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A MAJOR ENERGY CONSERVATION RETROFIT OF A BUNGALOW

H.W. Orr and R.S. Dumont

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H.W. Orr

R.S. Dumont

Institute for Research in Construction

National Research Council of Canada

Saskatoon, Saskatchewan

S7N 0W9

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ABSTRACT

Construction details are presented for a major energy conservation retrofit of a bungalow. The procedure involved the addition of a well sealed air-vapour barrier to the exterior walls and roof of the house and addition of about 300 mm of glass fibre batt insulation. Insulation was also added to the interior of the basement walls and an additional layer of glass was added to each window.

The air leakage of the house as measured by pressure tests was reduced from 2.95 air changes per hour at 50 pascals to 0.29 at 50 pascals, a reduction of 90.1%.

Before and after measurements were taken of the space heating requirements of the house. The design heat loss of the house was reduced from 13.1 kW at -34°C to 5.45 kW by the retrofit.

As the retrofit procedure involved major alterations to the entire envelope of the structure, costs for the total retrofit were high. The total cost for the project, which included upgrading the shingles and the stucco on the house, was $23,700 in 1984 dollars. The energy conservation related costs were $17,200.

Of this, roughly 50% was for labour and 50% for materials. A prospective user of this method should consider the cost/benefit relationship and may wish to input his or her own labour, in some cases, to reduce out-of-pocket costs.

INTRODUCTION

This note presents a case study of a major energy conservation retrofit on a detached residence in Saskatoon, Saskatchewan, Canada.

Since 1973, a large number of publications have been produced which present methods for reducing the space heating requirement of residences. Most of the publications deal with such measures as basement wall insulation, caulking and weatherstripping and additional attic insulation. Several publications--The Super-Insulated Retrofit Book (1) by Marshall and Argue, and A Double-Wall Retrofit Project (2) by Warkentin present measures to further reduce the space heating energy consumption of houses by adding an air-vapour barrier to the exterior walls and then adding sufficient insulation to the outside of this barrier to prevent condensation from occurring.

The case study presented here is an extension of the work by the above mentioned authors in that the energy conservation measures are carried further. In addition, before and after air tightness and energy conservation measurements are presented for the house under study. The energy conservation measures for the house included the following:

1. Installation of a completely new air-vapour barrier over the walls, roof and basement walls.
2. Addition of 300 mm (12 in.) of glass fiber insulation batts to the walls, roof, and basement walls.

3. Addition of a third layer of glazing to all windows in the house.
4. Replacement of the gas furnace and water heater. Electric heaters were used for space heating during the post-retrofit energy consumption measurements.
5. Addition of a controlled ventilation system using an air-to-air heat exchanger.

DESCRIPTION

The house chosen for the retrofit was a bungalow built in 1968, located on an urban street running north-south in Saskatoon. The front of the house faces west. Photographs of the exterior of the house in the pre-retrofit condition are presented in figures 1 and 2. The house was of wood frame construction using 38 x 89 mm (2 x 4 in.) stud walls with stucco exterior with a poured-in-place, 200 mm thick concrete basement walls with a 90 mm thick cast concrete floor. Plan and section views of the house are presented in figures 3 and 4. In the pre-retrofit condition, the house had a calculated design heat loss of 13.1 kW (44,700 Btu/h) at -34°C (-30°F). An air leakage test was performed on the house prior to retrofit with the chimney and vents blocked. The house had an equivalent leakage area of 0.0483 m^2, and an induced air change rate of 2.95 air changes/h at 50 pascals negative pressure. This level of air leakage was slightly less than the average of 3.6 AC/h at 50 Pa for a group of 97 houses built over the period 1960-1980 in Saskatoon as reported by Dumont et al (3).

Energy consumption readings for the pre-retrofit house were gathered in the period January-April of 1982. During this period the house was unoccupied, the gas water heater disconnected, and the house maintained at a temperature of 21°C.

SEQUENCE OF THE RETROFIT

In August of 1982, the retrofit of the house began. The sequence was as follows:

1. Roof
2. Exterior Walls
3. Basement Walls
4. Windows

At a later stage in the project, the basement floor was to be insulated and a high efficiency natural gas heating system installed.

Each of these stages is discussed in turn.

1. Roof Retrofit

Although the roof was the first section to be retrofitted, the stucco and siding were removed first. The stucco was removed by having one person pry the stucco with a flat garden spade, and a second person pull the material away from the wall.

In order to allow a continuous air-vapour barrier at the junction between the wall and roof, and to avoid having to wrap the existing eaves and overhangs, it was decided to remove the eaves and overhangs. To accomplish this, the plywood soffits were removed, and the shingles were removed from the eaves and overhangs. A power saw was then used to cut through the roof sheathing and part way through the roof truss eave projection and roof ladder in line with the outside of the existing wall of the house. The sheathing from the eaves and overhang was removed along with the eave boards and barge board. Finally, the saw cut in the trusses was completed with a hand saw. This is shown in figure 5. Following this, the main part of the roof was worked on. The roof was divided into two sections along the peak, and each section worked on separately. This division was deemed necessary so as to minimize rain penetration into the house during times when the roof was without shingles and to provide a working area for installing the polyethylene on each half of the roof.

For each half of the roof, the sequence chosen was as follows:

a. The existing asphalt shingles were removed.

b. Strips of 9.5 mm plywood were nailed over the cut ends of the roof trusses.

c. 38 x 89 mm blocks were fitted between the ladder rungs on the ends.

d. The existing roof sheathing was covered with a single sheet of ultra-violet stabilized 0.15 mm thick polyethylene vapour barrier.

e. Strips of 9.5 mm thick plywood with a width of 150 mm were nailed at 1830 mm centers over top of the polyethylene to allow workers to stand on the roof without slipping. These strips were placed directly over every third roof truss.

f. Blocks were cut from 38 x 184 mm pieces and nailed in position on top of the plywood strips at the peak of the roof, at the edge, and half way in between as shown in figure 6.

g. Purlins of 38 x 184 mm were placed on edge running parallel to the long axis of the house as shown in figure 6. These provided a cavity for insulation and support for the 38 x 89 mm rafters. The 38 x 184 mm purlins were nailed against the brackets. The lowest purlin was fastened to the wooden block with galvanized iron metal straps as well as by nails. Finally, 9.5 mm plywood scraps were nailed between the 38 x 184 mm purlins and the sheathing at each truss. (This was necessary because of the 9.5 mm plywood strips placed over the polyethylene at an earlier stage).

h. The ladders of 38 x 89 mm material for the overhangs at each end of the roof were then placed.

i. The 38 x 89 mm rafters were then placed at 400 mm (16 in.) on center on top of the purlins as shown in figure 7. The spacing of the rafters was dictated by the span between the purlins. A 38 x 140 mm eave board was then nailed to the end of the new rafters.

j. The glass fiber insulation batts were then placed. A 216 mm (RSI 4.8) thick batt was first threaded under the rafters to fill the space provided by the purlins. These batts were placed perpendicular to the rafters, and a 90 mm thick batt was placed in the cavity provided by the rafters. The former batts were placed at right angles to the latter so as to minimize continuous air gaps through the insulation. The batts were cut and fitted to minimize air gaps.

k. Plywood roof sheathing (9.5 mm thick) was then nailed onto the rafters.

The first half of the roof was then covered temporarily with polyethylene for rain protection until the second half was completed.

Steps (a) through (k) were repeated for the second half of the roof with two additions: one, the polyethylene on the second half was joined to the polyethylene from the first half with acoustical sealant and a plywood strip, and two, the rafters on the second half of the roof were connected to the first half with galvanized metal straps over the ridge of the roof.

The roof was then shingled.

2. Wall Retrofit

Upon completion of the two halves of the roof, the walls were then addressed. The sequence was as follows:

a. A continuous air-vapour barrier consisting of 0.15 mm polyethylene was attached to the walls. Vertical strips of plywood 100 mm wide were nailed at 1240 mm intervals on to the studs to prevent wind forces from billowing the sheets. This wall polyethylene was sealed at the top plate with acoustical sealant and the joint was secured with a strip of lumber nailed over the joint. The polyethylene was also carefully sealed to the edges of all exterior door and window trim piecs and was sealed to the concrete foundation approximately 150 mm below the joist header.

b. At the lower part of the exterior wall, a pressure treated, insulated skirt was attached. A trench about 350 mm deep and wide was dug so as to allow an insulated skirt to be carried approximately 300 mm below grade. Two pieces of 38 x 89 mm wood were nailed together to form an "L". This "L" was attached to the concrete foundation walls in an inverted position using concrete nails inserted with a gun. Thirteen mm thick pressure treated plywood was cut into strips 600 mm wide and a 38 x 89 mm pressure treated piece was nailed to the lower edge of the plywood. Glass fiber insulation batts were fitted to each 2400 mm long panel and fastened to the foundation as shown in figure 8.

c. 300 mm wide strips of 13 mm plywood were nailed to 38 x 89 mm pieces. The 38 x 89 mm piece was aligned and the plywood was nailed to the top of the "L" mentioned above and shown in figure 8, step 5. These horizontal pieces were blocked temporarily until the wall strapping was nailed to it.

