MEMBRANES IMPROVE INSULATION EFFICIENCY

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ABSTRACT

It has been determined from extensive tests involving test models and home attics that loose fill and fiber batt insulation does not function as expected by the industry. The reason for this deficiency is current test methods do not accurately predict the magnitude of air infiltration into fiber insulation as used in home attics, radiant heat infiltration into the insulation during summer, or radiant heat loss through the insulation during winter conditions.

The use of (1) moisture permeable membranes over the insulation, and (2) layered membranes between fiber batts to form closed cells in the insulation both dramatically improve the efficiency of the fiber insulation.

The efficiency of this insulation will be improved to an even greater degree if these membranes reflect radiant heat as well as reduce convection air currents.

Extensive tests have also been conducted which show that if moisture permeable membranes are used over fiber insulation, the moisture content of the insulation will be reduced.

INTRODUCTION

This research study of insulation is unorthodox in that it was started as a science fair project when this researcher was in the fourth grade and knew nothing of insulation other than that the thermal efficiency of glass fiber insulation was supposed to be 1/3 that of polyurethane foam insulation. It was found that this is not the case.

The project took on a more serious nature when as an eighth grade student, this researcher's work was reviewed for approximately one year by a group of seven engineers with Arkansas Louisiana Gas Company at which time research was supported in the form of reviews and a research grant by this utility company.

All test equipment used in this research is readily available or can be constructed easily. One exception included a seven day graphic recorder for recording relative humidity and temperature. The recorder was loaned by Arkansas Louisiana Gas Company. Another piece of equipment was a ten channel digital temperature indicator. The indicator was used to measure temperature gradients through various insulation systems and the humidity and temperature recorder was used for moisture vapor studies.

The tests conducted in the early phases of this study were devised to better understand the phenomena which occur in insulation. Later tests were devised to measure and predict the in-place performance of insulation in attics. In order to fully understand the findings of this study, one must review a brief and edited chronological review of this research.

AIR INFILTRATION

The original test in this study was an attempt to show that one inch of polyurethane was thermally equal to three inches of fiberglass insulation. One box was built of each insulation with no backing using two inch by two inch wood around the edges to make the boxes structurally sound. Twenty-five ice cubes were placed in each box. The two boxes were placed in a garage near an electric clothes dryer outlet. The dryer was turned on and temperatures were measured inside each box using dial type photographic thermometers. The outside air temperature was also measured near the top of each box. The temperature inside the garage ranged between 68 °F to 70 °F. The temperature inside the box with polyurethane ranged between 52 °F to 58 °F while the temperature inside the box with fiberglass ranged between 81 °F to 88 °F. This showed that something was happening which could not be predicted based on current published test data on insulation.

In an attempt to better understand this discrepancy, three additional boxes were built. The three inches of fiberglass and polyurethane were removed from the two original boxes. One sheet of two mil polyethylene was installed on one of the boxes; two sheets of polyethylene were installed on the second box, one on the inside of the wood framing and one on the outside; two inches of fiberglass insulation was installed on the third box between the framing; two inches of fiberglass insulation with polyethylene on the outside of the insulation was installed on the fourth box; and two inches of fiberglass insulation with polyethylene on the outside and inside of the insulation was installed on the fifth box. Five hundred mililiters of 125 °F water was placed in each box. The temperature in each box was recorded for 1.5 hours. The data are plotted on Figure 1. This experiment demonstrated that there is a definite need for a membrane to be installed on insulation to stop air infiltration.

The next phase in this project was to measure temperature in and under insulation in houses. Hundreds of measurements were made on several homes in the Shreveport, Louisiana area and typical examples are discussed below. One of the tests was

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conducted when the outside air temperature was 30 °F, the attic temperature was 33 °F, and the temperature one inch above the sheetrock and nine inches deep in the insulation was 42 °F. The temperature inside the home near the sheetrock ceiling was 80 °F which is a 38 °F drop through one inch of insulation and the one-half inch sheetrock. This proved that the sheetrock was doing most of the insulating and the ten inches of insulation in the attic was of very little benefit.

