A NEW APPROACH TO AFFORDABLE LOW ENERGY HOUSE CONSTRUCTION

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The views and conclusions expressed and the recommendations made in this report are entirely these of the authors and should not be construed as expressing the opinions of the Alberta Department of Housing.

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FOREWORD

This study was made possible with funding provided by the Innovative Housing Grants Program of the Alberta Department of Housing. Originally conceived in 1978, the Program is intended to encourage, sponsor, and assist research and development in the fields of housing, site and subdivision design, energy conservation, site servicing and building product development. Generally, the aims of research funded by the Innovative Housing Grants Program are to reduce housing costs, increase the supply of appropriate housing or improve the utility or performance of dwelling units or subdivisions.

The main purpose of funding these studies is to examine the current issues in the field of housing and to develop innovations which offer improvements. Comments and suggestions regarding the information contained in these reports are welcome.

Innovative ideas come from a wide variety of applicants such as builders, developers, consulting firms, industry associations, municipal governments, educational institutions, non-profit groups and individuals. As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied.

Please send comments and suggestions or requests for further information to:

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I. INTRODUCTION

The purpose of this report is to document the research work leading to the construction of a number of demonstration houses using new techniques in Ontario. The report summarizes the results of these projects and recommends an approach to a demonstration project using improved construction methods in Alberta.

These demonstration houses were constructed using alternative building systems such as a painted gypsum board* air barrier/vapour retarder concept and alternative mechanical systems which included heating, air supply (ventilation and make-up air), and heat recovery. The report addresses this work in terms of performance, code requirements and estimated costs.

The report includes a summary of both the approach to and the results of the supervision, control and monitoring program which were conducted during construction of the nine demonstration houses in Brampton. The report shows the incremental construction costs by trade grouping. The report also includes the post completion performance measurements taken on the houses (air-leakage tests) and description of the monitoring program which has been designed to demonstrate the effectiveness of the new techniques.

Based on the experience gained in the Ontario demonstration project and subsequent work, the report develops methods which are suitable for Alberta and which are improvements on the demonstration project in Ontario. Included are the required research and demonstration of alternative mechanical systems, alternative methods of construction and construction details, a suggested monitoring program and evaluation procedures for the project.

*Note: Gypsum board, the generic technical name, and drywall, the more common trade name are used interchangeably throughout the report.

II. BACKGROUND

A few Canadian builders, building science researchers, entrepreneurs and passive solar energy purists have been successfully building low energy homes since 1977. These homes have been successful from the energy performance standpoint because of their emphasis on conservation of energy, or reduction of heating demand, rather than on an emphasis of energy collection, solar or any other form. One of the key areas of conservation in these homes has been the near complete elimination of energy loss due to air infiltration/exfiltration. In the typical Canadian home built since the Second World War, energy losses due to infiltration/exfiltration have been generally 40 to 50 percent of the total annual space heating requirements, so a substantial reduction or elimination of this component of energy loss has dramatic effects. In addition, the reduction or elimination of through-the-envelope air movement is a significant positive factor in reducing, and in some cases eliminating, interstitial (within the wall cavity) moisture problems in walls and condensation problems in roofs and attics. This is due to the fact that most of the moisture build-up within wall cavities and ceilings is a result of the movement of moisture-laden air into the cavities as opposed to the diffusion of water vapour through the building envelope components.

The majority of successful low energy homes built to date have accomplished significant degrees of building envelope airtightness through the utilization of a sealed, integral, polyethylene air barrier/vapour retarder. The approach is best described in the publication "Energy Efficient Housing - A Prairie Approach" published by the governments of Alberta and Saskatchewan (Dumont, Eyre; 1980).

However, problems exist with the utilization of an integral, sealed, polyethylene air barrier/vapour retarder in low energy home construction. Problems exist with high labour and supervision costs, chemical degredation, fragility, incompatibility with production techniques of tract housing and the inability of the polyethylene to resist wind and stack air pressures when unsupported. These problems have resulted in tract house builders resisting low energy house construction practices (discussed in detail in Appendix A - Problems with Polyethylene).

The problems with polyethylene low energy house construction techniques have resulted in not more than small numbers of low energy homes being built across Canada. No major production builder in Canada is currently building or contemplating building any significant numbers of low energy homes on a production basis. Only one-of-a-kind custom homes, built and sold at premium prices, are currently being constructed using the sealed, integral polyethylene film approach to achieve the levels of airtightness required for low energy homes.

In order to facilitate mass construction of low energy homes by production builders, it is necessary that techniques of achieving airtightness be more compatible with the realities of current production housing construction techniques, trades, materials and management. The development of such an approach is described below.

A. Non-Polyethylene Air Barrier/Vapour Retarder

The concept of using materials other than a polyethylene film as air barriers, vapour retarders and air barriers/vapour retarders has been postulated, supported and encouraged by a number of building science researchers, most notably by G.O. Handegord and R.L. Quirouette of the Division of Building Research, National Research Council of Canada, and J. Timusk of the Center for Building Science, University of Toronto.

The concept was demonstrated in 1972 by the Housing and Urban Development Association of Canada. HUDAC built one of their continuing series of experimental homes in Vancouver. This HUDAC Home, designated as their Mark VII Project, utilized 10 mm (3/8") fir plywood as both an air barrier and a vapour retarder. All the joints in the plywood were either caulked or otherwise sealed, and the floor system was supported on an interior ledger to prevent penetration of the building envelope by the ends of the floor joists. Interior finishes, such as gypsum board and prefinished wood panelling were then applied over the plywood. The house has performed unremarkably in the sense that no unusual problems developed with respect to the performance of the system as an air barrier and vapour retarder. However no provision was made for an adequate ventilation system and this omission led to humidity levels in the house which approached the saturation point. The "Plywood" approach did not enter the mainstream of residential construction practice for a number of reasons, one of them being that it was uneconomical to build due to its double interior cladding.

In 1981, W.G. Plewes wrote the CMHC distributed publication, "Exterior Wall Construction in High Rise Buildings". The publication outlined numerous approaches to incorporating non-polyethylene air barriers and vapour retarders in multi-storey construction (Plewes; 1981).

G.O. Handegord, also in 1981, wrote an unpublished paper titled "An Approach to Tighter Wood-Frame Construction" (Handegord; 1981). In this paper, Handegord proposed that a high degree of air tightness could be achieved through the utilization of the standard interior house cladding found in the typical tract house as the barrier to air flow and vapour diffusion. The proposed approach utilized the air tightness properties of gypsum board sheets and plywood or waferboard strips incorporated in a modified balloon wood framing technique. Handegord proposed going beyond the Mark VII approach by removing the expense of the double interior cladding inherent in that approach. Plywood was still an integral part of this new approach, as in the Mark VII Project, but now would be only used to provide for the continuity of the air barrier and vapour retarder between floors, where interior partition walls intersected with exterior walls and over the tops of interior partition walls where they came in contact with insulated exterior ceilings.

Resistance to vapour diffusion was to be provided for by "interior painting or by a vapour barrier film applied to the interior cladding elements prior to construction". Examples of such a vapour barrier film could be foil backed gypsum board or paint.

Continuity of the vapour retarder in such an approach is not as important as continuity of the air barrier. Once the possibility of movement of moisture laden air into the wall cavities is eliminated, only the less significant vapour diffusion process remains as a moisture transport mechanism. That paint or foil backed gypsum board on the interior surfaces of exterior walls would be adequate as vapour diffusion in such a case is largely a function of surface area. For example, ignoring the question of vapour retarder permeability, if 90 percent of the building envelope area is covered with a vapour retarder, then that retarder is 90 percent effective. This effect is discussed in detail in Appendix B - Vapour Movement.

Half scale models of this approach were built by Handegord and put on display at the Division of Building Research, National Research Council, in Ottawa. One year later, in the spring of 1982, the author was made aware of the models and Handegord's approach. After discussions with Handegord, the author felt the approach had considerable merit and endeavoured to get a full scale house built. However, the author felt that Handegord's approach needed modification before it could be applied to a full scale test house and proceeded to modify it. The modified Handegord approach was subsequently first demonstrated by the author in nine demonstration homes in Brampton, Ontario during the fall and winter of 1982.

The Brampton project was significant because the concept verified that a non-polyethylene air barrier could meet stringent air leakage requirements and because the project indicated that the concept had potential commercial viability for tract house builders. As a result of the Brampton Project, the author proposed going beyond the modified Handegord approach which used plywood and/or waferboard strips in combination with the painted gypsum board, and rely only on the painted gypsum board or "drywall" and existing framing members to provide continuity of the air barrier and the necessary vapour retarder.

The "Airtight Drywall Approach" was subsequently demonstrated by the author and J.K. Lischkoff, of the Center for Building Science, University of Toronto, in three projects in Ontario in the summer and fall of 1983: the Shelburne House, the Lawrence Park House and the London House.

The Shelburne and Lawrence Park Houses continued to employ a modified balloon framing technique. The experience gained from these last two projects enabled the Airtight Drywall Approach to be further modified and improved by the author in order to utilize standard platform framing techniques common to tract house building sites. This improved Airtight Drywall Approach was demonstrated in the London House. This last modification proved to be significant in that it eliminated incremental costs associated with balloon framing and overcame carpenters' opposition to the Airtight Drywall Approach technique for low energy home construction.

The Shelburne, Lawrence Park and London Houses will be described in Section IV.

B. Air Quality/Ventilation Concerns

As a result of significantly tightening the building envelopes of the houses discussed in this report, adequate ventilation and air quality concerns had to be addressed to avoid long term health and building problems. When the interaction of combustion equipment such as gas furnaces, gas water heaters and fireplaces is also considered, the air quality/ventilation problem can arise in the short term and can be dangerous. The recent CMHC funded report by Hatch Associates Ltd., "Hazardous Heating and Ventilating Concerns in Housing" (Robinson; 1983), assesses the potential for carbon monoxide poisoning as houses are made more airtight. The report points out the need for attention to the issue of air quality. The concerns were considered in two parts:

1) the problem of air quality; and
2) the problem of adequate combustion and make-up air.

The principles involved in successfully dealing with both of the problems are discussed in detail in Appendix C - Air Quality, Controlled Ventilation and Heating Systems. These principles were applied to the construction of the houses discussed in this report and can be summarized as follows:

1) the houses were assumed to be built airtight;
2) the necessary exchange of air for air quality reasons was accomplished by a continuously operating mechanical ventilation system;

3) the fresh air brought into the house for air quality reasons was mechanically distributed within the house enclosure to avoid dead areas in the house; and
4) all combustion equipment was separated or uncoupled from the influence of house interior air pressures.

The application of these principles lead to the following general approach:

1) ventilation to maintain air quality and to provide moisture control on a continuous basis was provided with the ventilation rate determined by the number of habitable rooms in the house; and
2) make-up air was provided for combustion and exhaust equipment when it was needed and in the amounts needed in addition to the continuous ventilation rate to maintain air quality and moisture control provided for in '1' above.

Specific examples of the application of the general approach are discussed in Section IV as they relate to particular demonstration projects. Air quality/ventilation considerations common to each of the projects are explained below.

C. Heat Recovery on Ventilation

When the approach to air quality and ventilation was applied in combination with the construction of airtight building enclosures or building envelopes it was thought to be convenient, practical and cost effective to apply some form of heat recovery on the system. However, the cost effectiveness of heat recovery systems is now being questioned by the author and other researchers (Handegord; 1984).

Heat recovery from the warm exhausted air is convenient in airtight houses because the locations where all incoming and outgoing air passes through the building envelope are known and in fact can be located for convenience by the builder or designer.

Practical heat recovery on the ventilation system in airtight homes can take one of two forms, either the use of a cross-current air-to-air heat exchanger or the use of a small heat pump to recover the heat in the outgoing stream of exhausted air. The air-to-air heat exchanger (ATAHE) system is the predominant approach currently used in Canada, although this will likely change over the next three to five years as heat pump systems, suitable for houses, become commercially available in Canada.

Air-to-air heat exchangers transfer the heat contained in the outgoing, generally warm, moist, stale exhaust air to the incoming, generally cold, dry, fresh air. Normally, there occurs no transfer of moisture nor any mixing or cross contamination of the opposing air flows. Although seasonal recovery efficiencies are on the order of 50 to 70 per cent, there are health concerns if the units are operated other than during the winter months. Viral and bacterial growth could occur on the heat exchange surface elements if the ATAHE is operated during hot, humid summer months. The advantage of ATAHE systems are that they are currently available in Canada. The disadvantages are numerous. ATAHE's are expensive, noisy, poorly serviced and generally usable only seasonably.

Heat pump recovery of the heat contained in the outgoing, generally warm, moist stale exhaust air normally results in the recovered heat being utilized to assist in meeting the domestic hot water requirements of a house rather than warm up the incoming, cold, fresh ventilation air as in an ATAHE system. A system is normally configured with the heat source for the pump located in the outgoing stream of exhaust air* and storing the heat in the domestic hot water tank. In this manner the source of heat for the heat pump is almost continuously in the 20 degrees Celcius range. At this source temperature the heat pump will operate with a high co-efficient of performance (COP), often greater than 3. A COP of 3 means that roughly three units of energy are moved from the source to storage (the sink) at the expense of, or consumption of one unit of energy, an effective efficiency of 300 percent. In conventional domestic hot water systems, where oil or electricity is used to warm the water at conversion, the efficiences (at the house) are in the range from 50 and 100 percent respectively. If we examine an electric hot water tank, which has a conversion efficiency of around 100 percent, a unit of electrical energy is converted to a unit of heat energy which is used to warm the water in the tank. If we compare this to a heat pump recovery system, which has a COP of 3, a unit of electrical energy is used to move 3 units of heat energy from the outgoing stream of ventilation air to the domestic hot water tank. This results in a savings in electrical energy to heat domestic hot water of two thirds over that of conventional electric domestic hot water tanks. The advantages of this approach are that it may be utilized year round and it results in energy savings for heating hot water, energy savings which are comparable to ATAHE Systems. The heat pump system will likely be one half the cost of current ATAHE systems.

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*Fresh air can be supplied in numerous ways. For some options refer to Appendix C: Air Quality.

The ATAHE system of heat recovery on ventilation and the heat pump recovery system both result in moisture and humidity control within an "airtight" house. Control of moisture in both cases is as a result of exhausting interior moist, warm air and replacing it with exterior cold, dry air. Interior humidities can be set by the occupant who controls the rate at which this replacement of air, or ventilation occurs.

ATAHE recovery systems were used on all of the houses discussed in this report.

III. FIRST GENERATION DEMONSTRATION OF THE DRYWALL APPROACH: BRAMPTON PROJECT

In the summer of 1982 the Ontario Ministry of Energy, in conjunction with the Housing and Urban Development Association of Canada (HUDAC), initiated Phase II of their Low Energy/Passive Solar Housing Demonstration Program. This program became known as the Three Subdivision Project and was located in Brampton, Ontario.

One of the participants in this project was Great Gulf Homes of Downsview, Ontario. They are one of the Metropolitan Toronto Region's largest and most experienced tract home building companies, responsible for some six hundred starts per year. Great Gulf builds homes primarily at the low cost end of the region's housing market, in the 100 m^2 to 200 m^2 size range.

Great Gulf submitted a proposal to participate in this demonstration project in July, 1982 and HUDAC and the Ontario Ministry of Energy accepted. Construction commenced on the project in late October, 1982 utilizing the modified Handegord approach. All nine homes were completed by the end of March, 1983.

A. Description of Houses

The houses were three and four bedroom, detached, single family dwellings ranging in size from 110 m^2 to 140 m^2 in area. All were two storey construction with full basements and had a front attached garage as the main architectural feature. Houses with elevations and floor plans identical with typical "tract" subdivision construction were built (Photographs 1, 2, 3, & 4 on pages 13 and 14). These standard elevations and floor plans had already been utilized by the builder in other houses in the subdivision.

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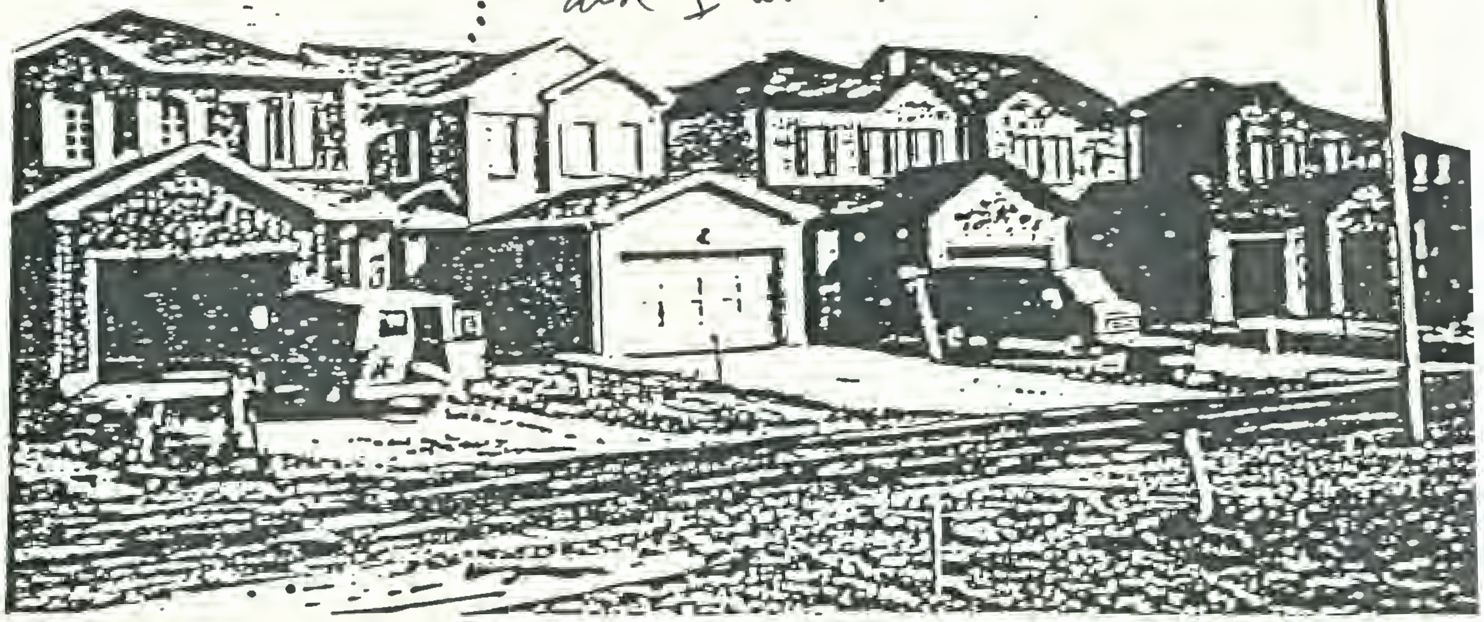
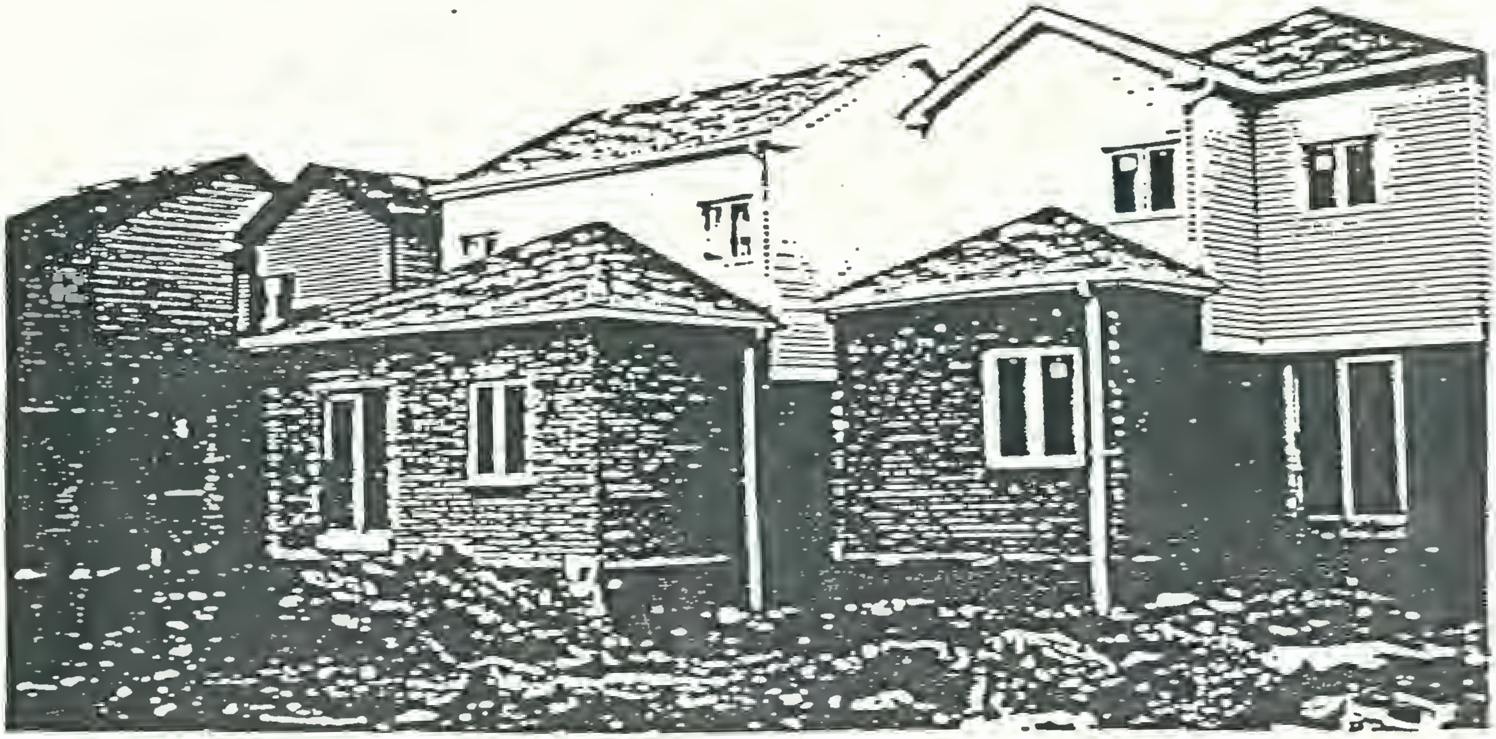


Photograph One



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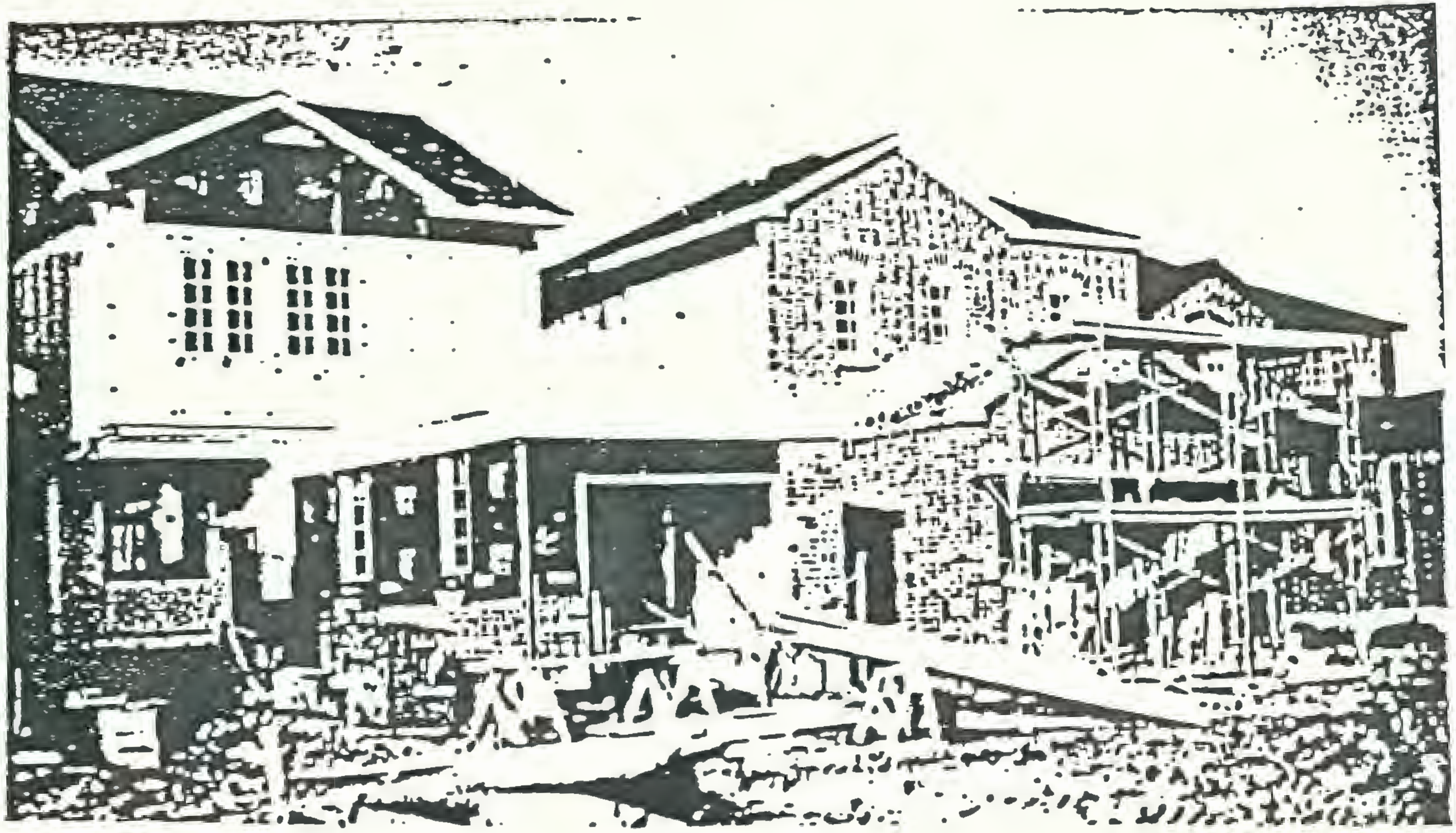

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Selling prices for the homes, including lots, ranged from $73,900.00 to $84,900.00. An incremental price premium of $1,800.00 was added to each house to help cover the added energy features. This incremental cost to the home purchaser was only a "sale price" increase and did not fully reflect the actual incremental costs (see Incremental Costs, page 29). A further $6,500.00 per house "incentive payment" was provided by the Ontario Ministry of Energy to be used by the builder to offset actual incremental costs. Combining the sale price increase of $1,800.00 and the government incentive payment of $6,500.00 gave the builder a $8,300.00 per home buffer to offset actual incremental costs associated with the project.