d. The wall strapping was then attached. As shown in figure 10, the 38 x 89's were stood on the 38 x 89 mm plate and were nailed into the sides of the rafters with 90 mm nails. A chalk line was snapped to the underside of the rafters to mark the correct position. The strapping was then plumbed and toe-nailed into the 38 x 89 mm plate. Strapping was installed along the walls until the window and door openings were reached. To provide additional support for the new outer wall, a 1.0 mm thick, 22 mm wide perforated metal strap (commonly used in plumbing applications to support piping) was then attached at 1200 mm on center as shown in figure 10. The strap was screwed first into the 38 x 89 mm bottom plate and then into the wall stud on the inner wall. The strap was then tightened by adding one or more screws down from the top of the strap. Openings around the windows and doors were framed in with 38 x 89 mm material with clearance for 13 mm plywood and an allowance for a slope at the sill. Pressure treated plywood was used on the sills, and untreated plywood on the other three surfaces. The windows and doors were left in their original position on the inner wall. A view of a typical window treatment is shown in figure 9. Plywood of 13 mm thickness was used to tie between the exterior window and door trim and the outer wall strapping. The plywood was used to sandwich the vapour barrier between the exterior trim and the plywood. The plywood was later covered with pre-finished galvanized metal on the sill and stucco on the remaining exposed surfaces.

e. Upon completion of the wall framing, insulation batts were placed in the newly formed wall cavity; RSI 4.9 batts were laid horizontally in the wall cavity and RSI 2.1 batts were placed vertically between the wall uprights.

f. The wall was then sheathed with 9.5 mm plywood so as to allow the stucco to be installed.

g. Pre-finished aluminum eavestrough, soffit and fascia were installed.

3. Basement Wall Retrofit

The basement wall retrofit on the inside of the house was fairly conventional. A section view of the finished wall is shown in figure 11. As it was intended to insulate the concrete floor with polystyrene insulation, the stud wall was raised 80 mm off the existing basement floor. A total of 300 mm (RSI 7.0) of glass fiber batt insulation was placed in the basement walls. A 0.15 mm polyethylene moisture barrier was applied on the concrete wall up to the ground level.

The bottom plate was anchored to the floor by drilling 10 mm holes into the floor 1200 mm on center. Spikes 200 mm long were nailed through holes in the bottom plate into the holes pre-drilled in the floor.

A caulked and sealed 0.15 mm polyethylene vapour barrier was installed on the warm side of the insulation. On top of the stud wall, the joist spaces were blocked with 50 mm thick pieces of polystyrene. The edges of the polystyrene were caulked using acoustical sealant.

4. Window Retrofit

A commercial contractor was hired to place a third glazing layer on the windows of the house. The third glazing was placed on the outside of the sealed windows and on the inside of the openable windows, which were of the awning type.

Photographs of the house in the post retrofit stage are presented in figures 12 and 13.

AIR LEAKAGE MEASUREMENTS ON THE HOUSE

A number of air tightness measurements were made on the house at various stages of the retrofit. The house had an initial reading of 2.95 AC/h at 50 Pa. Following completion of the retrofit, the house pressure test had been reduced to 0.29 AC/h at 50 Pa. Results of the pressure tests are presented in table 1. A further test was done with masking tape temporarily placed on the windows, and the leakage was further reduced to 0.22 AC/h at 50 Pa.

The original stucco finish provided a considerable amount of air tightness to the walls of the house, as the equivalent air leakage increased by 0.0279 m^2 or 58% as compared to the pre-retrofit condition when the stucco was removed. Following the completion of the retrofit, a pressurization fan was placed in the ceiling hatch, and the attic space was pressurized with a calibrated flow nozzle. The ceiling leakage area accounted for about .0252 m^2, or 52% of the original total leakage area. By subtraction, the leakage in the walls, windows, and doors accounted for 0.0231 m^2 or 48%.

In February of 1983, an air exchange test using nitrous oxide was performed with the house in a sealed condition. An initial charge of about 100 parts per million N_2O was injected into the house, and measurements of the N_2O levels were made over the next 24 hours. During this period, the measured air change rate was 0.02 air changes per hour at a time when the outside temperature was -12°C and the average wind speed was 12 km/h.

This amount of air change would be insufficient for ventilation needs. Consequently, the house has been fitted with a controlled air management system using an air to air heat exchanger. The air to air heat exchanger had a maximum installed flow rate of 75 L/s (160 cfm), which is equivalent to 0.5 air changes per hour.

ENERGY CONSUMPTION MEASUREMENTS ON THE HOUSE

In the pre-retrofit condition, energy consumption records of the space heating were taken over the period from January to April, 1982. A plot of the total energy consumption of the house as a function of the degree day/day values is presented in figure 14 for this period. A least squares curve fit yielded a slope of 233 W/°C and a Y-intercept of 2370 W. The heating system was a 32.2 kW inout (110,000 Btu/h) natural gas atmospheric vent forced air furnace. A steady-state furnace efficiency of 78% was calculated using measurements of the furnace gas CO_2 and the stack temperature.

Following the retrofit, the natural gas furnace was disconnected and electric heaters used. The existing furnace fan and ductwork were kept, and continuous fan circulation used to distribute heat from the space heaters. A 2000 W space heater was placed downstairs and two-1500 W heaters upstairs. A plot of the energy consumption of the house in the post retrofit condition is shown in figure 14. The slope of the energy consumption curve is 83.2/W°C, and the Y-intercept is 869 W. At a design temperature of -34°C, the steady-state power consumption of the house was reduced to 5.45 kW, as compared with the value of 13.1 kW for the pre-retrofit condition (assuming an efficiency of 70% for the natural gas furnace).

COMPARISON WITH PREDICTIONS OF A COMPUTER MODEL

In order to check whether the results achieved were in line with predictions, the house energy consumption was analyzed using the computer program HOTCAN(4). The model uses a month by month prediction technique to estimate the annual space heating requirements. Physical characteristics of the house such as the areas and thermal resistances of each of the components are used. Solar gains and internal heat gains are included in the model.

In the post retrofit case, there arose the interesting case of the effective surface area of the ceiling for heat loss having been increased due to the placement of additional insulation on the roof, rather than in the attic. It can be shown that the new ceiling thermal resistance referenced to the original ceiling area may be expressed as:

$$Rn = R1 + \frac{A1}{A2} R2$$

where

Rn = new value of thermal resistance referenced to the ceiling area (m^2-K/W)

$R1$ = original resistance of ceiling (m^2-K/W)

$A1$ = ceiling area (m^2)

$A2$ = area of insulated roof and gable ends (m^2)

$R2$ = resistance of roof and gable ends (m^2-K/W)

The new insulation added is slightly less effective in that it covers a larger area. The factor A1/A2 was equal to 0.85 for this particular house. Although this is not a serious penalty, it could be quite significant in a situation with a more steeply pitched roof.

Figure 15 presents the HOTCAN predictions for the pre- and post-retrofit states of the house. For the pre-retrofit comparison, a constant furnace efficiency of 70% was chosen. This efficiency of 70% is somewhat higher than the values of 55 to 65% that are often quoted as a total system efficiency for atmospheric vented natural gas furnaces. In the HOTCAN program, the house air exhausted through the chimney is treated as an explicit heat loss for the house. Consequently, a furnace efficiency of 70% was felt to be reasonable in this HOTCAN calculation. In the post retrofit case, electric heating only was used; hence no assumption of furnace efficiency was required.

COST OF ENERGY MEASURES

This particular project entailed some additional costs in that a number of research-related items were included that would not ordinarily be done. These additional costs were related to additional air tightness tests performed as the work proceeded.

In the project, there were costs related to renovation as well as those to energy conservation. The former included new roof shingles, stucco, fascia, eavestrough, soffit, and renovations to the entry.

Although the original stucco was in good condition, on an older house this is often not the case.

In the cost breakdown presented in Table 2, the renovation costs are expressed in a separate column.

The total cost for the job amounted to $23,700; the cost for the energy measures alone was $17,200.

The cost for the major components of the retrofit are shown in Table 3.

DISCUSSION

The technique of wrapping the exterior of the entire building with a polyethylene air-vapour barrier proved to be a very effective method of reducing air leakage in the building. As mentioned earlier, this particular house, after retrofitting, proved to the the tightest house in Saskatchewan measured to date by the National Research Council. Although expensive, this technique of wrapping the exterior of the roof insulation would be an effective method of reducing air leakage and condensation in shed and cathedral roof construction where it is not possible to gain access from an attic space to perform the air tightness measures.

A less expensive technique could have been used to seal and insulate the ceiling; namely, sealing and insulating from the attic space. This would have been considerably less expensive, although it is likely that it would not have been as effective in sealing the space. In addition, equivalent insulation could have been added to the attic at a lower cost than the exterior technique that was used. Such a job of sealing and insulating could have been done for a cost of about $1,200, as opposed to the cost of $3,900 that this job entailed. However, insulating from the inside would not have resulted in as tight a house.

