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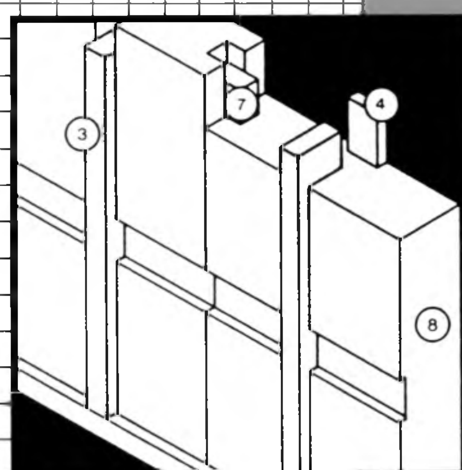
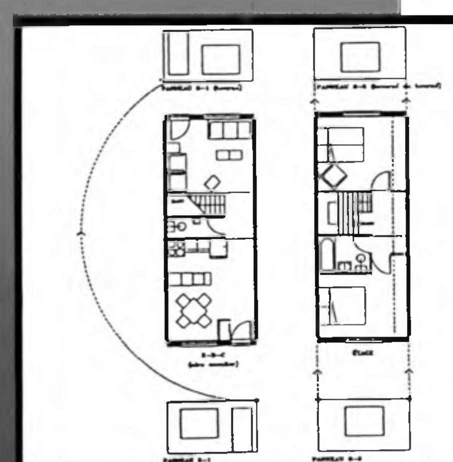
Industrialization of Narrow-Front Rowhousing

Using Wall Panel Systems





Industrialization of the Grow Home

INDUSTRIALIZATION OF NARROW-FRONT ROWHOUSING
USING WALL PANEL SYSTEMS

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ABSTRACT

The purpose of this study was to examine how the Grow Home can be adapted to an industrialized method of production using prefabricated panel systems, and to determine what implications this would have in terms of quality, economy and technical performance. The project included an evaluation system currently available in North America, an adaptation to the unit's design, and a cost estimate comparing prefabricated systems with conventional construction methods.

Following a survey of 109 manufacturers, 9 types of panel systems were selected for evaluation based on 55 responses received. A method for evaluating prefabricated panel systems based on 34 variables was developed to assess the adequacy and suitability of the options available for a given context. The results indicated that all types of prefabricated panels could provide a level of quality which is superior to that of conventional construction, particularly in the area of energy efficiency and craftsmanship. The only drawbacks to the use of prefabricated panel systems were found in their flexibility relative to conventional construction, particularly for on-site modifications, and in their disruption of the builders' traditional operational routines.

A framework for the industrialization of the Grow Home was developed by adapting the unit's design to provide sufficient flexibility for the builder and economies of scale for the manufacturer. Architectural, modular and technical design criteria were established based on feedback from manufacturers, builders, and occupants of existing Grow Home projects. A wide range of options for the dwelling's layout was generated using a small number of simple, standard components. Nine panel configurations were proposed in all, six for the front and back elevations and three for the side walls of the end units. The use of small, standard interior partitions provided various configurations for entrances and bathrooms, while enabling changes to be made fairly easily on site in response to a client's request.

The potential for prefabricated systems to reduce construction costs was addressed by examining the costs of several prefabricated components, including exterior walls, floors, partitions and dividing walls. The analysis demonstrated that prefabricated panel systems can, for the most part, provide a competitive alternative to conventional construction. The magnitude of the savings, however, can vary significantly depending on the type of panel system, the degree of prefabrication and the component in question. By extending the scope of prefabricated components to include floors and partitions, it was found that substantial savings (up to 6%) were possible. For the construction of 30 or more units, this represents savings of up to $95,000 ($3,150 per unit).

The evaluation, adaptation and cost analysis revealed several aspects of industrialized housing which could benefit from a more comprehensive and detailed investigation. Recommendations for further study were proposed in 4 areas: 1) transportation and lifting considerations, including optimization of panel weight, size and configuration to maximize transportation and assembly efficiency, 2) indirect cost savings associated with shorter construction periods, reduced material wastage and after-sale service, 3) development of products, software and services to better suit the needs of builders and buyers, and 4) marketing studies aimed at assessing the potential for specific types of prefabricated assemblies in the North American context, and at promoting their benefits.

ABRÉGÉ

La présente étude a pour but d'examiner la manière dont la Maison évolutive peut être adaptée à une méthode de production industrialisée au moyen de panneaux préfabriqués, ainsi que d'en établir les répercussions sur les plans de la qualité, de l'économie et de la performance technique. Le projet comportait une méthode d'évaluation couramment employée en Amérique du Nord, une adaptation du design, de même qu'une estimation comparative du prix de revient de panneaux préfabriqués et des méthodes de construction traditionnelles.

Après avoir sondé 109 fabricants, neuf types de panneaux muraux ont été retenus aux fins de l'évaluation parmi les 55 réponses reçues. La méthode d'évaluation des panneaux préfabriqués fondée sur 34 variables a été mise au point pour déterminer dans quelle mesure les possibilités offertes dans un contexte donné étaient appropriées et convenables. D'après les résultats, tous les types de panneaux préfabriqués sont d'une qualité supérieure à celle de la construction traditionnelle, surtout en ce qui a trait à l'efficacité énergétique et à la qualité d'exécution. Les seuls inconvénients que présente l'emploi de panneaux préfabriqués tiennent à leur maniabilité relativement aux méthodes de construction traditionnelles, particulièrement s'il faut apporter des modifications sur place, et au fait qu'ils perturbent le cours normal des travaux de construction.

Un cadre propre à la construction industrialisée de la Maison évolutive a été élaboré par l'adaptation du plan de l'habitation dans le but de procurer une marge de manoeuvre suffisante au constructeur et des économies d'échelle au fabricant. Les critères de conception architecturale, modulaire et technique ont été établis à partir des vues exprimées par les fabricants, constructeurs et occupants des ensembles résidentiels évolutifs. Une vaste gamme de plans schématiques ont été dessinés pour l'habitation, comportant un nombre limité de composants simples et courants. En tout, neuf configurations de panneaux ont été proposés, six pour les élévations des façades avant et arrière, et trois pour les murs latéraux des dernières maisons de la rangée. Grâce à l'emploi de cloisons de petite dimension et d'usage courant, il a été possible d'obtenir différentes configurations pour les entrées et les salles de bains, de même que d'apporter sur place et sans trop de difficultés les modifications demandées par le client.

