"ECONOMIC COMPARISON AND THERMAL PERFORMANCE OF SEVERAL DIFFERENT INSULATED WALL CONSTRUCTIONS"

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ABSTRACT

Field measurements were performed on five electrically heated, unoccupied houses with different types of exterior wall sections, to determine their comparative energy consumption characteristics. Three of the houses used fiberglas insulation and various types of stud frame construction while the remaining two houses utilized log construction techniques. The data generated over the 15 day test period was in close correlation to comparative, predicted patterns calculated using the Net Annual Heat Loss Factor (NAHLF) method. The tests also showed that the energy savings predicted for the extra insulation levels in the stud frame walls were realized in practice. Both log structures exhibited higher heat losses than any of the frame walls, primarily due to very high air infiltration rates. An economic analysis revealed that the extra costs for the stud walls, triple glazing and higher ceiling and floor insulation levels were easily justified. A comparison between electric resistance heating costs in Canada and the United States indicated that American insulation levels should be as high or higher than Canadian levels despite the climatic differences.

Key Words: energy conservation, housing, air infiltration, log structures, Net Annual Heat Loss Factor method, building economics

INTRODUCTION

There currently exists little experimental data on heat losses from residential structures, largely due to the general lack of past concern for conservation. With the advent of the energy crisis, a great deal of attention has been focused on this subject as well as on methods of predicting the performance of various conservation measures. The purpose of the research described in this report was to provide field data on the performance of some different wall types and to attempt to verify one analytical prediction technique.

FIELD TESTS

During the winter of 1977, field measurements were performed on five electrically heated houses with different types of exterior wall construction to determine their comparative energy consumption patterns. The test houses were located in Wabowden, Manitoba which has a rather severe climate with 7,500 degree-days Celsius (approximately 13,500 Fahrenheit) per year. All of the structures were very similar in size, layout and orientation. The wall con-

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structions were as follows:

1) a standard 51 mm x 102 mm (2" x 4") stud frame with 89 mm (3.5") of fiberglas insulation,

2) a 51 mm x 152 mm (2" x 6") stud frame with 140 mm (5.5") of fiberglas insulation,

3) a frame wall employing two staggered 51 mm x 76 mm (2" x 3") studs on a common 51 mm x 152 mm (2" x 6") plate with 140 mm (5.5") of fiberglas insulation,

4) a log structure with 178 mm (7") diameter machined logs and

5) a "Stackwall" structure which used large numbers of small diameter logs laid perpendicular to the 610 mm (24") thick wall.

The four non-standard houses also had higher levels of insulation in other areas than the standard house. This included RSI = 7.8 m^2 C/W (R = 44 ft^2 hr °F/Btu) in the ceilings instead of RSI = 2.87 m^2 C/W (R = 16 ft^2 hr °F/Btu), and RSI = 1.51 m^2 C/W (R = 8.57 ft^2 hr °F/Btu) in crawl space above-grade walls instead of RSI = 1.28 m^2 (R = 7 ft^2 hr °F/Btu). These houses also had triple instead of double glazing. The window area on the east facing walls was 3.3 m^2 (35.5 ft^2) per house, and on the west facing walls was 4.2 m^2 (45.2 ft^2) per house, while the north and south walls had no windows.

The tests were conducted over a 15 day period during which the houses were unoccupied. The energy consumption of each house was measured with a recording demand meter and thermocouples were strategically located throughout the houses to record surface and air temperatures. Daily wind measurements were also taken with a hand-held anemometer.

Due to the short test period involved, it was not possible to accurately extrapolate the test data to estimate the annual energy consumption patterns. To calculate the annual benefits of the various wall sections, and other features, the Net Annual Heat Loss Factor (NAHLF) method was employed.[1] The NAHLF method is a modified version of the standard ASHRAE degree-day procedure for residential applications, but accounts for such factors as solar radiation incident upon the building envelope, solar gain through windows, variation of air infiltration rate with wind speed and temperature differential, and internal heat generation from people and electrical equipment.