The basement wall retrofit proved to be expensive, with a very high ratio of labour to material costs. This particular house already had finished interior basement walls, and the technique used in this project involved a considerable amount of moving of pipes and ductwork.

This report should not be taken to mean that the Institute for Research in Construction recommends these measures as a procedure to be applied in all cases. Without question, there are many instances in which economics, based on a cost-benefit analysis, would not support the application of measures described here. Where retrofitting is contemplated, careful consideration should be given to the prevailing circumstances. A variety of factors affect the feasibilityof applying the techniques described here. Among these are:

1. The condition of the siding and shingles. If these are to be removed--because they have failed, for aesthetic or other reasons--that cost might be reasonably excluded from the cost assigned to the energy retrofit.
2. If the heating system is to be replaced, or if the house is to be increased in size so that the existing system is no longer adequate, allowance should be made for the fact that the retrofit may have a favorable effect on those costs associated with the heating system.
3. The costs of fuel or electricity for heating are, naturally, a very important consideration.
4. For some people, the security of living in a house that requires little space heat may be important, particularly if the utility supply is unreliable.
5. For those people who wish to provide their own labour for part or all of the retrofit, the total dollar cost would be reduced.

ACKNOWLEDGMENTS

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Table 1. Pressure Test Readings

	Air changes per hour at 50 pa	Equivalent leakage area (m^2)
Pre-retrofit	2.95	.0483
After stucco removal	4.55	.0762
Post-retrofit	0.29	.0064

Table 2. Cost of Retrofit and Renovation Measures
1984 dollars

	Energy Conservation		Renovation	
	Labour	Materials	Mat. + Labour	TOTAL
Roof	1731	2213	1814	5758
Exterior Walls	3187	3641	3469	10297
Front Entry			1240	1240
Basement Walls	3438	1012		4450
Windows	55	802		857
Air-to-air Heat Exchanger	363	754		1117
	8774	8422	6523	23719

Table 3. Cost Summary

	Cost	Area m^2	Cost per Unit area $\$/m^2$
Roof	$ 5,758	107.4	$53.61
Exterior Walls	$10,297	94.4	$109.00
Basement Walls	$ 4,450	120.9	$36.81
Windows	$ 857	14.8	$65.33