Pour déterminer dans quelle mesure les panneaux préfabriqués étaient susceptibles de réduire le prix de revient de la construction, nous avons examiné les prix de plusieurs composants préfabriqués, dont les murs extérieurs, les planchers, les cloisons et les murs de séparation. L'analyse a révélé que les panneaux préfabriqués peuvent effectivement concurrencer, pour la plupart, les méthodes traditionnelles. Toutefois, l'ampleur des économies peut varier considérablement selon le type des panneaux, le degré de préfabrication et le composant en question. On a constaté qu'en incluant les planchers et les cloisons dans les composants préfabriqués il est

possible de réaliser des économies appréciables (jusqu'à concurrence de 6 %). Pour la construction de 30 logements ou plus, les économies s'élèveraient jusqu'à 95 000 $ (3 150 $ l'unité).

L'analyse d'évaluation, d'adaptation et de coûts a fait ressortir plusieurs aspects du logement industrialisé qui devraient faire l'objet d'une enquête exhaustive et détaillée. Les recommandations formulées de mener une étude plus poussée portaient sur quatre domaines : 1) facteurs relatifs au transport et au levage, y compris l'optimisation du poids, des dimensions et de la configuration des panneaux pour assurer l'efficacité du transport et du montage; 2) économies indirectes résultant de durées de construction écourtées, d'une quantité moindre de matériaux gaspillés et du service après vente; 3) mise au point de produits, de logiciels et de services correspondant davantage aux besoins des constructeurs et des acheteurs; 4) études de commercialisation visant à évaluer le potentiel de certains types d'assemblage préfabriqués dans le contexte nord-américain et à en promouvoir les avantages.

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EXECUTIVE SUMMARY

The purpose of this study was to examine how the Grow Home can be adapted to an industrialized method of production using prefabricated panel systems, and to determine what implications this would have in terms of quality, economy and technical performance. The project was carried out in three phases. The first phase consisted of research on systems currently available in North America, and an evaluation of options considered appropriate for the Grow Home. In the second phase, the unit's design was adapted to suit the prefabrication process and provide flexibility for the builder, and a cost estimate was carried out to determine whether significant savings could be achieved with prefabrication, using the adapted version of the Grow Home. Finally, the results of the study were analyzed and recommendations drafted based on the findings.

● SURVEY AND EVALUATION OF PANEL SYSTEMS

In the first phase of the study, a survey of panel manufacturers in North America was undertaken. A list of 304 companies was compiled, one third of which were contacted for information. Responses from 55 manufacturers were received, and 9 types of panel systems were selected for evaluation based on their potential to provide cost savings and their applicability to residential development. A method for evaluating prefabricated panel systems was developed to assess the adequacy and suitability of the options available. The model consisted of two sets of attributes which were correlated, weighted and quantified for a particular application. A set of 28 requirements (or desirable qualities) was drafted, and 34 qualifiable and quantifiable evaluation criteria were generated from these requirements. A weighting factor was attributed to each criterion to reflect its importance in a given context. The evaluation was conducted with emphasis towards the builder's perspective, under the premise that the ability of any prefabricated system to gain widespread acceptance depends on how well it suits the builder's interests.

All factors considered, the prefabricated panel systems scored higher than conventional construction methods. While the ratings varied significantly for some of the criteria, the total scores differed by a narrow margin. Generally, prefabricated systems rated higher on criteria related to technical performance and level of craftsmanship. Characteristics related to the environment and durability were found to be fairly equal among the systems evaluated. The only drawbacks to the use of prefabricated panel systems were found in their flexibility relative to conventional construction, specifically for on-site modifications, and in their disruption of the builders' traditional operational routines, which may hinder their acceptance into the market.

The evaluation of the various systems indicated that all types of prefabricated panels could provide a level of quality which is superior to that of conventional construction, particularly in the area of energy efficiency and craftsmanship. Whether these characteristics of prefabricated systems can attract the average builder, either directly or indirectly by providing a more marketable product, remains questionable. Any product, innovative or otherwise, will gain support only when it promotes the interest of the person who pays for it. In the case of residential construction, the party who eventually assumes the energy costs is not the builder, making it unlikely that the panels' superior energy efficiency in itself will attract the interest of the average builder. The ability of prefabricated systems to offer higher quality and energy efficiency for the same price or lower, however, can be an attractive and effective marketing tool for builders.

● DESIGN ADAPTATION AND COST ANALYSIS

A framework for the industrialization of the Grow Home was developed in the second phase of the study by adapting the unit's design to make it more suitable to the fabrication process. The design process was aimed at providing sufficient flexibility for the builder and economies of scale for the manufacturer by generating a wide range of options for the dwelling using a small number of simple, standard components. Architectural, modular and technical design criteria were generated based largely on interviews and consultations with the manufacturers and feedback acquired from a post-occupancy evaluation of Grow Home projects. Because the design process involved the manipulation of standard components within established modules, a CAD software, used as a design tool, provided an efficient method of generating and testing alternatives. While environmental considerations were accounted for in the evaluation of the panel systems, the unit's design was adapted to address cost, quality, marketability and accessibility. Both semi-detached and rowhouse versions of the Grow Home were considered, and four aspects of the house were examined: general dimensions, stair configuration and orientation, interior partitions and exterior walls. Wider units of 4.9 meters, which could be adapted more easily for accessibility than the 4.3 meter units, were considered in all stages of the design development.

Although no prefabricated system can equal the flexibility of stick-build construction, the number of options generated for the interior plan with a limited number of standard components provided sufficient selection for interior layouts and exterior elevations. Nine panel configurations were proposed in all: six for the front and back elevations and three for the side walls of the end units. The panels could be combined in various ways to accommodate the options for interior layout. Rowhouse versions of the home could be built with anywhere from two to four panels, while semi-detached or end units would require 3 to 6. The use of small, standard interior partitions generated various configurations for entrances and bathrooms, while enabling changes to be made fairly easily on site in response to a client's request.

The potential for prefabricated systems to reduce construction costs was addressed by examining the costs of several prefabricated components, including exterior walls, floors, partitions and dividing walls. An elemental cost breakdown was drafted for labour and material using conventional construction methods, compared to actual costs submitted by 7 Grow Home builders, and used as a basis for cost comparisons between prefabricated and conventional construction. The analysis demonstrated that prefabricated panel systems can, for the most part, provide a competitive alternative to conventional construction. The magnitude of the savings, however, can vary significantly depending on the type of panel system, the degree of prefabrication and the component in question.

