cubed type, nodulated type, and batts.

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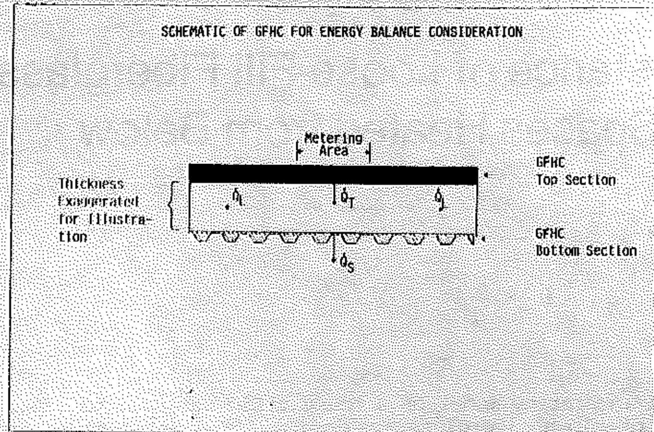

Figure 7. Schematic of GFHC for energy balancd consideration

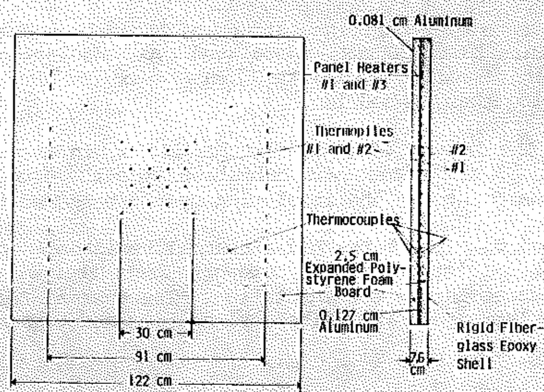

Figure 8. Schematic of GFHC top section

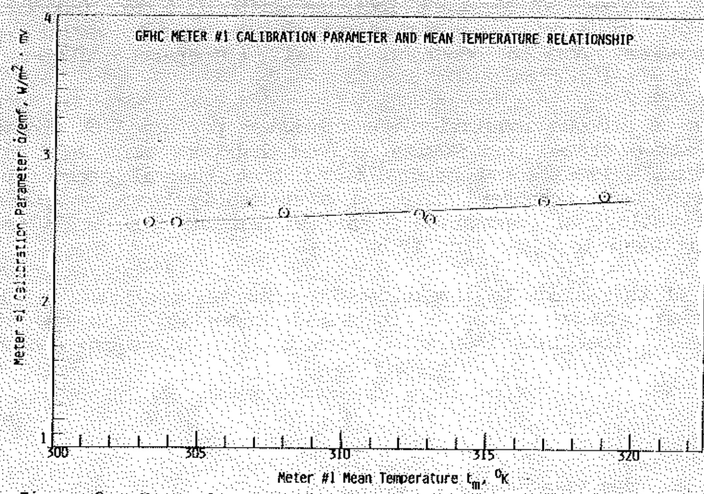

Figure 9. Homemade meter #1 calibration parameter and mean temperature relationship

ATTIC TEST-CELL CONSTRUCTION AND INSTRUMENTATION

A cross section of the test cell is shown in Fig. 1.

The attic test cell was constructed as described below so as to minimize the heat flow through the attic test cell bottom and walls. The thermocouples in the attic test cell bottom and walls were placed at several locations so that the heat flow through these sections could be estimated.

Initially, a 2 in. (50 mm) thick layer of extruded polystyrene insulation board, dimensions 12 ft. (3.66 m) square, was placed over the concrete floor. A layer of polyethylene, 6 mil (150 μm) was placed over the insulation board, with overlapping edges on all sides. A layer of aluminum foil was placed over the polyethylene and 9.5 in. (12.7 mm) thick wood strips were placed on the aluminum foil to act as vertical spacers. Three such layers (insulation board, polyethylene, aluminum foil, wood spacers) were built up. On top of the third layer of wood strips, a 0.375 in. (9.5 mm) thick plywood layer covered the model. Small-diameter magnet wire, which served as the heating element for inputting heat to the lower side of the loose-fill insulation, was strung on 1.5 in. (3.8 cm) spacings. On top of the plywood one-and-a-half-inch-long nails (38 mm) nailed into the plywood served as support posts for the wire. The total resistance of the magnet wire was about 13.2 Ohms. A layer of galvanized sheet metal was placed over the wood strips of the top layer to give a uniform temperature heating surface and a final 6 mil (150 μ m) polyethylene covering was placed over the sheet metal.

Finally, a wood frame was built around the layered construction with a 2 in. (50.8 mm) thick layer insulation board covering the interior walls to serve as a container for the loose-fill insulation. The polyethylene sheets were brought out underneath the frame, rolled up, and nailed to the outside frame wall. Three-inch thick SM board 7.62 cm was placed in the cavity between studs in the frame.

Thermocouples were taped to both sides of each horizontal layer of insulation board at four locations in the attic test cell: center, north, northeast, and edge. Thermocouples were also located on the bottom side of the plywood layer, the top of the sheet-metal layer, and on the surface of the loose-fill insulation at all four locations. An additional thermocouple was placed on the heating element as shown in Fig. 2.

In the wall, thermocouples were taped to both sides of a 2 in. (50.8 cm) thick SM board at four different heights. This was done at two locations, at the center of the east wall and at 6 in. (152 mm) south from the northeast corner.

A string of six thermocouples was placed in the center of the attic test cell at various heights to give a vertical temperature profile at one location within the insulation.

INSTALLATION OF INSULATION

Three different types of insulation were tested in the attic model, loose-fill cubed fiberglass 3/4 to 1 1/4 in. (20 to 30 mm), nodulated type, and fiberglass batts. These are described below.