Legend: 1 Insulation And Membrane On Both Sides
2 Insulation And Membrane On One Side Only
3 Insulation Only
4 Two Membranes Only
5 One Membrane Only

Outside Air Temperature = 30 °F

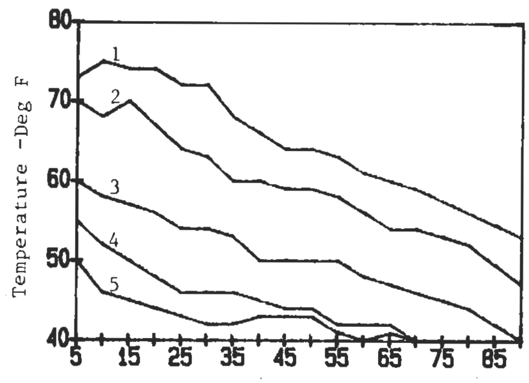

FIGURE 1 Temperature Reduction Inside Box Versus Time

A two mil membrane of polyethylene was installed between two rafters of this home over the existing insulation. Temperatures were checked at various depths with a digital trendicator. At this time, the winter conditions had moderated but there was a substantial improvement in the efficiency of the insulation when a membrane was installed. During the following summer, temperatures were checked when the attic temperature was 125 °F. Without a membrane over the insulation, the temperature next to the sheetrock was 114 °F or an 11 °F drop through the insulation. The temperature next to the sheetrock inside the room was 82 °F or a 32 °F drop through the sheetrock, again showing that the insulation was of very little benefit and only 1/3 as effective as sheetrock. Between the rafters, under the insulation with a membrane, the temperature was checked and found to be 92 °F next to the sheetrock or a 33 °F drop through the insulation and a 10 °F drop through the sheetrock, showing that the insulation with a membrane was three times as effective as sheetrock.

In order to more accurately measure temperature in and through the attic insulation, a home simulator was constructed. This simulator was constructed of 3/4 inch plywood with two inch by four inch pine used at the corners and edges to give structural support. The box measured approximately three feet wide by three feet long by four feet high. A piece of 1/2 inch sheetrock was installed three feet from the floor of the simulator and provisions were made to install 15 inch wide batt insulation on top of the sheetrock. The area was divided into four 15 inch by 19 inch cells in order to compare various insulation systems. The insulation system tests were configured as shown on Figure 2 using two mil clear polyethylene as a membrane.

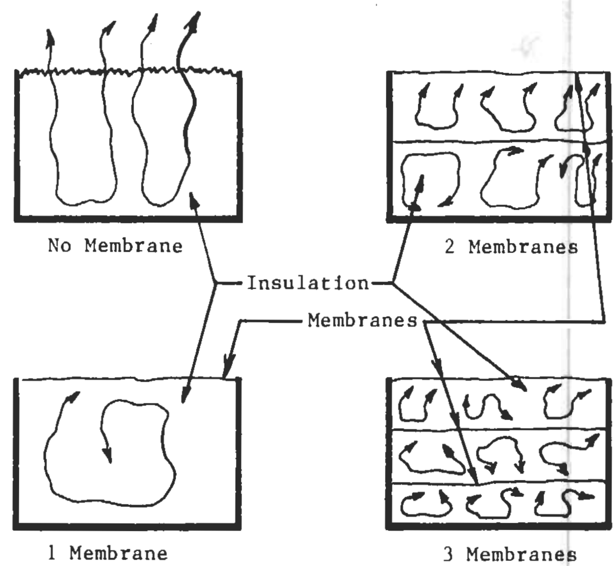

FIGURE 2 Air Circulation and Convection Heat Flow in Various Insulation Configurations

A 200 watt light bulb was placed in the simulator to generate heat and the simulator was placed inside a 53 °F cooler and a 36 °F cooler. Temperatures were measured inside the simulator, inside the cooler, and in the air space under the insulation at the top of the sheetrock. The insulation was also removed from one cell and the air space temperature next to the top of the sheetrock was measured. The data are presented in Figures 3 and 4. As can be seen, there is a significant improvement in the efficiency of the insulation with membranes.

