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A Survey of Some Essential Features

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INTRODUCTION

In response to the rapid rise in energy prices since 1973, efforts have been directed to reducing energy consumption in all sectors of the economy. In the housing sector, one approach which has developed has been the introduction of houses which incorporate thermal improvements to the envelope of the structure so as to dramatically reduce the requirement for space heating. The houses have been described by a variety of terms: "low energy houses"[1], "super-insulated houses"[2], "energy efficient houses"[3] or "lo-cal houses"[4]. This paper is a condensation and simplification of more detailed material found in References 5, 6 and 8.

The term which will be used here is "low energy houses". The adjective "super-insulated" is incomplete as low energy houses may have a number of additional features - air tightness, controlled ventilation with heat recovery, use of south-facing windows for solar gain, and high efficiency heating systems - which are not encompassed by the adjective "super-insulated".

The energy conservation features employed in most low energy houses in the Prairie region have been air tightness, increased thicknesses of insulation, air-to-air heat exchangers and south-facing windows. A more detailed description of such low energy houses is found in Reference 5.

AIR TIGHTNESS

Although several approaches to air tightness in residences are possible, the most popular method to date in the Prairie region has been the use of polyethylene film as a combined air and vapour barrier.[5] Special care is taken at all joints to ensure continuity of the air barrier. A low-priced butyl-based caulking material known as acoustical sealant has been used to seal the polyethylene sheets to one another. Care is taken to ensure that each joint in the polyethylene is securely fixed between rigid members. In addition, windows and doors with relatively good air seals are generally chosen.

Some 40 low energy houses in Saskatoon, constructed using these air tightness techniques, have been pressure-tested.[6] A fan was placed in the doorway of the house, subjecting it to a negative pressure up to about 100 Pa. The volume flow of air was recorded, and an equivalent leakage area calculated according to the Canadian General Standards Board standard.[7] The results of these pressure tests are reproduced in

Table 1, along with the results averaged from some standard houses not incorporating the special air tightness features. The low energy houses had an average equivalent leakage area 47% lower than the standard houses. Because of this, it has generally been found necessary to provide controlled ventilation to maintain air quality.

With air tightness it is possible to utilize an air-to-air heat exchanger; heat from the exhaust air stream preheats the incoming air.[8] In typical houses in Western Canada, heat exchangers with a design air flow capacity in the range of 30 to 100 L/s (60 to 200 cfm) have been installed. There are several Canadian manufacturers of domestic air-to-air heat exchangers, and a large number of North American and European producers.[9] In areas with sub-zero temperatures, the heat exchangers are generally equipped with automatic defrost cycles to remove frost and ice buildups within the units. In a sample of 5 heat exchangers tested by Lawrence Berkeley Laboratory, approximately 43 to 75% of the available sensible heat was transferred from the outgoing to the incoming air.[10]

SUPER-INSULATION

The second element in the low energy house strategy is the use of high levels of insulation.[8] In Western Canada, low energy houses have generally used specially thick wall constructions to incorporate insulation thicknesses approximately two to three times the minimum standard. Table 2 gives the insulation levels used on most of the low energy houses.

A large number of wall designs have emerged to accommodate the high insulation levels. There are 3 wall types in widest use, with several combinations and variations:

1. Single stud walls using exterior insulating sheathing boards,
2. Single stud walls using interior horizontal wood strapping,
3. Double stud walls.[8]

The latter two designs often incorporate the air-vapour barrier within the wall structure. The three wall designs are shown in Figure 1. By locating the air-vapour barrier as shown in the latter two wall designs, the barrier is more readily protected from penetrations by electrical wiring and plumbing, and from damage by subsequent trades during construction. A more detailed description of single- and double-stud wall construction is given in Reference 8.

