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by

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ABSTRACT

Approximately 50 low-energy passive solar houses have been constructed in the Saskatoon area to date. Quantitative measurements are now presented on the space heating and total energy consumption of a group of these houses.

The average space heating energy consumption for electrically heated, detached residences built before 1970 in the Saskatoon area is about 670 MJ/m^2 of total floor area for a heating season of 6077 Celsius degree-days. Of the 13 low-energy buildings surveyed, the total energy consumption figures varied from 121 to 499 MJ/m^2 during the winter of 1979-80, with all but two of the buildings in the range of 121 to 240 MJ/m^2. Average consumption for the 13 buildings was 218 MJ/m^2. Features common to the low-energy houses are:

i) improved air tightness with controlled ventilation,

ii) insulation levels approximately three times the present minimum standard,

iii) use of south windows for passive solar gain.

Introduction

From 1977 to 1979 approximately 50 low-energy houses have been constructed in the Saskatoon area, with insulation levels approximately three times those of 1975 Canadian minimum standards. Ceiling insulation levels have varied in the range of RSI 7 (R40) to RSI 14.8 (R84); wall insulation levels, in the range of RSI 4.9 (R28) to 10.6 (R60); and floor insulation levels in the range of RSI 0 to RSI 4.9. On a number of the houses night insulation for windows has been used as well.

To limit air leakage, special sealing techniques have been used for most of the houses. One of the main features is the use of 150 micrometre (6 mil) polyethylene carefully caulked at all joints and penetrations. The booklet, Low Energy Passive Solar Housing[1], details the air tightness measures used on many of the houses.

To provide needed ventilation air in a number of the houses an air-to-air heat exchanger of a novel design[2] has been incorporated; air flow rates in the range of 40 L/s (80 cfm) are used with it. The heat exchanger operates with an effectiveness of approximately 0.7. In typical outside temperature conditions of -20°C in winter it will raise the outside air from -20°C to about +10°C. A common control scheme incorporates a relative humidity sensor to control operation of the fans. A number of schemes have been used to defrost the heat exchanger, and these are described in the previously mentioned booklet.[2]

In most of the houses in the Saskatoon low-energy hous sample passive solar collection has been used to suppl ment space heating. A few exceptions have no major window areas oriented to the south, but generally this has been caused by improper lot orientation. For thos with south-facing windows the approach has been to use modest amount of glazing, generally in the range of 6 per cent south window area in relation to the total floor area. With this size of south window few proble of overheating have occurred in wood frame housing; th thermal capacity of the interior materials of the hous is sufficient to limit temperature swings from solar gain. For a number of the houses, the south window performance has been upgraded by the use of night insu tion or triple glazing. A listing of the physical si and thermal characteristics of the low-energy houses i provided in Table I.

Measured Energy Consumption

No extra monitoring equipment was installed on most of the houses. Instead, utility-supplied meters for electricity and natural gas were used, and readings we taken on a monthly basis from September 1979 to May 19

Space Heating Energy Consumption as a Function of Heating Degree-Days

With conventional housing on the Canadian Prairies it is usually possible to determine a linear relation between the total energy consumption of a house and th number of degree-days.[3] A plot for a typical pre-197 house located in Regina is shown in Figure 1.[3]

A linear relation between total energy consumption an degree-days per day describes the two variables. The slope of the curve may be regarded as an indication o the space heating performance of the house.

If a building has a slope of 24.4 MJ/degree-day and th annual degree-days for the location are 6,000, then th annual space heating load would be approximately the product of these numbers (i.e., 146,000 MJ or 146 GJ) The analysis is somewhat complicated by the fact that electrical usage for lighting and for the furnace fan increases with greater degree-day per day figures. F standard houses, however, this is usually a minor correction of the order of 10 per cent or less.

With low-energy houses, the total energy consumption

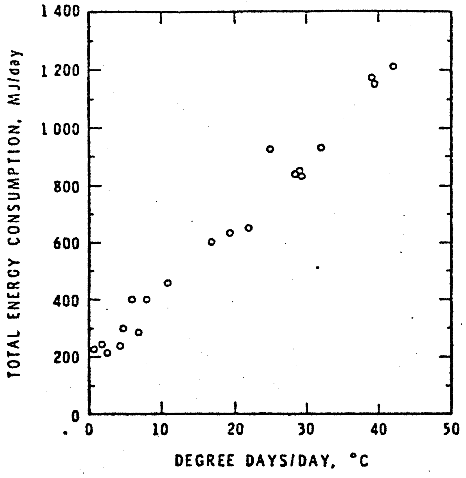

Fig. 1. Total energy consumption versus degree days per day, standard house.