B. Construction Details

The houses were constructed with concrete foundation walls on typical strip footings. However, the house foundations were not connected to the attached garage foundations. The two foundations were designed to move independently of one another. Above grade, this was reflected in a control joint that was visable on either side of the garage where the garage walls came into contact with the walls of the house. This uncoupling of the foundations was done to negate the possible effect of soil freezing next to the unheated garage. If soil next to the garage freezes, the ground can heave the garage foundations. This can damage the house foundations if the garage foundations are connected to the main house foundations.

The concrete foundations walls were cast 200 mm lower than normal to allow for the laying of a course of insulated "styropour" blocks as shown in Figure 1, page 16. The "styropour" blocks were 300 mm wide and installed so they were cantilevered 100 mm over the outside face of the concrete foundation walls. The 100 mm cantilever allowed for the installation of 150 mm thick, high density rigid fiberglass draining insulation (Koenigshof, 1974; Elmroth & Hoglund, 1975; Tao, Bomberg & Hamilton, 1980; Timusk, 1980; Deacon, 1981) on the exterior of the concrete walls (Figure 2, page 17). The draining insulation was fastened at the top of the wall with galvanized eavestrough nails and large plastic washers to a cast-in-place wood nailer strip in the concrete wall. At the bottom of the wall, the draining insulation was held in place by 20 mm diameter clean crushed stone which was part of a typical perimeter weeping tile drainage system. The upper, exposed, above grade portion of the draining fiberglass insulation was protected by a concrete parge coat over metal lath nailed directly into the styropour blocks (Figure 2 page 17). This method of protecting the insulation proved to be both unattractive and uneconomical (see Table 2 - Brampton Project Incremental Costs, page 29). In addition, the protective coating was installed too late during the construction process of these houses. The exposed portions of the draining fiberglass insulation had already suffered substantial damage from tradesmen going about their duties in "typical" fashion. Although the insulation retained its draining characteristics, the damage to the insulation caused reduction in insulation value.

The styropour blocks were intended to provide a thermal break between the brick veneer and the foundation wall. However, the cost of installing a single course of rather expensive insulated blocks on the top of a cast concrete wall from a scaffold proved expensive.

Control joints were provided in the concrete wall every 5 meters and at locations of stress concentrations such as one side of openings for the basement windows. This was done in recognition of the commonly overlooked fact that almost all concrete residential basement walls crack. The operative thought was, "If the walls are going to crack anyway, they may as well crack where you can live with the (control) crack".

A plywood skirt was utilized to provide for continuity of the air barrier between the basement foundation wall and the first floor exterior walls (Figure 2, page 17). A modified balloon framing technique was used at the first floor subfloor to prevent the floor joists from penetrating this plywood skirt. The joist were initially supported via joist hangers nailed through the plywood skirt to the header and sill plate. This practice was not continued after two buildings were framed, due to cost and time considerations. It was replaced by the use of a 38 x 89 mm ledger nailed through the plywood skirt to the sill plate. Nailing schedules were determined by taking into account the appropriate floor loadings. The bottom of the plywood skirt was caulked to the concrete basement wall, which along with the concrete basement floor provided continuity of the air barrier below grade. The vertical butt joints between the 12 mm plywood strips making up the plywood skirt were also sealed with caulking compound. The top of the plywood strip was designed to protrude 30 mm above the first floor subfloor. When the gypsum board sheets were fastened to the interior surface of the main floor exterior studs, the gypsum board sheets lined up flush with the 30 mm high plywood lip protruding above the plywood subfloor forming a butt joint. The butt joint was caulked and behaved as a control joint to deal with building frame movement. A similar approach was used between the first and second storeys at the second floor subfloor (Figures 3 & 4, pages 21 & 22). The gypsum board sheets, when installed, taped and filled using typical gypsum board taping and filling compounds, acted as the air barrier on the exterior first and second floor walls as well as on the second floor ceiling (Figure 5, page 23).

Adequate vapour resistance to meet Building Code requirements was provided by the application of a proprietary latex vapour retarding paint. However, the necessity of such a special vapour retarding paint is questionable. Typical interior grade latex paints, applied conventionally, can be shown by calculation to be an adequate vapour retarder (see Appendix B - Vapour Movement).

Where interior walls intersected exterior walls and where the tops of interior partitions intersected insulated ceilings, plywood strips were installed such that each plywood strip extended 25 mm on each side of the intersecting framing members. The butt joints that were formed with the gypsum board interior cladding were sealed by the normal application of gypsum board tape and filler. In this manner continuity of the air barrier was provided.

During the framing process, several different types of plywood and waferboard were tried. It was found through experience that certain types of waferboard were so susceptible to rain and moisture that the resultant swelling rendered some of the waferboard strips useless. The rain and moisture damaged waferboard strips caused considerable remedial work. The "Aspenite" type of waferboard strips proved to be the most cost effective and performed in a satisfactory manner.

Several different types of caulking and sealing compounds were also used. Silicone based caulking compounds, although easy to work with during cold weather, were found to be inappropriate because of their inability to bond to dusty or damp surfaces. Acrylic based "mono" caulking compounds were used most throughout the project with acceptable results. Some minor cracking of the compound has become visible after one year.

Some of the vertical butt joints between "Aspenite" or plywood strips were taped using various different tapes. Standard duct tape was found to adhere better upon initial application than most of the tapes, although all the tapes were difficult to apply in very cold weather. The long term performance of the various tapes needs to be investigated.

The joints between the Aspenite or plywood strips and the gypsum board were taped using gypsum board tape and a premium taping "Durabond 90", compound that has good adhesion properties to wood.

However, the premium taping compound proved to be more difficult to work with than standard taping compounds and this was reflected in a cost increase in the taping (see Incremental Costs, page 29).

The main exterior walls were framed with 28 x 140 mm studs at 600 mm on centre. The stud cavities were filled with friction fit fiberglass batts, R.S.I. 3.5 (R-20). The exterior walls were also sheathed with 75 mm, R.S.I. 2.0, Type I expanded polystyrene.

The exterior cladding installed on the houses was conventional "jumbo" brick on all four sides of the first storey, and prefinished aluminium siding on the two sides and rear on the second storey. The brick veneer and the aluminium siding were both installed in an "open rain screen"* manner.

Special "stub-ended" roof trusses were installed to maintain the thickness of ceiling insulation where it met the exterior wall insulation. The heels of the trusses were 600 mm deep to accommodate the ceiling insulation which was blown fiberglass insulation, R.S.I. 10.5 (R-55). The heels of the roof trusses were covered with cladding in order to avoid the roof from appearing unusually thick. However, this detail added a 600 mm strip of siding and brick around the perimeter of the building.

In examining the incremental costs (page 29) of maintaining the full thickness of the ceiling insulation at the truss ends, it is quite evident that from a pure energy payback point of view the approach was not cost effective. However, an intermediate approach used on later projects, where

*"Open rain screen" refers to a design where water that may gain access into the wall cavity is led back out of the wall cavity through a clearly defined or "open" path. Hence the building envelope is rain protected or "rain screened".

additional exterior cladding would not be required, proved to be both cost effective from the energy conservation point of view and to make sense from a building science point of view by reducing the possibility of mould and mildew occuring at the outside corners of upper storeys. This intermediate approach was used in the Shelburne House, and is discussed in Section IV of this report.

The windows in all nine houses were upgraded from typical double glazed sliding windows commonly utilized in tract houses to triple glazed casement windows. The windows were installed without any special techniques by the carpenters. Once the windows were installed, the gypsum board interior cladding was returned directly to the frame of each window and door unit. The joint between the gypsum board and window or door unit was then caulked to effect continuity of the air barrier. The bead of caulking was subsequently hidden by an appropriate piece of trim. This particular detail was a significant savings in labour and materials over details currently being used to provide continuity of the air barrier at building envelope openings in polyethylene air/vapour barrier systems.

Gypsum board installation techniques used on this project differed from the techniques used on typical tract houses in that the procedure involved double taping of numerous seams and also a higher quality taping compound, Durabond 90, was used.

Incremental framing labour costs proved to be much higher than originally anticipated. This was largely due to the initial poor co-ordination of trades which resulted in the carpenters doing a lot of the fill-in work that should have been done by others, or that was not necessary to be done at all. This problem was resolved towards the end of the project, too late to have a significant effect on the overall framing costs (see Incremental Costs, page 29).

The same trade that normally caulks the exterior of typical tract houses to reduce rain penetration was the trade utilized to apply caulking compound at the necessary interior locations. This proved to work well after the required co-ordination details were worked out.

All nine houses were heated with electric baseboard heaters and domestic hot water requirements were met by the installation of electric hot water heaters. This of course eliminated the concern of adequate supply of combustion air. Interior air circulation was provided by the installation of a thermostatically controlled two-speed fan that continuously circulated air from the upper storeys of the houses to the lower storeys. This also served to de-stratify the interior air/temperature profile. Continuous ventilation, required to satisfy air quality concerns, was provided by the installation of a continuously operating, fan driven, air-to-air heat exchanger.

Continuity of the air barrier at electrical outlets was achieved in two ways. In the first four buildings framed, "polypans" were used. Electrical boxes were installed in these polyethylene enclosures and the electrical wire penetrating the enclosure was caulked. A continuous, heavy bead of caulking was applied to the lip of each polypan before an appropriate sheet of gypsum board was installed at each electrical box. The bead of caulking was compressed by the gypsum board sheet and formed a seal between the polypan and the gypsum board. This approach had its difficulties, among which was the near impossibility of getting the drywall tradesmen to apply the bead of caulking to each polypan.

In the remaining houses, continuity of the air barrier at electrical outlets was achieved by the installation of commercially available gaskets directly under the cover plates of each switch or outlet. This was simple, effective and inexpensive. The electrician installed the gaskets at the time when he installed the cover plates.

Where electrical wires penetrated the gypsum board/plywood air barrier, they were caulked by the electrician to prevent air leakage. This proved to be an aggravation to the electrical trades. The electricians who worked on the project were quite willing and happy to run a wire virtually anywhere and in any manner as long as they did not have to pick up a caulking gun. When supervision was not constant, the sealing of electrical wire penetrations through the envelope did not occur.

Site supervision of the nine demonstration buildings was considerably greater than usual for tract construction. During the project it was not unusual to have the Project Engineer on site every other day during the critical construction phases such as the framing and caulking phases of each building. Although the level of site supervision was greater than that of a conventional tract built home, it was lower than the level necessary for a sealed polyethylene air/vapour barrier tract built low energy home.

C. Monitoring and Testing

Air leakage tests for the nine buildings were conducted after the gypsum board was installed and taped and the appropriate caulking compounds applied. All the tests occurred before the finish carpentry had been started. The tests were conducted by an independent testing contractor according to the CGSB Standard for air leakage testing utilizing the fan depressurization method. The results of the tests were found in Table 1, page 27.

Table 1

Brampton Project Air Leakage Test Results
(air changes per hour at 50 pascals negative pressure)

Lot 74	0.84
Lot 79	1.50
Lot 81	0.88
Lot 82	1.14
Lot 83	0.94
Lot 84	1.09
Lot 85	1.21
Lot 86	0.90
Lot 106	1.01

All the air leakage met the demonstration program's requirement of 2.0 air changes per hour (acph) or less, at 50 Pascals negative pressure and would have met the R-2000 Program standard of 1.5 acph or less at 50 Pa. The house on Lot 79 was tested before any caulking was carried out. This was done to test the air leakage sensitivity of the approach to poorly or incorrectly installed caulking. It is quite significant to note that the home on Lot 79 also met the R-2000 Program's air leakage requirements without any caulking. Ignoring the non-caulked air leakage rate at 50 Pa for the house on Lot 79 and averaging the other eight air leakage rates yields an average of 1.0 acph at 50 Pa.

Continuous ongoing performance monitoring on an hourly basis for the next two years has begun. The ongoing performance monitoring consists of an on-site microcomputer reading and storing information from numerous temperature, humidity, energy consumption and time of operation sensors. The microcomputer is linked via telephone lines to a microcomputer located at the Center for Building Science, University of Toronto where detailed performance analysis is being conducted. Further details of the monitoring approach can be found in Appendix D.

Heat loss simulation tests were conducted on three of the nine houses during the Spring of 1983. The purpose of the tests was to determine the energy performance characteristics of the houses in their "as-built" states. Results of the testing carried out on the three houses, have not yet been released by the Ontario Ministry of Energy. It is speculated that difficulty was experienced by the testing contractor in obtaining meaningful data and that the analysis of the data collected is not complete. A test procedure is described in Appendix E - Heat Loss Simulation Testing.

Performance simulation and work was conducted on the nine Brampton Project homes using the Division of Building Research, National Research Council's computer simulation program, HOTCAN. The computer runs were based on the actual measured air leakage rates and installed levels of insulation. A sample run for one of the Brampton homes can be found in Appendix F - HOTCAN Computer Simulations. This predicted performance will be compared with the measured performance obtained as a result of the monitoring program.

D. Incremental Costs

The total incremental cost for meeting the demonstration program's energy budget requirements and air leakage requirements was $5,780.00 per home averaged over the nine homes. The detailed breakdown of these costs is given in Table 2 - Brampton Project Incremental Costs, page 29.

Table 2

Brampton Project Incremental Costs*

Forming (savings in concrete due to lower foundation walls)	-	$ 250.00
Basement Windows (none installed)	-	80.00
Taping Expense (Durabond 90)	+	200.00
Insulation in Ceilings and Walls	+	360.00
Framing Labour	+	1,400.00
Electrical (baseboard heaters)	+	800.00
Insulated Blocks	+	350.00
Protective coating for draining insul.	+	200.00
Roof Trusses & Additional Cladding	+	400.00
Caulking	+	300.00
Insulating Sheathing	+	900.00
Exterior Draining Insulation	+	600.00
Windows & Doors (T/G instead of D/G)	+	850.00
Savings on Conventional Heating System	-	1,500.00
ATAHE Installed	+	1,000.00
Framing Materials	+	250.00
TOTAL	+	$5,780.00

* Average over nine homes

** Engineering and additional supervisory costs not included

The typical house built as part of the Brampton Project sold for $73,000.00. The lot price accounted for $30,000.00 of the selling price while hard construction costs were $30,800.00 ($28.00 per square foot not including the energy features or incremental costs) and the remaining $12,200.00 made up the builder's soft costs and profit.

The construction of a hypothetical "tenth house" utilizing the same framing approach without incorporating the insulated blocks, the special raised heel roof trusses necessitating the additional cladding, or the parging on metal lath approach for protecting the exterior draining fiberglass insulation, but with a conventional heating system such as a forced air electric furnace, would result in an incremental cost of $4,600.00 as shown in Table 3: Incremental Cost of Hypothetical Tenth Brampton House.

Table 3

Incremental Cost of Hypothetical Tenth Brampton House

Gypsum Board Taping	+ $ 200.00
Framing Labour	+ 1,000.00
Caulking	+ 300.00
Insulation	+ 1,000.00
Windows	+ 850.00
Heating System (ATAHE)	+ 1,000.00
Framing Materials	+ 250.00
TOTAL	+ $4,600.00

Such a building would also have similar energy performance and air leakage characteristics to the nine houses already built. However, it would be unlikely for the incremental costs using this approach to drop significantly from this level even after considering the experience gained from repetition.

E. Lessons Learned

Knowledge gained from the Brampton Project substantiated the viability of the concept of a non-polyethylene air barrier/vapour retarder. Incremental costs in the $5,000.00 range for achieving the degree of airtightness required, along with the levels of insulation installed, compared favourably with incremental costs experienced by other tract builders who have built houses with similar degrees of air tightness and similar levels of insulation. Flair Homes of Winnipeg experiences a premium of $6,000.00 to $7,000.00 when building one of their airtight, double-walled houses even after having built approximately thirty in number. Guardi Homes of Toronto built one airtight, polyethylene house under the Federal Government's R-2000 program and experienced incremental costs in the $14,000.00 to $15,000.00 range. Lincolnberg Homes of Edmonton experienced an incremental cost of $14,000.00 building an R-2000 home.

The operative words in the above comments are "other tract builders". The average incremental costs for houses constructed under the R-2000 program are in the $6,000.00 per house range. There are few tract builders participating in the R-2000 program and those that are, are experiencing incremental costs above the average. This is due to the fact that there is a great deal of difference between applying airtight polyethylene air/vapour barrier construction techniques for tract builders who build large number of homes per year and to whom interruptions are costly and the techniques used by a custom home builder who may build fewer than ten homes per year. The tract house building environment is a world apart from the custom home building environment.

It has been reported that recent marketing studies conducted in the Metropolitan Toronto region* have indicated that the majority of home buyers were unwilling to spend more than $2,000.00 to $2,500.00 more per house for energy saving features. As such, the whole concept of low energy home

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* Similar findings occured in Calgary and Edmonton, Alberta. See "Design Preferences and Trade-Offs for Moderately Priced Housing in Alberta", November 1983 Alberta Department of Housing.

appeared uneconomical unless this incremental cost ceiling could be achieved. Great Gulf felt further development was required before this incremental cost ceiling could be reached and, at least for the moment, have deferred plans to incorporate the approach in their regular housing production.

However, the Brampton Project did lay the foundation for further work in the non-polyethylene air barrier/vapour retarder approach and led to the considerable modifications that were proposed by the author and subsequently demonstrated in the Shelburne, Lawrence Park and London houses.

IV. IMPROVING THE DRYWALL APPROACH: SHELBURNE, LAWRENCE PARK AND LONDON HOUSES

In the summer of 1983 the author proposed using the Drywall Approach to achieve a non-polyethylene air barrier/vapour retarder based on the lessons learned in the Brampton Project. Two homes utilizing the Airtight Drywall Approach were built that summer: the Shelburne House in Shelburne, Ontario and the Lawrence Park House in the City of North York. A third house was also built in the fall and winter in London, Ontario.

A. Description of the Shelburne House

The Shelburne House consisted of a new single family residence constructed near Shelburne, Ontario. The house has a floor area of 170 m2 and is heated with an electric forced air heating system. The building is a two-storey slab-on-grade structure, bermed two metres high on three sides. The building could be considered as a one storey building with a finished walkout basement that contains the kitchen, living room, dining room and master bedroom suite.

B. Construction Details of the Shelburne House

The foundation system consists of a preserved wood foundation with a concrete slab floor. Type IV extruded expanded polystyrene insulation (Styrofoam SM) was placed below the preserved wood footing plate and over a 150 mm granular drainage pad. Type I expanded polystyrene was placed over the remainder of the granular pad. The concrete slab was then cast directly over the insulation (Figure 6, page 34). Type IV extruded expanded polystyrene was chosen to be installed under the footing plate because it is able to resist the higher compressive loads experienced beneath the footing plate.

Fiberglass draining insulation was installed on the exterior of the preserved wood foundation. Because of its positive drainage characteristics the joints of the pressure treated plywood were not caulked and no polyethylene sheeting was applied to the foundation wall. Normally in conventional preserved wood foundation systems such measures are required. The fiberglass draining insulation was nailed only at the top of each insulation sheet and held in place at the bottom of the foundation wall by the granular material comprising the granular drainage pad. A low density fiberglass wall batt was split into 25 mm layers and placed over this granular material around the perimeter of the foundation. This split wall batt acted as a filter to prevent contamination of the granular drainage pad by backfill material.

The installation of the insulation on the exterior of the wood foundation system, under the footing plate and floor slab served to thermally uncouple the foundation from the ground. The resultant thermal gradiant lowers the relative humidity and moisture content of the wood members comprising the foundation system to levels that could mean that the studs need not be pressure treated to resist dry-rot and to ensure long term durability. However, long term tests are required to confirm this hypothesis and pressure treated members were therefore used. The advantages of pressure treated materials are their low susceptibility both to wood rot and to infestation from insects such as termites.

The air barrier in this house consisted of the taped gypsum board internal cladding and the vapour retarder was the paint film applied to the surface of the gypsum board in the normal course of finishing the home. The paint utilized was standard semi-gloss latex paint applied in one coat over a standard latex primer.

This provided the necessary vapour diffusion resistance (see Appendix B - Vapour Movement).

Continuity of the drywall air barrier was assured by modifying the first generation framing techniques and co-ordinating the construction trades. The house was framed so that the interior portions on the uppermost storey were installed after the ceiling and perimeter wall gypsum board was installed and flat-taped (gypsum board taped and given one coat of joint filler). Only load-bearing interior partitions on the lower storey were installed before the exterior wall gypsum board was installed and flat-taped. However, these interior load-bearing partitions were installed so that they stopped 50 mm short of intersecting a perimeter wall. In this manner the gypsum board on the perimeter walls was installed in a continuous manner behind an intersecting interior partition. The order of construction was as follows:

1) the carpenters framed the basement walls, the main floor subfloor, the main floor perimeter walls and installed the roof trusses and roof;
2) the gypsum board installers installed the gypsum board on the perimeter basement walls, the perimeter walls on the main floor and on the underside of the roof trusses.
3) the gypsum board installed up to this point was flat-taped;
4) the carpenters came back and framed the interior partitions on the uppermost storey;
5) the electrical, mechanical and plumbing was installed in interior walls, in the floor cavity or surface mounted on the gypsum board already installed; and
6) the gypsum board installers returned to install the remaining gypsum board on all interior partitions and on the ceiling of the lower storey.

Continuity of the air barrier between storeys was accomplished by caulking the gypsum board at the top of the lower storey perimeter walls to the continuous floor header (Figure 7, page 38) and by caulking the gypsum board at the bottom of the perimeter walls to either the concrete slab floor or to a portion of the floor header left exposed by not running the plywood subfloor right out to a perimeter wall (Figure 6 pages 34). Continuity of the air barrier at the insulated ceiling was accomplished with gypsum board (Figure 8, page 39).

The house is heated by a forced air electric heating system. The HOTCAN heat loss calculation, (Appendix F, HOTCAN Computer Simulations), indicated that a 10 kw electric furnace would be more than adequate. Compared to the ductwork normally found in houses having forced air heating systems, it was simplified and the amount of ductwork was greatly reduced. This was done by creating a pressurized floor plenum between storeys, a feature allowed by the Ontario building code. Floor trusses instead of floor joists were used as the framing members for the subfloor with the truss space between the ceiling below and floor above used as a heating plenum. The cost increase in going to a floor truss system was more than offset by the cost savings associated with a greatly simplified mechanical system. Floor registers were simply cut into the floor where needed.

Heating ducts in the poured concrete slab were installed to effect a perimeter heating system. The ducts themselves were two 100 mm diameter, solid, corrugated, polyethylene "weeper" pipes that were imbedded side-by-side in the concrete. Site constructed wood register boxes were appropriately located and connected to the perimeter ducts. This approach for slab-on-grade heating systems worked well and proved to be very cost effective. The return air registers for the system were located on each storey at the ceiling levels to take advantage of the stratification of the air-temperature profile.

Air quality concerns were dealt with via the installation of a continuously operating air-to-air heat exchanger (ATAHE). The heat exchanger was installed so that it withdrew air in a continuous manner from the two bathrooms and from the kitchen area. The heat exchanger was adjusted to continuously operate in its low speed mode. It was set to operate in its high speed mode only when occupant-set internal relative humidity was exceeded. The relative humidity was set by adjusting a humidistat control mounted directly on the ATAHE. Fresh air drawn into the house by the heat exchanger's intake fan was ducted to the pressurized floor plenum created by the use of floor trusses between storeys. In this manner, the fresh air was mixed with the continuously circulating air of the forced air heating system and hence effectively distributed throughout the house. The ducting of the fresh air from the heat exchanger into the floor plenum also served to dampen noise transmission from the heat exchanger.

For summer operation, the heat exchanger was field modified by the addition of a shut-off switch connected to the intake fan of the heat exchanger. During the summer, only the exhaust fan of the heat exchanger operates with the heat exchanger intake fan shut down. A separate intake duct connected to the return air side of the forced air furnace, with the two speed furnace fan operating continuously at low speed (heating elements not operating of course), provided the fresh air required for air quality reasons during the summer. For winter operation, this intake duct was closed via a damper and the heat exchanger intake fan was switched on, drawing fresh air into the house in its usual mode of operation. This modification to the typical heat exchanger installation approach, namely the disconnection of the heat exchanger intake fan was done to prevent any condensation occuring on the intake side of the heat exchanger during warm, humid summer conditions. Condensate on the heat exchange surfaces, when at warm temperatures, can provide an ideal breeding ground for a whole range of bacteria that may cause health problems for the house occupants. Fresh air continuously brought into the house enclosure, through the intake side of the heat exchanger, will pick up unwanted and possibly dangerous bacteria that may be present and distribute the bacteria throughout the house.