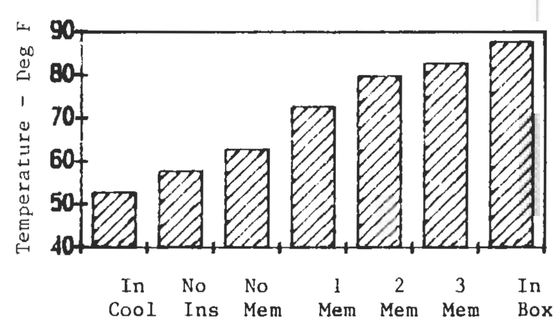

FIGURE 3 Temperature Inside Cooler, Inside Simulator, and Next to Top of Sheetrock Under Various Insulation Configurations

The increase in efficiency of the insulation which is protected by membranes is due to a decrease in heat induced natural convection in the fiber insulation. This phenomenon is contrary to

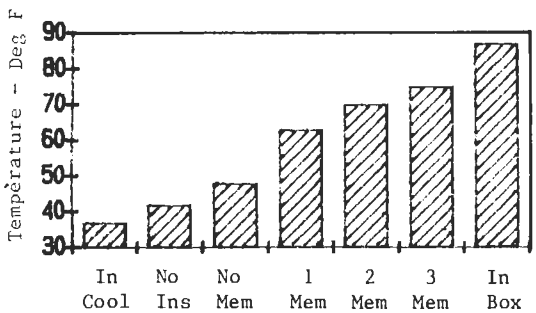

FIGURE 4 Temperature Inside Cooler, Inside Simulator, and Next to Top of Sheetrock Under Various Insulation Configurations.

current accepted concepts of insulation but was observed by Kenneth E. Wilkes, and James L. Rucker of Owens Corning Technical Center and is described in their report entitled Thermal Performance of Residential Attic Insulation (1). This convection was indicated by heat flux transducers under the insulation, a lack of uniform temperature at the top of the insulation as measured by an array of thermocouples, and convection currents above the insulation photographed with an infrared camera. Dr. Wilkes states that many of these conditions are contrary to theory and that theories have not been found which apply to the open top surface such as fiber insulation. This study, even more than Wilkes' study, indicates that the convection currents and air infiltration into fiber insulation is much more serious than previously expected.

RADIATION

In mid January, 1985, several perforated polyeth lene films became available for tests. One of these films was a 1.25 mil white perforated polyeth lene film. This material uses TiO_2 as the white pigment. The unique advantage of this is that the titanium in the pigment reflects radiant heat. Three tests were conducted to evaluate this new membrane. Tests number 1 and 2 used the home simulator used in previous tests. For test number 1, seven inches of "R" 22 fiberglass insulation was placed in each of the 15 inch by 19 inch cells. One clear two mil polyethylene film was placed over one cell; one white 1.25 mil perforated polyethylene film was placed over the second cell; one clear two mil film was placed horizontally midway in the insulation and another clear film over the insulation in the third cell; and the same configuration using the white 1.25 mil perforated film in the fourth cell. Tabulated data are shown on Table I and are plotted on Figure 5. These data clearly show an improvement if the white material is used. It is hypothesized that radiant heat was being reflected back into the insulation, thus addressing radiant heat loss as well as convection heat loss.

Test number 2 used the same box with no insulation in one cell, seven inches of "R" 22 insulation in the second cell, insulation with one clear two mil film over the insulation in the third cell, and the same configuration using a white 1.25 perforated film in the fourth cell. The tabulated data are shown on Table I and plotted data are shown on Figure 6. The white membrane configuration clearly is the most effective in this

TABLE 1 - TABULATED DATA

Test #1

Outside Air Temp.	Temp. Under One Clear Membrane	Temp. Under One White Membrane	Temp. Under Two Clear Membranes	Temp. Under Two White Membranes	Temp. Inside Box
22°F	43°F	48°F	52°F	53°F	57°F
18°F	42°F	46°F	51°F	52°F	57°F
18°F	51°F	56°F	61°F	64°F	68°F
28°F	60°F	65°F	69°F	71°F	74°F

Test #2

Outside Air Temp.	Temp. With No Insulation	Temp. Under Insulation Only	Temp. Under One Clear Membrane	Temp. Under One White Membrane	Temp. Inside Box
28°F	35°F	60°F	72°F	74°F	77°F
30°F	36°F	62°F	70°F	74°F	78°F
36°F	45°F	66°F	71°F	73°F	85°F
51°F	61°F	78°F	86°F	88°F	94°F

Test #3

Room Temp.	Insulation Only	Temp. Under One Clear Membrane	Temp. Under One White Membrane	Temp. Under Aluminum Foil	Temp. Inside Box
68°F	115°F	122°F	137°F	138°F	145°F

test and the reason is speculated to be the same as test number 1.