A commercial installer blew in the cubed fiberglass loose-fill insulation to give an insulating value of 57.6 $hr.ft^2 . {}^oF/Btu$ ($10\ m^2/C^oW$). A very smooth surface was attained.

The cubed insulation was blown in at a pressure of 2 psi (13.8 kPa) using a 3 in. (7.6 cm) diameter nozzle. Five and three quarter bags of insulation weighing 33 lb (15 kg) each were installed to give an installed mass of 1.317 lb/ft^2 (6.694 kg/m^2) or density of 0.527 lb/ft^3 (8.443 kg/m^3) on average.

Instructions printed on the insulation bags specified a minimum installed thickness of 30 in. (0.762 m) and a minimum installed mass of 1.28 lb/ft^2 (6.2 kg/m^2) to achieve an insulation value of RSI R-57.6 $hr/ft^2 - {}^o/F$ BTU) RSI 10.1 $m^2/{}^oCW$. Thus, the insulation met the manufacturer's installation specifications for the cubed fiberglass.

It was observed that the installed cubed-type insulation settled 5 to 10% over a period of two weeks. Settling was uneven over the surface with the largest amount taking place near side walls.

In a later test the nodulated type of fiberglass was installed by a local contractor using the same blowing technique as was used for the cubed type. This insulation was installed at an even depth of 27 in. (0.686 m) and a mass per unit area of 2.34 lb/ft^2 (11.44 kg/m^2), with an expected thermal resistance of (R81.5) RSI 14.4. This insulation was allowed to settle for a period of two weeks at which time its average depth was measured at 24 in. (.610 m.).

The fiberglass batts were tested with two thicknesses, one with 6 in. (152 mm) and another with three layers of 6 in. (152 mm) batts. Each batt layer was laid at right angles to the adjacent layer and had an expected thermal resistance of RSI 3.5 (R20). In each case the batts were placed by hand.

EXPERIMENTAL PROCEDURE

The experimental procedure required that the attic be at steady-state operation. Once at steady-state, the heat input (electrical input to magnet wire) was measured and the heat loss through the attic bottom and walls was calculated by measuring the temperature difference (via thermocouples) across each component the insulation board in the attic bottom and walls and then using the relationship:

$$q_{loss} = (T_{IN} - T_{OUT})/R_{insulation\ board} \tag{1}$$

where:

- T_{IN}, T_{OUT} are surface temperatures of the insulation board (thermal resistance known)
- R is the thermal resistance of the insulation board in ft^2 $^\circ$F hr/BTU (m^2 $^\circ$C/W)
- q_{loss} is the calculated heat flow in BTU/hr ft^2 (W/m^2)

The heat loss to the attic bottom and walls was typically calculated to be less than 10 percent of the total heat input to the attic test cell.

The difference between heat input and heat loss through the attic bottom and walls was assumed to be the heat flow upward through the loose-fill insulation. A resultant thermal resistance was calculated for the loose-fill insulation using the relationship:

$$R_{ins} = \Delta T_{ins}/(q_{in} - q_{loss}) \tag{2}$$

where:

- ΔT_{ins} is the temperature difference across the loose-fill insulation
- q_{in} is the heat input to the attic test cell
- q_{loss} is the heat loss through the attic bottom and walls calculated in (1)
- R_{ins} is the calculated resistance of the loose-fill insulation

To achieve a different temperature difference across the loose-fill insulation a step change in the electrical input to the magnet wire was made. The attic test cell was allowed to come to steady state over a period of approximately 48 hours. The time constant for the attic test cell was experimentally found to be about 11.5 hours when the attic test cell contained cubed type loose-fill insulation. Thus, the stablization period for the test cell after a step change in the input was greater than 4 time constants long.

The temperature of the air above the sample and surrounding the test cell was approximately 21°C, but it probably varied 2 degrees Celsius above and below this mean temperature throughout the day as the experiments had no real method of controlling this temperature. The different temperature differences across the loose-fill insulation was thus achieved by varying the temperature at the bottom of the sample. The maximum temperature at the bottom of the loose-fill insulation was approximately 100°C when the ΔT_{ins} was 80°C.

The test cell resembles an attic in that the heat flow is vertical from the bottom to the top of the sample of loose-fill insulation. However, the mean operating temperatures of the test cell are much higher than would be measured in an actual attic on a cold winter day. The effects of these elevated temperatures are discussed in the next section.

Figures 3 and 4 show wall temperature profiles. The wall temperatures at the corner are lower than at the center, however, the temperature difference across the wall is essentially the same at both places.

The proximity of the centre, north and northeast points in Fig. 5 indicates that heat flow is fairly unidirectional in this zone.

RESULTS AND DISCUSSION

Using the experimental procedure described previously the steady-state heat flows through the cubed-type insulation were measured along with the temperature differentials. These were used to calculate the overall insulating effect or resistance for each steady state test condition.

Figures 3 and 4 show wall temperature profiles for the center of the east wall and near the north-east corner on the east wall. The wall temperatures at the corner are lower than at the center, however, the temperature difference across the wall is essentially the same at both locations.

Fig. 5 shows a vertical temperature profile within the cubed type insulation at various locations throughout the attic model. The proximity of Center, North and Northeast points indicates that heat flow is fairly unidirectional in this zone. From this graph is appears that at the center of the test model most of the temperature drop across the insulation occurs within the bottom 40% of the loose-fill insulation. This may be partly a result of the higher density of insulation near the bottom and partly a result of convection of cool air down at the center. Surface temperature contours revealed a 2 ft. (0.6 m) wide ring averaging 6 ft. (1.8 m) in diameter which was much warmer than the remaining surface of the loose-fill insulation. This phenomenon appeared to be more prominent at high ΔT_{ins} with the warm surface ring geometrically centered in the attic test cell. The experimental evidence of the vertical temperature profile and the thermal surface contours support the assumption that a large convetion cell was apparently set up within the loose-fill insulation at a large temperature difference across the insulation. Since the vertical temperture profile at the attic center appears to be in a region of cool descending air, these vertical temperature profiles may be misleading on an average loose-fill insulation elevation basis.