C. Monitoring and Testing of the Shelburne House

An air leakage test was conducted on the house by an independent testing contractor utilizing the Canadian General Standards Board (CGSB) fan depressurization method. The house tested at 0.72 air changes per hour at a negative pressure of 50 Pascals. This degree of airtightness, coupled with the levels of insulation in the envelope, resulted in a house which exceeded the "R-2000" energy performance standard for low energy homes as determined by HOTCAN (Appendix F - HOTCAN Computer Simulations).

D. Incremental Costs of the Shelburne House

Incremental construction costs on this building, using the Airtight Drywall Approach as described, were significantly reduced over the Brampton project incremental costs. The total incremental cost of the Shelburne House compared to the cost of a conventionally built house of a similar size and appearance was $1,870.00 (Table 4 - Shelburne House Incremental Costs over Standard Construction, page 42).

Table 4

Shelburne House Incremental Costs
Over Standard Construction

Framing Materials	No Additional Cost
Framing Labour	No Additional Cost
Gypsum Board	No Additional Cost
Insulating Sheathing	+ $ 900.00
Insulation	+ $ 300.00
Air-to-Air Heat Exchanger	+ $1,000.00
Floor Truss System	+ $ 600.00
Caulking	+ $ 300.00
Heating System	- $1,800.00
Forced Air Furnace	+ $ 570.00
TOTAL	+ $1,870.00

It must be noted that this home was not built in a tract building environment and as such the incremental costs of this home if built using this approach in a tract building environment would be higher. However, the incremental costs should only be marginally higher as tract building trades were used and the level of supervision was lower than on the Brampton project.

E. Description of the Lawrence Park House

The Lawrence Park House represented the extension of the "Drywall Approach" to the residential renovation field. The Lawrence Park Project consisted of the "super-retrofit" of an existing 60 year old, uninsulated, masonry home in the City of North York, Ontario (a suburb of the Metropolitan Toronto Region). The existing home, approximately 140 m2 (1500 s.f.) in floor area, also had a two storey (plus basement) 140 m2 addition added to it.

F. Construction Details of the Lawrence Park House

The existing plaster work in the masonry home was removed and strapped wood frame walls were added to the interior of the perimeter masonry walls to allow for the addition of R.S.I. 3.5 R-20 fiberglass insulation batts.

The addition to the house was framed in a similar manner to the Shelburne House. The major difference was in the utilization of a preserved wood floor instead of a cast concrete slab in the basement (Figures 9, 10 & 11 on pages 44, 45, 46).

Continuity of the gypsum board or drywall air barrier in the renovated portion of the project was achieved utilizing the Airtight Drywall Approach. It proved to be relatively simple compared with past experience on previous renovation/retrofit projects where the conventional polyethylene methods were used to achieve continuity.

The difficulty in obtaining continuity of air barrier and vapour retarder using current polyethylene approaches in renovation projects where floor joists intersect perimeter walls is well known. Methods developed in the Lawrence Park House to overcome the difficulty turned out to be low in cost and effective in performance.

Gypsum board sheets were installed on the perimeter strapped masonry walls as is customary in normal gypsum board installation techniques except that the upper gypsum board sheets were notched along their top edges. The notching detail was necessary to fit the drywall to the flooring where the floor joists ran perpendicular to the direction of the drywall and intersected perimeter masonry walls. The notched gypsum board sheets were then caulked around each floor joist and also caulked to the bottom of the existing subfloor at the top of the wall. The lower row of the horizontally installed gypsum board were caulked at their bottom edges to the existing subfloor. In this manner continuity of the air barrier between storeys in the existing building was obtained.

Where interior partitions intersected with perimeter walls, the gypsum board was installed so that it ran in a continuous fashion along the perimeter wall. This was accomplished by the removal of the first stud in the interior partition wall, where it intersected the perimeter wall. This stud was then replaced when the gypsum board was applied to interior partitions, in a manner similar to the Shelburne House.

G. Incremental Costs of the Lawrence Park House

Incremental costs in the Lawrence Park House were impossible to assess due to the nature of renovation work. However, the per square metre installation cost of the gypsum board interior finish was consistent with the then going rate for new construction in Toronto. Framing costs were also consistent, along with all the mechanical service costs.

H. Description of the London House

The London House is a 250 m2 detached single family dwelling. It was constructed in a subdivision setting utilizing tract building tradesmen. However, the large size, elevations and uniqueness of the design classify the house as a custom home. The London House was built to exceed the airtightness levels and insulation levels specified by the joint HUDAC/Energy, Mines and Resources R-2000 Program although it was built without any government grants.

I. Construction Details of the London House

The experience gained from both the Shelburne and Lawrence Park Houses led directly to the improved construction details utilized in the London House. Two significant changes were made in the London House details as a result of this experience. The framing technique was modified so that typical platform framing was utilized and the amount of caulking of seams and joints in the building envelope was greatly reduced by the use of compressible gaskets placed between the members and materials that bear together as explained in '2' below.

Typical platform framing was utilized with the following modifications:

1) The continuous floor "header" around the perimeter of the building at the second floor level was recessed 62.5 mm, (2 1/2"). This 62.5 mm recess was insulated with rigid expanded polystyrene insulation (Figure 14, page 53). This external insulation of the header with rigid insulation allowed the inner surface of the header to remain warm in order to reduce the possibility of condensation. The header retained the function of providing air barrier continuity between the first and second floor as in the Shelburne and Lawrence Park Houses.

2) Closed cell compressible gaskets (specifications for gasket material can be found in Appendix G - Gasket Specifications) were installed in a continuous fashion both at the top of the header, between the header and the subfloor sheathing, and at the bottom of the header, between the header and the top plate of the first floor perimeter wall (Figure 14, page 53). Also at the top of the first floor perimeter walls an additional continuous compressible gasket was installed between the top plate

and the perimeter wall gypsum board. These three continuous compressible gaskets provided for air barrier continuity between the first and second floors and reduced the amount of caulking that was required compared to the Shelburne and Lawrence Park houses. The vertical seams in the wood header occuring at corners and where two of the framing members making up the header butt together still had to be caulked as in the previous houses.

3) First floor interior partitions were framed such that they came to within 50 mm of intersecting the exterior perimeter walls in a similar fashion to both the Shelburne and Lawrence Park houses. However, the 50 mm gap was straddled at the top plates of the "pseudo-intersecting" walls by a flat, 20 gauge galvanized steel plate laid flat on top of the top plates covering the 50 mm gap and nailed to both the perimeter wall and interior wall top plates. In this manner, the perimeter walls and interior walls were tied together resulting during the framing stage, in a more rigid structure throughout the construction process.

4) Full height interior basement insulation was utilized over a cast concrete basement with control joints. On the exterior, these control joints were covered with a 600 mm (24") wide strip of rigid exterior fiberglass draining insulation for moisture control. The first floor (subfloor) construction was typical platform framing with no changes from standard construction. Air barrier continuity across the first floor framing members was achieved by using the notching detail and by caulking the gypsum board sheets as was done in the retrofit portions of the Lawrence Park House (Figures 12 and 13, pages 51 and 52).

The process and order of construction was similar to that of the Shelburne House where interior portions on the second floor were not installed until after the second floor ceiling gypsum board was installed. Electrical and mechanical systems were similar to those of the Shelburne and Lawrence Park houses except that an induced draft forced air furnace with typical sheet metal ducting was used in place of a forced air electric furnace and pressurized floor plenum as was the case in the Shelburne House to avoid puncturing the exterior envelope, low profile surface mounted electrical boxes were installed on the perimeter gypsum board clad walls again similar to both the Shelburne and Lawrence Park Houses. Exterior insulating sheathing was also utilized with the seams taped in the manner described in previous buildings. Window and door openings were also the same as was described in previous houses.

J. Monitoring and Testing of the London House

No ongoing monitoring is being carried out on the London House except for tabulation of the monthly energy costs as provided by the local utility companies. Monthly energy cost data is not presently available as the house has only recently been completed and occupied.

An air leakage test utilizing the fan depressurization method was conducted on the house and indicated that the air change rate at 50 Pascal negative pressure differential was 0.94 acph which is well under the R-2000 requirement of 1.50 acph maximum.

K. Incremental Costs of the London House

Incremental cost of construction, over standard construction, for the London House was $4,240.00. A breakdown of the total incremental cost as shown in page 54, Table 5 - London House Incremental Costs.

A pressurized floor plenum heating system was not utilized at the choice of the home owner although it would have had the result of a net reduction of $1,000.00 on the experienced incremental costs. In addition, had an electric furnace been utilized in place of the gas furnace a further reduction of $300.00 would have occurred. The $1,500.00 incremental cost of the insulating sheathing is a direct reflection of the large size of this home. A comparable cost to a typical 130 m2 (1400 s.f.) tract home for insulating sheathing would be $800.00 or approximately half of the experienced cost on the London Home.

Table 5

London House Incremental Costs

Basement Slab Insulation	$ 400.00
Framing Labour	no charge
Framing Materials	no charge
Heat Exchanger	$1,000.00
Induced Draft Medium Eff. Furnace	$ 300.00
Insulating vs. plywood sheathing	$1,500.00
Full Height Interior Basement Insulation	$ 800.00
Compressible Gaskets	$ 40.00
Caulking	$ 200.00
TOTAL	$4,240.00

L. Lessons Learned

Several important lessons were learned from the construction of the London House. They are outlined as follows:

1) The approach utilizing the modified platform framing technique is a significant improvement over the modified balloon framing techniques used on both the Shelburne

and Lawrence Park houses. It is so similar to standard platform frame construction that no incremental costs were experienced on the framing labour.

2) Utilizing gaskets is a significant improvement over caulked joints, especially for ease and speed of installation. The advantage during cold weather construction provided by the gaskets over caulking cannot be stressed enough. Gaskets such as "sealant backer rod" used in commercial construction are also less than 20% of the cost of caulking. Furthermore, they proved to be more popular with the various trades. The use of the gaskets reduced the amount of caulking to the extent that the only caulking necessary to be done could now be done after the building had been closed in and protected from the elements with a degree of warmth provided to the caulking tradesmen.

3) Attempting to tape the "Tyvek" exterior air barrier or "weather barrier" seams between the rigid fiberglass insulated sheathing under cold winter conditions proved to be an exercise in frustration. The tape consistently did not adhere to the sheathing face. Furthermore, the expense of the tape seemed to be excessive.

4) The use of full height interior basement insulation with a concrete wall and appropriately detailed control joints can be as effective as external draining insulation from the perspective of heat loss and prevention of water ingress. The latter approach has cost and marketing advantages over external rigid draining fiberglass insulation in that a finished basement is provided.

V. PROPOSED SECOND GENERATION APPROACH

Based on the experience gained from the first generation demonstration of the "Drywall Approach", and the evolutionary improvement of the approach in the Shelburne, Lawrence Park and London houses, a second generation approach to affordable, production oriented, low energy tract housing was developed. A proposed house design that is based on this approach, complete with typical cross sections and details, is shown beginning on page 57.

A. Description of the Approach

The Airtight Drywall Approach has been modified to be compatible with the most common foundation system in Alberta, cast-in-place concrete. In fact, the evolved second generation Airtight Drywall Approach requires very little modification to typical platform wood frame construction.

Where a cast concrete foundation system is utilized, control joints are located every 5 metres and at any stress concentrations caused by basement windows and doors. These control joints are clad on the exterior with strips of rigid draining fibreglass insulation ("Baseclad" or Glasclad"). Full height fiberglass batt interior insulation is installed in a 50 mm x 100 mm (2 x 4) stud wall covered with drywall.

The concrete floor slab is poured before the basement perimeter wood frame wall. The slab is poured over 75 mm of Type II expanded polystyrene. Continuity of the air barrier is achieved by gasketing the gypsum board to the bottom plate of the frost wall which in turn is gasketed to the concrete floor slab. (Figure 20, page 63).