Legend: 1 Outside Air Temperature
2 One Clear 2 Mil. Membrane
3 One White 1.25 Mil. Perforated Membrane
4 Two Clear 2 Mil Membranes
5 Two White 1.25 Mil. Perforated Membranes
6 Temperature Inside Simulator

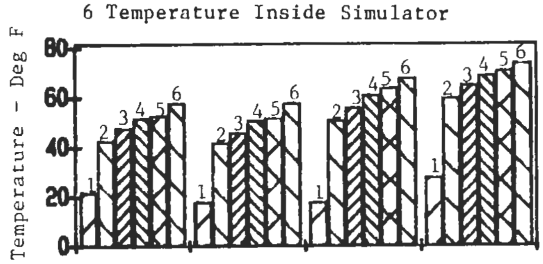

FIGURE 5 Outside Air Temperature, Temperature Inside Simulator, and Temperature Next to Top of Sheetrock Under Various Insulation Configurations.

Legend: 1 Outside Air Temperature
2 No Insulation
3 7 Inches Insulation Only
4 One Clear 2 Mil Membrane
5 One White 1.25 Mil. Perforated Membrane
6 Temperature Inside Simulator

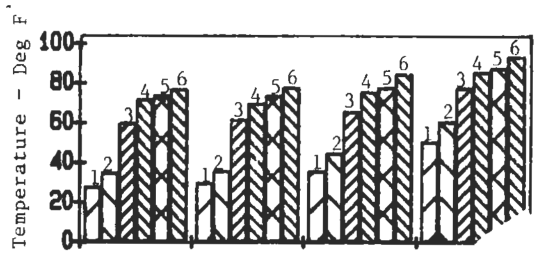

FIGURE 6 Outside Air Temperature, Temperature Inside Simulator, and Temperature Next to Top of Sheetrock Under Various Insulation Configurations.

Test number 3 was conducted using four-six inch square, three-1/2 inch deep cells with 1/2 inch sheetrock under the insulation. This test used 3-1/2 inches of "R" 11 insulation in each cell with no membrane over one cell; clear two mil polyethylene over one cell; white 1.25 mil perforated polyethylene over another cell; and aluminum foil over the fourth cell. The objective of this test was to try to evaluate radiant heat effect since aluminum foil is considered to be an effective barrier for radiant heat transfer. The tabulated data from this test are shown on Table I and the plotted data are shown on Figure 7. The temperature in each cell next to the top of the sheetrock was observed throughout this test and, in all cases, the temperature under the white material and the aluminum foil was the same ± 1 °F while the temperature under the clear membrane and the insulation only was significantly lower.

After the heat source under the cells was turned off the temperature stabilized, data for test number 3 were recorded. It was determined from these tests that:

1. The white perforated polyethylene material is as effective in reducing convection heat loss as the clear material.
2. The white perforated material is as effective in reducing the radiant heat loss as aluminum foil.

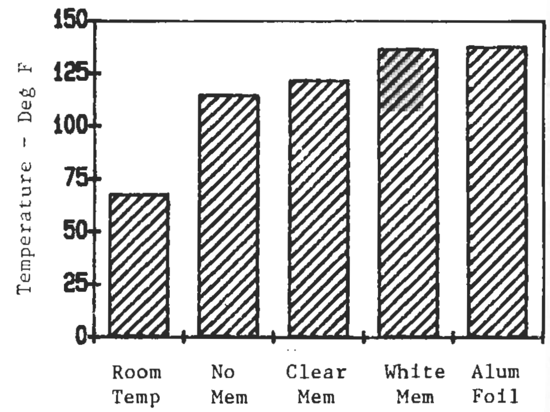

FIGURE 7 Temperature Inside Room and Temperature Next to Top of Sheetrock Under Various Insulation Configurations.