The results are presented for the cases of the cubed type insulation as installed, with airflow over the top surface and as compressed or compacted to 1.58 times the original installed density in Figs. 6, 7 and 8 respectively.

Figure 6 indicates that as the temperature difference across the cubed type insulation increases, the 'apparent' thermal resistance of the insulation decreases. The convection cell set up in the cubed type insulation, as described previously, is likely a major cause of the lowered thermal resistance values at high temperature differences and perhaps at low temperatures differences also.

Because the high temperature difference tests required a high mean insulation temperature, it is expected that more heat is transferred by radiation in these results than would be present at lower mean temperatures of the loose-fill insulation. ASTM standards require that insulation for commercial sale be tested and rated at a mean insulation test temperature of $75^{\circ}F$ ($23.9^{\circ}C$).[3] It should be noted that most of the insulation tests performed here were not at a mean insulation temperature of $75^{\circ}F$ ($23.9^{\circ}C$), but were at a higher mean temperature. The experimental results presented were not corrected to reflect the effects of elevated mean test temperatures. Extrapolation Mumaw's results for thermal conductivity, k, variation with product density showing mean temperature effects, for a loose-fill insulation density typical of the cubed type, one might expect up to 35% increase in radiation when using a mean temperature of $125^{\circ}F$ ($51.7^{\circ}C$) (typical of $\Delta T_{ins} = 108^{\circ}F$ ($60^{\circ}C$)) as opposed to $75^{\circ}F$ ($23.9^{\circ}C$) (standard test temperature) (See Fig. 6). At low ΔT_{ins}, (less than $36^{\circ}F$ ($20^{\circ}C$)), the increase in radiation can be expected to be a maximum of 10%.

According to Bankvall[4], the radiation coefficient approaches one half of the total thermal conductivity value at insulation densities typical of this experiment .53 lb/ft^3 (8.5 kg/m^3). Thus the R values in Fig. 6 for ΔT_{ins} between $36^{\circ}F$ and $108^{\circ}F$ ($20^{\circ}C$ and $60^{\circ}C$) could be corrected from 5 to 18% respectively to relate the results to a mean test temperature of $75^{\circ}F$ ($23.9^{\circ}C$) to correct for increased heat transfer due to radiation.

The test results are not corrected for the increase in thermal conductivity of air with temperature. The thermal conductivity of air at $125^{\circ}F$ ($51.7^{\circ}C$) is approximately 8 percent higher than that of air at $75^{\circ}F$ ($23.9^{\circ}C$) at atmospheric pressure. Pratt also states that the contribution to total conductivity of loose-fill insulation (for low densities) by air conduction is about 50%. Thus, the correction to R-values due to an increase in air conductivity as a result of higher mean test temperatures would be less than 5%.

It is noted that the effect of a loose polyethylene covering on top of the insulation was essentially negligible, even though the test results indicated a very slight reduction in the overall thermal resistance of the insulation. This suggests that natural convection is primarily within the insulation, and not at its interface with the surrounding air.

Figure 7 shows that airflow over the insulation surface increases the rate of heat transfer through the insulation and thus decreases the apparent R value especially at high flow rates.

It is noted that at high temperature differences across the loose-fill insulation, airflow over the insulation has little effect. It is believed that the natural convective forces present at such high temperature differences are so strong that additional airflow over the insulation surface has little effect.

Figure 9 shows the effect of compacting the cubed type insulation to a density of .833 lb/ft^3 (13.34 kg/m^3) from .527 lb/ft^3 (8.443 kg/m^3). Compaction has little or no effect on the insulation thermal resistance at low ΔT_{ins} across the loose-fill insulation, but compaction increases the apparent thermal resistance quite significantly at higher ΔT_{ins} across the insulation. This result suggests that this type of attic insulation should be installed at a much higher density than .5 lb/ft^3 (8 kg/m^3) in cold climates.

Compaction of the loose-fill insulation to 1.05 lb/ft^3 (16.84 kg/m^3) did not increase on the insulation's thermal resistance. It is noted that 1.05 lb/ft^3 (16.84 kg/m^3) is near the limit of compaction, as large pressures are needed to attain this level of compaction. A compaction pressure of 73.2 kg/m^2 (15 lb/ft^2) was required to compact the cubed type insulation to this density. In actual application in an attic, it would be difficult to compact the insulation to this density without damaging the ceiling.

The fiberglass batts tested performed well over a range of temperature differentials across the insulations, as seen in Fig. 9. The 6 in. (152 mm) batt was cited by the manufacturer as R-20 hr./ft.^{2} ^oF BTU (RSI-3.5 $m^2/^oC$-W. The experimental results remained within 10% of this value even at high temperature differentials across the batt insulation. With three layers of batts tested, R-60 (RSI 10.5), the thermal resistance estimated from experimental results remained above that cited by the manufacturer until the temperature differential was greater than 90^{o}F (50^{o}C). At high temperature differentials, this lowered apparent R value may be the result of increased radiative heat transfer within the insulation caused by higher than normal mean testing temperatures, the onset of increased convective heat transfer within the insulation at high temperature differentials, or some deterioration in the test-cell heat resistance.

For attic insulation in houses on the Canadian prairies, a temperature difference of 90^{o}F (50^{o}C) across the insulation would be close to the maximum temperature difference that houses are designed for. The average indoor-to-outdoor temperature differences are far below 90^{o}F (50^{o}C). Thus, for the prairie climate, the fiberglass batt insulation seems to perform well. Previously measured data for the cubed-type insulation is included in Fig. 9 for comparison. The curves for loose-fill cubed type insulation correspond to a manufacturer's rating of R-57.6 (RSI 10.1).