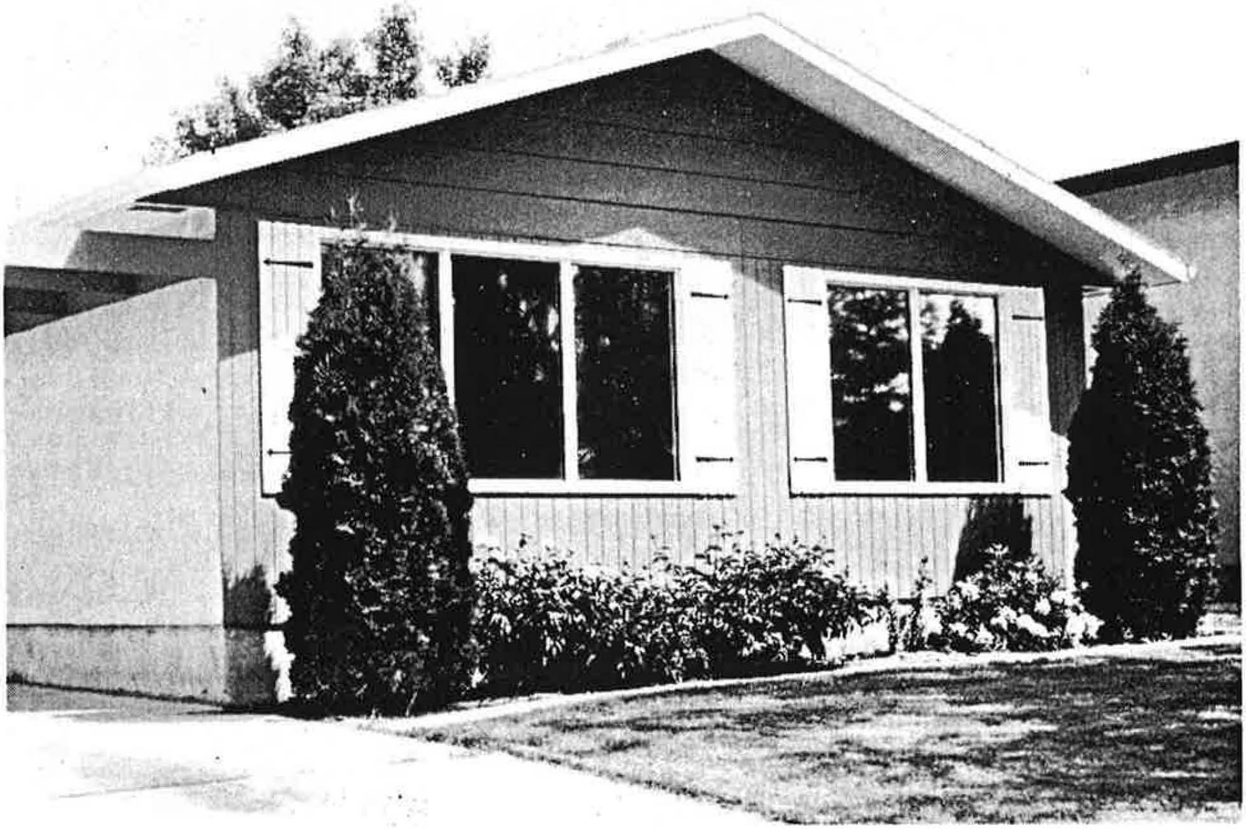

Figure 1, View of house from northwest--pre-retrofit

Figure 2. View of house from northeast--pre-retrofit

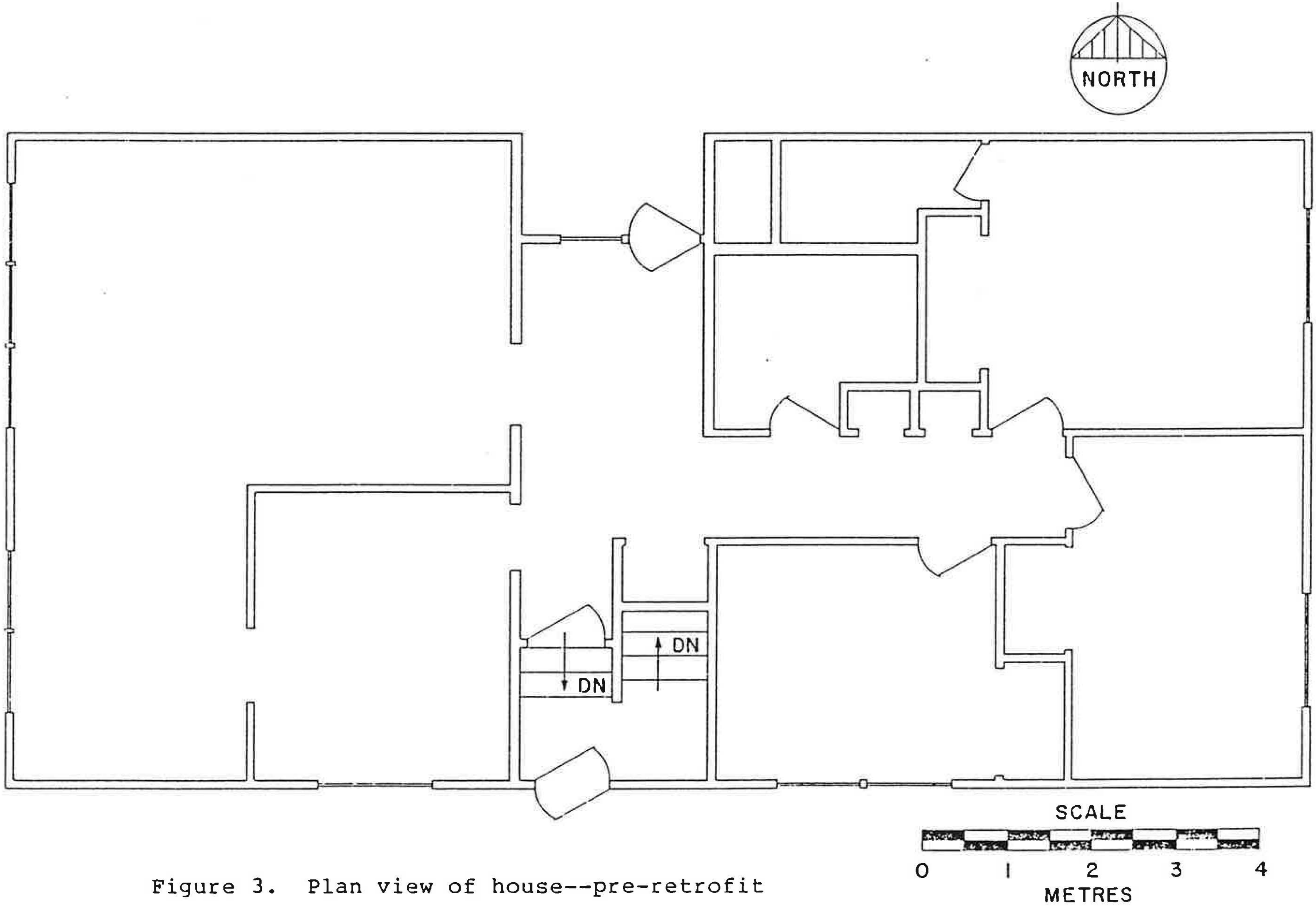

Figure 3. Plan view of house--pre-retrofit

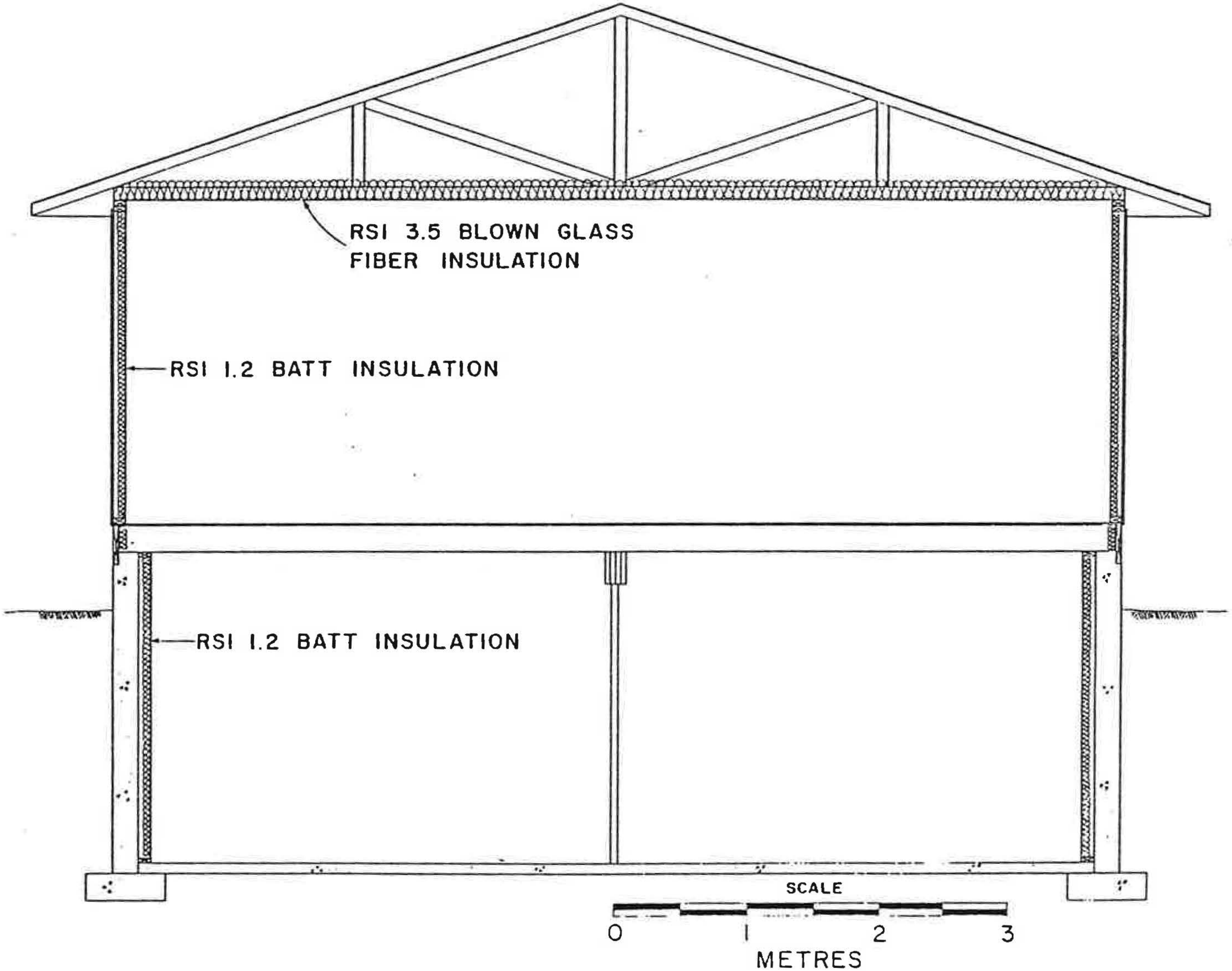