Open sheathed panels and other prefabricated components using conventional construction methods provided the highest percentage savings over the equivalent stick-build value, averaging 50% for exterior walls, demonstrating that system for system, economies through prefabrication are possible. Savings comparable to those of the open sheathed panels can be achieved with the other types by increasing the degree of prefabrication. The addition of interior and/or exterior finishes to these panels, for instance, was able to produce more competitively priced systems. The total cost reductions which were achieved, however, usually in the area of 2-3%, may not be sufficient to lower the selling price of the house. This was due partly to the relatively small percentage of the total house cost attributed to the envelope (approx. 14%). By increasing the number of prefabricated components to include floors and interior partitions, it was found that substantial savings (up to 6%) were possible. For the construction of 30 or more units, this represents savings as high as $95,000 ($3,150 per unit). The question is whether these savings in themselves provide sufficient incentive for the average builder to adopt a new or unfamiliar method of construction.

Other incentives for builders to integrate these systems into their normal, established operational routines may need to be considered. One possibility has to do with simplifying the management of construction tasks. If the prefabricated system does not interfere with the normal operational routines of the average builder, the chance of acceptance may be enhanced. This may be achieved in three ways: by enhancing the flexibility of the systems, by designing the product so that it integrates smoothly with the other operations, or by providing a complete package, whereby a product is manufactured, delivered and installed by the same party.

As is the case with the introduction of any new product, the challenge lies in educating both the builder and the buyer as to the advantages of prefabricated construction. The consumer needs to be instructed on the potential energy savings which could be gained from air-tight construction. The builder needs to be made aware of the fact that prefabrication may result in less material wastage and, consequently, lower expenses for clean-up and trash removal. The faster assembly process could translate into savings in overhead and financing costs. Construction delays due to poor weather conditions could be reduced, and the possibility of vandalism and theft is decreased since the envelope can be closed in a matter of hours. Specialized labour requirements are reduced, as are warranty commitments, which are passed onto the manufacturer. Emphasis needs to be placed on how the construction task can be simplified, and, consequently, the managerial burden relieved.

● RECOMMENDATIONS

The evaluation, adaptation and cost analysis revealed several aspects of industrialized housing which could benefit from a more comprehensive and detailed investigation. Several recommendations for research, development and marketing were proposed in 4 areas:

•Transportation and Lifting:

Determine the exact implications of transportation and lifting costs for various locations in Québec, Canada and abroad, taking into consideration availability and cost of labour, material and equipment. The study should be aimed at optimizing such product characteristics as panel weight, size and configuration to maximize transportation and assembly efficiency in terms of erection time and crew size.

•Indirect Cost Savings:

Assess indirect costs of prefabricated construction to provide a more realistic estimate of the potential savings which improve the cost equation for the builder and, ultimately, for the consumer. There are three main factors that may lower costs for the builder which were not quantified: 1) reduction in construction time, caused by both shorter assembly periods and less delays due to bad weather, which result in reduced overhead, financing and supervision costs, 2) less material wastage and associated clearing costs, caused by efficient use of materials, and a reduction in the amount of material stored on site, which results in less damage due to exposure, vandalism and theft, and 3) less after-sale service requirements, since the assembly of components under controlled conditions ensures that the materials are dry, clean and straight, resulting in a higher general level of craftsmanship.

•Development of Products, Software and Services:

Design and develop products to suit the builders' and buyers' needs more closely, and, consequently, accelerate widespread acceptance. Specifically, this includes increasing the degree of prefabrication within the components, and expanding the scope of prefabricated components. The degree could be increased to include interior and/or exterior finishes, and electrical and/or plumbing services, and expanding the range of available exterior finishes to provide a wider selection. The scope of prefabricated components could be increased by developing cost-effective and suitable prefabricated alternatives for subsystems other than the exterior walls, including dividing walls, floors, roofs and partitions.

Software development could provide efficient tools to perform one or more of several functions: optimize resource efficiency (labour and material) for prefabrication of components, monitor production and distribution of an inventory of materials and prefabricated components, cost estimation, and interactive graphic software to be used by the prospective buyer in laying out his unit and selecting finishes.

Increase the range of services through the provision of transportation, lifting, installation, labour, training and inspection by the manufacturer, as well as warranties and a commitment to after-sale servicing.

•Market Studies:

Aimed at assessing the potential for specific types of prefabricated assemblies in the North American context and at promoting their benefits. An assessment of various architectural, technical, practical and legal considerations could produce valuable guidance for development by identifying the strengths, weaknesses and incompatibilities of a particular prefabricated system in any given market.

Finally, there is a need for promotional efforts to educate builders and buyers as to the advantages of prefabricated construction, and to create a positive atmosphere around industrialized housing in general and prefabricated subsystems in particular. With a predisposition to higher quality, better energy efficiency and a potential for competitive pricing, the prospects appear to be promising.

1. INTRODUCTION

1

It is commonly believed that the industrialization of housing holds many advantages over conventional construction methods. The assembly of units, panels or components under factory-controlled conditions yields a higher quality product which generally results in more energy-efficient homes. Due to the quick and efficient assembly which takes place on-site, the effect of poor weather conditions, particularly in cold climates, is reduced as is the potential for damage due to inadequate material storage and vandalism. Clean-up time and material costs are also reduced due to less wastage, construction management and trade coordination can be simplified, and the need for large teams of skilled on-site labour for multiple-unit construction is substantially lowered. While the potential for cost reduction is significant, particularly for standard designs and high production volumes, many of the savings can be offset by delivery, installation and inventory costs, as well as by higher fixed costs associated with keeping a plant under operation during the winter months when the demand is low, and during years of reduced construction activity.

Despite its many advantages, the use of prefabricated homes in Canada has been slow in gaining acceptance. In fact, sale of manufactured homes has decreased to about 7% in 1992 from its peak in 1974 , when it accounted for 20% of total housing starts [2]*[5]. In Québec, 16% of homes built in 1990 were prefabricated, 7% using panelized construction and 6% modular [10]. On the other hand, manufactured housing has been on the increase in countries such as Japan, the United States and Sweden. In the United States, manufactured housing accounts for 58% of housing starts, with 15% attributed to mobile homes and 37% to panelized construction [1]. In Sweden, this figure runs close to 90%. The reasons for the relatively small percentage of manufactured homes in Canada are varied and remain a question of debate. A conference held in Calgary on the subject in 1985 concluded that there are three major issues which need to be addressed: quality, image and price [3]. A recent study sponsored by CMHC reviewed the experiences in other countries, and found that there were two broad areas of opportunity for manufactured housing in Canada: the provision of affordable housing to families which could not otherwise afford to buy, and the use of advanced technology to reduce production costs and increase quality [2].