The difference in performance between the cubed-type and fiberglass-batt insulation curves may largely be attributed to heat transfer by air convection in the loose-fill insulation. It is noted that the density of the batts is almost twice the density of the uncompacted loose fill, .953 lb/ft^3 versus .527 lb/ft^3 (15.27 kg/m^3 versus 8.443 kg/m^3) while the density of the compacted loose fill is near that of the batts.

Figure 10 compares cubed and nodulated insulation. According to the manufacturer's installation specifications regarding minimum weight and depth, the nodulated insulation installed, 11.44 kg/m^2 (2.34 lb./ft.^{2}), should have a nominal thermal resistance of R 81.5 (RSI 14.4).

It should be noted that according to the manufacturer's installation specification the cubed insulation thermal resistance should be RSI 10.1 (R 57.6). It should be noted that the cubed insulation settled 3 in. (76.2 mm) during the two weeks immediately following installation.

The test results indicate that the estimated thermal resistance of the nodulated insulation stayed close to that cited by the manufacturer at very low temperature differentials. The scatter in the results at very low temperature differences is due to the fact that no test data were rejected and that there were large uncertainties in the results at very low temperature differences, especially with very large amounts of insulation. The absolute error in temperature measurement was 1 ^{o}F (0.5^{o}C). Thus at low ΔT_{ins}, the error in temperature measurement created uncertainties in the results and caused a great deal of scatter in data points. The small fluctuations in room air temperature where the attic test cell was located also created uncertainties in the results, especially at low ΔT_{ins}. Thus the attic test cell may have not been at steady-state operation when data was acquired for thermal resistance calculations of the sample insulation. At a temperature differential of 90^{o}F (50^{o}C), the calculated thermal resistance was 83% of the nominal value cited by the manufacturer.

A comparison of the curves in Fig. 10 indicates that the same type of thermal resistance drop occurs as the temperature differential increases, although for the curve for the nodulated insulation, the effects are much less.

It is noted that the nodulated-type insulation is more than twice as dense as the cubed type and is 23% denser than fiberglass batts. It is noted also that the nominal thermal resistivity (thermal resistance per inch of thickness) of the nodulated type is slightly less than that of fiberglass batts, R 2.9 in. versus R 3.3 in. (RSI 0.20/cm versus RSI 0.23/cm). It is speculated that the horizontal alignment of the fibers in the fiberglass batts used in the tests is largely responsible for its higher performance (resistivity) at lower densities than is the case with loose-fill fiberglass material. It is expected that such differences between batts and loose-fill fiberglass insulation would be much less in cases where the heat flows horizontally or down rather than up as was the case in the test facility used in this investigation.

The nodulated-type insulation was also tested after it was compressed to an average depth of 18 in. (.457 m) and an average density of 1.56 lb/ft^3 (25.0 kg/m^3). The results of these tests are shown in Fig. 10. The consequence of compressing the nodulated type by this amount was that the total thermal resistance decreased a small amount; however, the resistivity or resistance per unit depth increased very slightly or remained nearly the same. This result is in contrast with the original result tests of the cubed type which showed a large increase in the total thermal resistance after that loose-fill fiberglass was compressed. In the case of the cubed type insulation, it was speculated that the compression process not only increased the density of the material but also tended to align the glass fibers in the cube-like layered elements of the material in a horizontal direction. In the case of the nodulated insulation with its random orientation of fibers, it is speculated that little or no fiber alignment occurs with compression and that compression of the nodulated type tends to reduce its total thermal resistance.

The results for the fiberglass batts tested met or exceeded the manufacturer's specific thermal resistance. It is felt that the test results for the loose-fill fiberglass insulation are a good indication of the actual thermal resistance of these products when installed at large thicknesses and that the uncalculated errors in the test facility caused by edge heat losses and increased radiative heat transfer at higher mean testing temperatures are small relative to the effects measured.

CONCLUSIONS

It is concluded from these investigations that the performance of large thicknesses of loose-fill fiberglass insulaton that is heated from below will depend upon the density of the insulation, the temperature difference across the insulation and may depend upon the orientation of the internal fibers. Low density .527 lb/ft^3 (8.443 kg/m^3) loose-fill cubed type insulation showed a significant decrease in thermal insulating effect for large temperature differences across the insulation. Compaction of this insulation to a density of .833 lb/ft^3 (13.34 kg/m^3) dramatically increased the performance of the insulation at high temperature differences across the insulation. The effect of compaction on the insulation was speculated to cause some horizontal alignment of the internal fibers. This would help reduce the natural convection of air vertically within the insulation.

It was also concluded that low or modest air-flows, (less than 1.5 ft/s ft^2 ceiling area (5 m/s^2 ceiling area)), over the top of loose-fill, low density, fiberglass insulation will not significantly reduce its insulating value, but that high airflow rates (greater than 3.1 ft/s ft^2 ceiling area (10 m/s per m^2 ceiling area) will reduce the thermal resistance of low-density loose-fill insulation. For the Prairies, a typical wind speed of 33 mph (14.8 m/s) may induce the higher air flow rates in attic but this condition would be atypical.

REFERENCES

1. Variations of the Thermal Conductivity Coefficient for Fibrous Insulation Materials, a thesis, by John R. Mumaw, Ohio State University, 1968.
2. Heat Transmission in Low Conductivity Materials, by A.W. Pratt, Dept. of Buildings, University of Aston, Birmingham, England.
3. ASTM Designation: C518-76, Steady State Thermal Transmission Properties by Means of the Heat Flow Meter, Part 18, 1978, Book of ASTM Standards.
4. Heat Transfer in Fibrous Materials by Claes Bankvall, in Journal of Testing and Evaluation, Vol. 1, No. 3, May 1973, pp. 235 - 243.

