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Experimental Low Cost Arctic Housing for Alaskan Bush Areas

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EXPERIMENTAL LOW COST ARCTIC HOUSING FOR ALASKAN BUSH AREAS*

by

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PURPOSE

Adequate and healthful housing has long been recognized as a pressing need of Alaskan Arctic and Subarctic residents. The need is complicated by the requirement that the cost of purchasing, operating and maintaining such housing be within reach of this predominantly low income group.

In the past, lack of adequate shelter, and sanitary facilities, and insufficient and unsafe water supplies have led to a mortality rate among Alaskan Natives that is many times higher than any peer group in the Nation. Infant mortality and tuberculosis have been especially high, and many of their causes relate to inadequate housing.

Figure 1 shows a typical Native Alaskan home in one of the villages. It is a sad commentary that such conditions exist in an area where the need for protection from severe weather is so great.

Wintertime temperatures, often falling below -40° F for long periods, are commonplace. Often these temperatures are accompanied by high winds which can create chill factors equal to -110° F and lower. Adequate housing to meet these needs should be high on our list of priorities.

The foremost design considerations are: (1) adequate protection from the environment (this includes considerations of adequate space, insulation, ventilation, sanitation, and of utmost importance, durability), and (2) a price within the means of the average Native family. The second is a most difficult requirement to satisfy since it is almost diametrically opposed to the first, and Alaskan costs make it doubly hard to meet. The one asset most Native families have is time, which can offset the labor costs which constitute a large portion of the final construction cost.

It is difficult to place a higher priority on either of these requirements, since one without the other is a blueprint for failure. A compromise which incorporates the best qualities of each is essential. With these aims in mind, the Environmental Sciences Branch of the Arctic Health Research Center set out to create a laboratory for housing research where techniques, materials, and new products could be tested. The laboratory consists of an experimental house incorporating many new innovations in housing, and providing a facility for future work.

ARCTIC CONSIDERATIONS

Building in the Arctic presents certain special problems that must be considered in the design and construction of the structure. Some of these problems are unique to the Arctic and some are only amplified in the northern environment. Examples are:

Vapor Barriers: During the winter months, outside air contains very little water vapor. Its relative humidity is often quite high, but this is only a measure of the fraction of the total water vapor that can be carried by the air at any given temperature. At -25° F air can only carry 2% of the vapor it can carry at 75° F. At these low temperatures, even 100% relative humidity represents very little water vapor. If this cold, saturated air is then heated to an inside temperature of 75°F, the relative humidity drops to 2%. Air this dry is very uncomfortable. It promotes static electricity, and can cause irritation of skin and mucous membrane tissue and dehydration. Activities inside the home tend to eliminate some of this, and additional humidification in one form or another is provided in many homes. This, however, creates another problem. The extremely high vapor gradients provide a driving force for vapor which will completely fill unprotected insulation with water vapor. Vapor of course turns to ice at the 32°F isotherm and the insulation no longer provides any insulating value. Vapor barriers therefore are of utmost importance. Extreme care must be taken to see that they are adequate and properly installed.

Permafrost: So much of Alaska is underlain by permafrost that building on these lands cannot be avoided in many cases. When a structure is built over permafrost, proper design and construction can avoid very costly deterioration of the foundation. Heated structures in contact with the ground will invariably suffer extensive damage if detrimental permafrost is present. Detrimental permafrost is defined as permanently frozen, silty, soil with moisture content above 30%. Silt content of the soil can be as low as 3% and still cause problems.

Multiple Glazing of Windows: Studies have shown that the most economical design for windows in arctic regions incorporates triple glazing. Considering heat loss along with the initial cost of materials and installation, overall costs are at a minimum with triple glazing. If window areas are not too large, double glazing is acceptable and has the advantage that replacement after breakage is less expensive. If breakage rates are high, then double or even single windows become economically more advantageous, although single panes are never desirable from comfort considerations.

Insulation Thickness: Alaska weather varies from 8,000 to 20,000 degree days of heating. Insulation thickness varies accordingly. The optimum thickness of often less than comfort standards dictate in remote regions due to the high cost of construction. In these cases, comfort standards should, if possible, prevail. Optimum thickness for the Fairbanks area is usually found to be between six and eight inches in the walls, and close to ten inches in ceilings.