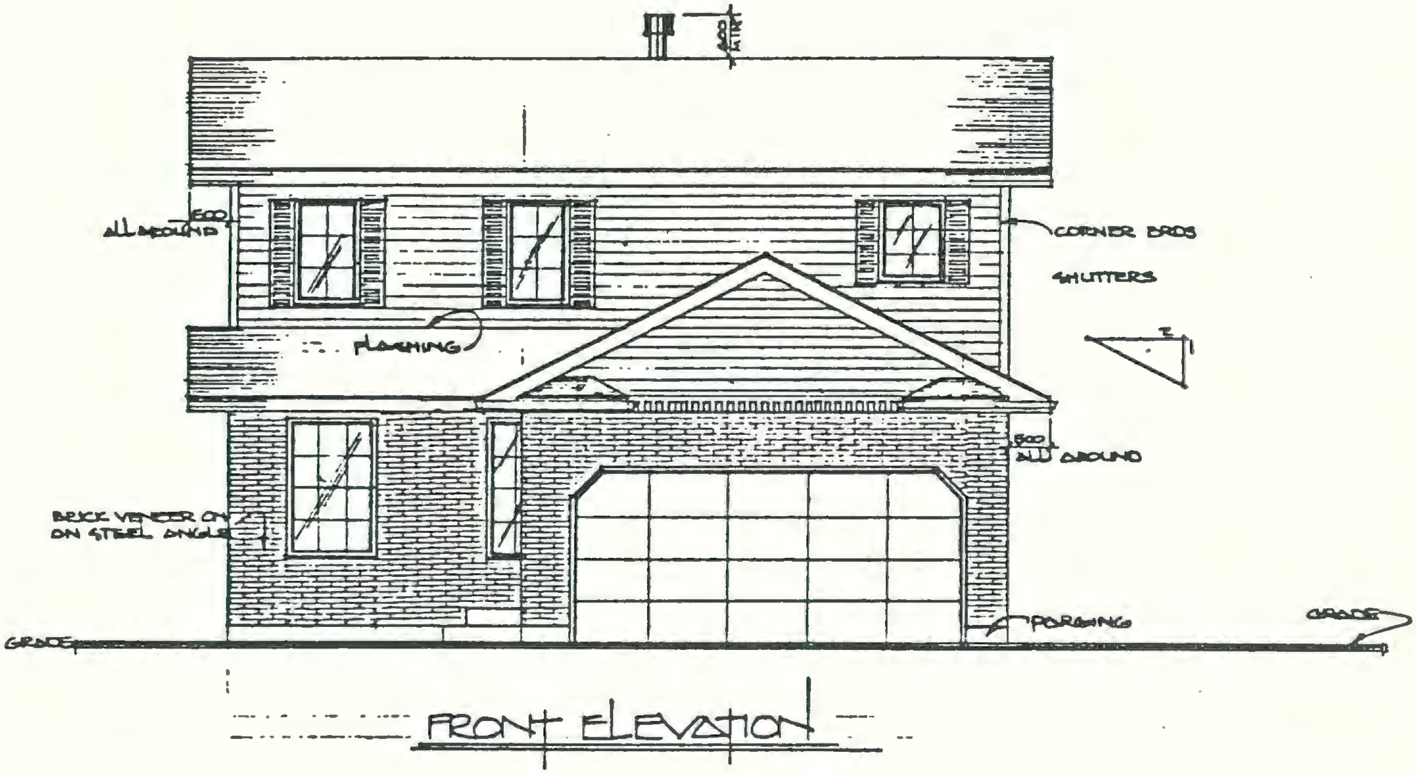

FIGURE 15: Typical Elevation - Proposed Alberta Demonstration House

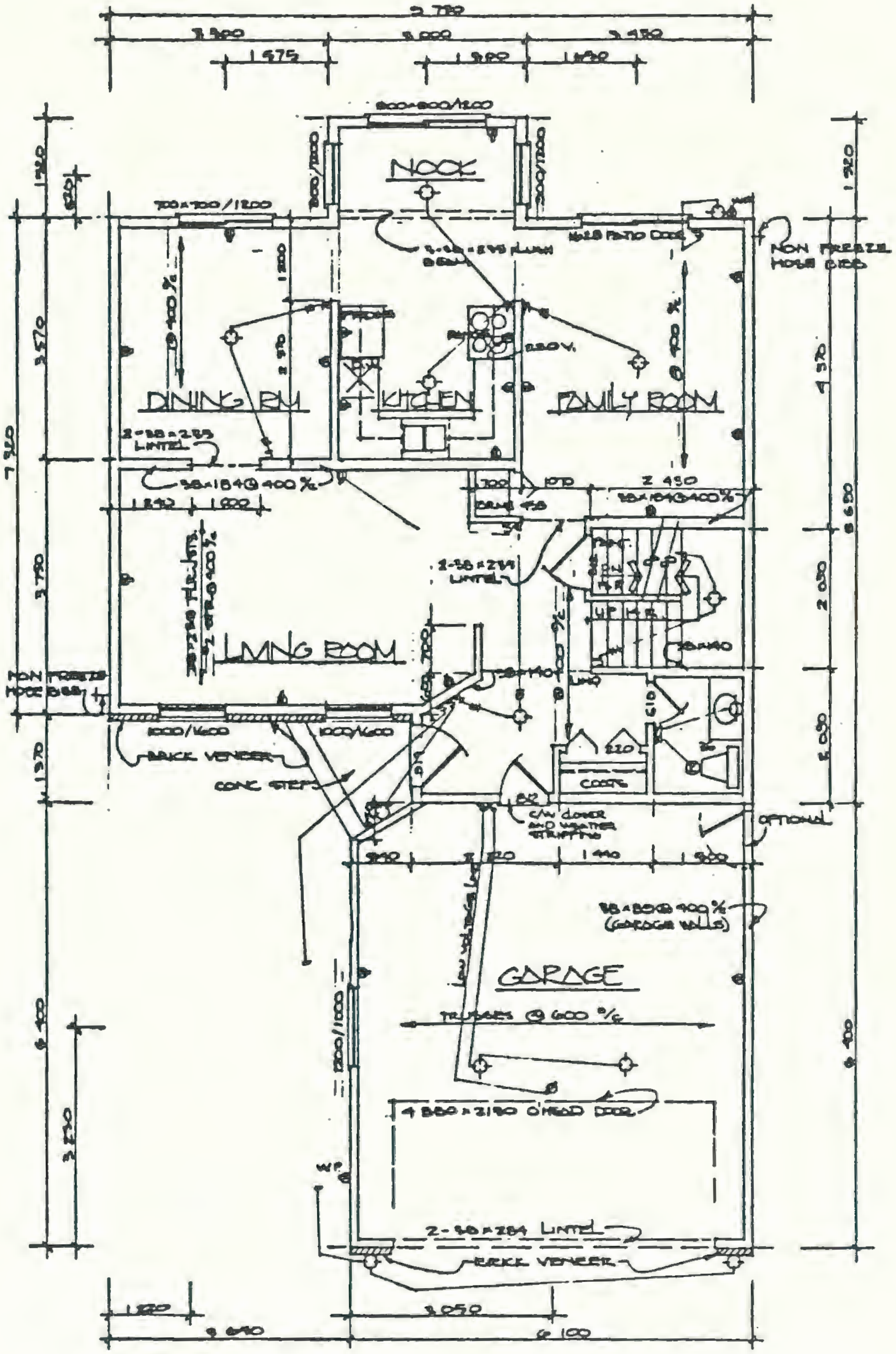

FIGURE 16: Main Floor Plan - Alberta Demonstration House

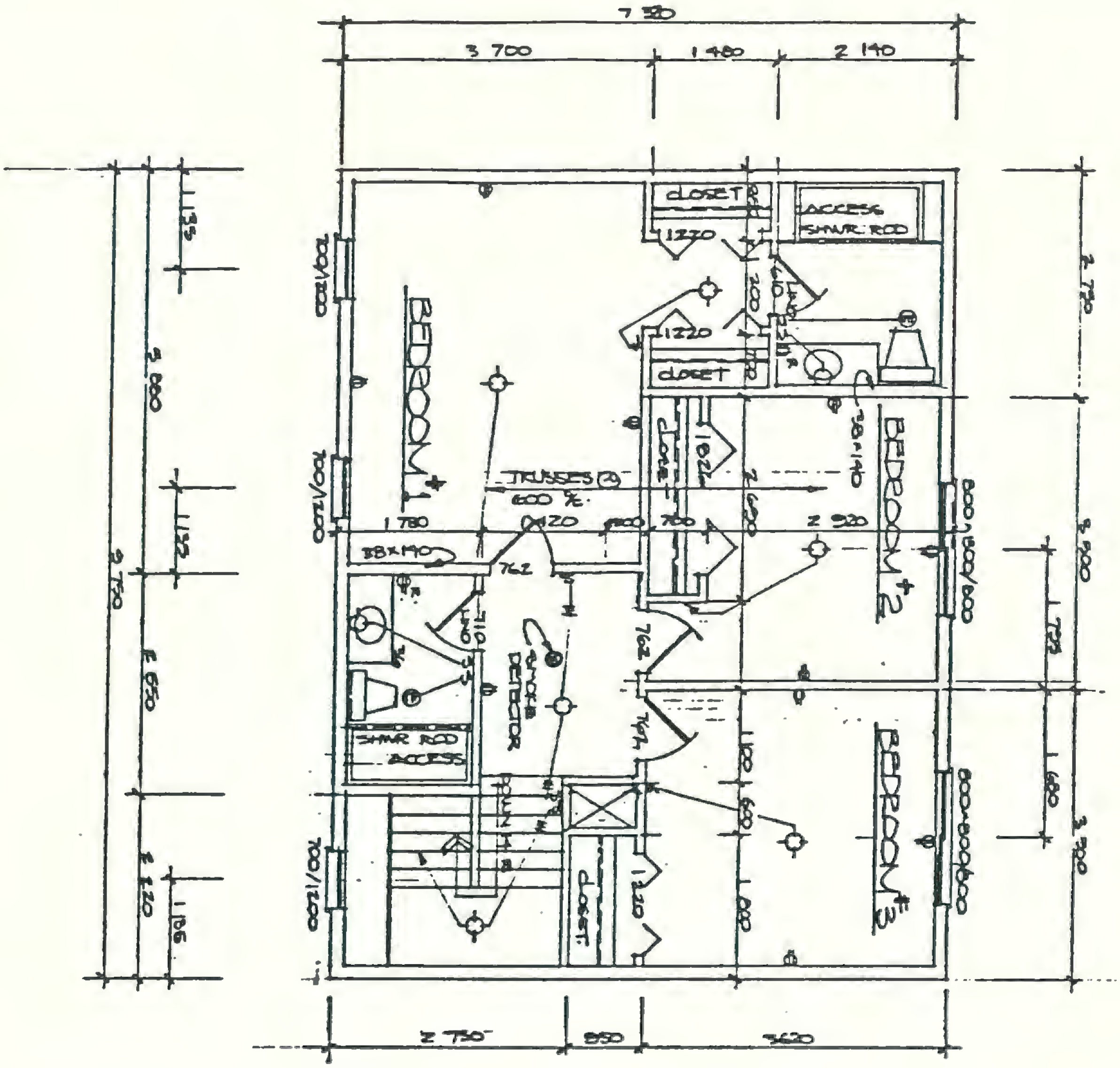

FIGURE 17: Second Floor Plan - Alberta Demonstration House

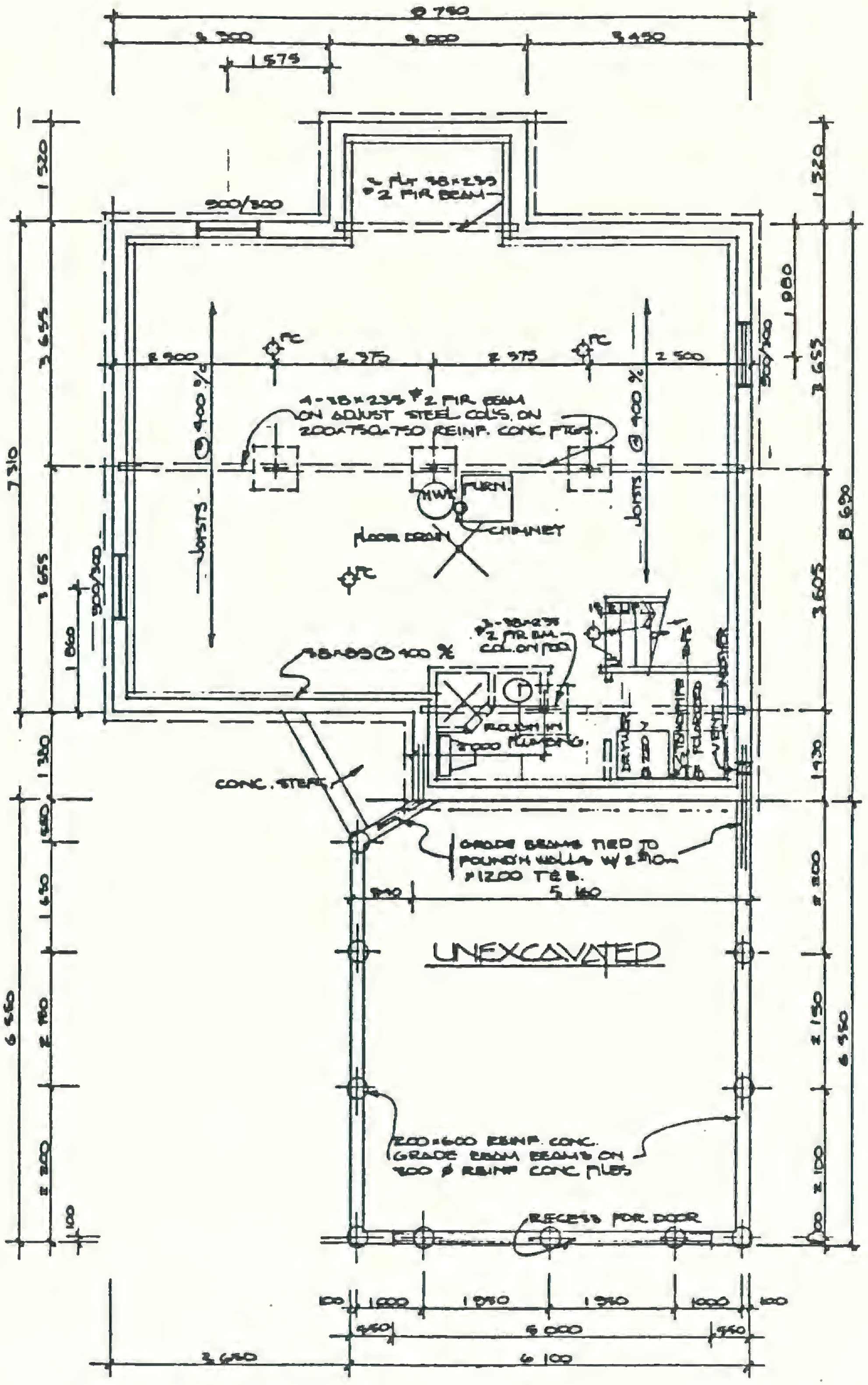

FIGURE 18: Foundation Plan - Alberta Demonstration House

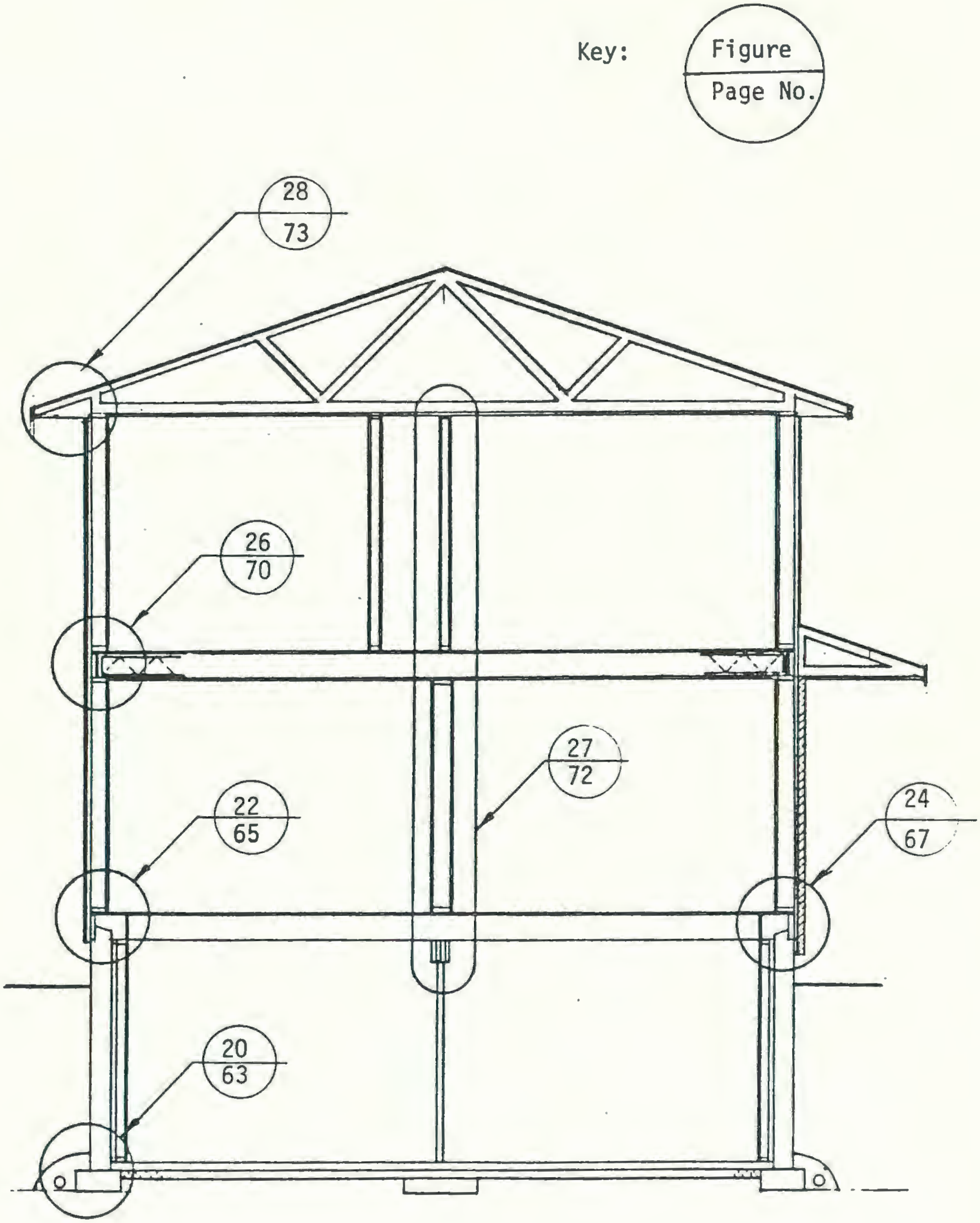

FIGURE 19: Location of Key Details on Cross Section - Alberta Demonstration House

Where floor joists are cast into the top of the concrete foundation wall the drywall which is applied to the stud wall is notched to fit between the floor joists and caulked. This method to achieve air barrier continuity at the first floor subfloor is the same as was developed previously and is shown in (Figure 22, page 65). An alternative to notching to achieve air barrier continuity is to install continuous gaskets* at the top and bottom of the floor system header, and on both sides of the top plate of the frost wall (Figure 23, page 66).

The Airtight Drywall Approach works equally well with preserved wood foundations (Figure 21, page 64). The approach utilizes the concept of moisture control to minimize the change of moisture content of the underlying soils as opposed to relying on the brute strength of foundation components to resist soil movement. This can be an advantage for some soil types such as expanding clay. Continuity of the air barrier at the first floor subfloor is achieved by utilizing balloon framing and caulking as in the first generation approaches previously described.

The framing of the Airtight Drywall Approach has been modified so that it is in fact platform frame construction. The exterior walls consist of 38 mm x 140 mm (2 x 6) studs spaced 600 mm (24") on center, filled with R.S.I. 3.5 (R20) fiberglass batt insulation and sheathed with 38 mm R.S.I. 1.2 (R7) "Glasclad" rigid fiberglass insulation for a total effective wall insulation value of R.S.I. 4.9 (R28). (Figure 22, page 65). This insulating sheathing is installed with the vapour permeable air barrier trade name ("Tyvek")

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* See appendix G - Gasket specifications.

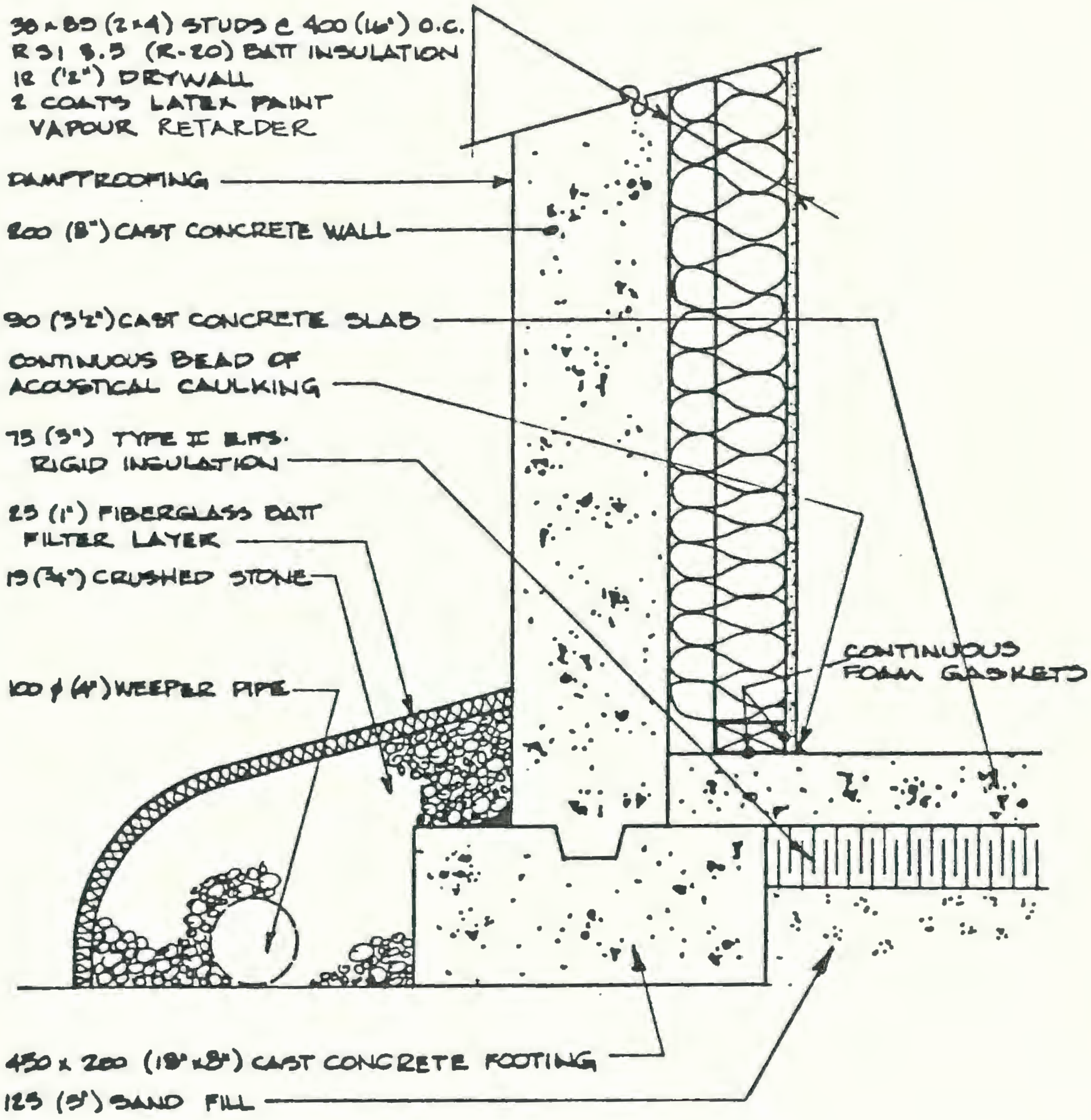

FIGURE 20: Concrete Footing and Foundation - Alberta Demonstration House

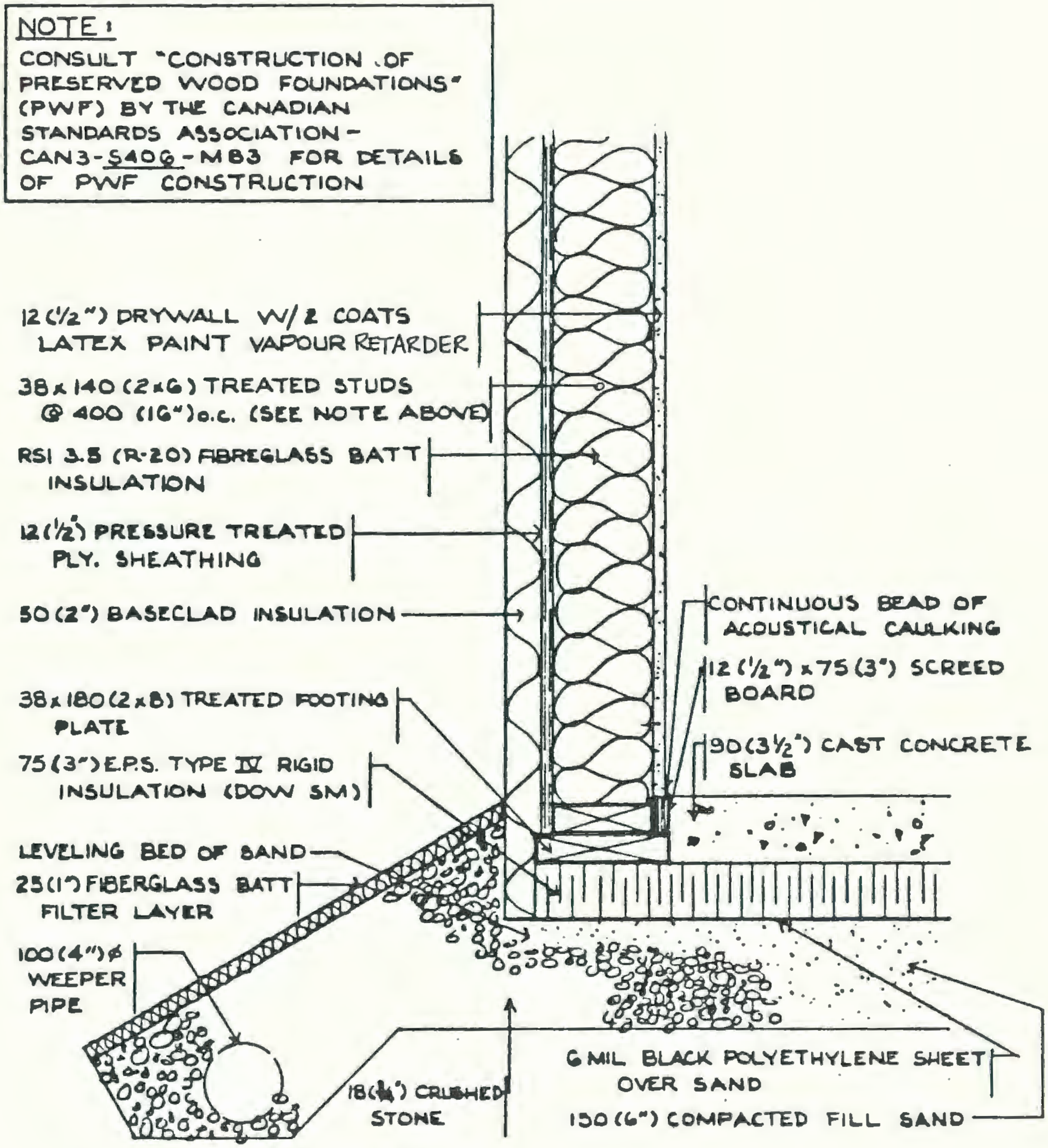

FIGURE 21: Alternative PWF Footing and Foundation - Alberta Demonstration House

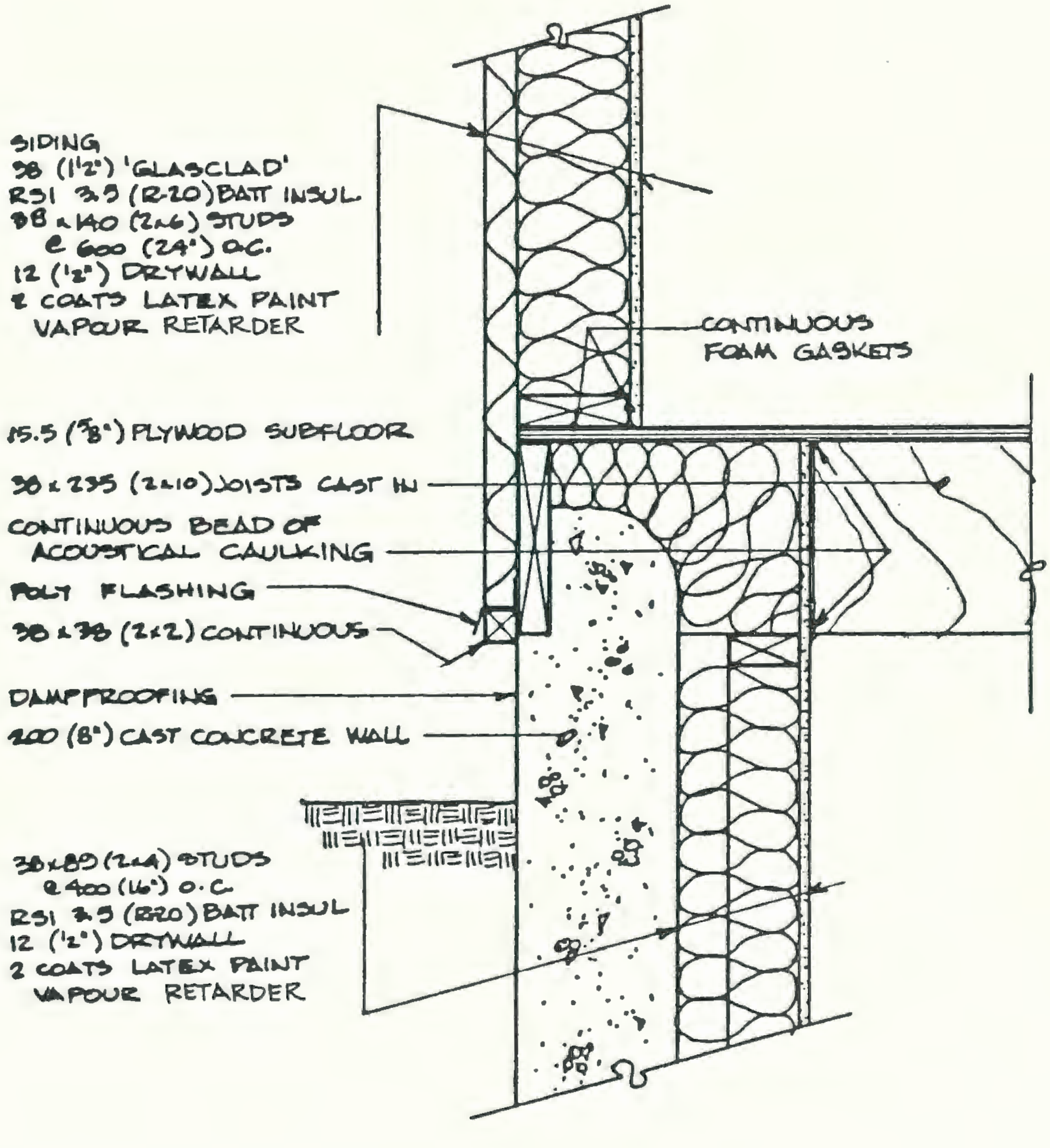

FIGURE 22: Top of Concrete Foundation Wall -
Alberta Demonstration House

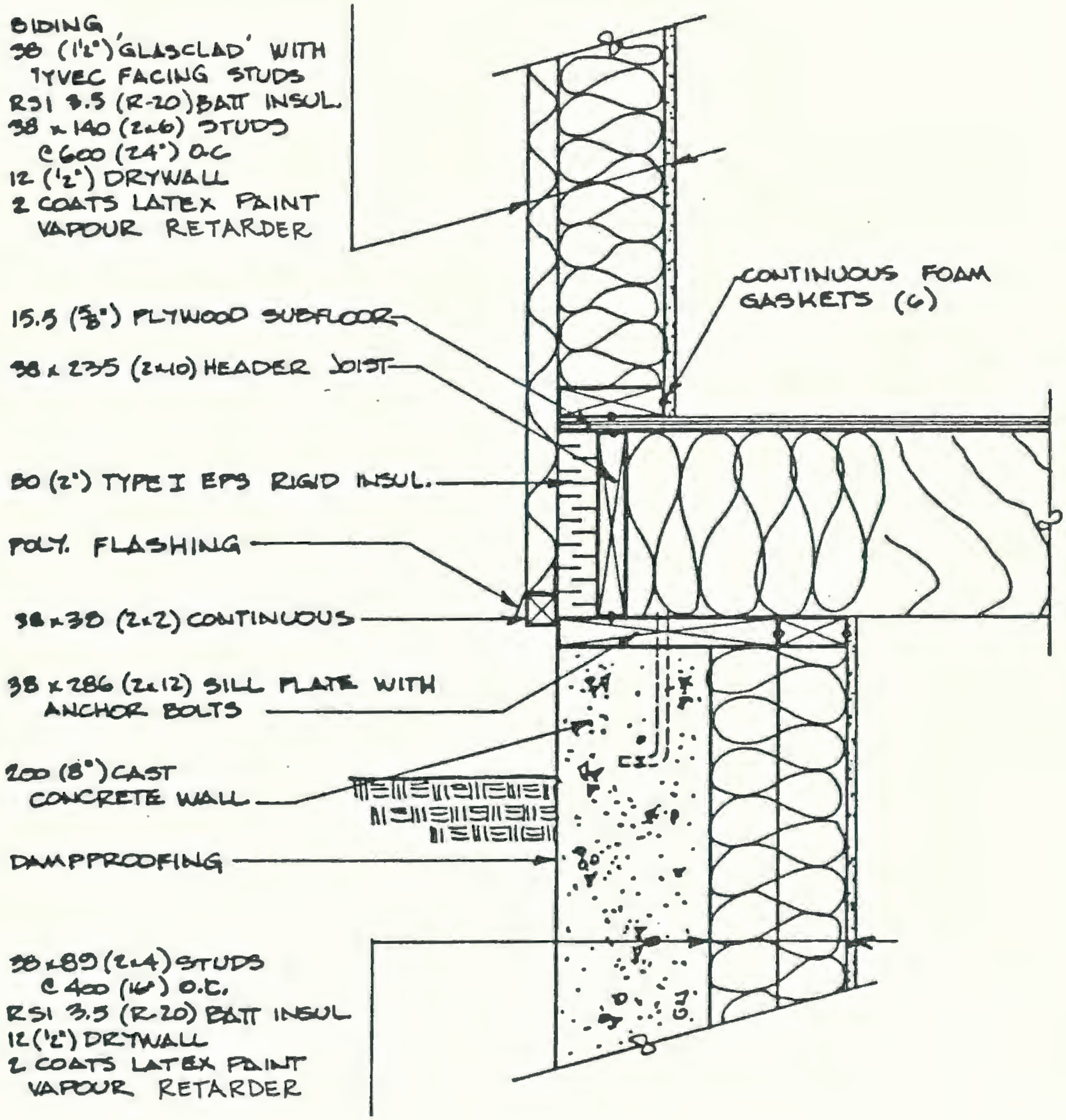

FIGURE 23: Alternative Detail for Top of Foundation Wall - Alberta Demonstration Project

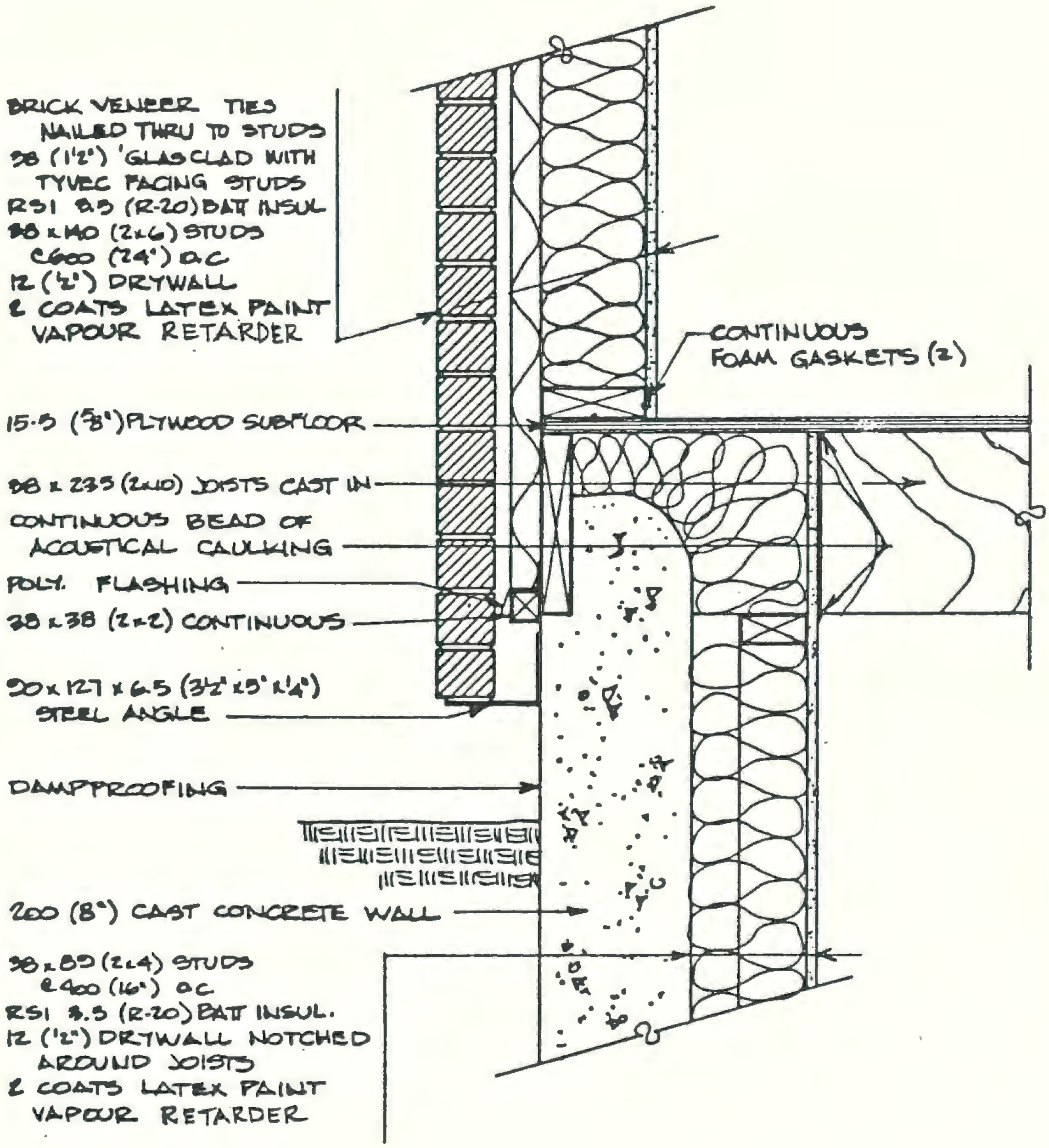

FIGURE 24: Top of Concrete Foundation Wall with Brick Cladding - Alberta Demonstration House

installed facing the studs. This reversed installation of the Glascald* allows for effective continuity fo the exterior air barrier without the usual requirement of taping the joints. The self draining Glasclad prevents moisture accumulation within the sheathing. The problems encountered with cold weather taping of Glasclad are of course eliminated with this method.