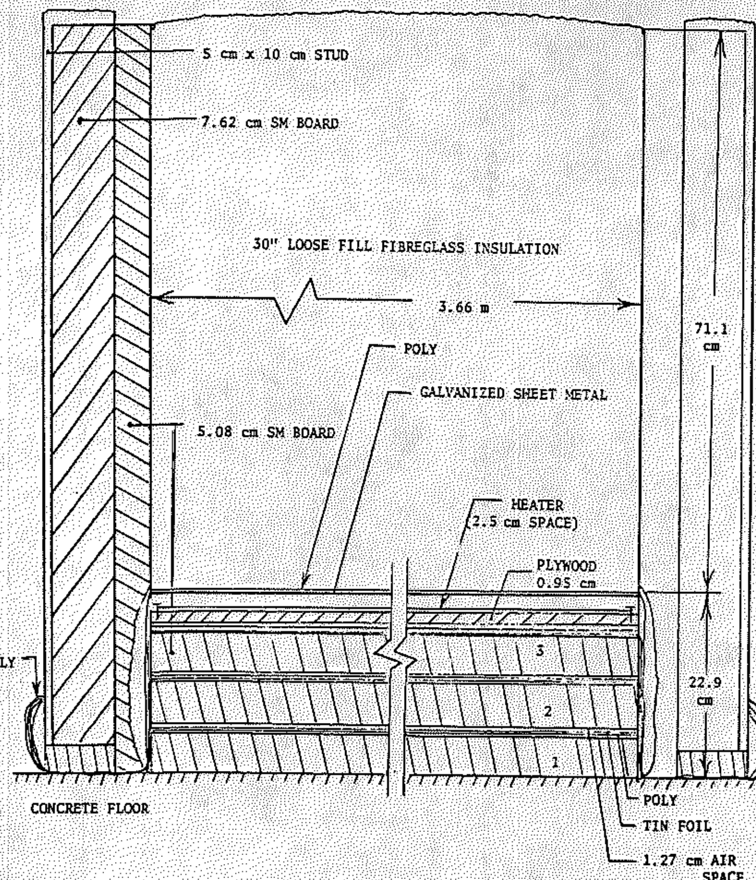

Figure 1. Schematic diagram of attic test cell construction

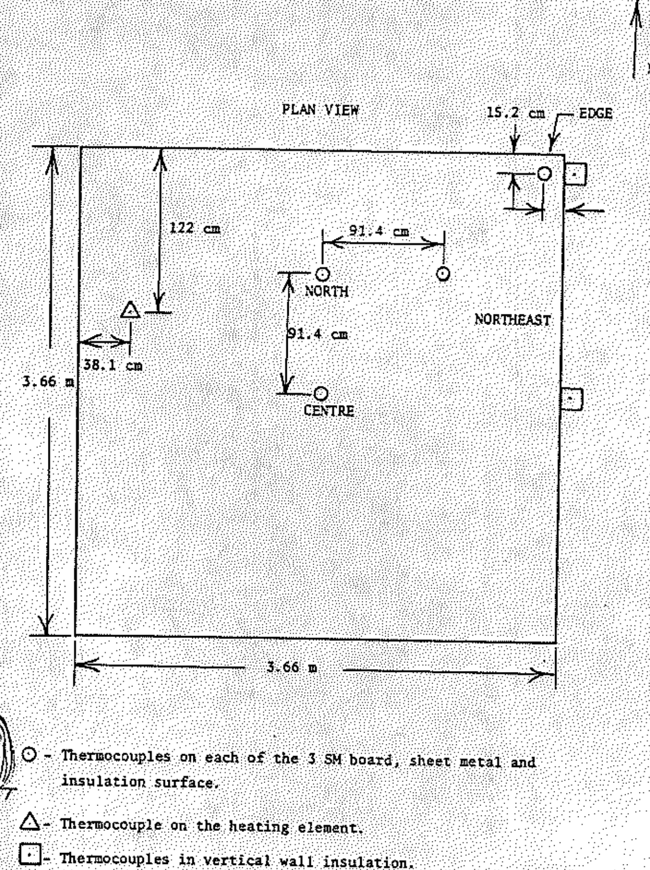

Figure 2. Schematic plan view of thermocouple location on both sides horizontal styrofoam SM board, top of sheet metal and on surface of loose-fill insulation of test cell