STRUCTURAL CONSIDERATIONS OF AHRC's EXPERIMENTAL HOUSE

One of the newest and perhaps most promising housing developments in the past few years has been the polyurethane-foam, sandwich panel. This panel can provide the interior finished wall, the insulation, and the exterior sheeting all in one panel. It claims to provide as much as three times the insulating properties of an equivalent thickness of fiberglass. The panel offers a means of providing easy and relatively quick assembly by unskilled labor, and when finished, it is extremely durable. Although foam costs are high, the total panel offers several savings. The manufacturer can purchase materials in quantity for substantial savings, and assembly can be performed on a production line basis, cutting labor costs at that point. Elimination of the need for skilled labor to assemble the house is perhaps the greatest economy of all. Wages in remote areas of Alaska for this kind of labor run the cost of conventional construction prohibitively high. The walls, both exterior and interior, are sandwich panels. An exterior framework of 6 by 6 beams and columns provides the structural support. Foam panels are fastened inside this framework and bear no load except their own weight. All electrical conduit and boxes are molded into the panels. Each sandwich panel consists of finished paneling on the inside, an unpainted plywood exterior, and 2-1/4 inches of polyurethane insulation.

The roof is of trussed construction with a slope of 3-1/2 inches in twelve. A ventilated attic space and foam panels in the ceiling provide a "cold roof" configuration. Asphalt shingles were used in this experimental model, but could easily be replaced by other materials such as aluminum, sod or other local

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materials. The inside ceiling is finished with acoustic tile stapled to the panels.

The floor consists of 1-1/4 inch plywood on two-by-fours spaced two feet on center, supported by plywood beams constructed with a one-inch plywood web, 18 inches wide with a two-by-four glued and nailed along both top and bottom to form a "channel-like" shape. Beams are spaced on 3 feet, 6 inch centers. This provides a double floor with an 18 inch air space between the inside floor and the bottom of the house. Two inches of rigid polyurethane insulation are glued to the exterior walls of the air space, thus insulating it from the outside. This results in a warm floor and in addition gives a "heat-scavenging" return air plenum for the heating system. This will be discussed in more detail later.

The structure is set on pilings, each pile set into the ground 12 feet deep. The top 7 feet of the pilings were wrapped with polyethylene film to prevent frost jacking. The top two feet of polyethylene were wrapped with tar paper to preclude ultraviolet degradation of the film. An open two-foot crawl space is left between the house and grade to prevent permafrost destruction. Eight piles were used, six under the main structure of the house, and two under the front entry.

Windows were used with care. In the arctic environment, the excessive heat loss through windows make their use undesirable; however, the confining nature of the winters can be somewhat mitigated by windows to allow visual access to the outdoors. Winter sunrises and sunsets are especially beautiful because of the low angle of the sun. Windows help the wife or mother who is confined indoors much of the day to feel more a part of the natural environment, and alleviate much of the "cabin-fever" prevalent during the winter months. Each room in the house was provided with at least one double-glazed window of adequate size and accessible for fire escape. The living room has three windows, each approximately six square feet.

LIVING AREA

Space is expensive, both in initial cost and in heating during the winter. However, recent studies show that the undesirable effects of crowding are significant enough that they must be considered in any housing which professes to have the health of the occupants in mind. This house contains 560 square feet of living space plus an additional 69 square feet of enclosed entrance hall. While minimal from a health standpoint, this is about as much room as Native economics will allow, and is spacious compared to current practice. The area is divided into six rooms, consisting of three bedrooms, living room, kitchen and bathroom. The bedrooms are small. As much space as possible has been reserved for the living room area where it is expected that the most time will be spent by the largest number of people. The kitchen is compact and contains a sink, cupboard space and room for a stove or refrigerator. If the family have both a stove and refrigerator, the refrigerator can be placed next to the stove, protruding only slightly into the living room.