Figure 4. Section view of house--pre-retrofit

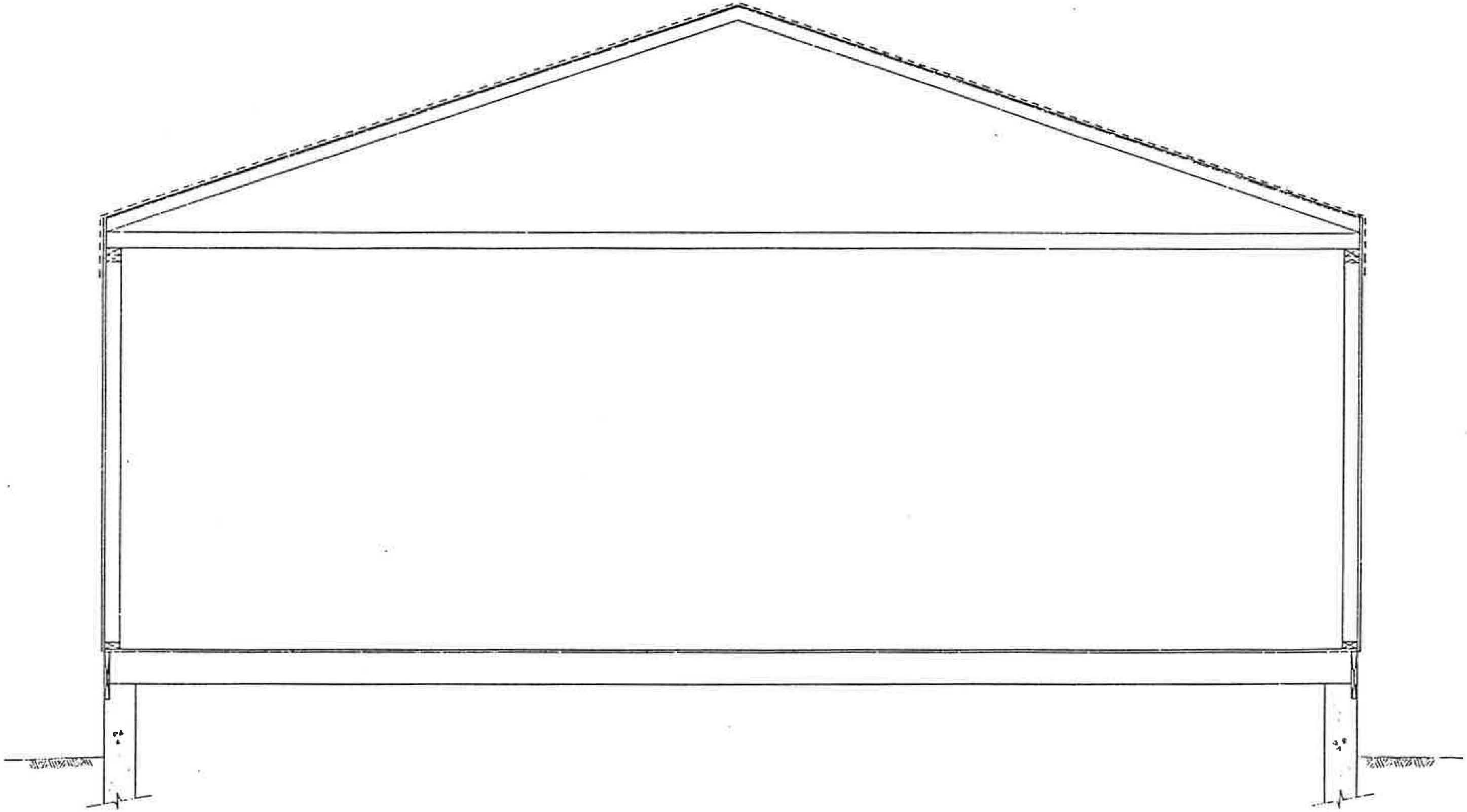

Figure 5. Section view of house after removal of eaves

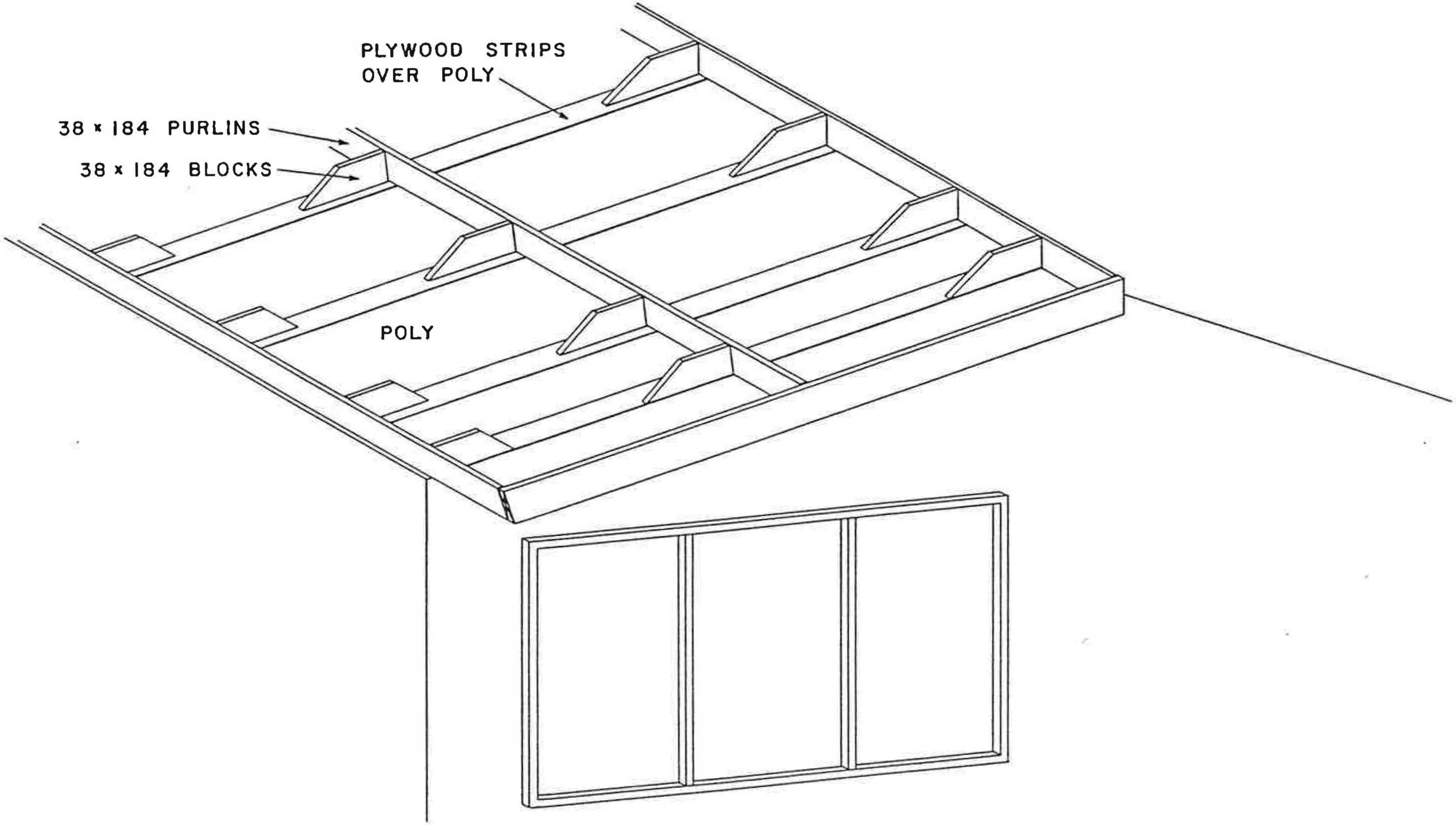

Figure 6. Placement of purlins on the roof

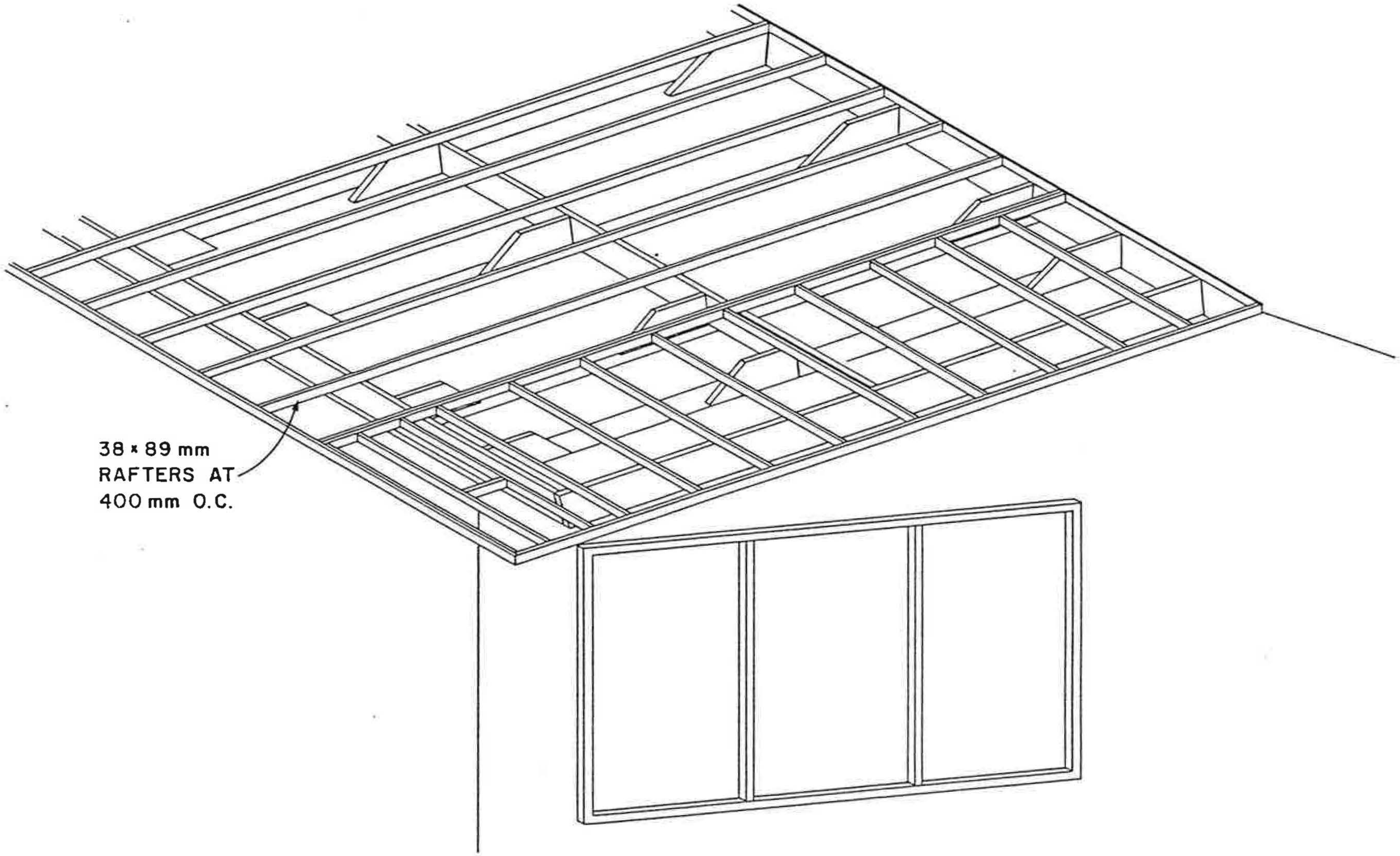

Figure 7. Placement of rafters on top of the purlins