versus degree-days per day curve is often not a simple linear relation. In a low-energy house with a rate of heat loss of the order of 100 watts per C deg temperature difference between inside and outside, internal heat gain and passive solar gain can readily provide a 24 h average of approximately 2,000 W. With this amount of heat gain the space heating system for the house need not cut in until the temperature difference between inside and outside is 20 C deg (2,000 W ÷ 100 W/C deg). With such a house the total energy consumption would no longer be linear with the degree-day figures. Figure 2 presents a plot of the total energy consumption versus degree-days for one of the occupied low-energy houses in Saskatoon. At the low degree-days per day figures the total energy consumption per day is relatively constant. Beyond a figure of about 10 degree-days per day, however, the total energy consumption per day increases because the internal heat gain and passive solar gain are no longer sufficient to meet the space heating load.

To provide a standard of comparison for the houses the space heating energy consumption per unit of total floor area was chosen as the measure of performance. Table II gives the energy consumption statistics for the winter of 1979-80. As may be seen, the space heating energy consumption of the low-energy houses varied between 121 and 499 MJ/m^2 over the heating season. Owing to the fact that occupancy commenced at somewhat different times in the autumn, not all the houses had accumulated the same number of degree-days during the monitoring period.

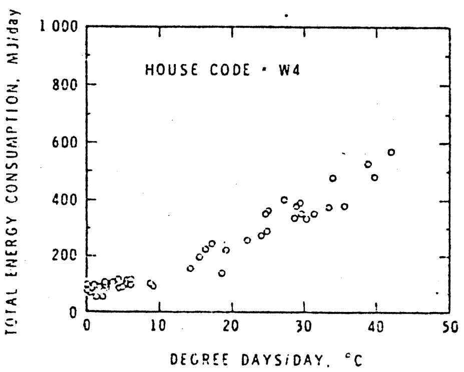

Fig. 2. Total energy consumption versus degree days per day, low-energy house

It was not possible to measure the space heating energy consumption directly. Total energy consumption was measured and the space heating energy consumption calculated by subtracting the measured total energy consumption per day in the non-heating season times the number of days in the monitoring period. Thus, for house B1 the total energy consumption during the monitoring period was 62.4 GJ. To estimate the space heating energy consumption, the measured total energy consumption per day in the non-heating season (86.4 MJ/day) was multiplied by the number of days in the monitoring period (256) and the result subtracted from the total energy consumption (62.4 GJ) to give 40.3 GJ. To determine the estimated space heating energy consumption per unit area, the estimated space heating energy consumption was divided by the total floor area (199 m^2) for a figure of 203 MJ/m^2.

For occupied houses for which a measurement of energy consumption during the non-heating season was not available, a figure of 105 MJ/day, the average for the measured houses, was used. Thus, for house B7 the estimated figure for space heating energy consumption was calculated by subtracting the product of 105 MJ/day and 105 days from the total energy consumption of 28.6 GJ.

For the three unoccupied houses (A1, AA4 and AA5), in which no hot water was used, a figure of 59.1 MJ/day was used as the estimated energy consumption during the non-heating season.

As may be seen from these calculations, it would have been preferable to install separate meters on all of the houses to measure more accurately the space heating load.

Figure 3 shows a histogram of the results presented in Table II. As five of the houses used wood heat for a substantial portion of space heating, these houses are shown in the separate upper histogram. Because the efficiency of wood heating apparatus varies, it is difficult to quantify the net heating contribution of the wood burned.

Discussion

A number of points have been clarified by the results presented in this paper. The first is that the increase insulation has dramatically reduced the energy consumption of the test houses over that of standard houses. The space heating energy consumption per square metre has been reduced on three of the low-energy houses to one-fifth that of standard pre-1970 dwellings. Even space heating energy consumption of the median house is one-third that of the standard pre-1970 dwelling.

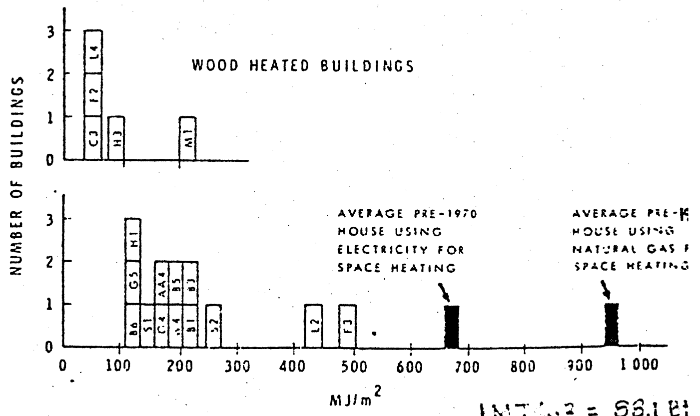

Fig. 3. Space heating energy consumption (electricity or natural gas) per unit total floor area for heating season