Since the lack of adequate sanitary facilities is one of the most serious needs of families in the bush areas, the bathroom is complete, containing a sink, bathtub, and water closet. The theory is that with available and comfortable facilities, more personal hygiene (the lack of which is a major cause of illness among families in the wilderness areas of Alaska) will be promoted. This assumes that the household has an adequate supply of safe, potable water, which is very often not the case. Great strides in this direction are being taken however, so it is desirable that the facilities be in place when such a water supply becomes available.

The front of the house opens into an enclosed and partially heated hall which provides an air-lock area. Here, winter clothes and footwear can be removed and stored before entering the house. This arrangement eliminates a direct opening from the outside to the interior of the house, thus attenuating the huge infiltration losses that accompany opening a door directly from the outside to the inside. Interior doors on the bedrooms and the bathroom are all folding doors, conserving space by eliminating the space used by conventional doors. A second exit is provided through one of the bedrooms. This provides a fire exit, but is not intended for general use in the winter.

HEATING SYSTEM

Several heating systems have been considered and are planned for eventual testing. To obtain accurate data on the performance of the house and its insulation, an electric baseboard heating system was installed first. This simplified the calculations since the exact amount of heat introduced to the house could be read off of a watt-hour meter, and uncertainties arising from combustion efficiencies, stack losses, and heat content of fuel are eliminated. It also represents the lowest initial-cost system available. After the performance details were measured, other types of heating systems were considered.

A forced air system was tested, drawing its return air from the insulated plenum under the floor. This system has the advantage of reclaiming much of the heat lost from the interior of the structure through the floor. Perimeter return air ports were installed leading from the living area into the floor plenum. These ports were placed in the floor around the outside wall and spaced to get equal flow from all parts of the house into the floor plenum. This draws cooler air in contact with the outer wall into the floor plenum and from there into the furnace. This system permitted the evaluation of the house's performance using a single, central heating source similar to those many families now rely on.

The final test will be of an oil-fired, kitchen stove. This is the type most frequently used by Natives in the bush areas of Alaska. It doubles as a cooking stove and furnace. Return air can be drawn from the floor plenum through a hole in the floor below the stove. Where electricity is available, a small circulating fan can be used; otherwise, circulation will be by gravity, using the return air grilles into the floor plenum in each room along the outside wall.

PERFORMANCE

Testing for the first year was aimed at establishing the thermal characteristics of the house, and monitoring the effects of weather on materials and structure. A mathematical model of the heat transfer losses from the house was developed and compared to actual measured losses. The model is derived as follows:

$$Q = (U_w A_w + U_c A_c + U_f A_f + U_g A_g)(T_i - T_o) = \Sigma (U_t A_t)(T_i - T_o)$$

If we take an average value for the overall heat transfer coefficient, U_t, each individual coefficient is directly proportional to U_t:

$$U_t = C_w U_w + C_f U_f + \ldots\ldots$$

Where C n is the proportionality constant, therefore we can write

$$Q = U_t (C_w A_w + C_f A_f + C_c A_c + C_g A_g) \Delta T$$

Where:

Q = heat flow out of the house (BTU/day).

U_t = overall heat transfer coefficient for the house (BTU/ft^2 -day-°F).

Subscript: w = wall; c = ceiling; f = floor; g = glass.

A = area of each different heat transfer area (ft^2).

T = temperature (°F).

C values have been designed using heat flux probe information obtained from each area.

Figure 5 shows the correlation of the calculated heat loss compared to the actual measured power consumption of the house. It is seen that a $U_{ave} = 2.33$ gives very good correlation with actual operating conditions.

One of the measures of a dwelling's performance is the comfort of the occupants. If the walls are cold, a person is uncomfortable regardless of the air temperature. Heat radiating from the body to the walls leaves the individual with a chilled feeling. It was noted by the researchers that even on the coldest days (-50°F outside), no discomfort was experienced while working in the house in short-sleeved shirts. Some drafts were noticed, especially around the doors, but weather stripping and a switch to foam-filled doors solved this problem. Another source of drafts was the corners of the structure. The corner contains a butted joint of two panels. Any deflection or warping of the panels can cause a draft in this area. Each panel developed a slight bow, with the center arching outward. A better seal, installed for the second winter's testing, largely eliminated drafts in the corner areas.