It should be noted that after this test was completed, the fiber insulation was inspected and found to be normal except under the aluminum foil. This insulation was saturated with water due to the fact that this foil is a true moisture vapor barrier. This test was repeated several times with the same results. This does indicate that possibly moisture accumulation in insulation using aluminum foil as a radiation barrier should be investigated due to its wide spread use at this time.

MOISTURE

To research moisture accumulation in insulation, the home simulator described earlier was modified. The top of the box was constructed similar to a house with one-half inch sheetrock as a ceiling. Two eight inch fiberglass batts were installed over the sheetrock. Two mil clear polyethylene was installed over one of the batts. A rack was placed inside the box which supported two pans of water and an electric light. An instrument was placed inside the box which recorded temperature and humidity. Numerous tests were conducted using this equipment. Temperatures were measured in the box, under the insulation next to the sheetrock, and in the 35 °F cooler in which this box was placed. Temperature gradients similar to those recorded previously were measured. The first tests were conducted using a 300 watt heat lamp directed at the sheetrock. The temperature under the insulation next to the sheetrock was over 100 °F and there was moisture condensation in the insulation which was covered by the membrane and in the insulation which was not covered by a membrane. The heat lamp was replaced by a 100 watt light bulb which reduced the temperature inside the box to 60 °F and a relative humidity of 70 percent. After approximately forty-eight hours, the moisture had evaporated and there was no evidence of condensation. Next, the 100 watt light bulb was replaced by a 200 watt light bulb which raised the

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temperature inside the box to 74 °F and a relative humidity of 80 percent. After seventy-two hours, moisture condensation was observed in the insulation with and without a membrane. This experiment was reversed several times and it was always observed that the condensation disappeared when the 100 watt light bulb was installed. Samples of the insulation were tested by Southwestern Laboratories Inc. after the 100 watt light bulb had been installed and after a forced dew point condition using the 200 watt light bulb had been observed. In both cases, the moisture content was higher in the insulation which was not covered by a membrane. It is speculated that air circulation or natural convection into the insulation from the cooler carried colder air into the insulation which was not covered by a membrane thus cooling the warm, moist air and causing a dew point condition. If the insulation is covered by a membrane, this condition does not exist.

The experiment was repeated in a -10 °F freezer in which the box was left for 45 days to determine if there would be ice build-up in the insulation. Samples of this insulation were taken to the testing laboratory and it was determined that moisture content in the insulation without a membrane was higher than the insulation which was covered by a two mil polyethylene membrane. There was a small amount of ice inside the insulation which was not covered by the membrane and a slight amount of ice on the surface of the two mil polyethelene.

These tests were repeated using the white perforated membranes. The white perforated film permits a free exchange of molecules at the surface of the membrane. Due to this free exchange, the differential vapor pressure (caused by the differential heat) dries the insulation. The results of the test are that the insulation covered by this material has a moisture content of less than 50 percent that of fiberglass covered with a clear two mil polyethylene and 20 percent or 1/5 that of in-place fiberglass insulation with no membrane.

DERIVATION OF THERMAL CONDUCTIVITY (K) AND THERMAL RESISTANCE (R)

All tests and experiments prior to January 1986 have been conducted to measure differential temperature through insulation and determine a relative efficiency of insulation with and without membranes. It is obvious that to withstand any challenge to the principles of this research and its conclusions, one must devise tests to measure the actual heat flux through construction materials as they are used in the industry and more particularly in attic construction.

To conduct these tests, the simulator described earlier was modified. A 110 volt thermostat was placed inside the simulator. The thermostat was attached to a two outlet plug. To this plug was attached a 5,000 Btu rated electric heater and a clock. The heater remained inside the simulator and the clock was placed outside the simulator so as to measure the time the heater was on over a period of days. The outside walls and bottom of the simulator were then insulated with four (4) inches of spray applied polyurethane foam insulation. This test equipment was then placed inside a 35 °F food cooler in Shreveport, Louisiana. The simulator was elevated approximately six (6) inches above the floor of the cooler so as to expose the bottom to the same conditions as the walls and top. Thus, any abnormal conduction heat loss through the bottom of the simulator was eliminated. The thermostat inside the box was set at 70 °F. The air temperature was measured using two dial type photographic thermometers to be 72 °F. The line current to the heater was measured to be 11.6 to 11.8 amps and 118 to 119 volts using a digital amp and volt meter. The current required for 5,000 Btu at 118 volts is 12.4 amps; therefore, it is assumed that the label on the heater is incorrect and the actual output is 4750 Btu which is used in the calculations.