In Table 3, figures from a paper by Dumont and Orr on the cost (in 1978-81) of insulated wood frame walls with thermal resistance values varying from RSI 2.1 (R12) to RSI 10.6 (R60) are reproduced.[8]

For economy reasons, batt or loose fill insulation has generally been used in ceiling applications. Glass fibre batts, sometimes with one of the rigid sheathing insulations, are most often used for walls. For basement walls, the preserved wood foundation system incorporating glass fibre batts has become popular. With concrete basement walls, the most popular technique has been the use of glass fibre batts in a wooden stud wall located on the inside of the concrete wall. A number of builders have incorporated additional exterior rigid insulation on the above-grade portion of concrete basement walls. When concrete basement floors are insulated, rigid polystyrene, often of the closed cell extruded variety, has been laid below the poured concrete. With crawl space designs under wooden floors, glass fibre batts have been most often used.

SOUTH-FACING WINDOWS

The third element in the low energy strategy is the use of windows facing south for passive solar gain.[8] In new house construction the layout of the house is planned so that about 75% or more of the windows are on the south side of the house. Most of the low energy houses built to date use standard gypsum board walls and ceilings, and wooden floors. In some designs, an attempt has been made to increase the thermal capacity of interior elements to absorb solar heat gains from the south windows. If large south windows are used, wide temperature swings may result.

A relatively small amount of south window area has been used on most of the houses. Typically, the ratio is 6% south window area to total floor area. On houses with a total floor area of 200 square metres including the basement, approximately 12 square metres of south window are used.

To improve the net heat contribution from south-facing windows, triple glazing or insulating shutters may be installed. Roof overhangs or awnings can prevent excessive heat gain during the summer months, by reducing direct solar radiation incident on the south windows. A fixed window overhang is often positioned so as to allow full sun into the south windows from the beginning of November to the first part of February. The ideal exterior shading would be movable, but for architectural reasons and simplicity an overhang is generally fixed.

The amount of heat gained from south-facing windows varies with location and time of year. Averaged over the heating season it may account for 25 to 50% of the total space heat required.

INTERNAL HEAT GAINS

Internal heat gains will often contribute a very substantial fraction of the space heating requirement in low energy houses. The typical household in Canada has an internal heat gain rate of about 1 kilowatt averaged over a 24-hour period. The heat sources are lights, appliances, domestic hot water usage, and body heat from occupants. For a family of 4 or 5 people, it is not uncommon in low energy houses for the internal heat gains to provide about 40% of the annual space heat requirement.

As the efficiency of home appliances and domestic hot water systems improves, it is likely that the internal heat gains will decline somewhat.

PERFORMANCE RESULTS

A number of studies have been done on the performance of low energy houses. A 1980 paper presents the results of a group of 13 low energy houses in Saskatoon.[1] Over a one-year period, the measured space heating energy consumption of the 13 houses averaged 218 MJ/m^2 (5.6 kWh/ft^2), as compared with the average for pre-1970 houses, of 632 MJ/m^2 (16.3 kWh/ft^2). Over the one-year monitoring period, the number of heating degree days accumulated was 5663°C-days (reference 18°C). In todays's (1982) energy prices, the cost of space heating would range from about $600 to $1500 per year or higher, for conventional houses and about one third of that for the low energy houses. The most energy-efficient house in the group had an energy consumption for space heating equal to 121 MJ/m^2 (3.1 kWh/ft^2) for that period.

A number of design errors have been identified as responsible for relatively high energy consumption on several of the 'low energy' houses. These included:

1. Excessive glass area on the south, resulting in large night-time heat losses, and overheating on sunny days;

2. Low insulation levels in the basement walls and floors, leading to high heat losses on a seasonal basis;

3. Inadequate air tightness levels due to improper detailing, or improper installation of the air-vapour barrier;

4. Use of double glazing instead of triple glazing or double glazing with night insulation on the windows;

5. Poor window overhang design on the south windows, resulting in undesirable shading of these windows during the heating season.

COST OF ENERGY CONSERVATION MEASURES

Although a number of owners of low energy houses have built or purchased their homes for reasons of increased comfort or ease of heating, the reductions in heating bills have been a major factor. The 1981 paper "Cost of Energy Conservation Measures for New Housing"[9] presents incremental cost figures for energy conservation features such as increased air tightness, heat exchangers, improved wall, ceiling and floor insulation, and the use of triple glazing. In that paper, a table presents the thermal properties of a theoretical house built to minimum standards and then upgraded. The annual space heating requirement of the house has been reduced from 510 MJ/m^2 to 74 MJ/m^2 per year. The cost of these improvements was $5020 (approximately 10% of the construction price of the house). Table 4 shows the energy conservation features which can be used to obtain this reduction in consumption.