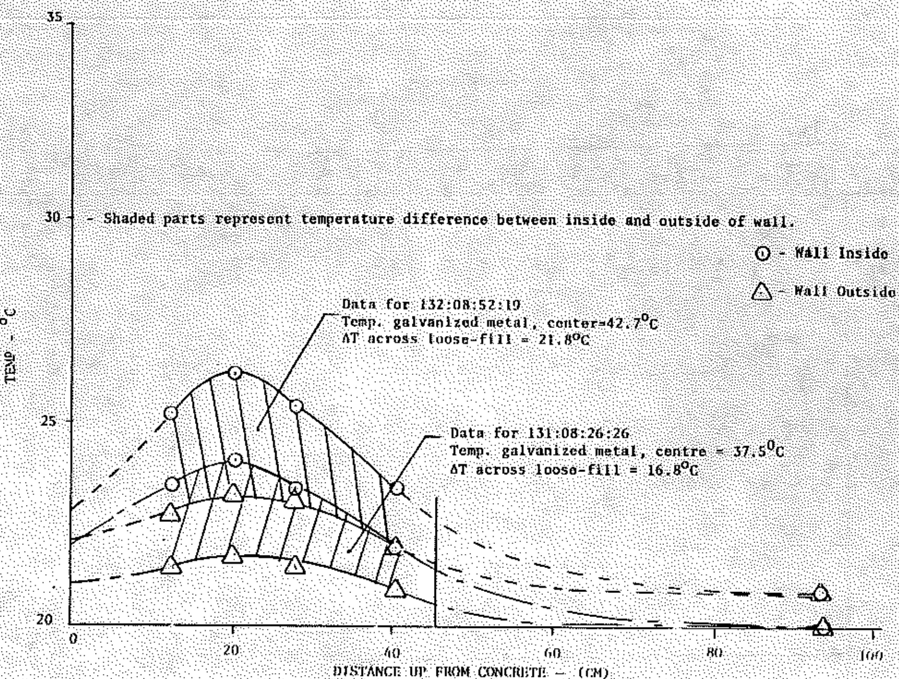

Figure 3. Attic model test - wall center temperature profile

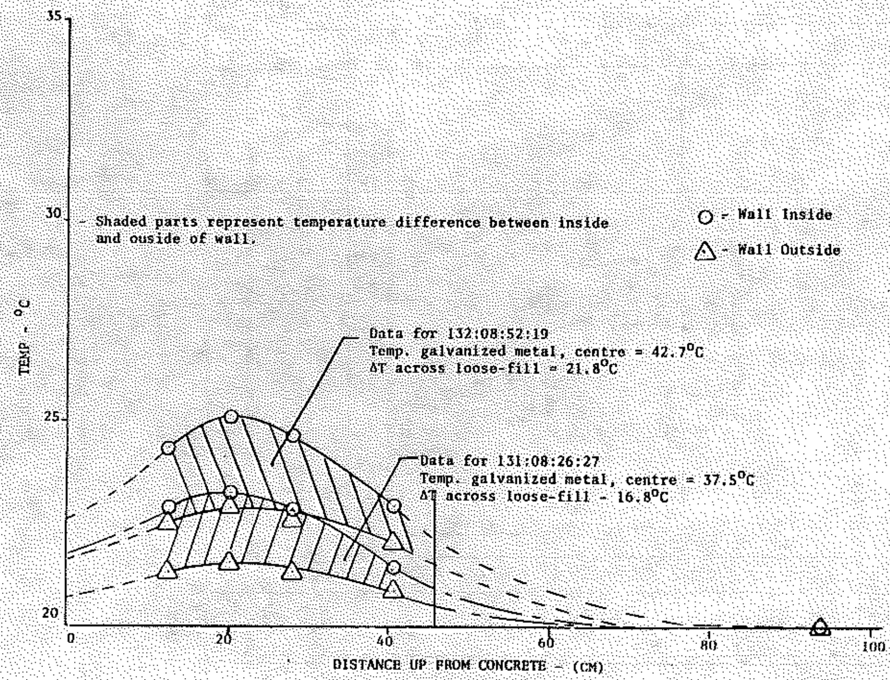

Figure 4. Attic model test - wall corner temperature profile

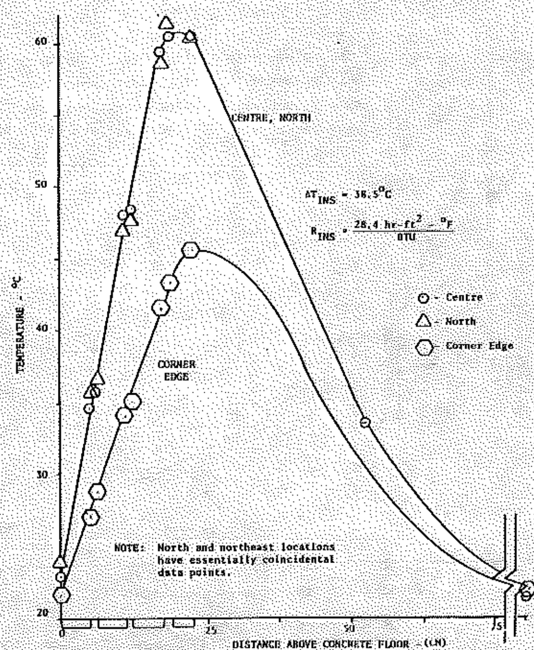

Figure 5. Vertical temperature distribution at various locations throughout attic model

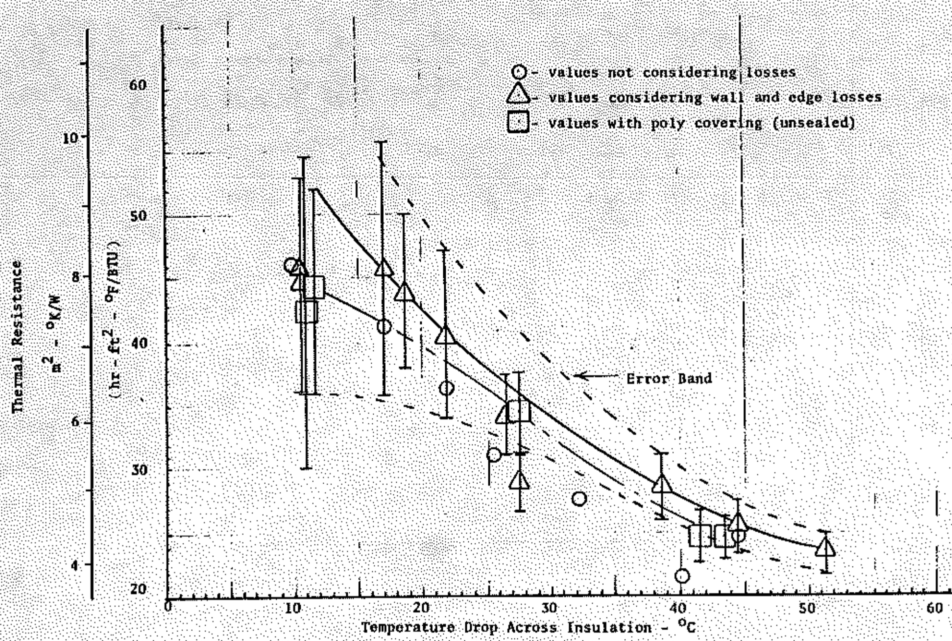

Figure 6. Thermal resistance versus temperature differential across loose-fill fiberglass insulation, density = 0.527 lb/ft³ (8.443 kg/m³), T(cold) 22.5°C