The results from the tests and the annual estimates predicted by the NAHLF method are given in Table 1. This shows the energy consumption per degree day per unit of floor area for each of the houses as a percentage of the 51 mm x 102 mm (2" x 4") house which acted as the reference structure for the test. The apparent air change rates were determined by first calculating the conduction losses using standard heat transfer analysis and then subtracting this figure from the total recorded losses.

Since the thermal mass of a structure can have a bearing upon its heat loss characteristics, a cool-down test was performed on each of the houses to determine its thermal "half-life". The half-life is defined as the time required for the air in a house to cool to half the original temperature differential between inside and ambient air. The half-lives of four of the houses are listed in Table 2.

DISCUSSION OF TEST RESULTS

Reference to Table 1 reveals several interesting facts. As expected, both the 51 mm and 152 mm (2" x 6") and 2 - 51 mm x 76 mm (2 - 2" x 3") walls produced significant energy savings of 12% and 19% respectively. The two log structures, however, reported higher energy consumption rates than even the 51 mm x 102 mm (2" x 4") house. One mitigating factor with respect to the Stackwall was that final sealing of the walls had not been completed. Normally the logs in a Stackwall will shrink considerably in the first year after construction. The wall is sealed by caulking around each individual log the following year. Since the house had been built the previous summer, the logs had not yet been caulked. Therefore, it is reasonable to expect a completed Stackwall to exhibit lower air leakage and hence lower heating costs than were experienced during the tests. The Stackwall results are presented as an upper limit and not a typical heating cost, although it appears doubtful that it would produce significant savings over a standard 51 mm x 102 mm (2" x 4") house. The 178 mm (7") diameter log house exhibited very high energy consumption which appears to be due to a combination of high infiltration and low thermal resistance.

All the air infiltration rates were somewhat higher than expected considering that the houses were unoccupied and the winds and inside to outside temperature differentials were quite low. This may however, be indicative of the workmanship experienced in the north. It is interesting to compare these values to those being attained in new energy-conserving housing in Canada today which are typically of the order of 0.10 air changes per hour.

The primary purpose of the cool-down test was to determine if the high thermal masses of the log structures increased their thermal inertia. As Table 2 indicates, the half-life and hence the thermal inertia of each of the log structures were lower than either the 51 mm x 152 mm (2" x 6") or the 2 - 51 mm x 76 mm (2 - 2" x 3"), likely due to infiltration around the actual logs which short-circuited the conduction paths. This indicates that claims of significant savings due to the high thermal inertia of log structures is not justified, at least where infiltration is significant. No transient thermal modelling of the houses was done for comparison, because it was obvious that simple conduction was not a dominant effect.

The results of the heating load analysis using the NAHLF method were quite encouraging. As indicated, the consumption patterns in the test structure as related to the reference house varied between -2% and 9% from those predicted by the NAHLF method. Had the houses been occupied, the results may have been somewhat different since there would have been additional internal gains due to the inhabitants and their electrical appliances. However, this would have been balanced somewhat by higher infiltration rates due to the occupant's lifestyle. It is also important to realize that the NAHLF method was developed for houses built to current insulation standards and becomes increasingly less accurate as the structure's insulation and airtightness levels are increased above these values.

ECONOMIC ANALYSIS

Any discussion of conservation must invariably address the problem of the cost-effectiveness of the proposed measures. To properly analyze the benefits of (for example) a different wall system, it is necessary to consider the present value of the expected life-cycle savings due to the wall. These savings will be equal to:

$$PW = (S_1)\,(SPWF)$$

where PW = present value of savings
S_1 = savings in first year
SPWF = series present worth factor.

This would represent the maximum investment which would be justified for the conservation feature. As demonstrated in the previous section, the first year energy savings can be accurately predicted by the NAHLF method which is then multiplied by the fuel rate to produce the first term in the above equation. The series present worth factor (SPWF) is given by:

$$SPWF = \frac{1-(1+i)^{-N}}{i}$$

where i = interest rate
N = length of term.