On a number of the low energy houses, there have been savings in the cost of installing a heating system, as the peak heat requirements are substantially reduced compared to standard housing. In the example mentioned above, the design heat loss of the house was reduced from 10.8 kW for the minimum standard house to 4.2 kW for the low energy house at an outside temperature of -34°C.

FUTURE DEVELOPMENTS

The low energy houses built to date have achieved considerable reductions in their requirements for space heating. A number of technical developments could further improve the cost effectiveness of the houses. Particularly needed is a window with an improved thermal resistance value compared with those presently available. A triple glazed window with 12.7 mm air spaces has a thermal resistance equal to about 0.57 m^2°C/W; this compares unfavourably with wall and ceiling resistance values in the range of 5 to 10 m^2°C/W, achieved on low energy houses. A number of other developments could improve the cost-effectiveness of these houses, including volume production of air-to-air heat exchangers which would reduce their cost. As of 1982, the installed cost of a heat exchanger was approximately $750-$1000 for a typical residence.

On a number of low energy houses, the annual water heating bill exceeds the space heating bill, indicating another possible area for development and savings.

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TABLE 1 PRESSURE TEST RESULTS FOR A SAMPLE OF HOUSES IN SASKATOON

Sample Age	Equivalent Leakage Area (m^2)	Number of Houses Tested
Low energy houses	0.0330	40
Standard houses		
Pre-1945	0.1078	19
1946-60	0.0709	20
1961-80	0.0621	97

TABLE 2 THERMAL RESISTANCE LEVELS USED ON LOW ENERGY HOUSES

	RSI($m^2 \cdot °C/W$)	($ft^2.F.h/Btu$)
Walls Above Grade	5 - 9	28 - 51
Ceilings	9 - 14	51 - 80
Walls Below Grade	3.5 - 7	20 - 40
Floors (Over Crawl Spaces)	3.5 - 5	20 - 28
Floors (Under Concrete)	1 - 2	6 - 12
Window Shutters	1 - 3	6 - 18

TABLE 3 WALL COSTS FOR INCREASING INSULATION LEVELS

Wall Design	Wall Thermal Resistance, ($m^2 \cdot °C/W$)	Wall Cost* per Unit Area, ($\$/m^2$)
1. Basic wall 38 × 89 mm single stud with glass fibre batts	2.1	13.44
2. 38 × 89 mm single stud with glass fibre batts and RSI 1.4 insulating foam sheathing	3.5	16.02
3. 38 × 140 mm single stud with glass fibre batts and RSI 1.8 insulating foam sheathing	4.9	20.54
4. 38 × 89 mm double stud with glass fibre batts; total insulation thickness = 267 mm	6.3	28.35
5. 38 × 89 mm double stud with glass fibre batts; total insulation thickness = 450 mm	10.6	35.16

*Excluding cost of interior gypsum board and exterior finish, but including costs for extra finishing work and extra roof and siding to accomodate the greater wall thickness.

TABLE 4 EFFECT OF UPGRADING A STANDARD HOUSE TO A LOW ENERGY HOUSE

	Standard House	Low Energy House
Thermal Resistance Values ($m^2 \cdot °C/W$)		
Ceiling	4.9	9.0
Walls	2.2	6.3
Windows	0.30	0.46
Basement Walls		
Above Grade	1.4	4.9
Below Grade	0.5	4.9
Floor	0	1.8
Air Change Rate per Hour	0.4	0.2 (with a heat exchanger)
	Double Glazed Windows	Triple Glazed Windows
Window Orientation		
S	3.25 m^2	10 m^2
N	3.25 m^2	1 m^2
E	3.25 m^2	1 m^2
W	3.25 m^2	1 m^2
Design Heat Loss at -34°C (kW)	10.8	4.2
Annual Space Heat Requirement for average year assuming 21°C inside temp. and internal heat gain of 887 W - Saskatoon location	99 GJ (27 400 kWh)	14 GJ (3 940 kWh)
	510 MJ/m^2	74 MJ/m^2