To evaluate the various insulation systems, two "R" 11 fiberglass batts were "stacked" over the sheetrock when required. The membrane used was a white four mil perforated polyethylene film similar to the 1.25 mil film used earlier, but structurally more sound. When one membrane was used, it was placed over the insulation system and when two membranes were used, one was placed over the insulation and one was placed between the "stacked" batts. To conduct a test for insulation only, the sheetrock was removed and a series of strings were stretched across the "ceiling" space to support the insulation.

Polyurethane foam insulation was sprayed onto 3/4 inch plywood to replace the sheetrock with material identical to the wall and bottom construction in order to determine an accurate Btu/Ft^2 loss for the simulator walls and bottom.

To conduct the evaluation of the various insulation systems, the box was placed in the 35 °F cooler. To conduct the first test, the two "stacked" insulation batts were placed over the sheetrock with no membranes used. The time the heater was on was checked and recorded at least two times daily for seven days. The temperature of the cooler was also checked and recorded at each time data were collected. The cooler temperature varied between 33 °F and 36 °F for all tests.

This first test was repeated with: (1) one membrane over the insulation; (2) one membrane over the insulation and one membrane between the batts; (3) with all insulation and membranes removed to test for sheetrock efficiency; and (4) with the sheetrock and all other materials removed then the insulation batts suspended in their normal place. These data are plotted on Figure 8. In all cases, the function was a straight line and all points plotted on the line (A-E).

Function (F) on Figure 8 is the calculated heat loss through the simulator walls and bottom using data obtained from the test with urethane on the top of the simulator. This function is used only to determine heat transfer through the various insulation systems tested to calculate thermal resistance "R" and thermal conductivity "K".

Functions "G" and "H" are determined using published "K" values for the urethane insulation (.13) and fiberglass insulation (.33) which are derived from the "Guarded Hot Plate Test" (A.S.T.M. C-177) and accepted heat transfer formulas.

Figure 9 is a graph of heat loss per hour versus differential temperature using data obtained at 35 °F differential temperature only. As more data at various differential temperatures are obtained these functions could change.

Note: 35 °F Cooler Temperature
Legend: A. Sheetrock Only, No Insulation
B. Insulation Only, No Sheetrock
C. 7 Inches Insulation Over Sheetrock
D. One Membrane, 7 Inches Insulation Over Sheetrock
E. Two Membranes, 7 Inches Insulation Over Sheetrock
F. Heat Loss Through Walls and Bottom of Simulator
G. Calculated Heat Loss Through Simulator and Fiber Insulation Using K = .33 for Fiberglass Batts and K = .13 for Urethane
H. Calculated Heat Loss Through Walls and Bottom of Simulator Using K = .13 for Urethane

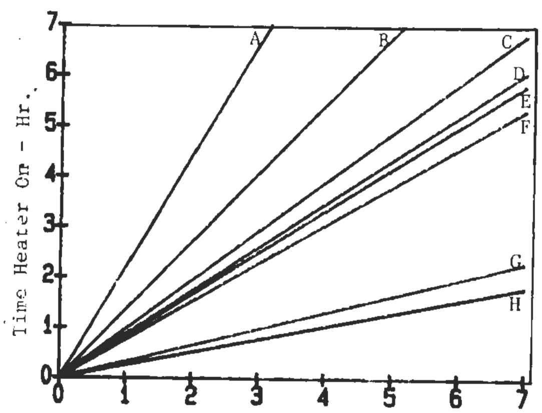

FIGURE 8 Time 4750 Btu Heater was Required to Run to Maintain 72 °F Interior Temperature Versus Time Simulator was in Cooler

Table II is tabulated data and calculations for the derivation of "R" and "K" values of the various insulation systems.