If the price of fuel is increasing by x per cent per year as a result of inflation and other factors, this can be taken into account by using an effective interest rate y, in place of the nominal rate i, through the following relation:

$$y = \frac{i-x}{i+x}$$

with y being substituted for i in the previous equation.[2] Values for SPWF are presented in Figure 1 as a function of its governing parameters. Also shown are two ranges of SPWF values generated for electric heating in Canada and the United States. These estimates were made on the following assumptions:

Interest rate - 12%
Canadian electrical energy cost escalation rate - 12%-14%
American electrical energy cost escalation rate - 16%-18%

These values are estimated from recent trends of electric utility rates in a number of areas in Canada and the United States. They reflect the lower Canadian rates anticipated from Canada's lesser dependence on fossil fuels for electricity generation. Applying these values, we arrive at SWPF values of from 20 to 32 for Canada and 41 to 53 for the United States. The possibility of SPWF values 28% to 165% higher in the United States is therefore very real. Since American utility rates are also (generally) higher than Canadian rates, it becomes evident that conservation standards in Canadian and American houses should be comparable. This is an interesting result since houses are usually insulated on the basis of the local climate (i.e. by the number of degree-days).

Table 3 illustrates the energy savings due to modifications for three of the test houses discussed. The Stackwall was omitted because it was not felt to be representative of what could be achieved with that type of construction. A SPWF of 28 was used (i = 11%, x = 13%, N = 25 years). The energy savings were calculated using the NAHLF method. The annual value of the savings assumes electric heating at Manitoba's current rate of 2.53¢/kW-hr.

From this analysis, it is obvious that large expenditures could be justified for the 51 mm x 152 mm (2" x 6") and 2 - 51 mm x 76 mm (2 - 2" x 3") structures, certainly far more than their actual cost. The log structure could not be justified.

One final point concerning the economics of residential conservation measures should be made. While the above analysis is correct and reasonable, it is obviously far beyond the economic sophistication of the typical homebuyer. To justify and convince buyers of the need for such features a simpler technique is suggested. This consists of comparing the first year costs to the homebuyer of the mortgage payments, heating costs and property taxes for a conventional and energy conservative house. Such an analysis performed for Manitoba for example, indicated that it was cheaper in the first (and any subsequent) year to purchase a massively insulated, near airtight house with RSI 7.0 (R40) walls, RSI 8.8 (R50) ceilings, RSI 3.5 (R20) basement and 0.10 air changes per hour than a conventional structure with RSI 2.1 (R12) walls, RSI 5.6 (R32) ceiling, RSI 1.2 (R7) basement and 0.60 air changes per hour.

CONCLUSIONS

The field test performed on five electrically heated houses produced the following conclusions:

1. The energy savings predicted for walls with 152 mm (6") fiberglas insulation are realized in practice.

2. The thermal performance of 178 mm (7") diameter log walls is poorer

than a standard 51 mm x 102 mm (2" x 4") wall with 89 mm (3½") of fiberglas insulation, largely due to air infiltration and higher conduction losses.

3. The thermal performance of a 610 mm (24") Stackwall with no caulking around the logs is also poorer than the standard house, again largely due to air infiltration.

4. The Net Annual Heat Loss Factor (NAHLF) method appears to offer an accurate and easy means of predicting annual heat losses for residential structures with conventional insulation standards.

5. The financial commitment required for such conservation measures as extra wall, ceiling and floor insulation is easily justified.

6. Conservation standards in houses with electric resistance heating should be comparable in Canada and most parts of the United States.

7. One criterion which can be used successfully to convince house buyers of the need for much higher conservation standards is to compare the total first year costs of the mortgage payments, heating bills and property taxes for a standard house and one with the higher standards. This will generally justify higher standards than are currently the norm. Future legislative concessions such as the elimination of property taxes on energy reduction measures will make it even easier to meet this criterion.

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TABLE 1. SUMMARY OF RESULTS

House	51mm x 102mm (2" x 4")	51mm x 152mm (2" x 6")	2-51mm x 76mm (2-2" x 3")	Stackwall	178mm D. Log (7")
Floor Area (M^2)	73.27	79.09	79.09	76.33	79.09
Total Power Consumption (kWh) during test period	1448	1382	1266	1783	2125
Power Consumption per square meter per degree-day (Wh/°C-DAY M^2)	47.3	41.8	38.3	55.9	64.3
Percent of 51mm x 102mm (2"x4")	100%	88%	81%	118%	136%
Apparent air infiltration rate (air changes/hour)	1.13	1.25	1.09	2.75	1.96
Predicted annual power consumption using NAHLF method (kWh/M^2) *	410	329	327	492	527
Predicted percentage of 51mm x 102mm (2"x4") using NAHLF method	100%	80%	80%	120%	129%
Percentage difference between measured and predicted values	---	9%	1%	-2%	5%

* Infiltration rates based upon those determined during the field measurements were used for the NAHLF predictions.