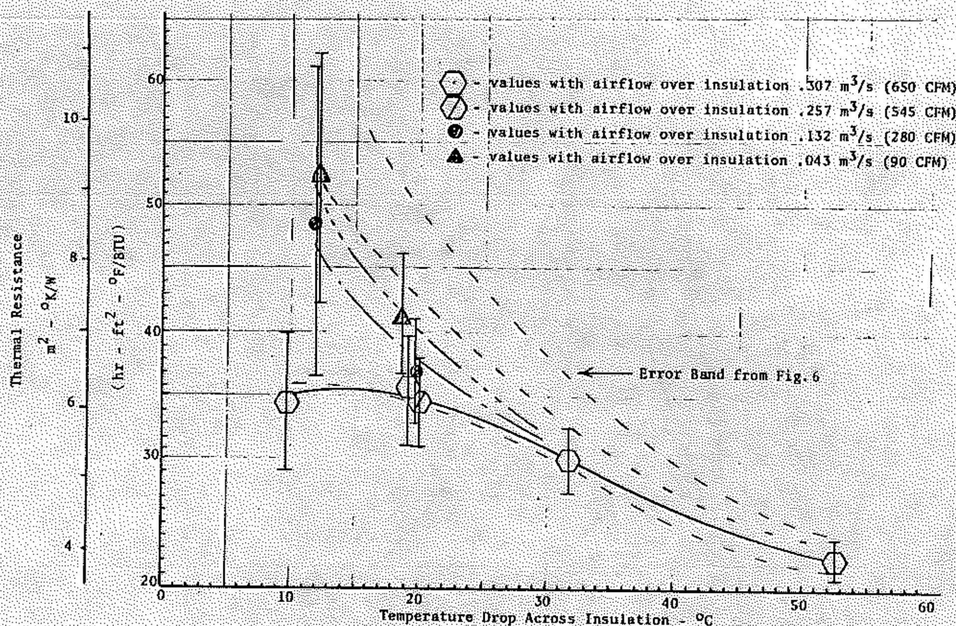

Figure 7. *Thermal resistance versus temperature differential across loose-fill fiberglass insulation, density = 0.527 lb/ft^3 (8.443 kg/m^3), T(cold) 22.5°C - Effects of airflow over insulation*

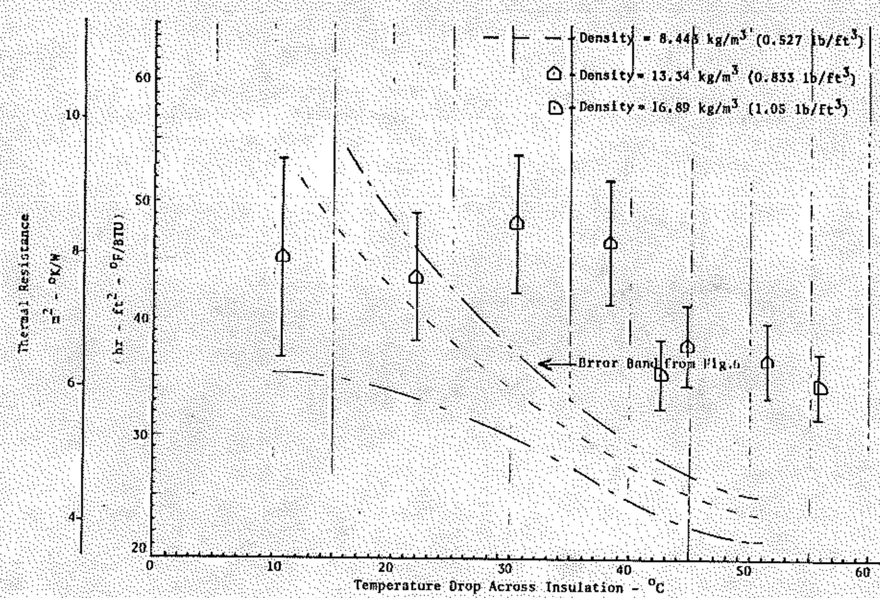

Figure 8. *Thermal resistance versus temperature differential across loose-fill fiberglass insulation - effects of compaction T(cold) 22.5°C*

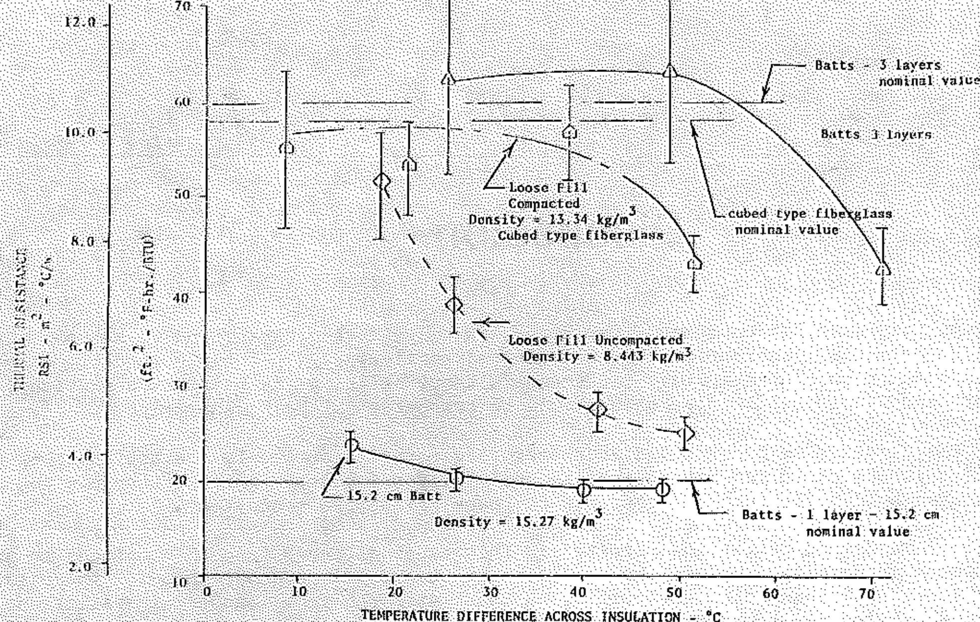

Figure 9. Thermal resistance versus temperature differential across fiberglass insulation T(cold) 22.5°C