Continuity of the air barrier between the first and second storeys is accomplished by utilizing the second floor header which is recessed 50 mm to allow for the installation or external insulation (Figures 22 & 23, pages 65 & 66).

The framing method provides for the elimination of double top plates on interior and perimeter walls and elimination of some redundant window and door headers. It also allows for the possibility of a pressurized air plenum between the first and second storeys through the use of prefabricated wood floor trusses. The cost savings resulting from a more efficient wall framing approach offsets the added cost of upgrading wall framing members from 38 x 89 mm (2 x 4) to 38 x 140 mm (2 x 6). The additional costs of floor trusses for the second floor system would be more than offset by the cost savings associated with eliminating most of the ductwork in the forced air heating system.

Space and domestic hot water heating requirements are both met in one of two ways depending on the relative costs of gas and electricity. Either electric forced air and electric hot water heating system or a medium efficiency, induced draft, forced air gas furnace and an induced draft gas hot water heater are used. The power venting of flue gases in induced draft appliances effectively eliminates downdrafting or vent failure. It allows the gas appliances to operate safely even when the house experiences minor negative pressures which

*For a detailed explanation of the application of insulating sheathing see Appendix H - Insulating Sheathing.

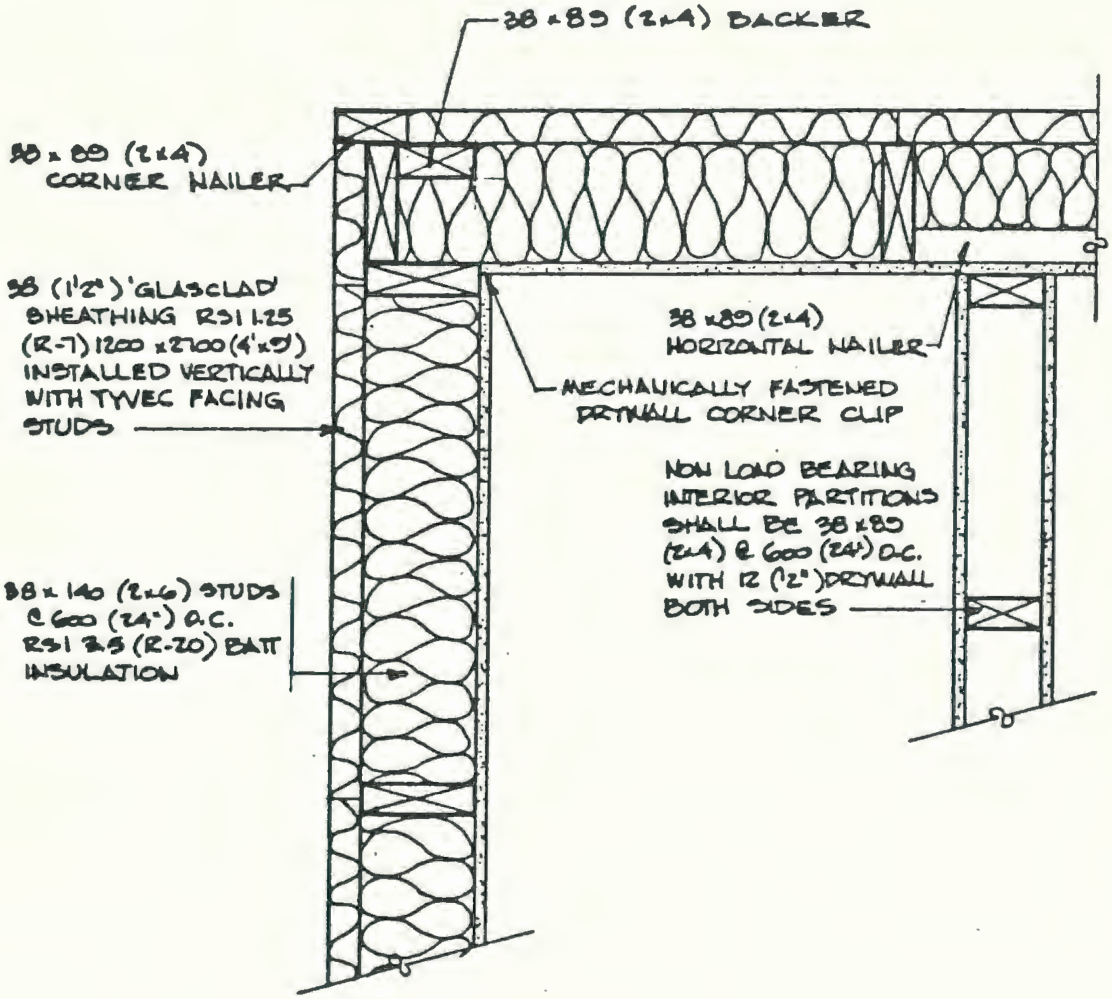

FIGURE 25: Corner Framing Details -
Alberta Demonstration Project

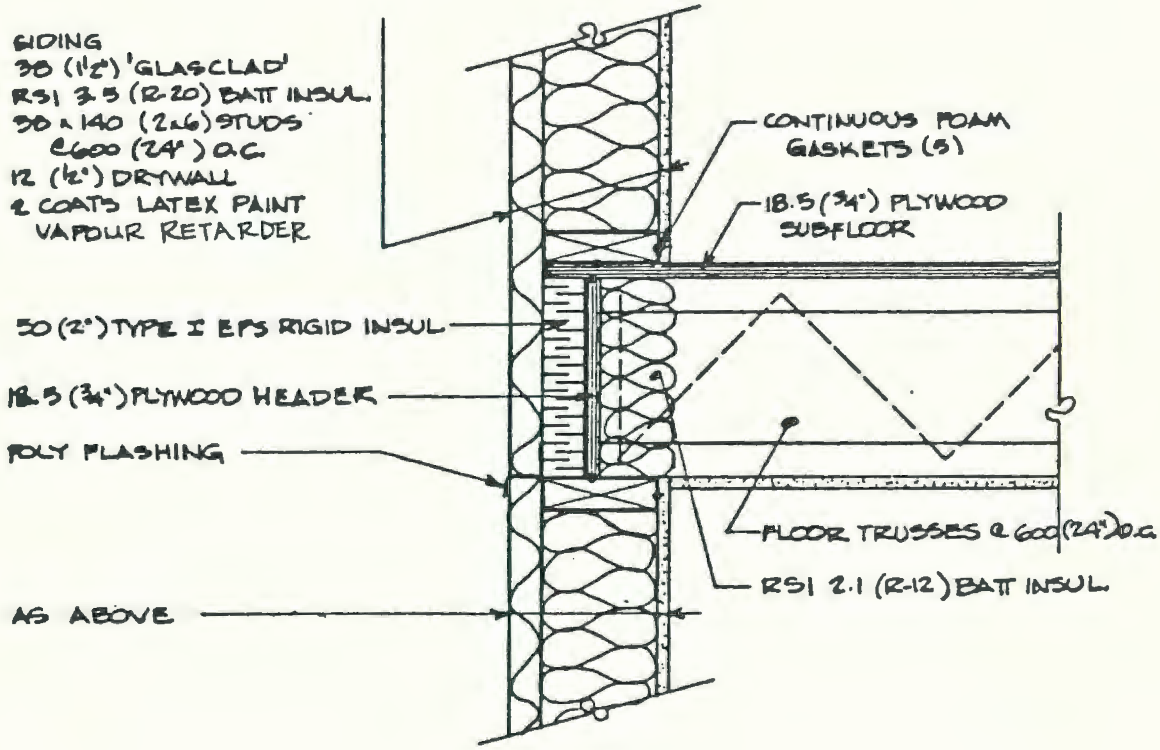

FIGURE 26: Exterior Wall at Second Floor - Alberta Demonstration Project

can result from the operation of other air consuming equipment or from environmental conditions around the house.

Air quality concerns are met through the installation of continuously operating fans in an air-to-air heat exchanger or by the installation of a central exhaust system with provision for make-up air. Where an air-to-air heat exchanger is used, it is installed such that it continuously draws air from all washrooms and from the kitchen area, effectively eliminating the need for typical bathroom exhaust fans. The kitchen stove hood is of the recirculating charcoal filter variety. Fresh air supplied from the heat exchanger will be dumped into the basement near a return air grill to the forced air furnace system. If a pressurized second floor joist system is used, the fresh air from the heat exchanger could be ducted to this second floor plenum and mixed with the supply air from the forced air furnace (Figure 29, page 74).

If instead of an air-to-air heat exchanger, a simple control exhaust system is installed which continuously draws air from all washrooms and from the kitchen area, provision for make-up air must be made. This is accomplished by installing fresh air inlet openings in each habitable room or by a fresh air intake opening ducted to the return air side of the forced air heating system.

Window and exterior door installation procedures remain the same as in the first generation Airtight Drywall Approach with the drywall simply returned and caulked to the window jamb (Figure 28, page 73). Electrical and plumbing service details remain virtually unmodified from the first generation approach.

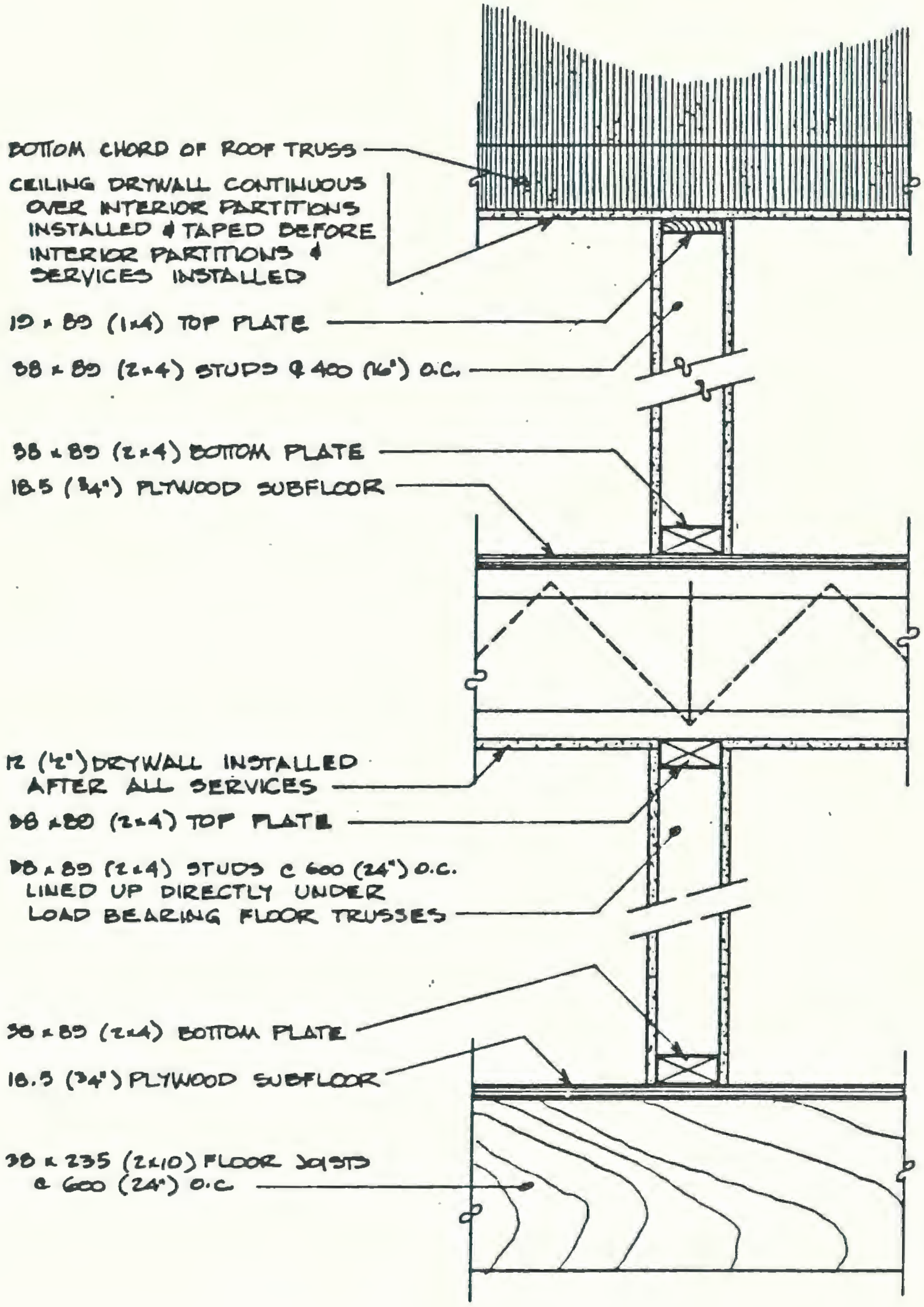

FIGURE 27: Interior Wall Details - Alberta Demonstration Project

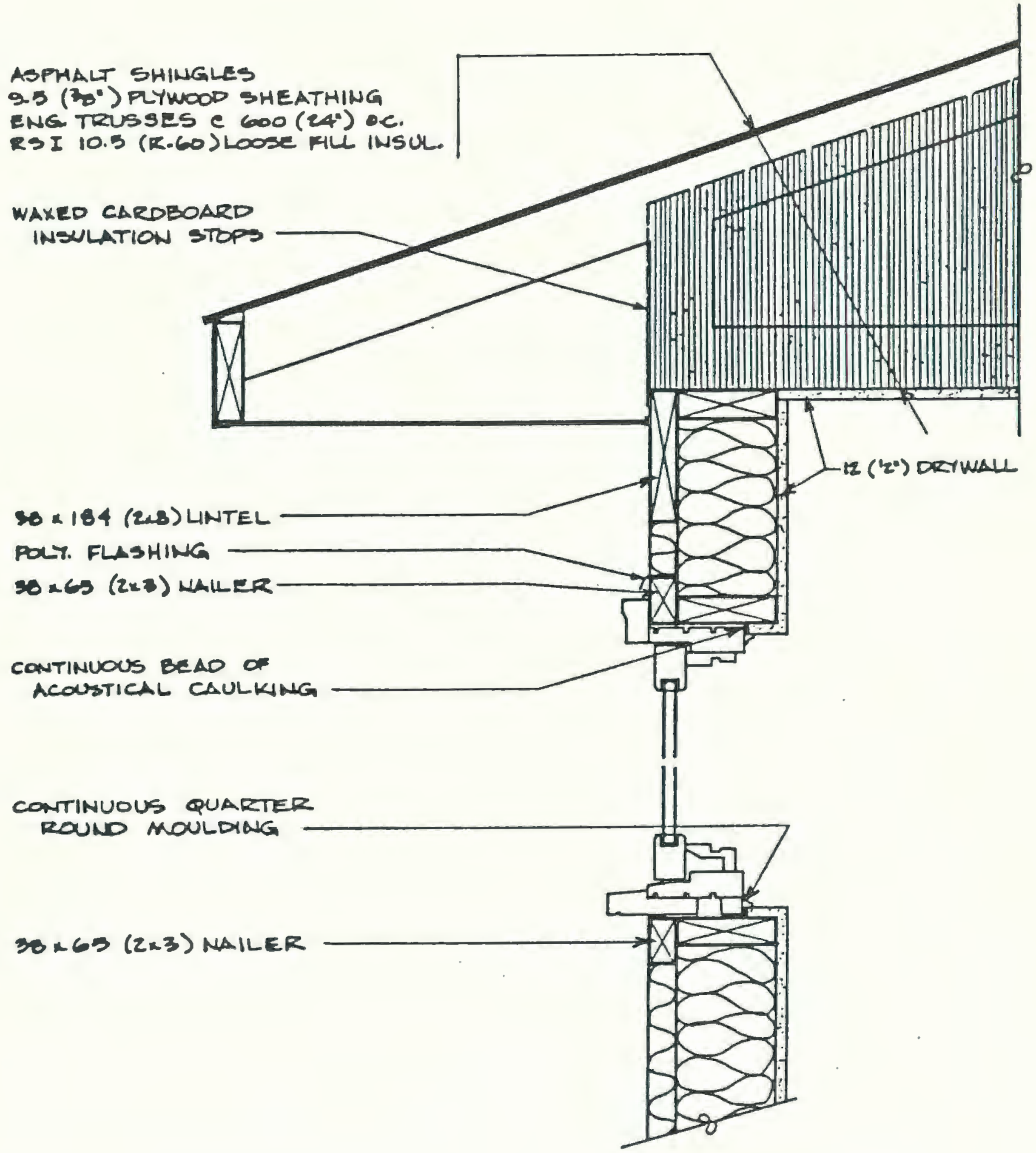

FIGURE 28: Exterior Wall, Window and Roof Overhang - Alberta Demonstration Project

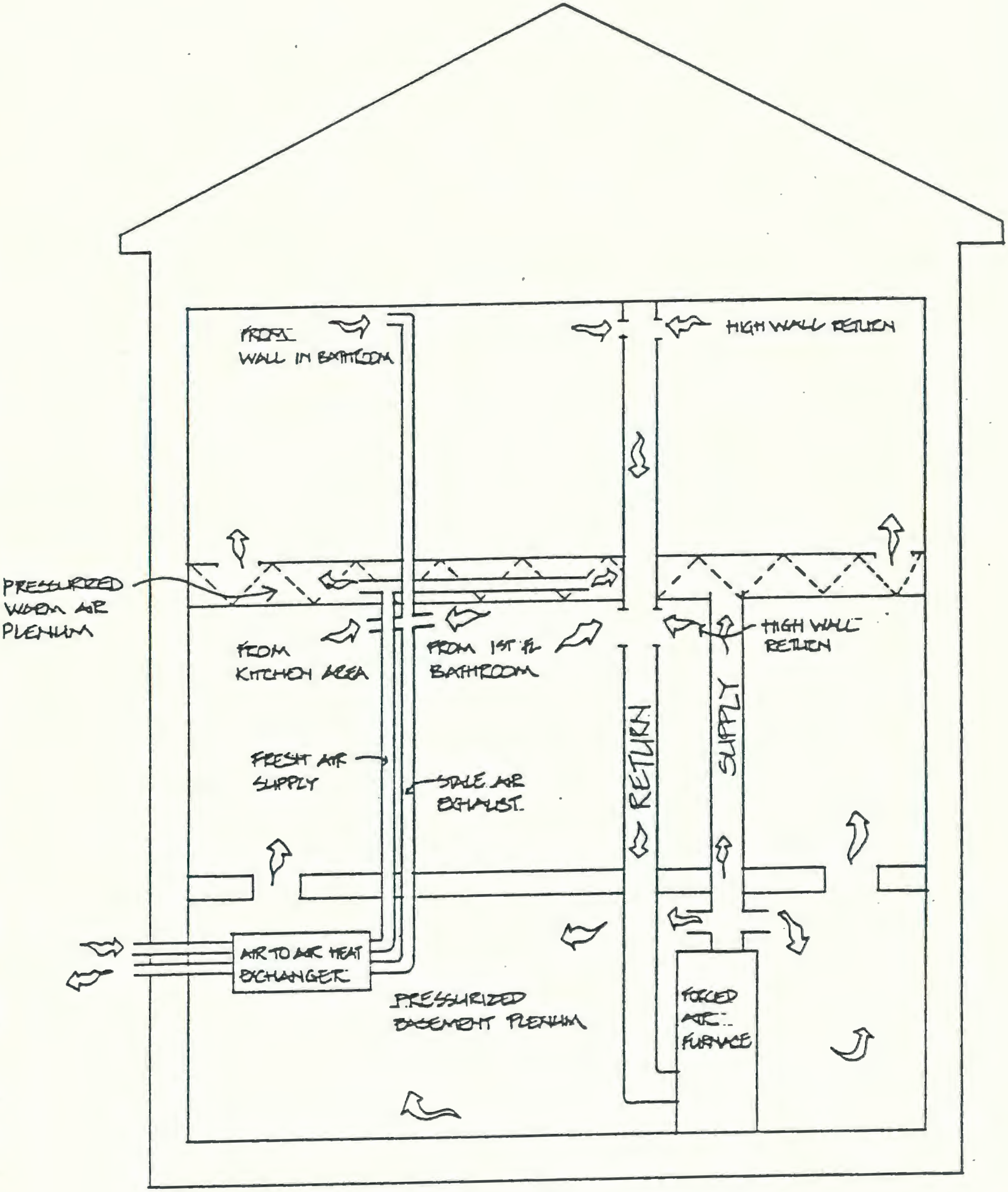

FIGURE 29: Heating and Ventilating Schematic - Alberta Demonstration Project

B. Incremental Costs

The estimated incremental costs (additional costs above standard construction) for the proposed second generation "Drywall Approach"* are estimated to be $3,700.00 for a 130 m2 (1400 s.f.) house. The incremental costs are broken down in Table 6 - Estimated Incremental Cost of Typical Second Generation Drywall Approach Home.

Table 6

Estimated Incremental Cost of Typical
Second Generation "Airtight Drywall Approach" Home

Interior basement and below slab insulation	+$1,110.00
Credit for using simplified framing procedures using 38 x 140 mm in place of 38 x 89 mm	-$ 350.00
Glasclad versus plywood sheathing	+$ 600.00
Additional Insulation above foundation	+$ 750.00
Medium eff. induced draft furnace	+$ 350.00
Medium eff. induced draft hot water heater	+$ 150.00
Air-to-air-heat exchanger (installed)	+$1,100.00
TOTAL	$3,700.00

C. Proposed Monitoring and Testing

The next stage in the development of the Airtight Drywall Approach is the construction of a number of "second generation" homes and the testing and monitoring of those homes. All the homes constructed should be tested for

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*For the purposes of the Alberta low energy demonstration project, the Federal government's R-2000, "Super-Energy Efficient" standard for energy efficiency is recommended.

airtightness utilizing the CGSB fan depressurization approach prior to occupancy. The homes should be monitored according to the approach described in Appendix D - Monitoring of Projects. As well heat loss simulation tests should be conducted as described in Appendix I - Air Quality and Combustion Air Testing.

VI. SUMMARY

The following conclusions can be drawn from the Brampton, Shelburne, Lawrence Park and London Houses and the previous research work upon which these projects were based:

1. There are significant building science problems associated with current popular approaches to building airtight polyethylene low energy homes specifically in the areas of long term durability of the polyethylene, and ability of the polyethylene to resist wind and stack air pressures in the wall cavities. The problems of the durability of sheet polyethylene films used as air barriers and vapour retarders can only be overcome by the addition of additives or the use of other film materials such as teflon, and by structurally supporting film type air barriers to resist wind and stack air pressures.

2. There is little likelihood that consistently reproduceable continuity of the air barrier is possible in tract built homes using the current polyethylene air/vapour barrier system. Even if more durable materials are used in place of the standard polyethylene, and if this material is structurally supported to resist wind and stack pressure, the problem would still be an unrealistic over reliance on unusual dedication by the tradesmen to make the system work. Current incremental costs associated with "airtight" polyethylene low energy homes built by tract builders will prevent the approach from being adopted by the residential tract housing industry unless governments cover incremental costs by grants or legislate compliance.

3. The "Airtight Drywall Approach" is a system that is designed to be compatible with tract building techniques, meet R-2000

Standards and results in incremental costs that allow such homes to be marketed without ongoing incremental cost subsidies by government or consumers. The Airtight Drywall Approach uses a building science approach to address problems which commonly occur in present housing including interstitial moisture accumulation (moisture trapped within wall cavities) and associated degredation of the building envelope.

4. If required, the airtightness characteristics of the Airtight Drywall Approach homes can be inexpensively maintained with retouching (after years of occupancy) by removing baseboards and mouldings and reapplying sealing compounds. Cracks in the gypsum board (drywall) that may occur over the service life of such houses are visible indications of flaws in the continuity of the air barrier. The cracks are unlikely to be overlooked by occupants who will be inclined to have them repaired. In this manner occupants are able to re-establish air barrier continuity at minimum expense. This is not possible in conventional construction, where the building envelope's air barrier is hidden by internal or external cladding.

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APPENDIX A: PROBLEMS WITH POLYETHYLENE

Building envelope airtightness has been most commonly achieved in low energy home construction through the utilization of a sealed, integral, polyethylene air barrier/vapour retarder.

Successful utilization of this integral, plastic film approach has been accomplished only when a great deal of effort has been placed on quality control and supervision of the construction process by trained professionals. This has led to cost and time premiums to achieve the high degree of airtightness of the building envelope that is required. The time involved in the training of staff is extensive, and the increase in time required to construct each home is significant. In addition, since most building trades are paid on a piecework basis, any modification in practice which results in an increase in time per unit of work is regarded negatively and is generally successfully resisted by the trades. The modifications in trade practice are not continued when supervision is intermittent.

The polyethylene air barrier/vapour retarder, to be effective, must be supported to resist wind and stack air pressures. Recent work carried out at the Division of Building Research of the National Research Council of Canada by R.L. Quirouette indicates that simply suspending polyethylene between wall studs, caulking the seams and fastening battens over the joints may not be sufficient to allow the polyethylene to resist wind and stack air pressures. Under peak wind loading, the polyethylene will be sucked into a wall cavity, rupture its seal and compress the insulation (Quirouette; 1983). It is also possible to destroy the integrity of a painstakingly installed polyethylene air barrier/vapour retarder through the act of conducting an air leakage test utilizing the fan depressurization method (Lstiburek; 1982) which induces a relatively large negative pressure of 50 Pascals within the house.