With electric baseboard heating and a low level of activity in the house, stratification of the air would be expected and this did occur. Temperature differences of 2°C to 4°C were recorded. Thus the entire room is well within the comfort range, and the absence of a cold floor makes the area very pleasant for small children.

Another measure of the dwelling's comfort, especially in the North, is the cool-down rate. The typical procedure for a family with a wood- or coal-burning stove is to "stoke up" the stove before retiring and hope it will last the night. A house that gets so cold before morning that it requires the fire to be rekindled is looked upon with much disfavor. Therefore, the cool-down rate of the house is considered an important measure of the performance. The cool-down rate is a function of both insulation performance and the thermal mass of the structure. This is the primary reason for the popularity of the log cabin. Even though the insulating properties of logs with chinked cracks are poor, the high thermal mass makes them comfortable on cold winter nights, and their cool-down rate is very slow. By the same token, it takes "forever" to get one heated up, as any sourdough who has come off the trail to a cold cabin can testify. On two occasions the power was cut off to the house, and the cool-down time was measured. It was found that it required 13 hours from the time that all heat was cut off until the interior temperature dropped to 32°F. This was with an average outside temperature of 0°F. In eight hours the inside temperature had dropped to 38°F. If we assume a "banked" stove would continue to burn for three hours after retiring, then the inside temperature would only drop to 45°F.

Relative humidities of at least 20 percent were found desirable, and to attain such, a humidifier was installed in the test facility. It was found that in order to maintain a 20 percent relative humidity, between five and eight gallons of water per week were required. This amounted to nearly 200 gallons over the test period.

Of particular concern were the vapor barrier characteristics of the panels. If the cells of the foam fill with condensed water vapor, its insulating value will be lost. The permeability of polyurethane foam is not considered adequate as a vapor barrier by itself when used in the high vapor diffusion gradients of the North. The glue seams in the plywood interior paneling may give some help, but the question of what the total composite vapor barrier would yield was still unanswered. To test this, a 40 percent relative humidity was maintained inside the house for a period of three months during the winter, while outside temperatures dropped as low as -50°F. At the end of this period, a core sample of the wall was taken. The core was weighed to 0.1 gm on a micro-balance and then placed in a desiccator. Weight changes were monitored until stabilization occurred. At this point, it was assumed that all unbound water vapor had been removed. The sample was then removed from the desiccator and allowed to remain in normal room atmosphere to reach equilibrium with surrounding air. Again, weight changes were monitored, and as the weight stabilized a net percentage hydration was calculated. A net weight change of 2.63% was found. This indicated some water pick up, but probably not enough to be of any significance. Further monitoring, of course, is in process. Heat loss per degree day gives another enlightening view of the performance of the urethane insulation. It is seen from Figure 2 that the loss per degree per day is essentially a straight line, indicating that the insulating quality of the urethane did not deteriorate throughout the testing period. Much of the concern over the effectiveness of urethane as a vapor barrier is relieved; however, much longer test periods must be used to completely resolve the question.

ECONOMICS

In order to keep costs within the budgets of the low income families for whom the house is intended, initial expenditure is of primary importance. The total cost of materials for the house was $9,300. If we ignore shipping expenses, this amounts to $14.78 per square foot of floor space. This compares most favorably to a typical cost for conventional construction in the Alaska area of $35 per square foot.

Labor for erecting the facility amounted to $12,267 for 717 man-hours. This cost, of course, would be eliminated if the owner did his own work. The panels used for this particular house were manufactured in the lower forty-eight states and then shipped to Alaska. Shipping was a substantial portion of the cost of the house, amounting to $2,553. This cost could be minimized by using panels manufactured in Alaska since the raw materials for the foam can be shipped at a lower rate than the foam itself. Shipping costs were somewhat high since an entire trailer had to be rented, but only two-thirds of it was used. If these costs are included, the total only jumps to $18.81/ft^2, which is still very low for the Alaskan market.