TABLE 2. COOL DOWN RATES OF TESTED HOUSES

House	Test Period (hours)	Temperature Drop °C	Half-life (hours)
51mm x 152mm (2"x6")	3.50	7.8	10.4
2-51mm x 76mm (2-2"x3")	3.50	8.9	12.3
178mm Log (7")	3.35	7.2	10.0
Stackwall	3.50	6.7	8.7

TABLE 3. ENERGY SAVINGS DUE TO HOUSE MODIFICATIONS

	51mm x 152mm (2" x 6")	178mm D. Log (7"D)	2-51mm x 72mm 2-2" x 3"
Energy savings due to wall modifications alone (kW-hr/year)	2300	-14,230	2500
Annual value of savings	$58	-$360	$63
Present value of future savings	$1624	-$10,080	$1764
Energy savings due to all Modifications (kW-hr/year)	6420	-9170	6620
Annual value of savings	$162	-$232	$167
Present value of savings	$4536	-$6496	$4676

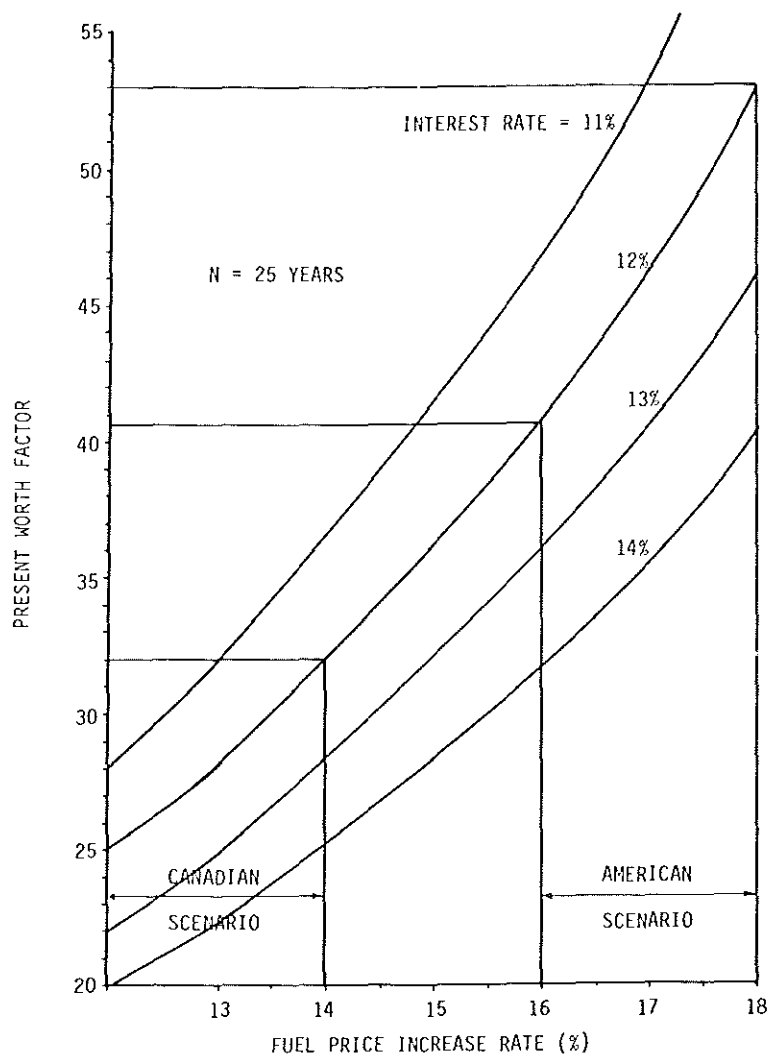

FIGURE 1. PRESENT WORTH FACTOR vs FUEL PRICE INCREASE RATES