Polyethylene must also be protected during the construction process from being punctured, torn, or otherwise rendered ineffective. Furthermore, sheet polyethylene undergoes a chemical degradation process that is now beginning to raise concerns among the building science community. The process is oxidation. Most polyethylenes contain anti-oxidants which tend to migrate out of the polyethylene over an extended period of time. When the anti-oxidants are no longer present, the polyethylene becomes brittle and cracks under very low stresses. The process involving oxidation is accelerated at higher temperatures. When the polyethylene is kept at constant room temperature over several years such as is the case when polyethylene is used as an air barrier/vapour retarder and installed immediately behind gypsum board or "drywall" on the warm side of an insulated wall, the process may be rapid enough that brittleness can occur, depending on the composition of the polyethylene, within five years (Bowerman: 1983). A study, recently commissioned by Canada Mortgage and Housing Corporation to examine 40 randomly selected older houses, is investigating the actual rate of this degredation process. Once the polyethylene becomes brittle, normal wind and stack air presures are all that are required for fracture of the polyethylene to occur. Doubt about the long-term integrity of the polyethylene air barrier/vapour retarder has far-reaching implications. The impact of this particular degradation mechanism of the polyethylene air barrier/vapour retarder may prove to be devastating to woodframe construction.

The addition of improved anti-oxidants to polyethylene, as is done in the Scandinavian countries, or the use of dark coloured polyethylene which is more resistant to oxidation may become an accepted method of dealing with this particular degradation mechanism. Another approach may be the use of another film material such as teflon that is not susceptible to this type of degredation. A teflon film, structurally supported to resist wind and stack air pressures and protected during the construction process, may be an acceptable solution in the building science sense. Cost effectiveness, however, will likely prove to be another matter.

APPENDIX B: VAPOUR MOVEMENT

Two transport mechanisms govern the movement of water vapour in building and wall assemblies. They are: firstly, vapour diffusion or the movement of water vapour through building materials; and secondly, the movement of moisture laden air through the cracks and joints within and/or around the building materials that make up a particular wall or building assembly. These two transport mechanisms act independently of one another and the magnitude of their effect on total vapour movement is commonly misunderstood.

It has been shown (Quirouette: 1983) that the movement of water vapour through a 1 mm diameter hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of vapour diffusion through that same 1 mm diameter hole.

In Canadian Building Digest 175, J.K. Latta states: "Air leakage is now considered to be the prime cause of most condensation problems in walls and roof spaces. If, therefore, a building can be made tight against air leakage it may not need a vapour barrier, as defined. On the other hand, if there are openings that permit air to leak from the warm side to the cold side of the insulation, adding a vapour barrier (even of zero permeance) that does not seal off the openings will be useless." (Latta; 1976).

Continuity of the air barrier is the single overriding factor in controlling the movement of water vapour into wall and building assemblies. If the movement of moisture laden air into a wall or building assembly is eliminated, vapour diffusion as a moisture transport mechanism is not significant.

The equation used in calculating water vapour diffusion through materials is based on a form of Fick's Law, and is as follows:

$$W = M\ A\ 0\ p$$

Where

W = total weight of vapour transmitted in nanograms (ng)
A = area of cross section of flow path, in square meters (m^2)
0 = time during which the transmission occurred in seconds (sec)
p = difference of vapour pressure between ends of the flow path, in Pascals (Pa)
M = permeance coefficient, perms, or ng. per (sec) (Pa) (m^2)

From this equation it can be seen that vapour diffusion is a function of the permeance co-efficient, vapour pressure differential, length of time of transmission and surface area. In a typical house, operated at a given, occupant selected, internal relative humidity and temperature the vapour pressure differential and the length of time of transmission are easily determinable and generally fall within a narrow range. If the permeance of the vapour retarder is fixed, at say a permeance close to that of a Type II vapour retarder, the equation shows that when 90 percent of an area of the building envelope area is covered with a vapour retarder, then that vapour retarder is 90 percent effective.

In other words, continuity of the vapour retarder is not as significant as continuity of the air barrier. For instance, a paint film applied only on the interior exposed surface of the building envelope coupled with a continuous, effective air barrier will act as an effective vapour retarder. This is shown below.

According to the CGSB standard CAN2-51.33-M80, Vapour Barrier, Sheet, for Use in Building Construction, a Type II vapour retarder considered suitable for most usual conditions in a house is arbitrarily classed as a material having a permeance of 45 ng/Pa/s/m^2 before aging and 60 ng/Pa/s/m^2 after aging. Tests conducted by the Dow Chemical Company show that common paint types have the following permeances after aging for the specified coverages.

Paint Type*	Permeance	Coverage (5 litres)
Semi-gloss latex	33 ng/Pa/s/m^2	42 m^2
Flat latex	172 ng/Pa/s/m^2	43 m^2
Flat oil based	96 ng/Pa/s/m^2	42 m^2
Latex Primer	350 ng/Pa/s/m^2	23 m^2
"Insul-Aid" Primer	34 ng/Pa/s/m^2	40 m^2

From this table it can be seen that the requirement for a Type II vapour barrier can be met using paint films in the following manner:

a) One coat of semi-gloss latex paint over a single coat of a standard latex primer;

b) Three coats of flat latex over a single coat of a standard latex primer; and

c) One coat of flat latex over a single coat of "Insul-Aid" primer, a proprietary material.

It must be stressed that the requirement for a Type II vapour retarder in typical house construction is an arbitrary one. Recent research (Quirouette, 1983; Handegord, 1983) indicates that control of vapour movement through the use of a continuous air barrier and an effective vapour retarder is more effective than the use of an "absolute" (zero permeance) vapour barrier which may or may not be continuous. The key word to note is the word "control". An absolute permeance rating for a vapour retarder is not as important as how that vapour retarder is utilized in the wall or building assembly. It is not so much the complete elimination of moisture migration into a wall or building cavity that is important, but rather it is important that more moisture can leave a wall or building cavity than enters it.

It is becoming accepted among the building science community that a vapour retarder should have one tenth the permeance of the exterior cladding in a wall assembly if diffusion is relied upon as the only

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* Only published values have been given for some common paint types. Although no published values could be found for semi-gloss oil based, it is expected that they would show a permeance equal to or less than semi-gloss latex.

transport mechanism moving moisture out of a wall. This 1:10 rule allows for the control of the vapour movement due to diffusion rather than attempting to completely eliminate the vapour movement.

Applying the 1:10 rule in a wall assembly utilizing external fiberglass insulating sheathing, "Glasclad", which has a permeance of 1725 ng/s/Pa/m2, shows that a single coat of flat latex paint over a single coat of a standard latex primer, which together have a permeance of 115 ng/s/Pa/m^2, will act as an effective vapour retarder. This of course is conditional on the existence of a continuous air barrier. If a continuous air barrier is not present, then the permeance of the vapour retarder is of no consequence in preventing moisture movement into the wall assembly. A vapour retarder of zero permeance will not significantly improve the performance of a wall assembly if a continuous air barrier is not present.

It must be noted that diffusion is not the only mechanism of wall drying, and that satisfactory wall performance can be obtained with impermeable external sheathing, both insulating (extruded polystyrenes and foil-faced polyurethanes) and non-insulating (plywoods and waferboards). The operative principal is, as noted previously, that more moisture be allowed to leave a wall or building cavity than enters it. This can also be accomplished by allowing condensed moisture to drain out of a wall.

Condensation often occurs within wall and other building cavities without catastrophic effects. Buildings can often withstand short term moisture shocks, provided that regular drying is allowed to occur. It would be impractical to attempt to eliminate interstitial condensation from occuring under all conditions. However, it is practical to design walls and other building components in such a manner that when condensation occurs, it does not lead to building envelope deterioration. One such approach is the "draining" wall. The draining wall is similar to the "rain-screen" approach that has been successfully used in commercial/office construction. By flashing the bottom of a study wall which has a self-draining insulation such as Glasclad, interstitial moisture within the wall cavity will be led out of the envelope of the house. The concept of draining walls for residential construction was first presented by G.O. Handegord, in 1983 while at the Division of Building Research of the National Research Council of Canada.

APPENDIX C: AIR QUALITY
CONTROLLED VENTILATION AND HEATING SYSTEMS

A few fundamental assumptions are necessary when dealing with the problem of air quality. The first is to assume that all houses built, not just low energy houses, are "airtight". It is difficult in most cases to predict the envelope tightness of a home before it is built. To consistently build "tight" houses requires a great deal of effort on the part of a builder when he uses conventional means of airtightening. However, it is possible to "accidentally" build a tighter than average house. The problem is that a builder rarely knows when this happens. In addition, the normally random distribution of leakage openings in a typical house causes the instantaneous infiltration/exfiltration rate in the house to vary substantially due to the influences of wind pressures, stack pressures and pressures induced by air exhausting appliances. Thus, a house or areas of a house can have adequate air change at one point in time and not have adequate air change at a subsequent point in time. The variation can be so substantial that the infiltration/exfiltration rate may be on the order of 300 litres/second (8 times the usual continuous requirement) during a wind gust and moments later zero if the wind suddenly dies down and all the randomly distributed leakage openings accidentally and temporarily happen to fall along the neutral pressure plane. At the neutral pressure plane, no pressure differential exists across the building envelope. Since air movement occurs only when pressure differences exist, no air movement occurs through a leakage opening located at the neutral pressure plane. As the neutral pressure plane moves as a result of the effects of wind and stack air pressures, infiltrating openings become exfiltrating openings and vice versa. This has important effects on the amount of air change occuring at any particular point in time as well as the location of this air change. Therefore, the assumption of an airtight house makes practical sense.

The second assumption is to assume that all of the necessary exchange of air for air quality reasons will be accomplished by a continuously operating mechanical ventilation system. The designer or builder now only has to choose a ventilation rate. Unfortunately building codes do not adequately deal with the issue of ventilation rate. Although the issue is pressing, code authorities will not likely settle on a specific approach to ventilation or set a ventilation rate in the near future. The Technical Research Committee of HUDAC has adopted the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. standard on ventilation rates (ASHRAE Standard 62-1981) as the basis for their upcoming guide to builders on the design and installation of controlled ventilation systems. It is likely that the ASHRAE ventilation rates will be ultimately referenced by the various building codes, and as such it also makes practical sense for a builder or designer to base their ventilation rates on ASHRAE.

ASHRAE Standard 62-1981 has the following requirement for outdoor air:

- 5 litres per second (10 cfm) per habitable room.

This requirement is independent of house size, and includes bedrooms, living rooms, dining rooms, kitchens, bathrooms and any other rooms in the house except rooms in the basement. The standard also provides for additional air requirements for bathrooms and for kitchens as follows:

- 25 litres per second (50 cfm) for each bathroom supplied on an intermittent basis when a bathroom is used; and

- 50 litres per second (100 cfm) for kitchen exhausts on an intermittent basis when required.

This can be illustrated by considering a typical home with a living room, dining room, kitchen, three bedrooms, and one bathroom. Using ASHRAE Standard 62-1981, the ventilation requirements would be:

Total Rooms: 7 x 5 L/s = 35 L/s on a continuous basis
Bathroom: = 25 L/s on an intermittent basis only when in use
Kitchen: = 50 L/s on an intermittent basis only when in use
TOTAL = 35 L/s + 75 L/s intermittent

The third assumption is that it is necessary to mechanically distribute the fresh air within the house envelope to avoid "dead" areas in the house. Dumping all the fresh air into one region of a house will do very little for the air quality in other regions of the house.

The three assumptions described above effectively deal with the entire question of air quality. The difficulty arises when a builder or designer applies them in the field. Numerous practical field solutions are possible. However, some are better than others from both a performance and cost point of view.

Once the air quality question has been adequately described, the question of adequate make-up and/or combustion air remains.

The entire combustion air/make-up air issue can be dealt with by the application of a single principle. Aerodynamically uncouple all combustion equipment from the influence of house interior air pressures. This can be accomplished by installing combustion equipment air from within the house or by providing a source of external air for those purposes. An additional solution is to provide equipment that is not sensitive to interior air pressure variations. Such equipment includes induced draft gas hot water heaters and medium efficiency induced draft gas furnaces. While both types of devices require combustion air from within the house, they have power fans to mechanically exhaust the products of combustion. That is, both devices mechanically induce a draft to occur and as such do not require draft control air to operate nor do they have a tendancy to backdraft from negative pressures that may occur within the house enclosure. The amount of combustion air required by both these devices is so low as not to influence or be influenced by typical pressure variations within the house. Fireplaces can be effectively uncoupled from the house enclosure by providing a combustion and draft control air duct running from outside the house to the firebox and by installing glass doors.

The application of the uncoupling principle effectively deals with the question of combustion/draft control air. Numerous specific field solutions are possible. Several solutions are outlined below.

Solution One

Install an induced draft forced air gas furnace with a duct leading from the outside directly into the return air supply to the furnace. In addition install an induced draft gas hot water heater and a central exhaust system venting all bathrooms. Install a standard kitchen exhaust system.

In this approach the central exhaust system runs continuously and the furnace fan is also set to run continuously. In this manner air quality and ventilation requirements are met as the furnace fan is constantly drawing in fresh air from the exterior and distributing it throughout the house and the central exhaust system is continuously exhausting stale air. The central exhaust system would be powered by a two speed fan with the high speed mode activated by timed switches in bathrooms when they are in use and by a centrally located humidistat.

The incremental costs of this solution would be:

induced draft furnace over std. gas furnace	+$350.00
induced draft water htr. over std.	+ 150.00
central exhaust system	+ 200.00
savings on bathroom fans	- 100.00
TOTAL	$600.00

Solution Two

It is the same as solution one except the central exhaust system and fresh air intake pipe to the return side of the furnace duct system is replaced with a continuously operating air-to-air heat exchanger.

The incremental costs of this solution would be:

induced draft furnace over std. gas furnace	+$ 350.00
induced draft water htr. over std.	+ 150.00
installation of air-to-air heat exchanger	+ 1,100.00
savings on bathroom fans	- 100.00
TOTAL	$1,500.00

Solution Three

Install an electric forced air furnace with a fresh air intake to the return air side of the furnace and install an electric hot water heater. In addition install a central exhaust system as in solution one.

The incremental costs of this solution would be:

central exhaust system	+$ 200.00
savings on bathroom fans	- 100.00
TOTAL	$ 100.00

Solution Four

Same as solution three except replace the central exhaust system and the fresh air intake to the return air side of the furnace and install an air-to-air heat exchanger.

The incremental costs of this solution would be:

installation of air-to-air heat exchanger	+$1,100.00
savings on bathroom fans	- 100.00
TOTAL	$1,000.00

Solution Five

Modify in solution one or solution three by replacing the fresh air intake pipe connected to the return side of the furnace duct system with individual fresh air intake openings located in each room of the house, except bathrooms and kitchen. These openings would be located on exterior walls, near the ceiling level. The openings would be small, allowing only 5 L/s flow at a design pressure difference of 7 pascals. The system would work as follows:

1) as air is exhausted out of the house enclosure by the central exhaust system, the neutral pressure plane is raised above the ceiling level, and the entire house is depressurized relative to the outside conditions.

2) due to the pressure difference across the building envelope (negative pressure on the interior, positive pressure on the exterior) fresh air will be drawn into the house through the individual fresh air intake openings located in each room.

The advantage of solution five is that each individual opening could be controlled by the occupant. Also potentially cold, incoming fresh air in this approach does not induce stress effects on heat exchange surfaces in forced air furnaces that can lead to corrosion and premature failure as is possible in the ducted intake pipe approach in solutions one and three.

The disadvantage of solution five is that the openings must be sized so as to allow only 5 L/s maximum, to prevent uncomfortable drafts, and that the system is practical only in very tight houses. In leaky houses, far too much air would have to be exhausted to achieve the depressurized condition, raising the neutral pressure plane above the ceiling, so as to induce infiltration forces across the entire building envelope. However, in very tight houses exhausting only the volume of air as calculated by ASHRAE for air quality reasons will serve to move the neutral pressure plane above the ceiling level. The operating cost impact of this solution when aplied to a tight house approximately a 10 percent increase in seasonal operating cost over a tight house with a continuously operating ATAHE with a seasonal recovery efficiency of 50 percent. This result makes it very difficult to justify heat recovery on ventilation on ventilation air at the present capital costs of installed heat recovery devices (ATAHE's and heat pumps).

The important fact to note when comparing the costs of the alternative solutions is that the costs given are for capital or installed costs only, not operating costs. Therefore, it would be simplistic to make a choice of system based on lowest installed capital costs. Energy consumption and energy pricing should have a significant impact on the choice among alternative solutions.

APPENDIX D: MONITORING OF PROJECTS

The monitoring program has been designed to concentrate on specific areas of interest to low energy home designers. The areas are:

a) space heating energy consumption;
b) air-to-air heat exchanger installed efficiencies;
c) tracking climatic conditions and indoor conditions resulting in heat exchanger frosting;
d) heat exchanger cycling and duration of frosting;
e) hot water energy consumption with the aim of examining the practicality of load scheduling; and
f) solar induced temperature swings.

Each house monitored has a number of temperature, humidity, and energy measuring sensors. In particular, there are north side and south side temperature sensors to pick up solar gain induced temperature swings. There are also basement temperature sensors and second storey temperature sensors which indicate the extent of house temperature stratification. These sensors provide a dry bulb temperature indication. A dry bulb temperature for the exterior temperature of each house is also taken. House interior relative humidity is also sensed. Where they are utilized, air-to-air heat exchangers are instrumented with temperature sensors, providing temperatures at the inlet and outlet streams on both sides of each heat exchanger. The input humidity of the exhaust air stream of each heat exchanger is also sensed. As well, the ATAHE's have fan speed and defrost sensors. In this manner ATAHE efficiency measurements can be obtained as well as total defrost times and conditions under which defrosting occurs. Total electrical energy usage is measured, as well as the subtotals for heating and for hot water. Gas consumption measurements for space heating and hot water heating are also measured where gas is utilized.

Total electrical energy usage is measured by modified kilowatt-hour meters, where the number of revolutions of the meter disc are optically sensed and totalled. For loads which have a fixed rate of energy usage, such as electric water heaters, "on time" of the device is measured. This method is also utilized for the case of gas furnaces and gas water heaters.

A small, local sensor microcomputer (sensor processor) located in each house, under the control of a central site microcomputer, processes the local sensor signals to a digital form and transmits the data back to the central site microcomputer. The central site microcomputer, processes the local sensor signals to a digital form and transmits the data back to the central site microcomputer. The central site microcomputer can collect data from up to eighty (80) local sensor processors (one local sensor processor per house) with each local sensor processor capable of processing the signals from up to 256 different sensors. The central site microcomputer is linked via a modem and dedicated telephone line to an off-site microcomputer where data analysis takes place. The telephone link allows the status of the system to be determined remotely (whether any sensor failure or data acquisition failure has occured and where the failure is located) as well as allowing data to be transmitted. The remote telephone link also allows the data collection software program or control program to be changed without site visitation should frequency of data collection need to be modified.

The central site microcomputer has a clock with battery back-up, to regulate the timing of data collection. This clock, a low-drift, crystal controlled device, is used by the control program to provide timing and to aid in the recovery of a proper data collection schedule after a power failure, should one occur. The data collected is stored in banks of ultra-violet light erasable, programmable read only memory computer chips (EPROM's). These EPROM's provide a non-volatile, solid state, rugged storage medium for the data, preventing loss of data in the event of a power failure. Storage for more than 60 days worth of hourly data is provided at each installation. Although data is collectable by means of the dedicated telephone line, the solid state memory still must be collected and unused memory installed every 60 days.

Data collection is made by exchanging an erased EPROM memory board with the EPROM board in the system. The collected EPROM memory board is returned to an off-site microcomputer where data manipulation takes place. The data from the EPROM boards is converted into a high-speed serial RS232-compatible data stream and read into the off-site microcomputer. After loading the data into the off-site microcomputer the EPROM boards are erased and used for subsequent interchanges of memory boards.

Concealed wiring is used for connections to the sensors located in finished portions of the instrumented houses. Local signal processors or interfaces, not requiring access after installation, are mounted indoors, on the main house electrical panel in sealed cases. Power for the interfaces comes from bell transformers, installed on the main electrical panels.

The central site microcomputer and support devices are mounted on the exterior of one of the houses within each study site. The equipment is housed in a steel, insulated box, with a key-operated lock. The box is sealed against water ingress and is temperature controlled, providing a stable environment for the electronic components.

The temperature sensors used are National Semiconductor LM135 and LM335 temperature sensing integrated circuits (IC's). They are adjustable for correct reading at a single temperature. The sensors are accurate over a plus or minus 40 degree Celsius range to plus or minus 0.5 degrees Celsius. Each device's thermal time constant in still air is approximately 30 seconds.

The signals from the temperature sensors are digitized by means of a National Semiconductor ADC0803, which has an adjusted error of plus or minus 1/2 bit. This analogue to digital converter provides a resolution of 0.5 degrees, giving a span of 128 degrees Celsius.

Sensing of relative humidity is done with a solid state sensor, the Phys-Chemical Research Corporation PCRC-11T sensor. These sensors have an accuracy of plus or minus 3 percent. Temperature compensation is provided in hardware. The signal is processed using an ADC0800 ratiometric analogue to digital converter as part of the local interface.

Relay interfaces are used to determine the "on time" of the various devices and applicances so monitored. These relay interfaces are connected across the electric gas valves in gas furnaces, and heating elements in electric furnaces. In this manner the devices have their on or off state read and recorded as run time in each hour.

Each local signal processor or interface communicates with the central site microcomputer over three pair cable using a MC14469 chip and differential drivers and receivers for high noise immunity. This provides the serial interface for data transmission and control between the central site microcomputer and the local signal processor. Each local signal processor has it's own local power supply, interfaces, analogue to digital converters for the temperature and humidity sensors, and the necessary status bits.

Each central site microcomputer interfaces with the local signal processors through the local interface serial data lines. Each unit is powered by it's own power supply, providing +5, +12, -12, and +25.5 Volts DC regulated supplies for the peripheral devices. Installed software in ROM (read only memory) provides for the collection, pre-processing and storage of data. The system itself, and its software, will automatically start following a power glitch.

A direct-connect, answer type modem, with a ring detect allows the central site microcomputer to detect when an off-site microcomputer is phoning it up for verification or data transmission. On detecting a ringing signal, the modem goes off-hook, and establishes communication with the off-site microcomputer. This may be done at any time, allowing verification of system operation or data transmission at arbitrary intervals.

Data is recorded as hourly figures, although many observations of each quantity are made in each hour. As appropriate, data is averaged and/or totalled over a one hour period, then stored.

APPENDIX E: HEAT LOSS SIMULATION TESTING

One of the objectives of the Canadian Standards Association (CSA) Committee on the Energy Evaluation and Labelling of Houses has been to develop a test method to determine the energy performance characteristics of a house in an "as-built" state. Towards this end, a great deal of work has been carried out by that Committee's Sub-Committee on Testing. It was thought initially by the Sub-Committee that a test procedure suggested by CMHC and carried out to a limited extent on homes in the Apple Hill subdivision in Ottawa was an appropriate test. However, the CMHC method was criticized for the difficulty it had in determining a suitable value for the thermal mass effect of a house under test (the house time constant) and whether it was in fact necessary to determine that parameter.

It is proposed that the test procedure be modified so as to determine the house "UA product" as opposed to determining the house time constant. The UA product is a mathematical representation of the resistance to heat flow over the entire envelope area of a particular house. The following is the simple steady state heat balance of a house:

(Solar Gains) + (Internal Gains) + (Furnace Output) = (Envelope Losses) + (Ventilation Losses) + (Infiltration/Exfiltration Losses)

where:

Envelope Losses = U x A x (To - Ti)

and where: To = average outside temperature
Ti = average inside temperature
A = total envelope area of house
U = average thermal transmittance of envelope.

Determining appropriate value for each of these components is the heart of any simulation program used for analysis and design, and also the heart of any extensive monitoring and testing program. An accurate experimental determination of these components in "as-built" houses assists the validation and development of existing simulation programs which, in time, can be more effectively used during the design stage of housing construction. The experimental determination of the components of the heat balance equation must be concurrent with an effective monitoring program to close the validation loop.

The terms of components of the heat balance equation can be determined in a low-cost and straightforward manner by obtaining steady-state conditions in a house. The critical two components being (a) envelope losses and (b) infiltration/exfiltration losses. If envelope losses can be isolated, then the UA Product (U x A) can be determined. It follows from experience that this factor, more than any other (infiltration/exfiltration being a close second), determines the seasonal heating performance of a house.

The test method proposed determines the UA product and therefore, can be considered a true "heat loss simulation test". Time constant values of a house can be approximated mathematically after a visual inspection of a house and/or by having knowledge of the house's construction, although it is not necessary to determine for the purposes of the test procedure proposed here. Furthermore, the time constant's influence is arguably not significant in the majority of Canadian homes since internal temperatures do not widely fluctuate, and since the solar apperture is seldom substantial in relation to floor area. The proposed test method does not seek to determine the time constant value experimentally.

Description of Test Procedure

The following test procedure for the heat loss simulation test is proposed:

1) The tests should be conducted at night in order to uncouple the effect of solar gain from the total heat balance of the house in question. The effect of clear sky irradiance will still have to be taken into account, even for cloudy nights; however, its effect is small in magnitude and can be reasonably approximated by calculation.

2) The tests should be conducted during a period of relatively constant exterior temperature below 10 degrees Celcius, under conditions of fairly constant wind direction, below 15 km/hr wind speed and after the house has had several hours to stabilize its heat flows. The test would be conducted over several hours (six hours should be sufficient to ensure reasonable results. Interior house temperature would be kept relatively stable through the normal operation of the homes' heating system. The amount of heat added by the heating system during this period would be carefully monitored along with other internal gains from the hot water system, lights and appliances, and occupants. The house need not be vacant during the test.