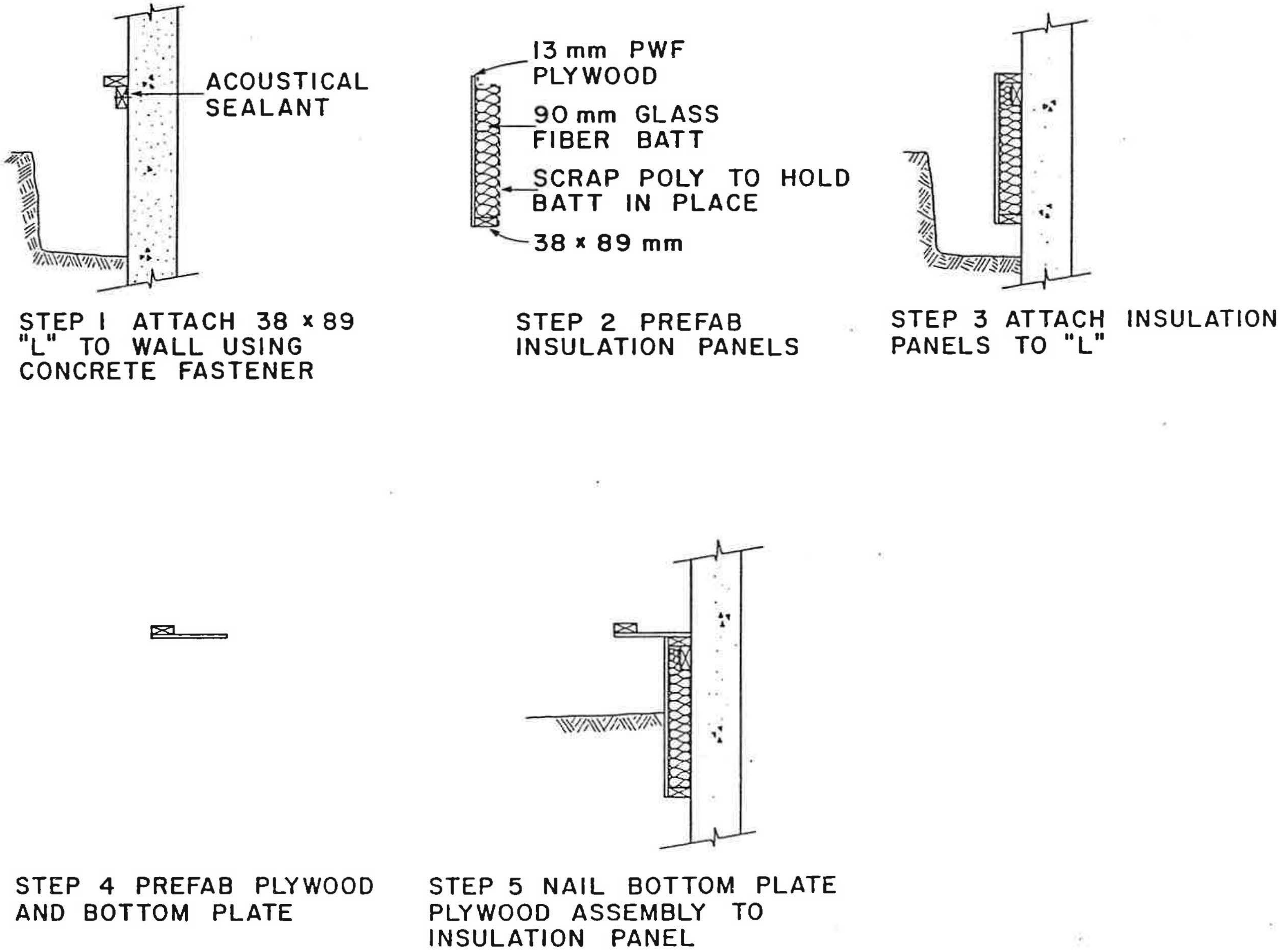

Figure 8. Pressure treated skirt assembly at ground level

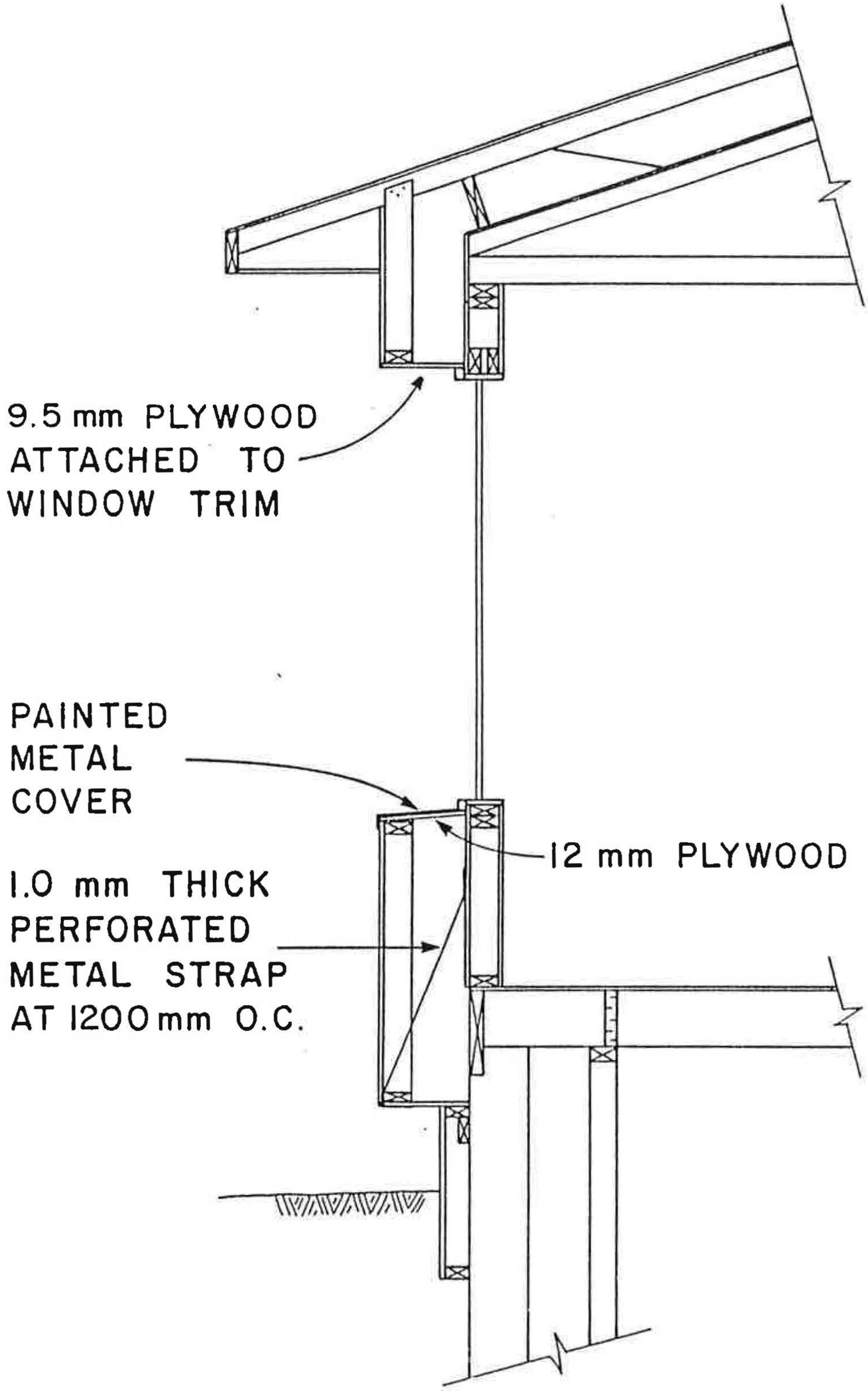

Figure 9. Window treatment for exterior wall

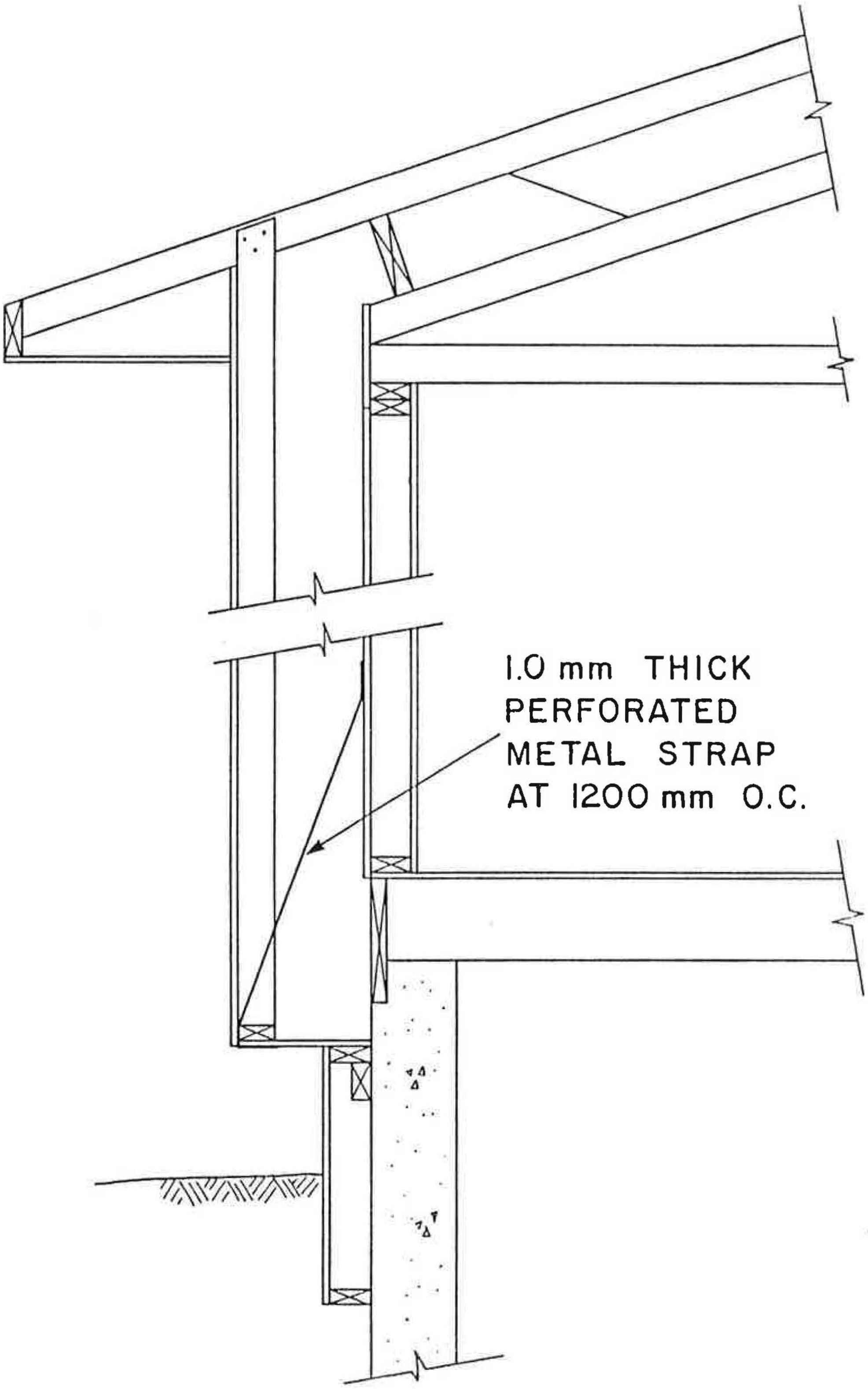

Figure 10. Attachment of second wall members to the house