It seems that an essential starting point in the promotion of manufactured housing has to do with the reduction of construction costs and, ultimately, selling price. Although some forms of prefabrication have been estimated to cost less than conventional construction methods, the savings are often minimal and do not in themselves provide sufficient incentive for home builders to change their established methods of operation, or for first-time buyers to be given an option which is substantially more affordable than what is already on the market.

*All figures within square brackets indicate endnotes on the References page.

The type of unit, along with its layout, configuration and size, will inevitably affect the cost in both conventional and prefabricated construction. It is conceivable that a design which is flexible, simple, efficient and small could provide more savings in its prefabricated form than it would for more conventional types of construction. In light of this potential, the purpose of this study was to examine the possibilities for prefabricating a specific design, and to provide guidance as to how it can be optimized to suit the manufacturing process and further reduce costs. The model used was the Grow Home - the product of a research effort aimed at addressing the problem of affordable housing in the urban context –which was successfully implemented in the Montreal area. The analysis addressed the builder's point of view, and was conducted in the context of the Québec housing market.

● 1.1 THE GROW HOME

The Grow Home is a 93 square meter rowhouse, 4.3 meters wide (figure 1.1). It was developed by a team of researchers from the Affordable Homes Program at McGill University in response to the affordable housing challenge, with contributions from the Société d'habitation du Québec and the Canada Mortgage and Housing Corporation [13]. On the ground floor was a kitchen, bathroom and living room. An unpartitioned second floor (which could eventually be finished to include two bedrooms and a second bathroom) was proposed in an effort to reduce costs and enable the owner to complete the unit at his or her own discretion. A full-scale prototype, sponsored by Dow Canada, was erected on the university campus and opened to the public for one month. Shortly after the demonstration unit was dismantled, several housing projects based on the Grow Home concept were started. Within the first 18 months, approximately 1000 units were built in some 25 projects in the Montreal area, ranging in price from $69,000 to $95,000.

The built projects revealed some interesting interpretations of the Grow Home concept. While the 4.3 - meter width was retained in all cases, each of the builders modified the design to suit the tastes and budgets of his own particular market. The original plan, which subdivided the space with a central plumbing/stair core, was altered in most cases to accentuate the full depth of the space (figure 1.2). The second floor was partitioned and finished in most of the projects, some with "luxurious" bathrooms having separate showers and whirlpool baths. Many of the builders provided brick veneer on the exterior to increase quality and project an image of permanence, while the remainder used a cement-based aggregate finish. All units were built with basements, which made it possible to add up to 46.5 square meters to the usable floor area, and indoor garages were included in about 15% of the homes. Vestibules and walk-in closets were added to the units in some of the projects, while separate garages were added to the sides in one other.

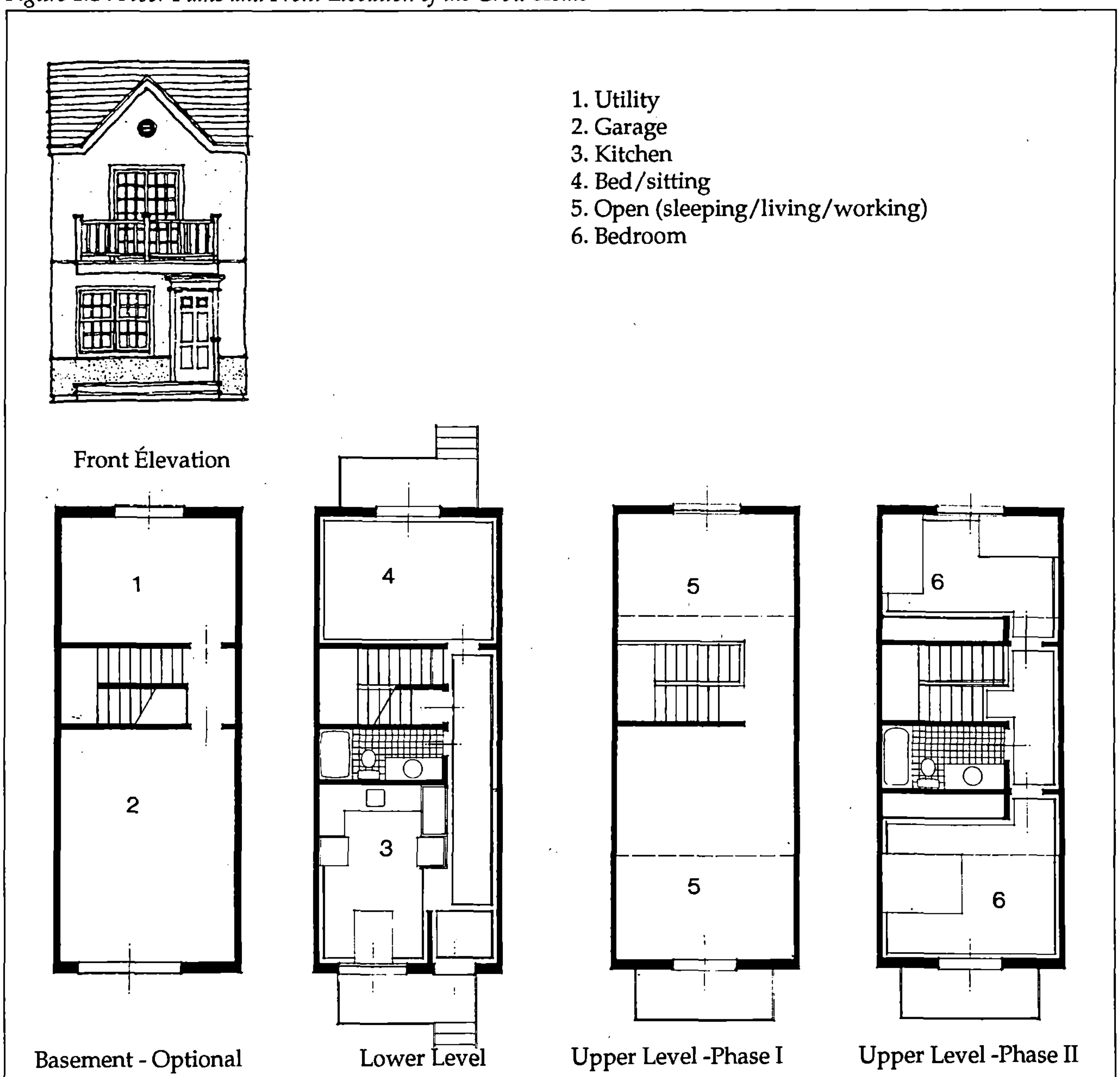
An evaluation of seven of the projects totalling 325 units was undertaken to determine the extent to which the projects were successful in accommodating the buyers' functional requirements and financial limitations [8]. The occupants of the homes were surveyed, and the builders interviewed. The results of the survey, however preliminary, were helpful in identifying the strengths and weaknesses of the concept as it was implemented. They indicated that despite the regulatory obstacles encountered and the less than ideal site plans which were developed in some cases, the projects were successful in addressing the market needs in terms of affordability, functionality and aesthetics. The builders, on the other hand, were receptive to the idea because it was flexible and efficient to build.