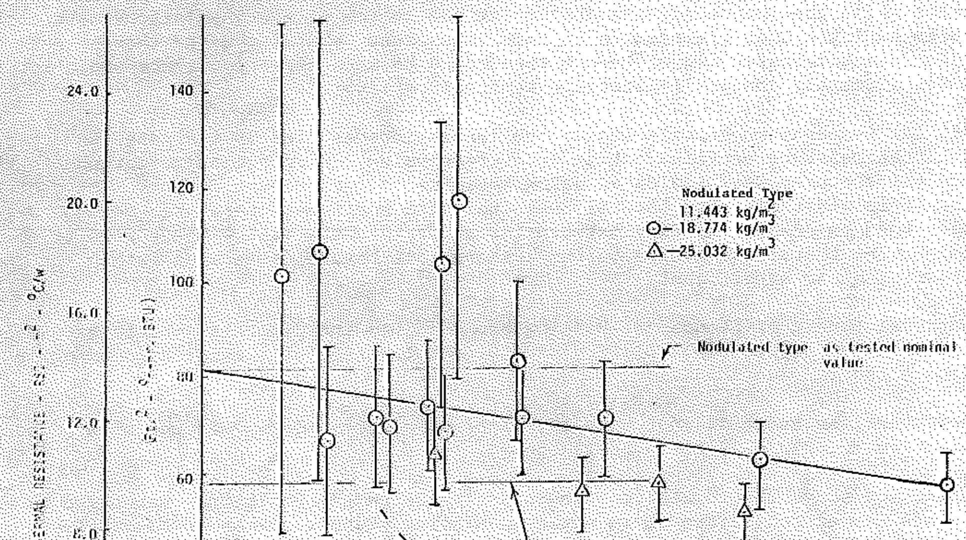

Figure 10. Thermal resistance versus temperature difference T(cold) 22.5°C

Discussion

D.L. McElroy, Oak Ridge National Lab., Oak Ridge, TN; It is very disturbing to see ASTM procedures rejected as inappropriate by the authors, particularly in their method of reporting R-values as a function of temperature difference without defining the boundary conditions, i.e., T(hot) and T(cold). Clearly, this should be corrected in their manuscript.

Also, the peculiar temperature: distance profile reported as due to convection is speculative. Edge losses could generate a similar profile, particularly if the bottom surface and input is assymmetric. The author's comments on these points are requested.

R.W. Besant: The method of testing reported in this paper differed from ASTM methods in an attempt to more accurately simulate the conditions that exist in standard housing where large amounts of loose fill insulation are used. The tests differed from standard installations in that the operating air temperature above the test cell was within one and one-half degrees Celcius of 22.5°C while the bottom surface was heated to the elevated temperatures indicated, whereas the top of the insulation temperature drops down as low as -30°C in cold-climate building attics while the inside air temperature at the bottom of the insulaiton stays close to 22°C. It is expected that the results in this paper must be modified for thes average insulation absolute temperature level before they could be used directly, since radiation heat transfer is significantly changed by absolute temperature level.

The vertical temperature profile inside the insulation reported in the paper was presented as a particular temperature profile, not as an average value. Significant variations in the upper surface temperatures were indicated using an infrared temperature sensor. The center regoin temperatures and those near the wall all indicated surface temperatures several degrees Celsius cooler than the region halfway between the center and the wall. These results coupled with the temperature profile suggested to the authors that naturalconvection iwthin the insulation was present and was significant.

D. Burch, National Bureau of Standards, Washington, DC: Did the fiberglass batts have paper on either the front or back sides? Did you investigate the size of the cavity housing or the air convection effect?

Besant: The fiberglass batts did not have any paper on eigher side. Only one size of test cell was investigated: 12 x 12 ft (3.66 x 3.66 m).

Air convection above the insulation was investigated under conditions that might be typical of wind-induced conveciton above attic insulation. The results showed small or negligible effects for moderate or low airflow rates over the loose fill insulation.

Natural air convection within the insulation was not investigated directly. However, top surface and air temperature data within the insulation and increased temperature difference effects on heat rates implied that natural air convection effects existed within the insulation and that these effects were more significant at elevated temperature differences.

S.L. Matthews, Rockwool Industries, Inc., Denver, CO: Was material installed at proper weight per square foot as shown on bag label? Was initial installed thickness greater than design thickness? Settling reported then was from installed thickness and not design thickness.

Besant: The loose fill insulation was installed by a professional installer at a weight per square foor within 6% of the bag lebelrecommendation. The loose fill insulation settled about 10% over a period of two weeks after the installation. Settling after the initial two weeks was negligible over a period of about one month. The amount of settling was not even over the entire surface as the installed loose fill insulation sirface was very even after installation, whereas after settling the surface was quite irregular. The density values reported in the paper were average values after settling.

The authors did not have a particular design thickness of insulation in mind except that it was attempted to simulate large thicknesses of insulation such as have been employed in many low-energy houses. A nominal thermal resistance of 10.7 RSI (60R) was attempted.

R.A. Wiley, Bonneville Power Admin., Eugene, OR: What was the moisture content of the insulation test? Did you test at different insulation moisture contents?

Besant: All the insulation tested was fiberglass, which absorbed little or no water vapor within the fibers themselves. No attempt was made to control the water vapor level in the surrounding air during the tests. Howeve, the relative humidity was observed to be between 30 and 35% in the surrounding air.