3) A number of tracer gas samplings would be conducted during the period of each test to uncouple the effect of infiltration/exfiltration from the heat balance of the house. The tracer gas analysis is required as opposed to a fan depressurization test approach, since a fan test can only determine the equivalent leakage area of the house in question, but not provide the distribution of that leakage area. The distribution of the leakage area coupled with the influence of the stack effect, the wind speed, wind direction, mechanical system, house geometry and surrounding terrain determine the instantaneous infiltration/exfiltration characteristics of the house. For this reason, knowing the leakage area of the house is not sufficient to uncouple the infiltration/exfiltration losses from the heat balance equation governing the house. However, tracer gas testing, conducted under constant conditions can fix this unknown within acceptable accuracy.

4) Ventilation losses would be obtained by monitoring the on-time of the ventilation system in the house, it's heat recovery efficiency and the volume of air exchanged. Temperature and humidity measurements of this air flow would be continuously monitored.

5) The envelope losses would now be obtained since all the other terms in the heat balance equation have been determined. The internal temperature distribution of the house would be monitored continuously during the duration of the test period along with fluctuations in external temperature. The envelope losses coupled with the internal/external temperature profile along with the house geometry (envelope surface area) will now yield the UA product.

APPENDIX F: HOTCAN COMPUTER SIMULATIONS

List of Hotcan Computer Program Runs

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                    * * * * * * * * * * * * * * * * * * * *
                    *                                     *
                    *          PROGRAM HOTCAN!            *
                    * NATIONAL RESEARCH COUNCIL OF CANADA *
                    *    DIVISION OF BUILDING RESEARCH    *
                    *    SASKATOON, SASKATCHEWAN, 1982    *
                    *        RELEASE S3-820809            *
                    * * * * * * * * * * * * * * * * * * * *

CLIENT NAME: GREAT GULF
ADDRESS    : BRAMPTON

USER DATA FILE NAME: JOSEPH03

DATA IS FOR TORONTO

                       *** BUILDING PARAMETERS ***

ELEMENT           AREA          RSI VALUE      HT LOSS       % SEASONAL
                   M2           M2-DEGC/W      W/DEGC          HT LOSS

CEILING          58.09          8.81
           TOTAL 58.09          8.81           6.59            5.95

MAIN WALLS       154.28         5.64
           TOTAL 154.28         5.64           27.35           24.69

DOORS            1.95           2.47
           TOTAL 1.95           2.47           .79             .71

BASEMENT AB.GD   9.94           5.64
           TOTAL 9.94           5.64           1.76            1.59

BASEMENT 600MM   19.89          4.23
           TOTAL 19.89          4.23           3.82            2.68

BASE. TO FLOOR   54.74          4.23
           TOTAL 54.74          4.23           21.73           15.25

FLOOR PERIMETER  26.49          2.64
           TOTAL 26.49          2.64           10.82           7.59

FLOOR CENTRE     23.61          2.64
           TOTAL 23.61          2.64           3.34            2.35

SOUTH WINDOWS    6.1            .56
           TOTAL 6.1            .56            10.99           9.92

NORTH WINDOWS    4.39           .56
           TOTAL 4.39           .56            7.91            7.14

EAST WINDOWS     0              0
           TOTAL 0              0              0               0

WEST WINDOWS     0              0
           TOTAL 0              0              0               0

AIR CHANGE       .2/HR          397.14 M3      24.5            22.12
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PROGRAM HOTCAN                          PAGE 2

CLIENT NAME: GREAT GULF
ADDRESS     : BRAMPTON

DESIGN HEAT LOSS AT  -17.2C =  3.64 KW
TEMPERATURES (DEG C) MAIN FLOOR =  21   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
WINDOW SHADING COEFFICIENTS: SOUTH =  .89     NORTH =  .89
                             EAST =  0        WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  3 M
                         AVERAGE OVERHANG WIDTH =  .5 M
                         AVERAGE HEIGHT ABOVE WINDOW =  10 M
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .5
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR = 70%


                *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH           THERMAL LOAD   MONTHLY        AUX HEAT REQ   TOT CONS
                  KWH/D        SOLAR FRAC       KWH/D          KWH/D
JAN              45.74          .29            32.43          60.43
FEB              45.44          .36            29.19          57.19
MAR              35.44          .45            19.64          47.64
APR              19.71          .67            6.51           34.51
                 6.22           1              0              28
JUN              0              1              0              28
JUL              0              1              0              28
AUG              0              1              0              28
SEP              0              1              0              28
OCT              8.34           .91            .75            28.75
NOV              22.99          .4             13.7           41.7
DEC              38.61          .27            28.2           56.2

ESTIMATED ANNUAL SPACE HEATING  14.17 GJ, OR  3935.15 KWHRS
ANNUAL SOLAR FRACTION =  .41
TOTAL ANNUAL ENERGY CONSUMPTION =  14155.15 KWHRS
S.E.E.H. PROGRAM REQUIREMENTS FOR TOTAL ENERGY CONSUMPTION =  16255.27 KWHRS


                     *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR TORONTO AS OF SEPT

ENERGY          COST           SPACE          HOT            LIGHTS AND
SOURCE          PER UNIT       HEATING        WATER          APPLIANCES

ELECTRICITY      3.5C/KWH      $ 137.73/YR    $ 178.85/YR    $ 178.85/YR
                                EFF.= 100%     EFF.= 100%     EFF.= 100%
NATURAL GAS      21C/M3        $ 114.06/YR    $ 188.51/YR
                                EFF.= 70%      EFF.= 55%          --
                 .39C/LITRE    $ 2.02/YR      $ 3.34/YR
                                EFF.= 70%      EFF.= 55%          --
PROPANE          .29C/LITRE    $ 2.39/YR      $ 3.79/YR
                                EFF.= 70%      EFF.= 55%          --
WOOD             55/M3         $ 304.13/YR    $ 493.65/YR
                                EFF.= 50%      EFF.= 40%
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PROGRAM HOTCAN                        PAGE 2

CLIENT NAME: GREAT GULF
  DRESS     : BRAMPTON

DESIGN HEAT LOSS AT  -17.2C =  4.14 KW
TEMPERATURES (DEG C) MAIN FLOOR =  21    BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
WINDOW SHADING COEFFICIENTS: SOUTH =  .89    NORTH =  .89
                             EAST =  0       WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  3 M
                         AVERAGE OVERHANG WIDTH =  .5 M
                         AVERAGE HEIGHT ABOVE WINDOW =  10 M
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .5
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR = 70%


              *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH          THERMAL LOAD   MONTHLY        AUX HEAT REQ   TOT CONS
                 KWH/D        SOLAR FRAC       KWH/D          KWH/D
JAN             54.41          .25            40.88          68.88
FEB             54             .31            37.39          65.39
MAR             42.56          .38            26.25          54.25
APR             24.68          .58            10.4           38.4
                9.44           .9             .98            28.98
JUN             0              1              0              28
JUL             0              1              0              28
AUG             0              1              0              28
SEP             0              1              0              28
OCT             12.13          .79            2.58           30.58
NOV             28.69          .33            19.26          47.26
DEC             46.4           .23            35.94          63.94

ESTIMATED ANNUAL SPACE HEATING  18.87 GJ, OR  5242.25 KWHRS
ANNUAL SOLAR FRACTION =  .36
TOTAL ANNUAL ENERGY CONSUMPTION =  15462.25 KWHRS
S.E.E.H. PROGRAM REQUIREMENTS FOR TOTAL ENERGY CONSUMPTION =  16255.27 KWHRS


                    *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR TORONTO AS OF SEPT

ENERGY         COST           SPACE          HOT            LIGHTS AND
SOURCE         PER UNIT       HEATING        WATER          APPLIANCES

ELECTRICITY     3.5C/KWH      $ 183.48/YR    $ 178.85/YR    $ 178.85/YR
                               EFF.= 100%     EFF.= 100%     EFF.= 100%
NATURAL GAS     21C/M3        $ 151.95/YR    $ 188.51/YR
                               EFF.= 70%      EFF.= 55%          --
   -            .39C/LITRE    $ 2.7/YR       $ 3.34/YR
                               EFF.= 70%      EFF.= 55%          --
PROPANE         .29C/LITRE    $ 3.05/YR      $ 3.79/YR
                               EFF.= 70%      EFF.= 55%          --
WOOD            55/M3         $ 405.15/YR    $ 493.65/YR
                               EFF.= 50%      EFF.= 40%
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                 * * * * * * * * * * * * * * * * * * * *
                 *                                     *
                 *          PROGRAM HOTCAN!            *
                 * NATIONAL RESEARCH COUNCIL OF CANADA *
                 *    DIVISION OF BUILDING RESEARCH    *
                 *    SASKATOON, SASKATCHEWAN, 1982    *
                 *          RELEASE S3-820809          *
                 * * * * * * * * * * * * * * * * * * * *

CLIENT NAME: GREAT GULF
ADDRESS    : BRAMPTON

USER DATA FILE NAME: JOSEPH03

DATA IS FOR TORONTO

                       *** BUILDING PARAMETERS ***

ELEMENT             AREA          RSI VALUE     HT LOSS       % SEASONAL
                     M2           M2-DEGC/W      W/DEGC         HT LOSS

CEILING            58.09          8.81
              TOTAL 58.09         8.81          6.59          5.35

MAIN WALLS         154.28         5.64
              TOTAL 154.28        5.64          27.35         22.2

DOORS              1.95           2.47
              TOTAL 1.95          2.47          .79           .64

BASEMENT AB.GD     9.94           5.64
              TOTAL 9.94          5.64          1.76          1.43

BASEMENT 600MM     19.89          4.23
              TOTAL 19.89         4.23          3.82          2.41

BASE. TO FLOOR     54.74          4.23
              TOTAL 54.74         4.23          21.73         13.71

FLOOR PERIMETER    26.49          2.64
              TOTAL 26.49         2.64          10.82         6.83

FLOOR CENTRE       23.61          2.64
              TOTAL 23.61         2.64          3.34          2.11

SOUTH WINDOWS      6.1            .33
              TOTAL 6.1           .33           18.21         14.78

NORTH WINDOWS      4.39           .33
              TOTAL 4.39          .33           13.11         10.64

EAST WINDOWS       0              0
              TOTAL 0             0             0             0

WEST WINDOWS       0              0
              TOTAL 0             0             0             0

AIR CHANGE         .2/HR          397.14 M3     24.5          19.89
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PROGRAM HOTCAN                        PAGE 2

CLIENT NAME: GREAT GULF
   DRESS    : BRAMPTON

DESIGN HEAT LOSS AT  -17.2C =  4.11 KW
TEMPERATURES (DEG C) MAIN FLOOR =  21    BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
WINDOW SHADING COEFFICIENTS: SOUTH =  .89    NORTH =  .89
                             EAST =  0       WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  3 M
                         AVERAGE OVERHANG WIDTH =  .5 M
                         AVERAGE HEIGHT ABOVE WINDOW =  10 M
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .5
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR = 70%

              *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH           THERMAL LOAD   MONTHLY         AUX HEAT REQ   TOT CONS
                  KWH/D        SOLAR FRAC        KWH/D         KWH/D
JAN              53.88          .25             40.36          68.36
FEB              53.43          .31             36.84          64.84
MAR              41.96          .39             25.69          53.69
APR              24.07          .59             9.9            37.9
                 8.84           .91             .76            28.76
JUN              0              1               0              28
JUL              0              1               0              28
AUG              0              1               0              28
SEP              0              1               0              28
OCT              11.68          .8              2.32           30.32
NOV              28.24          .33             18.81          46.81
DEC              45.91          .23             35.45          63.45

ESTIMATED ANNUAL SPACE HEATING  18.49 GJ, OR  5134.99 KWHRS
ANNUAL SOLAR FRACTION =  .37
TOTAL ANNUAL ENERGY CONSUMPTION =  15354.99 KWHRS
S.E.E.H. PROGRAM REQUIREMENTS FOR TOTAL ENERGY CONSUMPTION =  16255.27 KWHRS

                   *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR TORONTO AS OF SEPT

ENERGY          COST           SPACE           HOT             LIGHTS AND
SOURCE          PER UNIT       HEATING         WATER           APPLIANCES

ELECTRICITY      3.5C/KWH      $ 179.72/YR     $ 178.85/YR     $ 178.85/YR
                                 EFF.= 100%      EFF.= 100%      EFF.= 100%
NATURAL GAS      21C/M3        $ 148.84/YR     $ 188.51/YR
                                 EFF.= 70%       EFF.= 55%          --
  -              .39C/LITRE    $ 2.64/YR       $ 3.34/YR
                                 EFF.= 70%       EFF.= 55%          --
PROPANE          .29C/LITRE    $ 2.99/YR       $ 3.79/YR
                                 EFF.= 70%       EFF.= 55%          --
WOOD             55/M3         $ 396.86/YR     $ 493.65/YR
                                 EFF.= 50%       EFF.= 40%
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              * * * * * * * * * * * * * * * * * * * * *
              *               HOTCAN!                 *
              * NATIONAL RESEARCH COUNCIL OF CANADA   *
              *    DIVISION OF BUILDING RESEARCH      *
              *    SASKATOON, SASKATCHEWAN, 1982      *
              *        (RELEASE HOTCAN 4.01)          *
              * * * * * * * * * * * * * * * * * * * * *

CLIENT NAME: MARTIN
ADDRESS     : HONEYWOOD,ONTARIO

USER DATA FILE NAME: MARTIN1,2

DATA IS FOR OTTAWA

                      *** BUILDING PARAMETERS ***
ELEMENTS            HOUSE       AIR            HT LOSS        % SEASONAL
                    VOLUME    CHANGE           W/DEGC         HT LOSS

VENTILATION       17760 FT3    .17/HR           26.38          20.42

                   AREA        R VALUE
                    FT2       FT2-DEGC/W

CEILING           1100.00        56.00
          TOTAL   1100.00        56.00          10.37           8.02

MAIN WALLS        1292.00        28.00
          TOTAL   1292.00        28.00          24.35          18.85

DOORS               21.00        15.00
          TOTAL     21.00        15.00            .74            .57

BASEMENT AB.GD        .00          .00
          TOTAL       .00          .00            .00            .00

BASEMENT 2FT       176.00        28.00
          TOTAL    176.00        28.00           2.86           1.79

BASE. TO FLOOR     720.00        28.00
          TOTAL    720.00        28.00          10.78           6.74

FLOOR PERIMETER    348.00        12.00
          TOTAL    348.00        12.00           8.41           5.26

FLOOR CENTRE       612.00        12.00
          TOTAL    612.00        12.00          10.68           6.68

SOUTH WINDOWS      175.00         2.67
          TOTAL    175.00         2.67          34.57          26.76

NORTH WINDOWS       16.00         2.67
          TOTAL     16.00         2.67           3.16           2.45

  ST WINDOWS        16.00         2.67
          TOTAL     16.00         2.67           3.16           2.45

WEST WINDOWS          .00          .00
          TOTAL       .00          .00            .00            .00
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```
EAST WINDOWS           72.74          2.16
          TOTAL        72.74          2.16          17.77          6.55

WEST WINDOWS          171.84          2.16
          TOTAL       171.84          2.16          41.99         15.48

S-EAST WINDOWS           .00           .00
          TOTAL          .00           .00            .00           .00

S-WEST WINDOWS           .00           .00
          TOTAL          .00           .00            .00           .00

ADDRESS     : LONDON

DESIGN HEAT LOSS AT   -22C =  10.37 KW
DEGREE DAYS FOR KINGSTON IS  4067
TEMPERATURES (DEG C) MAIN FLOOR =  21   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .89   NORTH  =  0
                             EAST   =  .89   WEST   =  .89
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  3.36 FT
                         AVERAGE OVERHANG WIDTH =  .37 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  0 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .45
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR =  80 %

             *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH          THERMAL LOAD     MONTHLY       AUX HEAT REQ    TOT CONS
                  KWH/D        SOLAR FRAC        KWH/D          KWH/D
JAN              153.95           .25           115.52         143.52
FEB              151.74           .35            98.23         126.23
MAR              122.91           .45            67.69          95.69
APR               83.24           .62            31.68          59.68
MAY               48.54           .83             8.15          36.15
JUN               16.79          1.00              .00          28.00
JUL                 .00          1.00              .00          28.00
AUG                 .00          1.00              .00          28.00
SEP               19.64          1.00              .00          28.00
OCT               53.60           .64            19.23          47.23
NOV               88.83           .30            61.86          89.86
DEC              132.51           .23           102.12         130.12

             *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  42 %

ESTIMATED ANNUAL SPACE HEATING  54 GJ, OR          15,250 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =     14,697 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =    10,220 KWHRS
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HOTCAN                                                          PAGE  3

                         *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR ONTARIO                   AS OF 83/04/29

ENERGY             COST          SPACE            HOT              LIGHTS AND
SOURCE             PER UNIT      HEATING          WATER            APPLIANCES

ELECTRICITY         3.9C/KWH     $ 165.28/YR      $ 199.29/YR      $ 199.29/YR
                                  EFF.= 100%       EFF.= 100%       EFF.= 100%


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          This estimate of energy demand may not reflect actual
      energy requirements of a house due to variations in
      weather, performance of equipment, and the lifestyle
      of the occupants.

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                    *               HOTCAN!               *
                    * NATIONAL RESEARCH COUNCIL OF CANADA *
                    *    DIVISION OF BUILDING RESEARCH    *
                    *    SASKATOON, SASKATCHEWAN, 1982    *
                    *        (RELEASE HOTCAN 4.01)        *
                    * * * * * * * * * * * * * * * * * * * *

CLIENT NAME: JEFF 1,2
ADDRESS     : LONDON

USER DATA FILE NAME: TITE1,2

DATA IS FOR KINGSTON

                          *** BUILDING PARAMETERS ***
ELEMENTS                HOUSE      AIR               HT LOSS          % SEASONAL
                        VOLUME     CHANGE            W/DEGC           HT LOSS

VENTILATION           36544 FT3   .14/HR              44.69            16.48

                         AREA       R VALUE
                         FT2       FT2-DEGC/W

CEILING                1825.35       40.00
             TOTAL     1825.35       40.00            24.08             8.88

MAIN WALLS             2837.86       23.40
             TOTAL     2837.86       23.40            64.00            23.60

DOORS                    38.90       14.00
             TOTAL       38.90       14.00             1.47              .54

BASEMENT AB.GD          113.56       12.00
             TOTAL      113.56       12.00             4.99             1.84

BASEMENT 2FT            379.66       12.00
             TOTAL      379.66       12.00            12.15             2.86

BASE. TO FLOOR          916.88       12.00
             TOTAL      916.88       12.00            20.40             4.80

FLOOR PERIMETER         500.40         .00
             TOTAL      500.40         .00            31.21             7.34

FLOOR CENTRE           1079.48         .00
             TOTAL     1079.48         .00            22.57             5.31

SOUTH WINDOWS             4.29        2.16
                          4.29        2.16
                          8.89        2.16
                         11.48        2.16
                         11.48        2.16
                          9.34        2.16
                         14.66        2.16
                          5.74        2.16
             TOTAL       70.17        2.16            17.15             6.32

NORTH WINDOWS              .00         .00
             TOTAL         .00         .00              .00              .00
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EAST WINDOWS          72.74          2.16
           TOTAL      72.74          2.16           17.77            6.55

WEST WINDOWS         171.84          2.16
           TOTAL     171.84          2.16           41.99           15.48

S-EAST WINDOWS          .00           .00
           TOTAL        .00           .00             .00             .00

S-WEST WINDOWS          .00           .00
           TOTAL        .00           .00             .00             .00

ADDRESS     : LONDON

DESIGN HEAT LOSS AT  -22C =  10.37 KW
DEGREE DAYS FOR KINGSTON IS  4067
TEMPERATURES (DEG C) MAIN FLOOR =  21   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .89   NORTH  =  0
                             EAST   =  .89   WEST   =  .89
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  3.36 FT
                         AVERAGE OVERHANG WIDTH =  .37 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  0 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .45
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR =  80 %

              *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH         THERMAL LOAD     MONTHLY       AUX HEAT REQ     TOT CONS
                 KWH/D       SOLAR FRAC         KWH/D           KWH/D
JAN             153.95           .25           115.52          143.52
FEB             151.74           .35            98.23          126.23
MAR             122.91           .45            67.69           95.69
APR              83.24           .62            31.68           59.68
MAY              48.54           .83             8.15           36.15
JUN              16.79          1.00              .00           28.00
JUL                .00          1.00              .00           28.00
AUG                .00          1.00              .00           28.00
SEP              19.64          1.00              .00           28.00
OCT              53.60           .64            19.23           47.23
NOV              88.83           .30            61.86           89.86
DEC             132.51           .23           102.12          130.12

              *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  42 %

ESTIMATED ANNUAL SPACE HEATING  54 GJ, OR            15,250 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =       14,697 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =      10,220 KWHRS
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SEEH PROGRAM AUXILIARY ENERGY CONSUMPTION =            10,600 KWHRS

TOTAL ANNUAL ENERGY CONSUMPTION =                      25,470 KWHRS
TOTAL ANNUAL SEEH PROGRAM ENERGY BUDGET =              25,297 KWHRS
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HOTCAN

               *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR ONTARIO               AS OF 83/06/03

ENERGY          COST         SPACE         HOT            LIGHTS AND
SOURCE          PER UNIT     HEATING       WATER          APPLIANCES

NATURAL GAS      24.3C/M3    $ 406.86/YR   $ 218.13/YR
                              EFF.=  88%    EFF.= 55%          --


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    This estimate of energy demand may not reflect actual
energy requirements of a house due to variations in
weather, performance of equipment, and the lifestyle
of the occupants.

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               *              HOTCAN!                *
               * NATIONAL RESEARCH COUNCIL OF CANADA *
               *    DIVISION OF BUILDING RESEARCH    *
               *    SASKATOON, SASKATCHEWAN, 1982    *
               *       (RELEASE HOTCAN 4.01)         *
               * * * * * * * * * * * * * * * * * * * *

CLIENT NAME: LINCOLNBERG
ADDRESS    : EDMONTON

USER DATA FILE NAME: JOSEPH,2

DATA IS FOR EDMONTON

                    *** BUILDING PARAMETERS ***
ELEMENTS            HOUSE     AIR           HT LOSS       % SEASONAL
                    VOLUME    CHANGE        W/DEGC        HT LOSS

VENTILATION        19500 FT3   .2/HR         34.07         22.57

                    AREA       R VALUE
                    FT2       FT2-DEGC/W

CEILING             780.00      60.00
          TOTAL     780.00      60.00         6.86          4.54

MAIN WALLS         1790.00      28.00
          TOTAL    1790.00      28.00        33.73         22.35

DOORS                42.00      15.00
          TOTAL      42.00      15.00         1.48           .98

BASEMENT AB.GD      123.00      28.00
          TOTAL     123.00      28.00         2.32          1.54

BASEMENT 2FT        246.00      28.00
          TOTAL     246.00      28.00         4.00          1.75

BASE. TO FLOOR      492.00      28.00
          TOTAL     492.00      28.00         7.49          3.27

FLOOR PERIMETER     333.00      12.00
          TOTAL     333.00      12.00         8.11          3.54

FLOOR CENTRE        483.00      12.00
          TOTAL     483.00      12.00         8.43          3.69

SOUTH WINDOWS       117.00       2.16
          TOTAL     117.00       2.16        28.59         18.94

NORTH WINDOWS        80.00       2.16
          TOTAL      80.00       2.16        19.55         12.95

EAST WINDOWS         12.00       2.16
          TOTAL      12.00       2.16         2.93          1.94

WEST WINDOWS         12.00       2.16
          TOTAL      12.00       2.16         2.93          1.94
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S-EAST WINDOWS          .00          .00
          TOTAL         .00          .00              .00              .00

S-WEST WINDOWS          .00          .00
          TOTAL         .00          .00              .00              .00

ADDRESS      : EDMONTON

DESIGN HEAT LOSS AT  -32C =  7.47 KW
DEGREE DAYS FOR EDMONTON IS  5589
TEMPERATURES (DEG C) MAIN FLOOR =  21   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS <A>
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .89   NORTH  =  .89
                             EAST   =  .89   WEST   =  .89
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  4 FT
                         AVERAGE OVERHANG WIDTH =  1 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  2 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
    FORCED VENTILATION RATE (AC/HR) =  .5
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR =  70 %

            *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH          THERMAL LOAD    MONTHLY      AUX HEAT REQ    TOT CONS
                  KWH/D       SOLAR FRAC       KWH/D          KWH/D
JAN              109.28          .26           81.34         109.34
FEB               93.51          .38           58.24          86.24
MAR               78.31          .51           38.54          66.54
APR               45.94          .70           13.84          41.84
MAY               22.72          .92            1.75          29.75
JUN                8.67         1.00             .00          28.00
JUL                2.25         1.00             .00          28.00
AUG                4.99         1.00             .00          28.00
SEP               21.14          .91            1.83          29.83
OCT               38.25          .69           11.81          39.81
NOV               71.96          .35           46.55          74.55
DEC               97.45          .23           75.38         103.38

            *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  45 %

ESTIMATED ANNUAL SPACE HEATING  35 GJ, OR              9,970 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =        10,364 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =       10,220 KWHRS
SEEH PROGRAM AUXILIARY ENERGY CONSUMPTION =           10,600 KWHRS

TOTAL ANNUAL ENERGY CONSUMPTION =                     20,190 KWHRS
TOTAL ANNUAL SEEH PROGRAM ENERGY BUDGET =             20,964 KWHRS
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HOTCAN                                                              PAGE  3

                      *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR ALBERTA                     AS OF 83/01/04

ENERGY            COST          SPACE           HOT             LIGHTS AND
SOURCE            PER UNIT      HEATING         WATER           APPLIANCES

NATURAL GAS        10.2C/M3     $ 103.44/YR     $ 91.56/YR
                                 EFF.=  94%      EFF.= 55%           --


                 ************************************

        This estimate of energy demand may not reflect actual
    energy requirements of a house due to variations in
    weather, performance of equipment, and the lifestyle
    of the occupants.