The experience with the Grow Home demonstrated that the size, plan and configuration of the narrow-front rowhouse did not pose a problem for most of the buyers and builders. Its success indicated that there is a definite market need for the product, and that it is a viable alternative in the provision of affordable housing. Industrialization of the concept may provide ways of building it less expensively.

● 1.2 POTENTIAL FOR PREFABRICATION

In light of the fact that the provision of affordable housing is an important part of promoting manufactured housing, the Grow Home model was used because of its potential to reduce costs. Development, construction and operating costs are minimized by using simple and effective design strategies. The narrow-front rowhouse configuration allows significant reductions in land and infrastructure

Figure 1.1 : Floor Plans and Front Elevation of the Grow Home

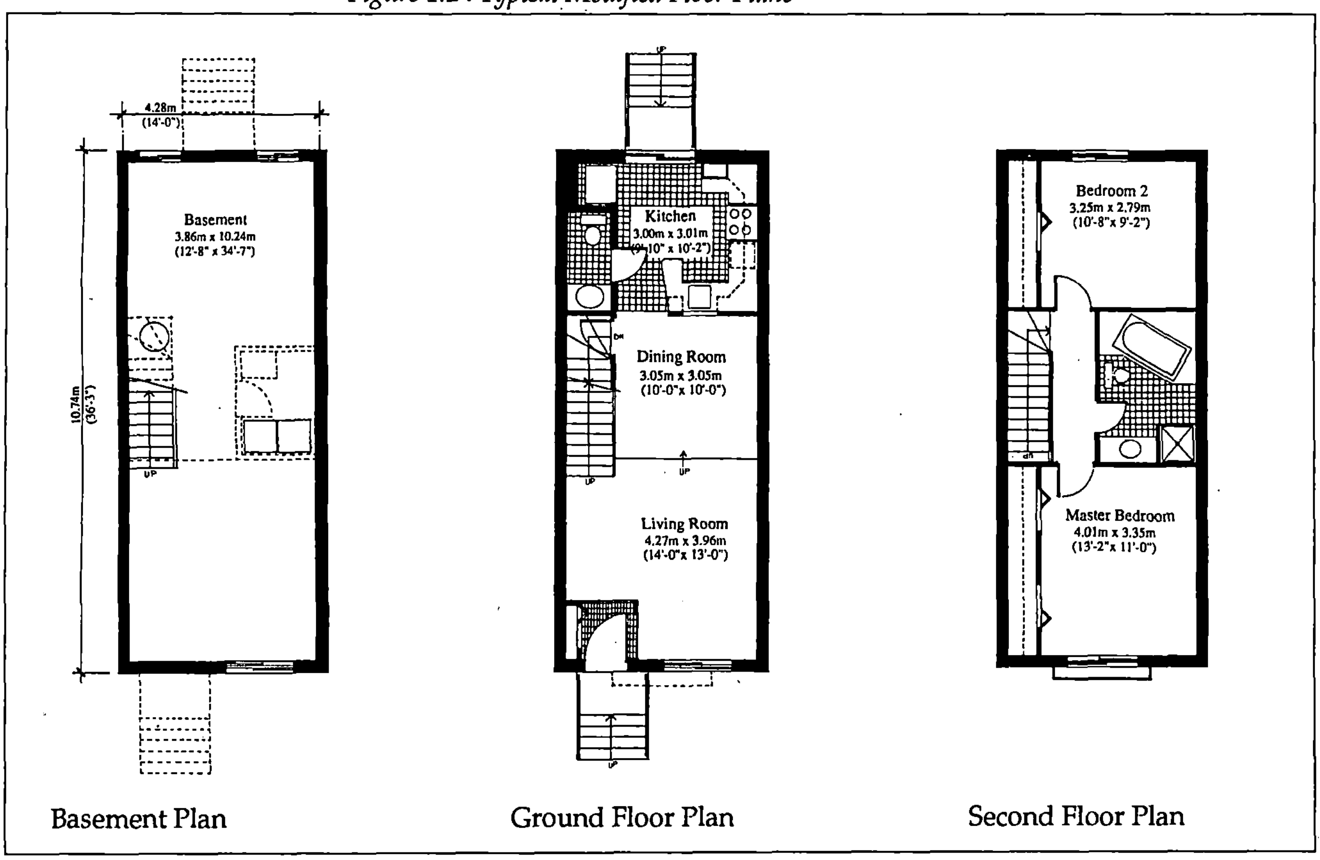


costs as well as operating costs since the heat losses are restricted to 2 exposed walls and a small roof area. The 4.3 meter dimension also represents the cut-off point for a floor structure consisting of 38 x 235 mm joists at 400 mm c/c; adding 300 mm to the width requires upgrading to a structure which may cost up to 25% more, particularly if conventional joists are used. The need for interior load bearing partitions is also eliminated, making the space very flexible.

Construction costs, kept below $40,000, are minimized by virtue of the house's small size, simple layout, and the efficient use of conventional construction materials. With the shrinking size of the average North American household, a smaller dwelling would not necessarily compromise the occupants' living comfort. By eliminating irregular contours and staggers, cost reductions could be expected at every level of the construction process, from foundation to roofing. A rectangular configuration, for instance, has about 20% less perimeter than an L-shaped unit of the same floor area. Both labor and material costs are reduced by simplifying the construction task and standardizing the dimensions of the structural and cladding elements. Complex joints and details are kept at a minimum.