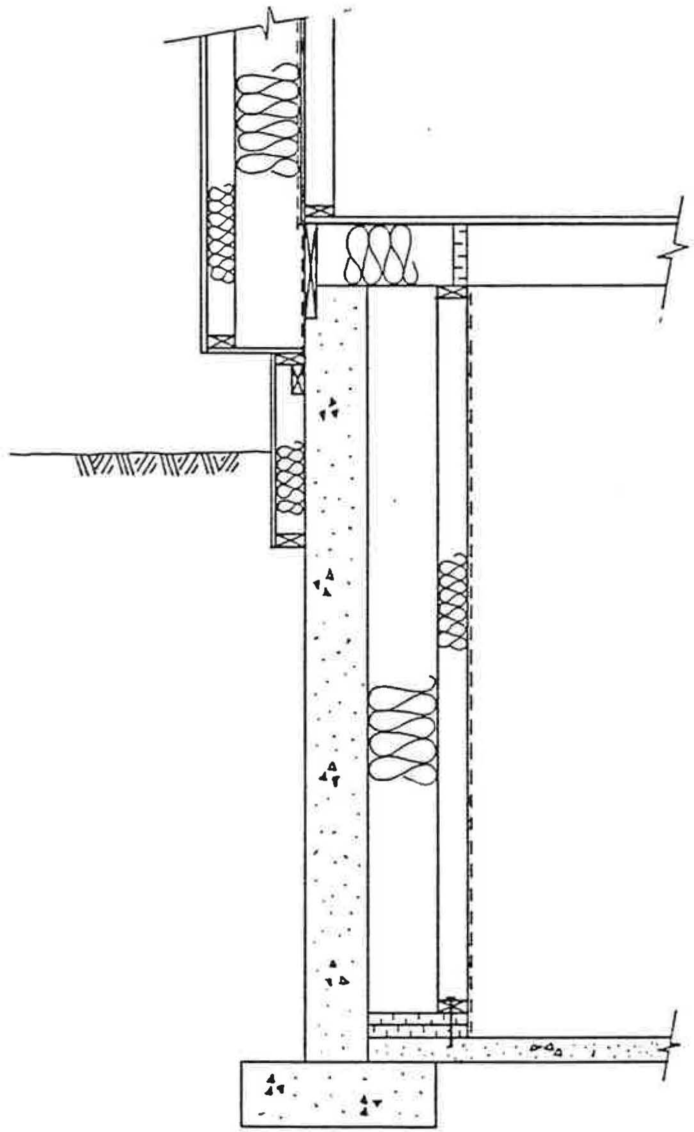

Figure 11. Basement wall interior retrofit section

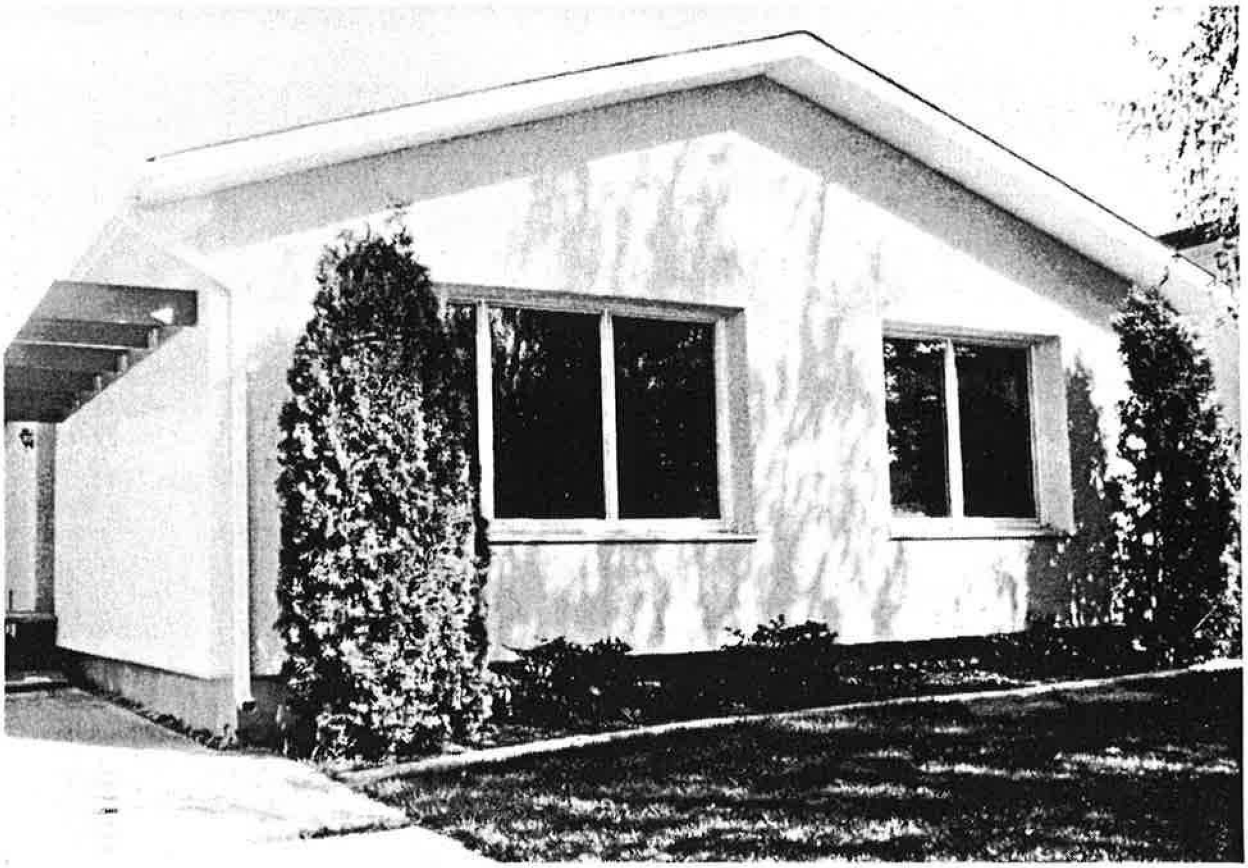

Figure 12. View of house from northwest--post-retrofit

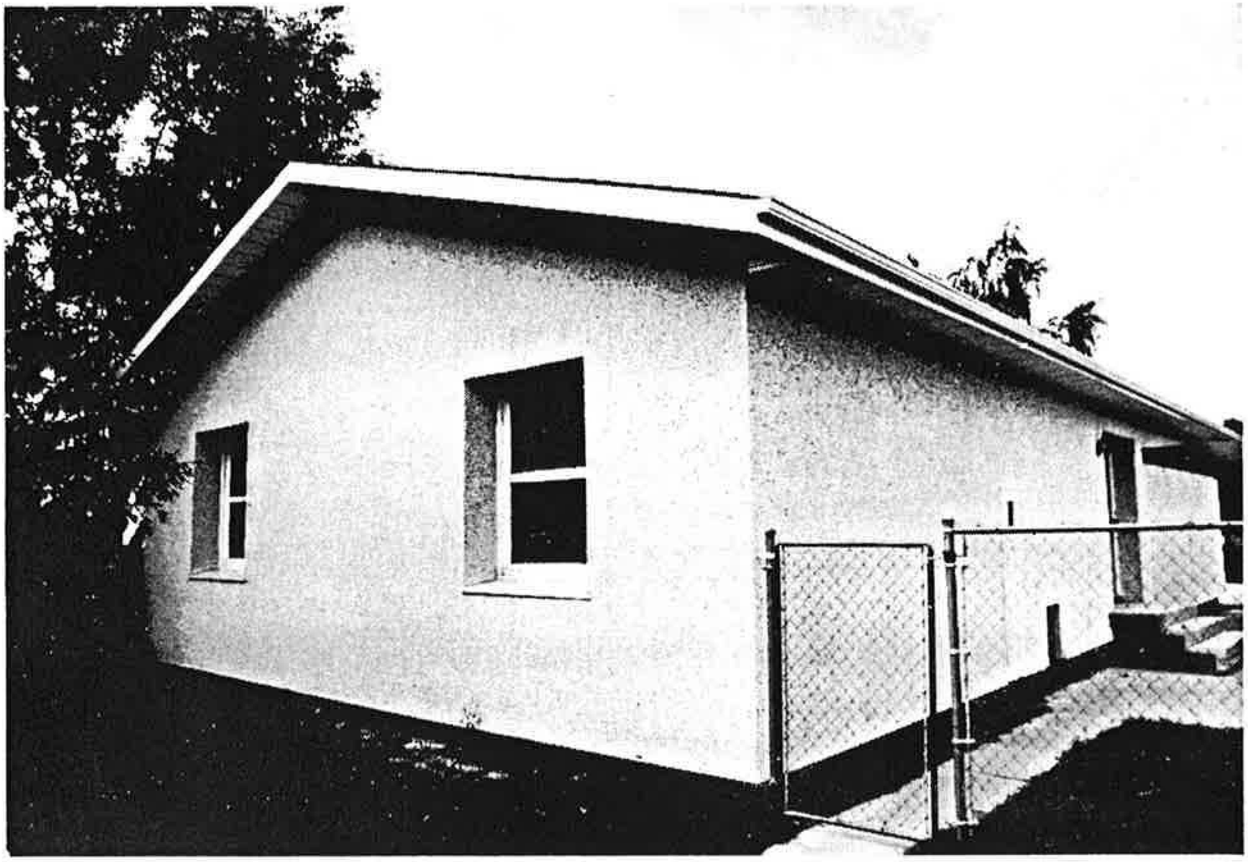

Figure 13. View of house from northeast--post-retrofit