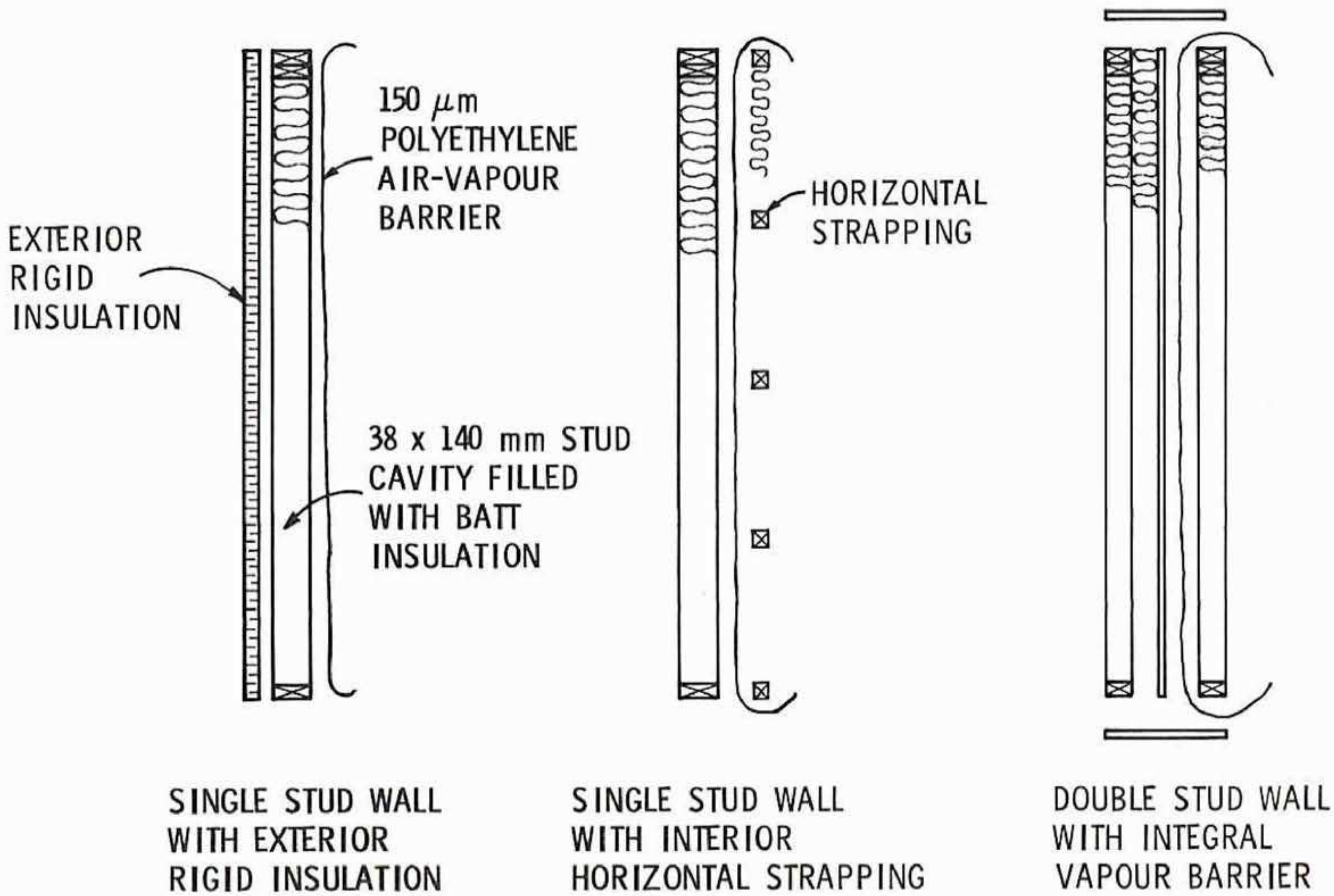

FIGURE 1

WALL DESIGNS USED ON LOW ENERGY HOUSES

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