Accounting for about one third of the total construction costs, the finishing operations in housing units are among the most labor-intensive. By allowing for a flexible interior space, the timing and magnitude of these costs can be manipulated. By leaving the second floor unpartitioned at the time of purchase, for instance (as an open loft space), a savings of about $5000 can be achieved. The space may then be finished by the owner at his or her own discretion. The flexibility of the design not only simplifies the task of modifying the layout, but it also enables the builders to offer a wide range of options to the buyers without significantly complicating the construction process. This was thought to be a key selling point in the built

Figure 1.2 : Typical Modified Floor Plans



projects, since it allowed the buyers to personalize their dwellings and adjust the design to suit their budgets. Last-minute changes could be made to the floor plan in response to particular demands, and by keeping the size and location of openings consistent, most builders were able to proceed with the construction of the structure and envelope before the interior layout was finalized.

The small size, simple configuration and efficient layout of the Grow Home provides an opportunity to exploit the advantages of the prefabricated methods of building to their maximum potential. They tend to maximize the efficiency of building erection, making it appropriate for several levels of prefabrication. The 4.3 x 11 meter rectangle, for instance, lends itself to easy modular prefabrication and transportation. The simple exterior configuration and symmetry allows for quick, uncomplicated panelized construction and assembly. Its technical design makes use of standard material dimensions, thereby minimizing the cutting and fitting operations as well as material wastage. This facilitates the prefabrication of packaged assembly kits. By using prefabricated roof trusses of standard size and slope, the roof construction is also quick and efficient. Spanning front to back, these trusses eliminate the need for structural partitions on the upper floor and make that space flexible.

The built projects made extensive use of prefabricated components. In addition to the roof trusses, door frames, window units, kitchen cabinets, railings, exterior concrete stairs and structural components (I-joists) were selected to simplify assembly and reduce construction time. The use of these components provides a starting point for the development of an industrialized version of the Grow Home, whereby other prefabricated systems and subsystems (walls, floors, roofs, foundations, etc.) would form part of a complete system package.

2. SCOPE AND OBJECTIVES

The purpose of this study was to examine how the Grow Home can be adapted to an industrialized method of production using prefabricated panel systems, and to determine what implications this would have in terms of quality, economy and technical performance. The analysis was aimed at providing a framework for the prefabrication and distribution of the Grow Home, and at determining what obstacles and concerns need to be addressed. As such, it was intended as a pre-feasibility study which will provide a basis for a more comprehensive and detailed investigation.

There were nine primary objectives of the research, as follows:

1. Adapt the Grow Home, technically and architecturally, so that its industrial production can be optimized.
2. Assess the technical, economic as well as quality implications of industrialized production of the Grow Home using a panel unit system.
3. Prepare preliminary design of the hardware and software of the industrialized system package of the Grow Home.
4. Analyze implications of transporting the industrialized system package.
5. Examine the possibilities of integrating other prefabricated components by Québec manufacturers into the industrialized system package of the Grow Home.
6. Prepare preliminary drawings and specifications for the hardware and software of the system package.
7. Compare, in terms of economy and quality, traditional stick-frame construction of the Grow Home with industrialized production using a panel unit system.
8. Prepare a report for the purpose of disseminating he research findings to the construction industry.
9. Identify and recommend a program for further research aimed at optimizing the industrialization of homes using prefabricated systems and sub-systems.

The scope of this research was limited to prefabricated panel systems. Other complete building unit systems such as modular or sectional prefabrication were not included in the analysis. Both semi-detached and rowhouse versions of the Grow Home, a concept in single-family housing, were considered.

The work was carried out in three phases: (1) product and market research, (2) design adaptation and cost estimation, and (3) analysis of results, recommendations for further research and report preparation. The first phase of the project dealt with the collection of information and evaluation of alternatives. Specifically, there were four tasks:

1. Conduct a survey of panel systems currently available in North America
2. Evaluate these systems in terms of technology, economy and quality
3. Select one or several specific panel system(s)
4. Conduct a survey of other prefabricated residential components manufactured in Quebec

In the second phase of the work, the Grow Home design was adapted to suit the industrialization process, and cost estimates for the selected alternatives were drawn. The work consisted of five tasks:

1. Preliminary design of the hardware of the system package:
   i. Start with the selected panel unit system(s) as a given and adapt the Grow Home to fit the system.
   ii. Optimize the Grow Home, in terms of sustainability, adaptability, accessibility as well as aesthetics.
   iii. Assemble a list of possible Quebec manufacturers and their components that would optimize the system package.
2. Preliminary design of the software of the system package (i.e. a framework for producing the Grow Home in an industrialized process) using a commercially-available CAD software.
3. Preliminary analysis of the implications of transporting the industrialized system package.
4. Preliminary drawings and specifications for the hardware and software of the system package, using a commercially-available CAD software.
5. Cost estimation of the industrialized system package using commercially available software, and assessment of the costs and benefits of the industrialized package relative to the traditional process of stick-build construction.

3. RESEARCH ON SYSTEMS AND PRODUCTS

In this first phase of the study, a survey of panel manufacturers in the United States and Canada was conducted, the types of systems available were categorized, and company literature was collected for each type of system. A method for evaluation was developed to provide a more logical, systematic and scientific approach to the selection of alternatives, based on the findings of previous research and structured from the builder's point of view.

The scope of the research was limited to those panel systems which had the highest potential for cost reduction, based on the results of a previous study [9]. The model to be used for the study was the Grow Home and its variations in two forms: rowhousing and semi-detached. Although the methods and approaches used in the analysis are generally applicable, they have been qualified or quantified for rowhousing in the context of the Québec housing market. Emphasis in the analysis was placed on the contractor's point of view, since it was believed that this would be the most appropriate approach for a practical investigation aimed at achieving widespread acceptance.