Breaking this down a little more, we find several items that could be considered luxury items in terms of Alaskan bush standards. One example is the ceiling tile. Using a painted ceiling instead of acoustic tile would save approximately $150 for material plus $200 on the labor cost. In addition, installation would be easier for the Native homebuilder. The foundation was another item that might be trimmed. If the home were built in a non-permafrost site, a standard block foundation could be used, saving approximately $100 for material and $600 for labor. If instead of shingles on the roof, sod were used (a proven workable alternative in Alaska) an additional savings of $200 for materials and $300 for labor would result. Subtracting these savings, a total materials and shipping cost could run as low as $15.60 per square foot. With the use of more Native materials, it is anticipated that this cost can be reduced even further.

CONCLUSIONS

Sandwich panels offer a unique solution to many of the problems that face the builder of a home in the "bush" regions of Alaska. Although insulating value of the foam falls short of the "three times better than fiberglass," it has a significantly lower thermal conductivity, and is much better at eliminating drafts. The ease of transporting panels (they can even be floated to the site) and elimination of the skill required for conventional building make them a promising development for future housing in our remote areas. Their performance and durability at this time seem to be adequate to withstand the severe weather and environment in which they must be used. Further tests, of course, are needed and planned, but many of the initial concerns seem to be negligible.

Heated plenum-type floors can adequately eliminate the cold floor syndrome which is prevalent in homes elevated above grade to prevent permafrost degradation. In addition, they provide an adequate "duct" for circulating air to maintain more uniform interior temperatures.

Thermal mass is somewhat lacking, and performance with a non-continuous heating system would be less than optimal; however, this can be alleviated with Native materials such as stones in the floor plenum.