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APPENDIX G: REQUIREMENTS FOR GASKETS

General Requirements of Gaskets

Gaskets proposed for use in drywall approach homes must have the following characteristics:

1) Gaskets must be sufficiently resilient to expand and contract and maintain its seal as the void between the two materials changes dimensions due to seasonal variations in building frame moisture content, building movement due to settlement, wind loads and snow loads.
2) Gaskets must be of sufficient dimension to be able to fill and effectively seal the cavity between the two materials thereby effecting a continuous air barrier. That is, gaskets of appropriate thickness and width are to be utilized to seal the two materials.
3) Gaskets utilized must be of sufficient compressibility so as not to cause visible deformations on interior cladding materials.
4) Gasket material must not chemically degrade or break-down due to fatigue over a period of 25 years, the minimum service life of the structure.
5) Gasket material must be able to be installed under extreme climatic conditions, such as cold weather.
6) Gasket material must not be water soluable and must not give off toxic fumes.
7) Gasket material must not chemically attack or be attacked by the building materials it is in contact with.
8) The method of gasket attachment must be compatible with the gasket profile and not compromise air barrier continuity.
9) Gasket profile must be such that it does not migrate over time.
10) Gaskets utilized must be sufficiently durable to withstand the construction process.
11) Gaskets utilized must be able to withstand the wind loads and other pressure forces that are expected to act upon it.

Example of Gasket Specification

SPECIFICATIONS

Material	Closed Cell Polyethylene Foam
Color	White
Density, Nominal, pcf	2 1/2
Flexibility, RT*	Pass
-65°F*	Pass
Compression Set, %*	3.9
Compression Strength, psi, ASTM D1621	
10% Deflection	2.5
25% Deflection	6.3
50% Deflection	15.1
Tensile Strength, psi, ASTM D412(L)	57
(W)	41
Tear Strength, lb./in., ASTM D1564(L)	27
(W)	21
Thermal Stability, % Change, AVG.*	1.0
Water Absorption, lb/ft*	0.01
Thermal Conductivity (K-factor)	.30
75°F ASTM C518-70	
Contact Corrosivity*	0

*Per Mil PPP-C-1752-A

APPLICATION

Gasket sealer is applied with either 6mm or 9mm heavy duty staples and between framing members (for example between the plywood sub floor and the bottom plate of the wall). The placement, thickness and width of gasket shall be as indicated on the drawings.

APPENDIX H: INSULATING SHEATHING

It has become apparent that one continuous air barrier on the warm side of the building envelope, depending on local climate and building materials, may be insufficient to prevent certain types of moisture problems such as mould and mildew formation. In addition the optimum thermal performance of the building envelope may not be achieved by the use of one warm side air barrier. The above concerns have led several noted building scientists and engineers to contemplate a "wind" or "weather" barrier to be placed on the cold side of the envelope in addition to the interior air barrier (Timusk; 1983).

Certain changes have already been made to the building code covering northern housing which identifies just such a weather barrier (Latta; 1983).

Depending on local climate conditions and method of building construction, the exterior weather barrier may not necessarily be continuous; partial continuity at corners and at the roof overhand-wall interface may be sufficient to remedy the aforementioned concerns.

One product currently available on the market which will provide a weather barrier is a rigid fiberglass board sheathing ("Glasclad") covered on one face with a vapour permeable but air-tight poly olefin facing known as Tyvek.

In order to obtain optimum thermal performance it would seem most reasonable to place the Glasclad on the exterior of the wall with the Tyvek facing outwards and with all vertical joints and top and bottom interfaces sealed with tape. However, several practical issues have to be addressed. Firstly, weather conditions such as snow and ice and rain make it difficult to apply the tape to the joints and wind tends to peel off the Tyvek during the construction process. The tape does not adhere to damp or moist or cold surfaces. Secondly, material properties of the tape, namely its field performance over time has yet to be proven. Thirdly, installation labour relating to the tape necessitates an extra degree of care which is difficult, if not impossible, to obtain on production building sites. Fourthly, the cost of the tape currently marketed by the 3M Company is high.

In light of these practical concerns it appears that the best solution is to install the Glascald such that the Tyvek weather barrier film faces inwards and the seams of the Tyvek are pressed firmly against the framing members. Not only are the air leakage paths through the joints greatly reduced, thus decreasing the potential for lateral blow through, but with the Tyvek facing in it is more or less protected throughout the entire construction process from tears and rips.

Work carried out to date at the Center for Building Science, University of Toronto (Timusk & Lischkoff; 1983) has shown that Glasclad with the Tyvek facing inward has performed better than Glasclad placed with the Tyvek facing outwards with respect to interstitial moisture movement. In one test the performance of a wall panel covered in Glasclad, Tyvek facing inwards, was compared to the performance of a wall panel covered with Glasclad, Tyvek facing outwards, under extreme conditions of temperature and relative humidity. Exposed to an outdoor temperature of -20 degrees Celsius and an inside relative humidity of 52 percent, the test wall with the Glasclad, Tyvek facing outwards, trapped three times more condensed moisture than the test wall with the Glascald, Tyvek facing inwards. In fact the Glasclad sheathing, Tyvek facing inwards, had collected less moisture than both a test panel covered with 50 mm of extruded polystyrene and a test panel covered with 13 mm wood fibreboard.

In both test panels covered with Glasclad, one with the Tyvek facing inwards, and one with the Tyvek facing outwards, any moisture which did accumulate was primarily trapped within the exterior sheathing only, leaving the framed cavity virtually dry. Thus it appears that the Tyvek membrane with a permeance of 1725 ng/s/Pa/m^2 compared to a Type II vapour retarder with a permeance of 45 ng/s/Pa/m^2 does not act as a true condensing surface when placed on the warm side of the Glasclad.

This cannot be said when the Glasclad is applied normally such that the Tyvek faces outwards. The Tyvek on the cold side of the Glasclad is now at a much lower average temperature over the heating season as compared to the Tyvek placed on the warm side. As a result the potential of trapping interstitial condensation increases while the vapour permeability may tend to decrease due to the Tyvek becoming clogged with ice crystals, thus becoming a vapour retarder.

Fears about placing a potential condensing surface somewhere within the wall assembly, away from the cold side, particularly when in contact with the framing members have not been substantiated by field experience. Surveys performed on houses in the United States with exterior walls covered with expanded polystyrene having a permeance of 68 ng/s/Pa/m^2 have found no framing members with execessive moisture contents. In fact just the opposite was found with the framing members having moisture contents in the range of 10 percent (Johnson; 1982).

In summary the evidence to date suggests that Glasclad placed with the Tyvek facing inwards has better moisture performance characteristics than Glasclad placed with the Tyvek facing outwards and may even have better thermal performance characteristics due to the dryer condition of the sheathing during the heating season. In addition, due to the excellent drainage characteristics of the fiberglass sheathing, this configuration also prevents wind driven rain from entering the wall cavity.

APPENDIX I: AIR QUALITY AND COMBUSTION AIR TESTING

The development of a low cost (less than $250.00 per home) field test procedure utilizing readily available off-the-shelf equipment is proposed. The procedure is based on pioneering work in this area conducted by J. Timusk of the Center for Building Science, University of Toronto and will determine the following parameters:

i) pressure effects of the various air exhausting devices found in homes over the expected service pressure differential range of those air exhausting devices;

ii) airtightness of the building envelope;

iii) the maximum negative pressure furnace/chimney combinations can tolerate;

iv) the magnitude of a safety factor, if one exists, between the point at which combustion equipment venting failure occurs and the point achieved with all air exhausting equipment operating, in terms of magnitude of additional negative pressure differential capable of being induced before stack failure occurs.

It is further proposed that the effectiveness of the following air quality/ventilation remedial measures be evaluated when they are utilized in typical and tight building envelopes:

i) the utilization of a central exhaust system coupled with intake air ducted directly from outdoors to the return side of a conventional gas furnace;

ii) the utilization of an air-to-air heat exchanger coupled both with an induced draft medium efficiency gas furnace and induced draft gas domestic hot water heater; and

iii) the uncoupling of a fireplace (without glass doors, or with leaky or poorly fitting glass doors) by the provision of a combustion supply outside air duct to the firebox.

The operating costs to the homeowner of the various measures would also be investigated along with the capital costs of installation of the systems proposed to be studied.

It is proposed that this work be carried out on six designated homes and that these designated homes be the three low energy homes proposed to be built under the 1984 Low Energy Housing Demonstration Project along with a control group of three typical, newly constructed homes similar to the three low energy homes but without any of the energy features.

Potential Contribution to Knowledge and Relation to Existing Research and Literature.

Under normal circumstances, stack action or the chimney effect in a fossil fuel burning furnace chimney is adequate to overcome the negative pressure generated by a fireplace and appliance fans such as those of clothes dryers, range hoods, bathroom exhausts and weather effects. However, the competition for air between the various air-exhausting mechanisms may reach a point where the furnace chimney becomes an air supply opening. If the interior negative pressure is sufficiently low to prevent a reversal of the chimney downdraft on a cold start, the combustion products will enter the building through the draft hood or the barometric damper. The house will now act as the chimney. It is believed that the likelihood of such an occurrence increases and thus there is a potential danger in both new housing as well as in existing housing where retrofit airtightening of the envelope is undertaken.

To our knowledge no attempts have been made to evaluate the failure potential of real chimneys and their furnaces as well as the characteristics of air-exhausting devices with their respective as-installed ductwork. Once such information is available it would be possible to extrapolate the data to estimate the potential for failure in other homes in other parts of Canada. A low cost test technique is necessary so that the evaluation of the failure potential of real chimneys and their furnaces can proceed.

The novel aspect of this proposal is that the technique makes it possible to determine the point at which a furnace and a chimney will fail.

Establishment of the Point where a Furnace and its Chimney Fail to Draft.

The basic part of this portion of the proposed investigation is the testing of envelope airtightness and the pressure characteristics of "as-installed" air-exhausting devices with their respective ductwork. It is quite separate from the furnace failure determination.

In this study it is proposed to induce a negative pressure differential in a dwelling by lowering the pressure in the home by means of a blower door to a point where during the operation of the furnace all combustion products enter the building via the draft hood or the barometric damper. The pressure differential would then be reduced and the pressure at which combustion products start to enter the "cold" chimney would be noted. This point defines the "total failure point".

Once warm combustion products enter the chimney, stack action will take over and natural venting will occur.

The negative pressure differential would then be reduced further to determine the negative pressure at which detectable levels of combustion products are beginning to spill out of the chimney and would define the "spillage point". Determination of this "spillage point" would occur after sufficient time was allowed to establish venting on start-up. Quantifying this sufficient time parameter would be one of this study's objectives and would result from experimentation.

It is believed that the worst conditions for cold start failure occur during relatively warm and calm days. It is preferential therefore that testing should occur during the beginning or the end of the heating season. It may be found, after some field experimentation, that determinable correction factors will enable testing to occur year-round. Figure A indicates the two "chimney failure" populations where frequency is plotted against negative pressure.

It must be pointed out here that the "failure pressure" of a stack and furnace combination is totally independent of the house they are located in and it does not hinge on the characteristics of the negative pressure generating appliances or devices. The combination of the house and the various devices is, of course, vital to generate the failure negative pressure.

House Envelope Tightness Characteristics

This aspect is well understood and techniques have been developed to measure airtightness characteristics. In this study a blower door will be used. Air-leakage pressure curves for three hypothetical houses have been presented in Figure B. Such characteristics will be established for the houses tested.

Pressure Flow Characteristics of Fans and Fireplaces

Figure C shows hypothetical curves for various combinations of air-exhausting devices. The actual curves for the devices would be established with the aid of the blower door. What is important to note here is that these curves are for air-exhausting devices in "as installed" conditions where they are coupled to real ductwork in a real house. Using the test procedure these air-exhausting devices and their associated ductwork are uncoupled from the envelope characteristics of the house they are installed in. The test procedure now in effect makes them house independent. A family of curves for various air exhausting systems (the air exhausting device coupled to its ductwork) would result if numerous houses where tested, which could ultimately be the basis of a design procedure for ventilation systems in old and new homes that could arise out of this work.

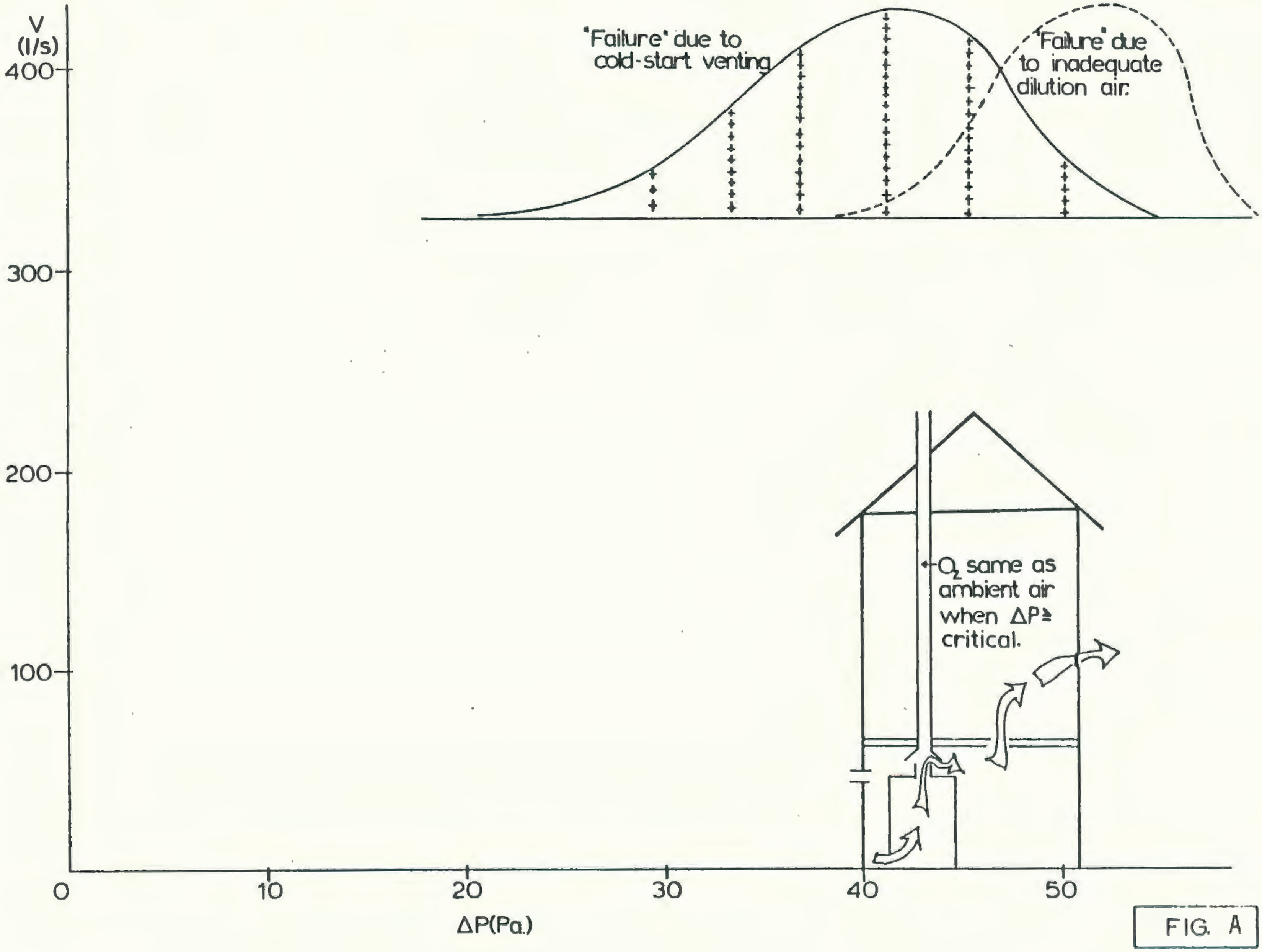
V
(l/s)
400
300
200
100
0
10
20
30
40
50
ΔP(Pa.)
'Failure' due to cold-start venting
'Failure' due to inadequate dilution air.
O₂ same as ambient air when ΔP ≥ critical.

FIG. A

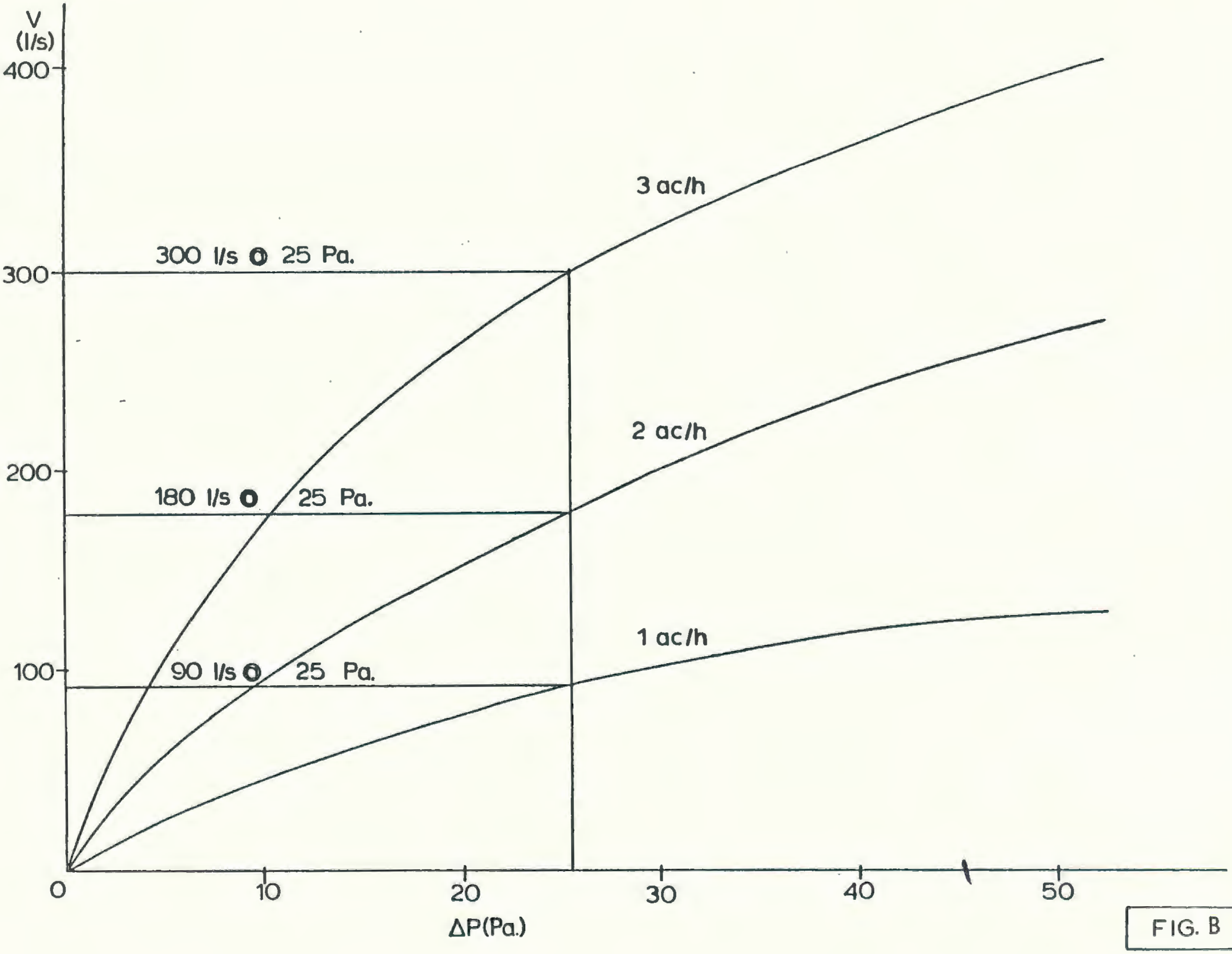
V
(l/s)
400
300
200
100
0
10
20
30
40
50
ΔP(Pa.)
3 ac/h
2 ac/h
1 ac/h
300 l/s @ 25 Pa.
180 l/s @ 25 Pa.
90 l/s @ 25 Pa.

FIG. B

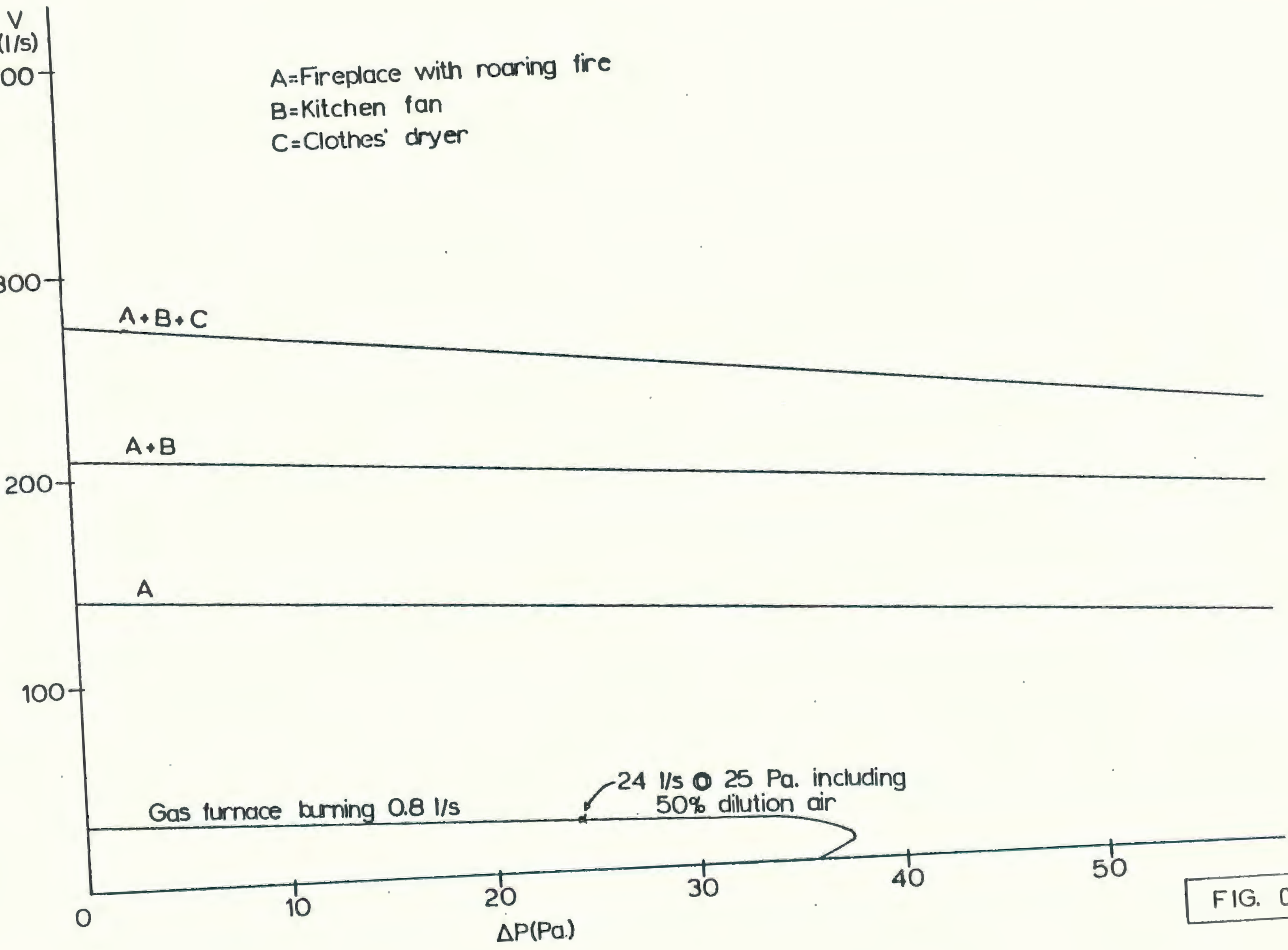
V
(l/s)
00
300
200
100
0
A=Fireplace with roaring fire
B=Kitchen fan
C=Clothes' dryer
A+B+C
A+B
A
Gas furnace burning 0.8 l/s
24 l/s @ 25 Pa. including
50% dilution air
10
20
30
40
50
ΔP(Pa.)

FIG.

How the Information Obtained From Numerous Similar Tests Would be Used

By statistical techniques it would be possible to establish what the probability of failure is by analyzing the statistically independent populations via the furnace-stack combinations, building envelopes and air-exhausting devices.

Evaluation of the Installed Effectivensss of Air Quality/Ventilation Remedial Measures

The proposed test procedure previously outlined would be the basis of evaluating the effectiveness of the remedial measures commonly recomended to alleviate concerns about air quality, combustion air and ventilation in airtightened houses. The remedial measures to be evaluated have been previously described.

Description of the Work to be Undertaken

The test procedure previously outlined would be developed and applied to the six homes in question. After the initial testing of all the homes, including the three control group homes, these three control group homes would undergo air leakage tightening utilizing standard air sealing techniques.

The following equipment would have been installed in the control group homes during their construction:

i) central exhaust systems and exhaust fans;

ii) combustion air supply air to fireplace fireboxes;

iii) conventional gas furnaces with intake air ducted from the outside directly into the return air side of the furnaces; and

iv) carbon monoxide sensors set to go into audible alarm mode (much like a smoke detector) if CO levels rise above safe limits so that home occupant safety is assured.

The installation process of all equipment would be documented and the installed effectiveness of the air/quality ventilation retrofit measures utilized would be determined by the re-testing of the three control group homes, this time after airtightening has occurred and with the retrofit measures functional.

The entire project work would be documented, data would be analyzed and a project report suitable for publication would be prepared.