TABLE I - LOW-ENERGY HOUSE FEATURES

House Code	Date of Completion	Total Floor Area (Based on Outside Dim) Incl. Basement sq m	Number of Occupants During Monitoring Period	Type	Insulation Levels RSI (m^2 °C/W)				Caulked Vapour Barrier	Air-to-Air Heat Exchanger	Insulating Shutters	Auxiliary Heating System	
					Wall	Ceiling	Basement Wall	Floor				Space Heat	Water Heat
A1	1980	179	0	Split level wood basement	5.1	10.6	5.1	0	Yes	Yes	No	Elec. furn.	Elec.
B1	1979	199	2	2 storey crawl space	7.75	10.6	-	3.5	Yes	Yes	Partial	Elec. B.B.	Elec.
B2	1979	195	2	2 storey slab on grade	5.3	7.9	-	1.7	Yes	No	No	Oil furn.	Elec.
B3	1979	300	3	Split level wood basement	7.9	10.6	3.5	0	Yes	Yes	No	Nat. gas	Elec.
B4	1979	112	2	Retrofit of trailer	7.8	9.2	-	4.9	Yes	Yes	No	Wood & elec. furn.	Elec.
B5	1979	306	4	2 storey wood basement	7.0	12.3	6.3	1.3	Yes	T.B.I.	No	Nat. gas	Nat. gas
B6	1978	287	4	1½ storey crawl space	7.0	10.6	-	5.3	Yes	Yes	No	Elec. B.B.	Elec.
B7	1980	164	2	Bi-level wood basement	5.3	8.81	4.9	-	Yes	Yes	Partial	Elec. B.B.	Elec.
C3	1978	260	4	2-storey slab on grade	7.0	10.6	-	2.61	Yes	Yes	No	Wood & elec. base	Elec.
F2	1979	290	4	2 storey conc.basement	7.0	10.6	1.3	-	Yes	Yes	T.B.I.	Wood & elec. furn.	Elec.
F3	1978	342	Office building	1½ storey wood basement	7.0	10.6	3.5	0	Yes	Yes	No	Heat pump & n. gas	Nat. gas
G4	1979	241	2	2 storey crawl space	7.8	10.6	-	4.9	Yes	Yes	No	Elec. B.B.	Elec.
G5	1979	297	2	1 storey wood basement	7.0	10.6	4.2	1.8	Yes	Yes	No.	Elec. furn.	Elec.
H1	1979	225	2	1 storey wood basement	5.3	8.81	4.9	-	Yes	Yes	Partial	Elec. B.B.	Solar & elec.
H3	1977	107	3	1 storey crawl space	3.5	7.0	-	3.5	Yes	T.B.I.	Yes	Wood & elec. furn.	Elec.
L2	1978	163	1	Split level wood basement & crawl space	6.3	10.6	3.5	-	Yes	Yes	No	Elec. furn.	Elec.
L4	1979	222	2	1½ storey retrofit	4.9	10.6	2.6	-	Yes	No	Partial	Wood & n. gas	Nat. gas
L6	1980	204	0	1 storey wood basement	5.3	8.81	4.9	-	Yes	Yes	Partial	Nat. gas	Nat. gas
M1	1978	260	6	1 storey wood basement	7.0	10.6	3.5	3.5	Yes	Yes	No	Elec. furn. & wood stove	Elec.
S1	1979	167	1	2 storey slab on grade	6.4	10.6	-	3.5	Yes	T.B.I.	T.B.I.	Elec. B.B.	Elec.
S2	1979	328	4	2 storey conc.basement	5.3	8.81	1.8	-	Yes	Yes	Partial	Elec. B.B.	Elec.
T1	1980	250	1	2 storey crawl space	10.6	10.6	-	-	Yes	Yes	No	Elec. B.B.	Elec.
W4	1978	242	5	2 storey wood basement	7.8	10.6	5.6	-	Yes	Yes	T.B.I.	Elec. furn.	Elec.
AA4	1979	204	0	1 storey wood basement	5.3	8.8	4.9	-	Yes	Yes	Partial	Elec. B.B.	Elec.
AA5	1979	200	0	1½ storey wood basement	5.3	8.8	4.9	-	Yes	Yes	Partial	Elec. B.B.	Elec.