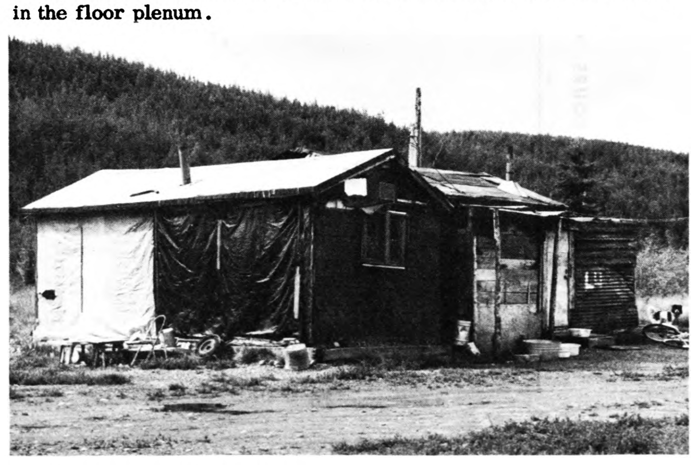

Fig. 1. Typical Native Alaskan Home

Fig. 2. Arctic Health Research Center's Experimental House

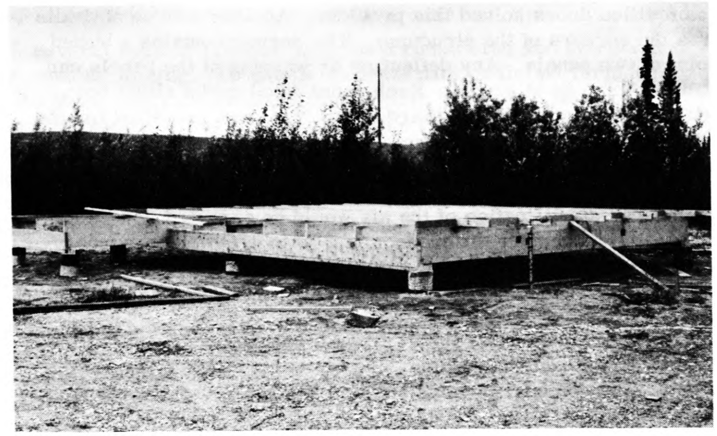

Fig. 3. Foundation and Floor in Construction