● 3.1. SURVEY OF PANEL SYSTEMS CURRENTLY AVAILABLE IN NORTH AMERICA

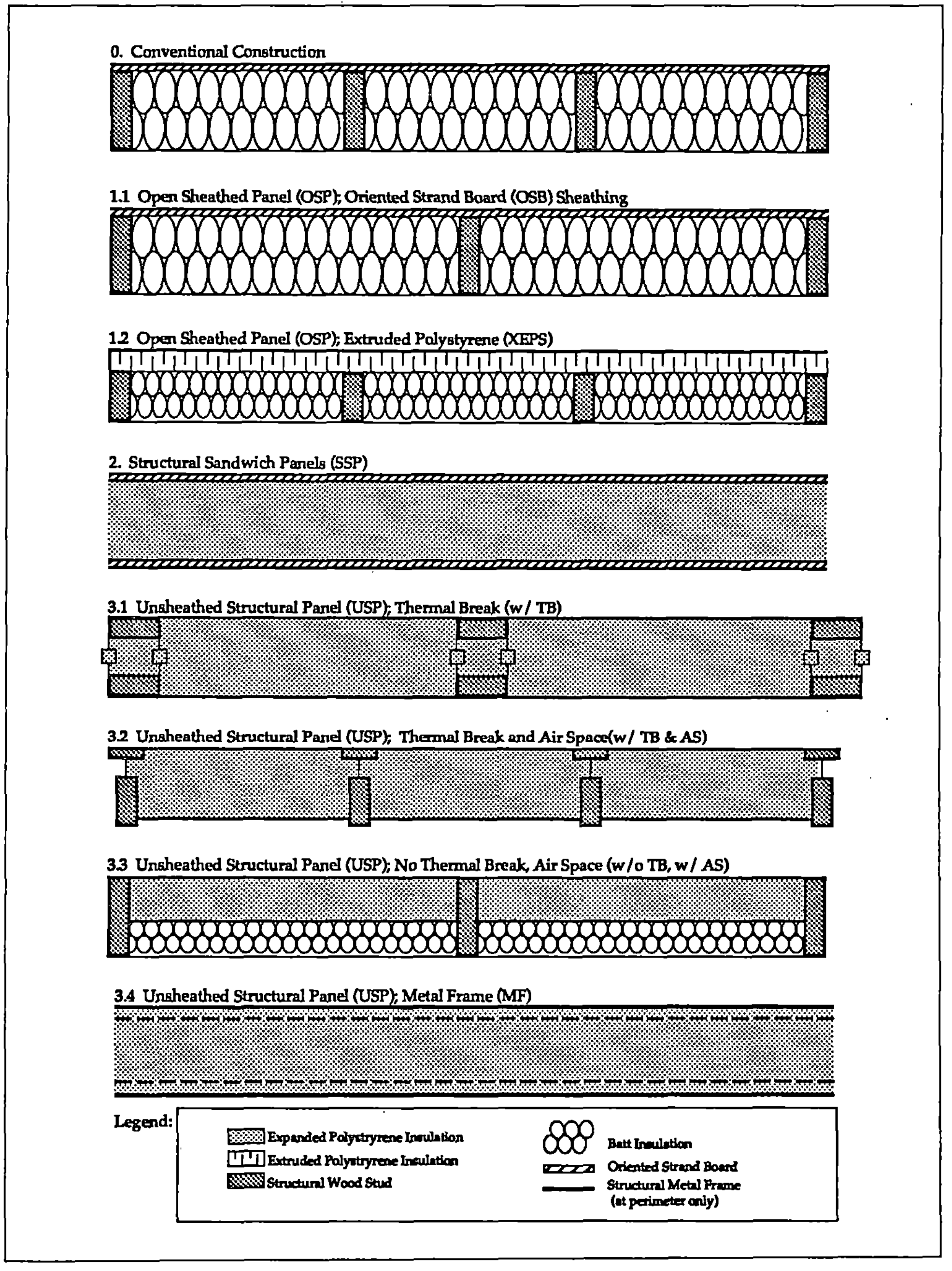
A list of panel manufacturers was compiled consisting of 304 manufacturers from across Canada and the United States. About one third (105) of these manufacturers were contacted and asked to provide basic information on their products and services. Eight of these were either out of business or had phone services disconnected. Responses from 55 manufacturers were received, 10 of which dealt exclusively with commercial construction. A general list of manufacturers is found in Appendix A, and Québec manufacturers of panels and components are listed in Appendix B.

There are numerous types of prefabricated systems, subsystems and components which can be combined at various levels to provide a complete systems package. A recent study by Ginter Inc. for the SHQ and CMHC evaluated the cost implications for various types of systems [9]. Based on the results of this study, 9 types of panels falling into three general categories were selected for evaluation because they appeared to be the most affordable and offered the greatest potential for further cost reduction. The cross sections of these systems are illustrated in figure 3.1, and are as follows:

1. Open Sheathed Panels (OSP)
   1.1 With Oriented Strand Board Sheathing (OSB)
   1.2 With Extruded Expanded Polystyrene Sheathing (XEPS)

2. Structural Sandwich Panels (SSP)
   2.1 With Moulded Bead Expanded Polystyrene (MEPS)
   2.2 With Extruded Polystyrene (XEPS)
   2.3 With Polyurethane or Polyisocyanurate (PUR/ISO)

Figure 3.1 : Horizontal Sections of Prefabricated Panel Systems



3. Unsheathed Structural Panels (USP)
    3.1 With Thermal Break (TB)
    3.2 With Thermal Break and Air Space (TB & AS)
    3.3 Without Thermal Break; with Air Space (AS)
    3.4 With Metal Frame (MF)

Conventional wood-frame construction methods were also evaluated to provide a basis for comparison. Each type of system has several variations depending on the manufacturer. Distinctions between these variations were made in areas where they were considered to be significant for the purpose of evaluation. The type of facing and insulation material, for instance, may vary from one manufacturer to another, as will the type of joint used for assembly. A brief description of each type of system and some of the variations are given in figures 3.2 to 3.11.