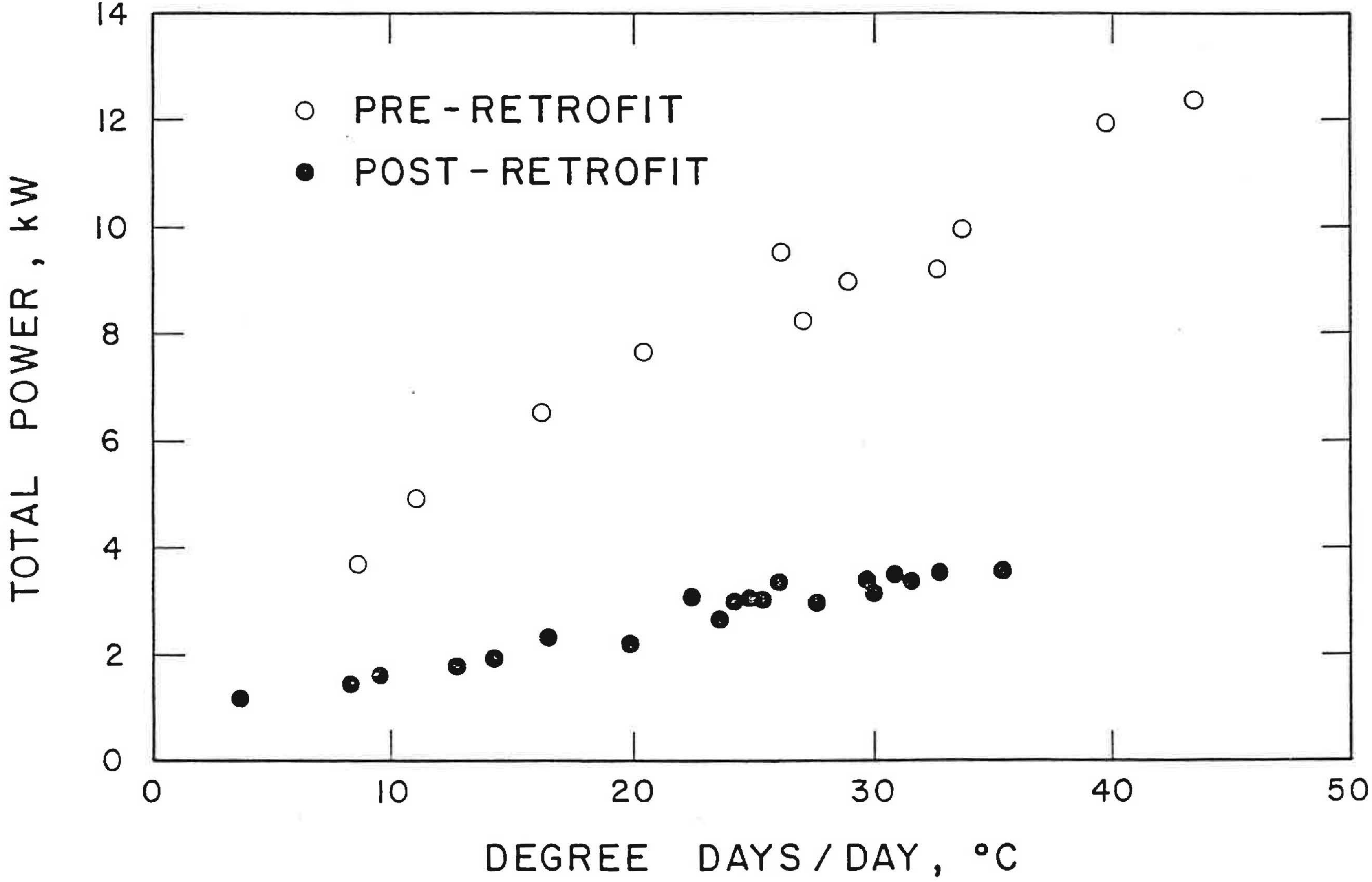

Figure 14. Energy consumption rate as a function of degree-days per day for pre- and post-retrofit states

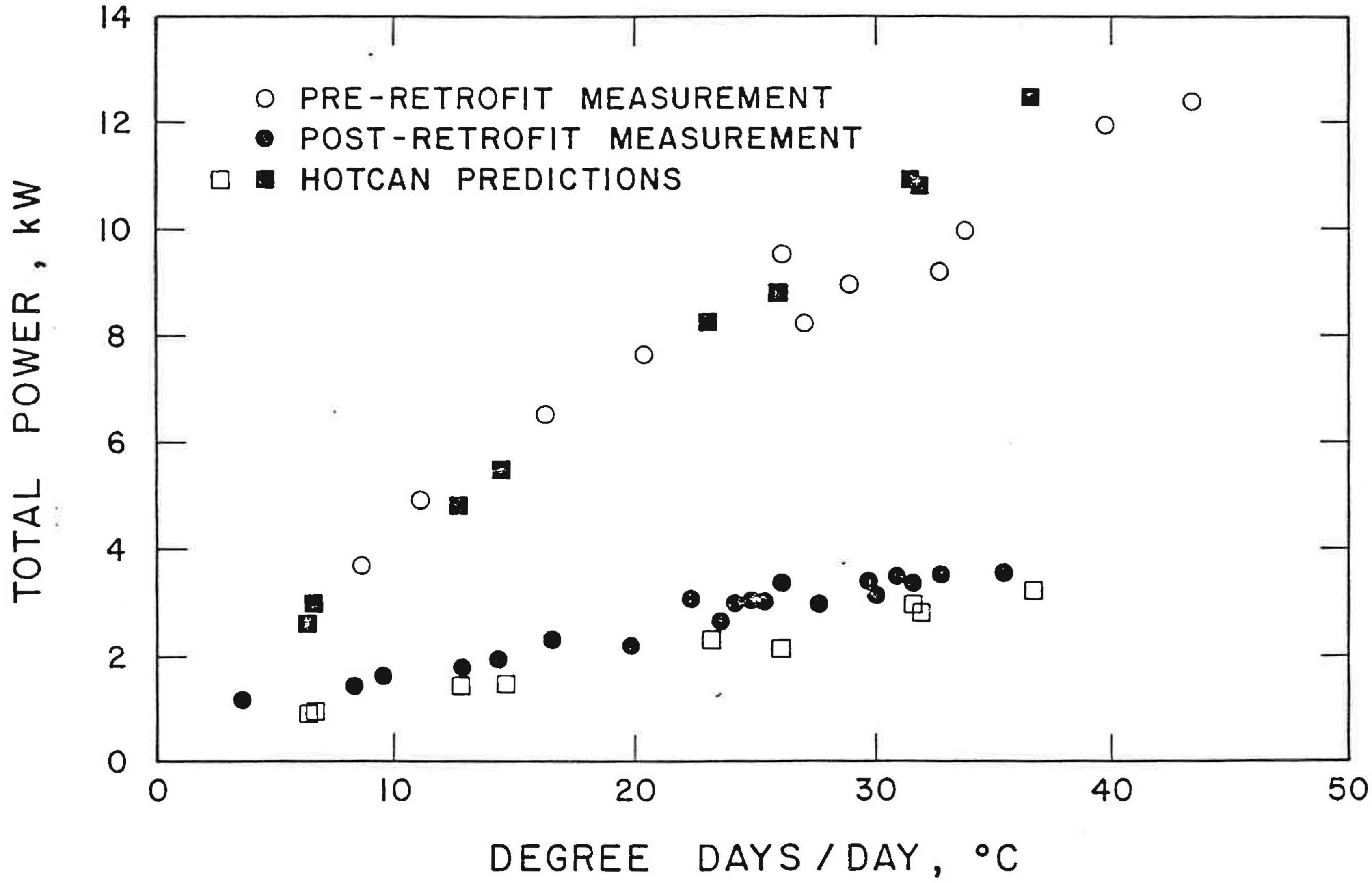

Figure 15. Comparison of actual and predicted energy consumption rate values for house in pre- and post-retrofit states