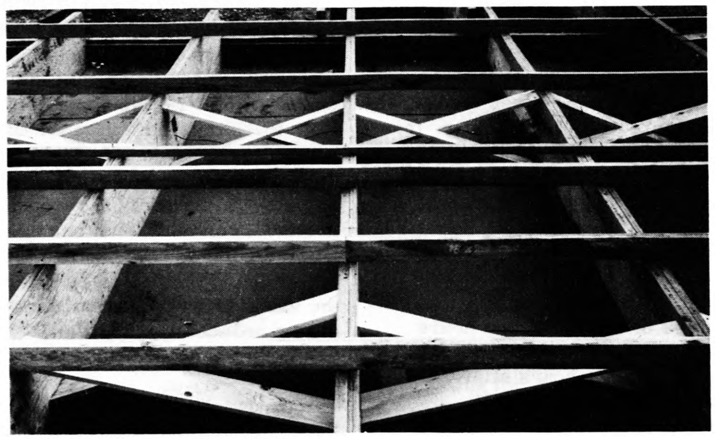

Fig. 4. Floor Plenum Area in Construction

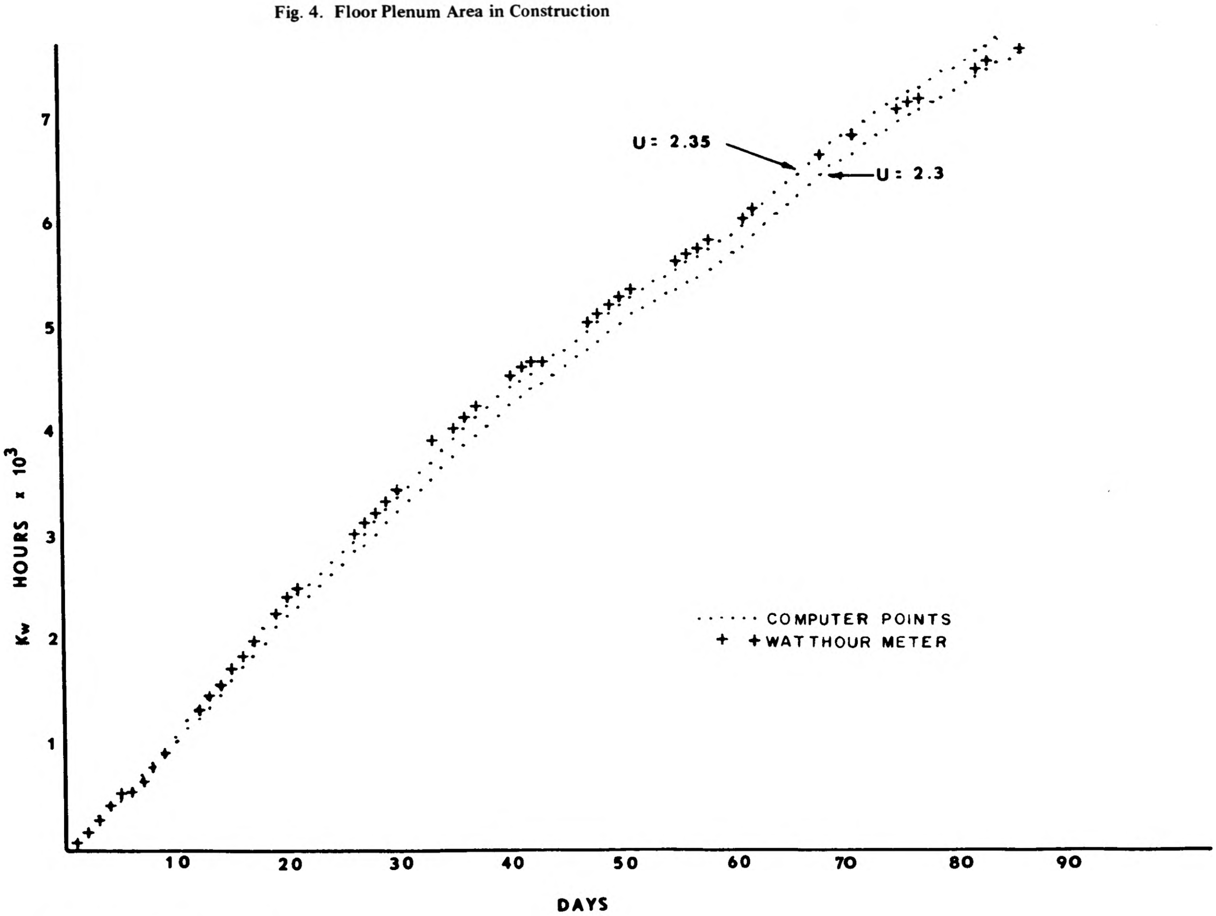

Fig. 5. Mathematical Model vs Actual Power Used

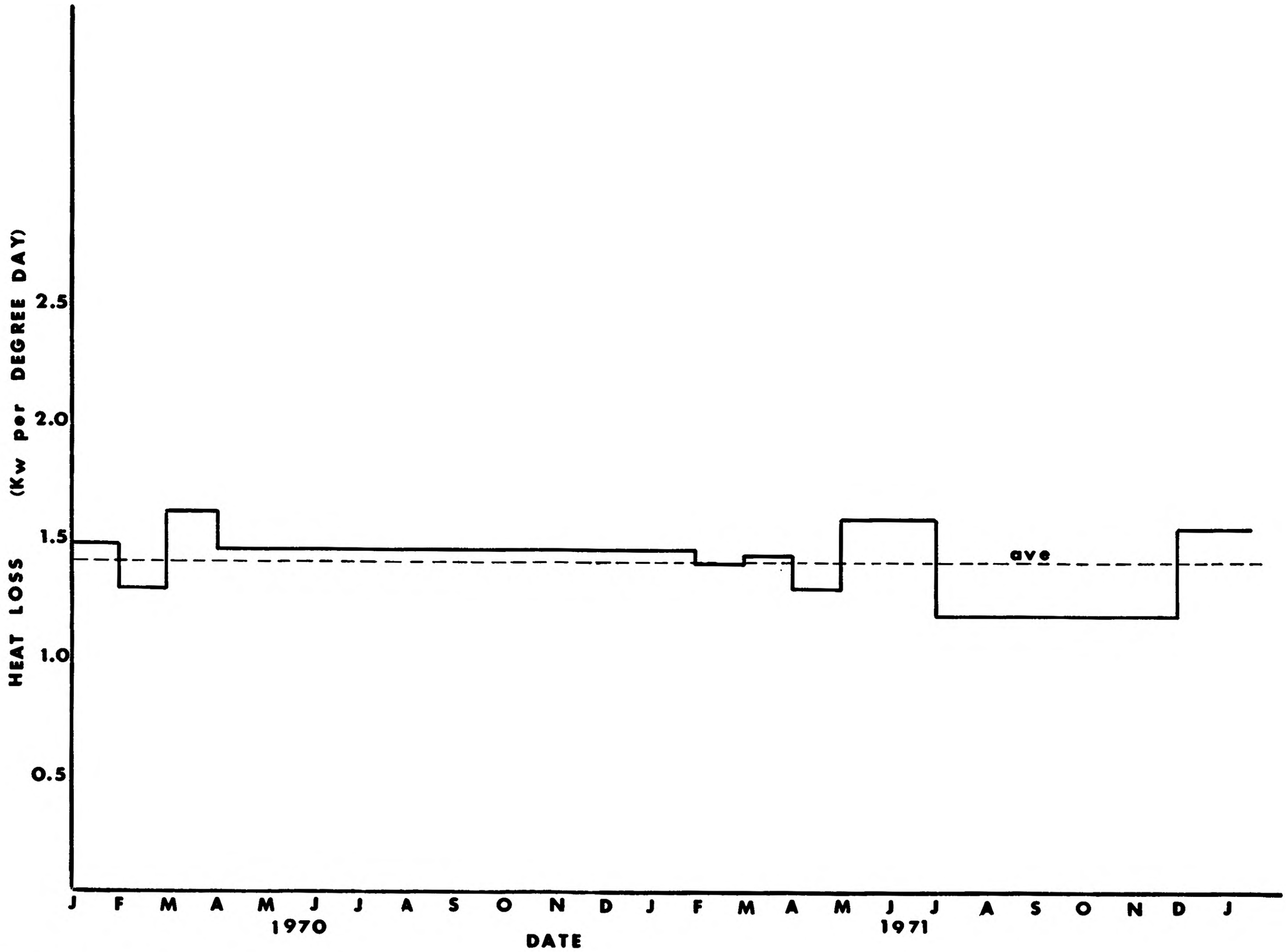

Fig. 6. Insulation Performance vs Time