TABLE II - ENERGY CONSUMPTION STATISTICS

House	Monitoring Period Start	Monitoring Period Finish	No. Days	Celsius Degree Days Relative to 18°C	Total Energy Consumption GJ	Measured Total Energy Consumption Per Day in Non-heating Season KW-h/Day	Measured Total Energy Consumption Per Day in Non-heating Season MJ/Day	Estimated Space Heating Energy Consumption During Monitoring Period (GJ)	Estimated Space Heating Energy Consumption For Heating Season (MJ/M^2)
A1	80/02/11	80/04/30	79	1733.7	15.18 EL	-	-	10.5	-
B1	79/08/18	80/04/30	256	5297.3	62.4 EL	24	86.4	40.3	203
B3	79/09/28	80/04/30	215	5152.2	36.6 EL 64.9 N.Gas	46.8	168.5	65.3	218
B5	79/05/03	80/04/30	363	5663.5	38.6 EL 91.2 N.Gas	56.4	203	56.1	183
B6	79/05/01	80/04/30	365	5696.9	74.4 EL	26.4	95.0	39.7	138
B7	80/01/15	80/04/30	106	2586.4	28.6 EL	-	-	17.5	-
C3	79/05/03	80/04/30	363	5663.5	77.8 EL wood	42.8	154	21.9 + wood	57 + wood
F2	79/10/26	80/04/30	187	4836.2	27.1 EL wood	20	72	13.6 + wood	47 + wood
F3	79/06/29	80/05/01	307	5348.6	67.7 EL 150.0 N.Gas	42.5	153	170.7	499
G4	79/09/20	80/05/01	224	5195.2	62.6 EL	-	-	39.1	162
G5	79/10/30	80/05/01	184	4780.7	43.1 EL	10.9	39.2	35.9	121
H1	79/09/20	80/05/01	224	5195.2	54.0 EL	-	-	30.5	136
H3	79/08/29	80/04/30	245	5276.9	33.4 EL wood	26	93.6	10.5 + wood	98 + wood
L2	79/09/21	80/05/01	223	5188.0	95.1 EL	-	-	71.7	440
L4	79/08/25	80/04/30	249	5284.9	15.5 EL wood 22.9 N.Gas	-	-	12.3 + wood	55 + wood
M1	79/05/04	80/04/30	362	5649.2	84.5 EL wood	21.6	77.8	56.3 + wood	217 + wood
S1	79/10/30	80/05/01	184	4780.7	28.5 EL	7.9	28.4	23.3	140
S2	79/11/11	80/05/01	172	4504.0	96.9 EL	-	-	78.8	240
T1	79/12/20	80/04/30	132	3461.9	28.9 EL	-	-	15.0	-
W4	79/05/22	80/04/30	344	5469.7	75.9 EL	24.8	89.3	45.2	187
AA4	79/11/11	80/05/01	172	4504.0	43.9 EL	-	-	33.7	165
AA5	80/01/30	80/05/01	92	2087.6	20.5 EL	-	-	15.1	-

1 GJ = 1 Gigajoule = 10^9 joules = 278 KW-h = 0.949 million Btu

It is clear that the design of the building must be carefully planned. House L2, as shown on Figure 3, had the second highest energy consumption of the group of low-energy buildings, although it has insulation levels (walls, RSI 6.3; ceiling, RSI 10.6; basement walls, RSI 3.5) that meet or exceed the levels used in the majority of the low-energy houses. The reason for this is a large amount of south-facing glazing - 32.5 m^2 (equal to 20 per cent of the total floor area); the night heat loss from these windows (5,880 W at -34°C outside, 21°C inside) seriously degrades the performance of the house. The building is a direct-gain structure with no additional thermal mass, and on sunny days it readily overheats, necessitating use of reflective blinds to limit heat gain.

A third point is that a low-energy building must be operated in an energy conserving manner. Building F3 is an office building that uses large amounts of outside air for ventilation. Thus, in spite of its high insulation levels it is a high energy user in relation to the rest of the low-energy houses. By reducing the outside air intake during the hours when the building is not used, the energy consumption for space heating could be reduced significantly.

A fourth point is that internal gains from electricity and hot water usage make up a very significant fraction of the annual space heating requirements. As may be seen from Table II, this varies greatly from one family to another. The average for the 12 houses measured is 29.2 KW h/day, but the values range from 7.9 to 56.4 KW h/day. This 7 to 1 variation can be partly explained by family size (the house with lower energy consumption had one occupant, the house with higher energy consumption, four occupants), but it is well to keep in mind these fairly large differences in internal gains when predicting the space heating and total energy consumption for a house.

A related point is that low-energy houses with small internal heat gains because of the lifestyle of the occupants will necessarily have a higher space heating load than will similar houses with greater internal heat gains. It would be useful to define a "reference" family whose internal heat gains are fixed in order that more accurate comparisons could be made among houses in different parts of the world.

Further monitoring of these and other low-energy houses is intended for the coming year. With monitoring it will be possible to isolate more clearly the space heating load from the remainder of the energy load in all of the houses. In addition, the authors plan to compare the measured and predicted space heating energy consumption of a group of ten such houses.

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