Note: 35 °F Cooler Temperature
Legend: A. Insulation Only, No Sheetrock
B. 7 Inches Insulation Over Sheetrock
C. One Membrane, 7 Inches Insulation Over Sheetrock
D. Two Membranes, 7 Inches Insulation Over Sheetrock

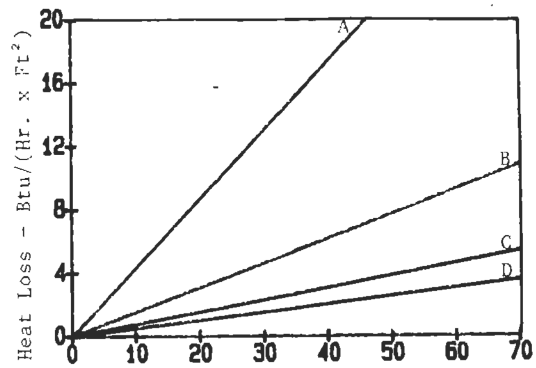

FIGURE 9 Heat Loss Through Fiber Insulation Versus Differential Temperature Between Cooler and Inside of Simulator

As can be seen, the energy usage reduction and economic savings are substantial if membranes are used in conjunction with fiber insulation. In fact, only one-third as much heat is lost through an attic if insulation and two membranes are used as there is using our current technology. The reason for this discrepancy is that materials are tested using the Guarded Hot Plate which sandwiches the test material between a hot plate and a cold plate and derives "R" and "K" values based on the conducted heat through the material. Then it is expected to function in an attic as it did in the test.

TABLE 2 - Derivation Of In Place "R" And "K" Values

		Units	7 Inches Insulation Only, No Sheetrock	7 Inches Insulation Over Sheetrock	1 Membrane Insulation Over Sheetrock	2 Membranes Insulation Over Sheetrock
①	Time Heater On For 7 Days	Hr.	9.5	6.82	6.07	5.82
②	Time Heater On For Loss Through Insulation ① - 5.33 Hrs. *1	Hr.	4.17	1.49	.74	.49
③	Heat Loss Through Insulation For Seven Days ② x 4750 Btu	Btu	19807	7077	3515	2327
④	Heat Loss Through Insulation ③ /(168 Hr. x 7.8 Ft^2)	$\frac{Btu}{Hr \times Ft^2}$	15.16	5.40	2.68	1.77
⑤	In Place Thermal Conductivity "K" (④ x 7 in.)/35°F	$\frac{Btu \times In.}{Hr. \times Ft^2 \times °F}$	3.03	1.08	.53	.35
⑥	In Place Thermal Resistance 7 inches/ ⑤	$\frac{In.}{K}$	2.3 *2	6.48	13.05	19.7

*1 5.33 hr. = time heater on for heat loss through walls and bottom of box.
*2 Published "R" Value = 22.

TABLE II

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The data obtained is very repeatable. Each function is a straight line with approximately fourteen (14) data points plotted on each function with no apparent scatter. Also, the test to obtain data for the heat loss through the walls and bottom of the simulator was repeated three (3) times. In one case there was a power failure which invalidated the data. However, the first day's data agreed with the other two tests. The other two tests produced a calculated loss through the walls and bottom of the simulator of 5.33 hours and 5.40 hours per week. This is less than a four (4) minute variation in the time the heater was on for seven (7) days.

To this researcher's knowledge there is no test for insulation efficiency which has this degree of accuracy. The tests conducted in this study do need to be repeated using: (1) larger test simulators; (2) various thicknesses of insulation; (3) more membranes; and (4) at various differential temperatures.

CONCLUSIONS

It is the opinion of this researcher based on the data obtained from this study that:

1. Heat transfer through fiber insulation in attics will be reduced by 50 percent to 70 percent if membranes are used through and over the insulation.
2. The "Guarded Hot Plate Test" does not appear to accurately predict the thermal in-place properties of insulation as used in attics.
3. More tests need to be conducted using membranes in conjunction with fiber insulation.

It is realized that this research is not complete. However, the evidence and data acquired from this study in each area indicates a significant improvement in the efficiency of insulation if membranes are used in conjunction with fiber insulation.

BIBLIOGRAPHIC REFERENCES

1. Wilkes, Kenneth E. and Rucker, James L., "Thermal Performance of Residential Attic Insulation," Energy and Buildings, May 1983 pp. 263-277.