Figure 3.2 Conventional Construction (0) (from Energy-Efficient Housing Construction, CMHC, 1982

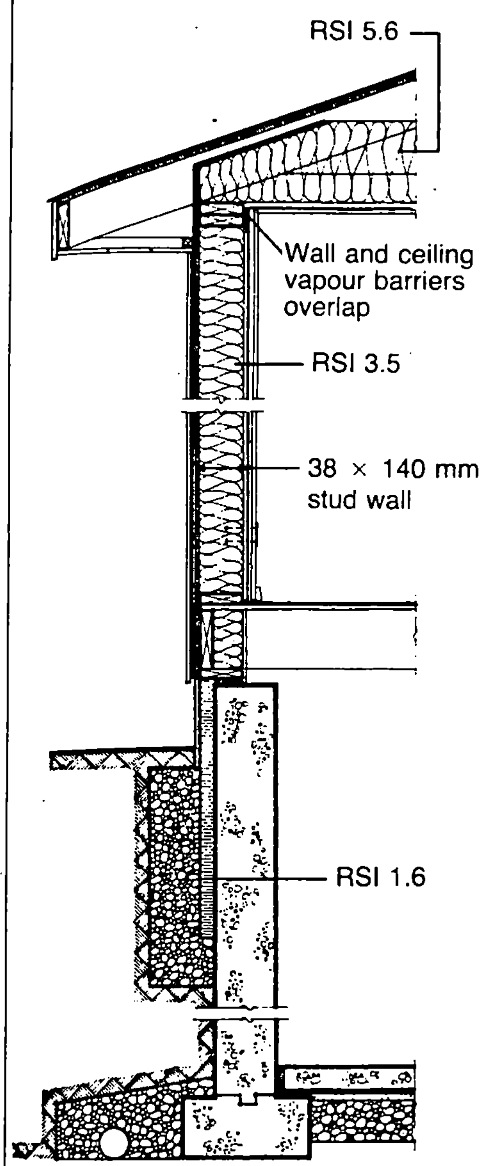
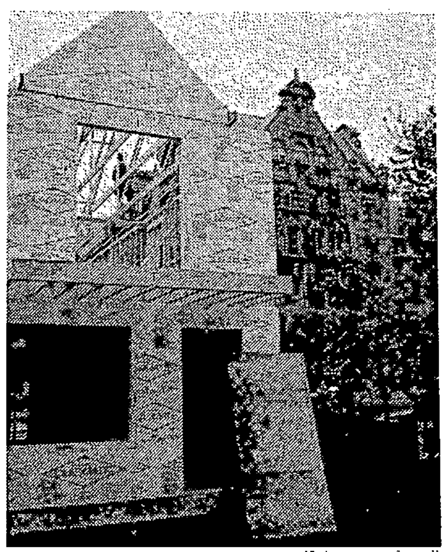


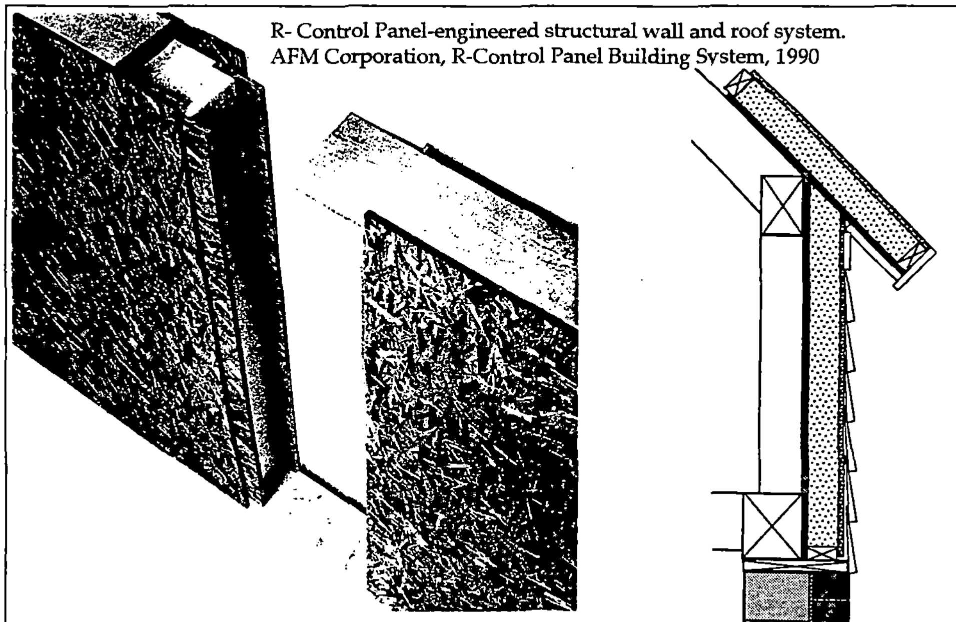
Figure 3.3 Open Sheathed Panels with XEPS Sheathing (1.2) (Construciton of Grow Home on McGill University Campus)

May 15,1990 2:00 p.m.



May 16, 1990 10:30 a.m.

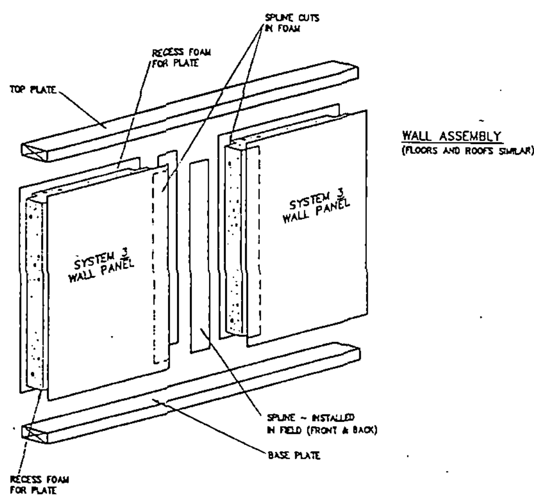
Figure 3.4 Structural Sandwich Panels (SSP) (2.0) Wall Sections



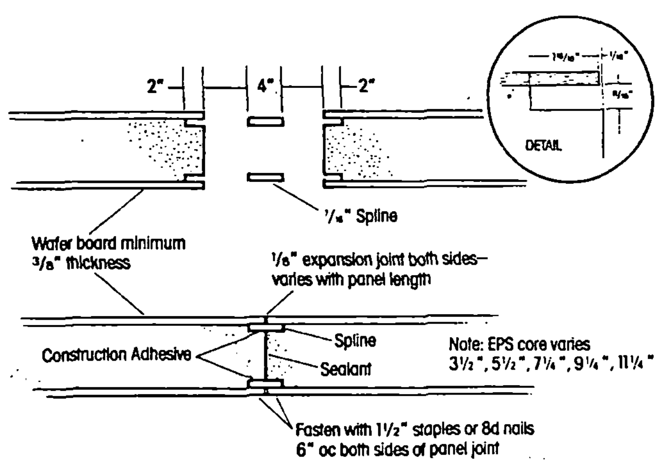
R- Control Panel-engineered structural wall and roof system.
AFM Corporation, R-Control Panel Building System, 1990

Harmony Exchange Stress-Skin Panels

Figure 3.5 Structural Sandwich Panels (SSP) (2.0) Joints, Double "Thin" Spline System

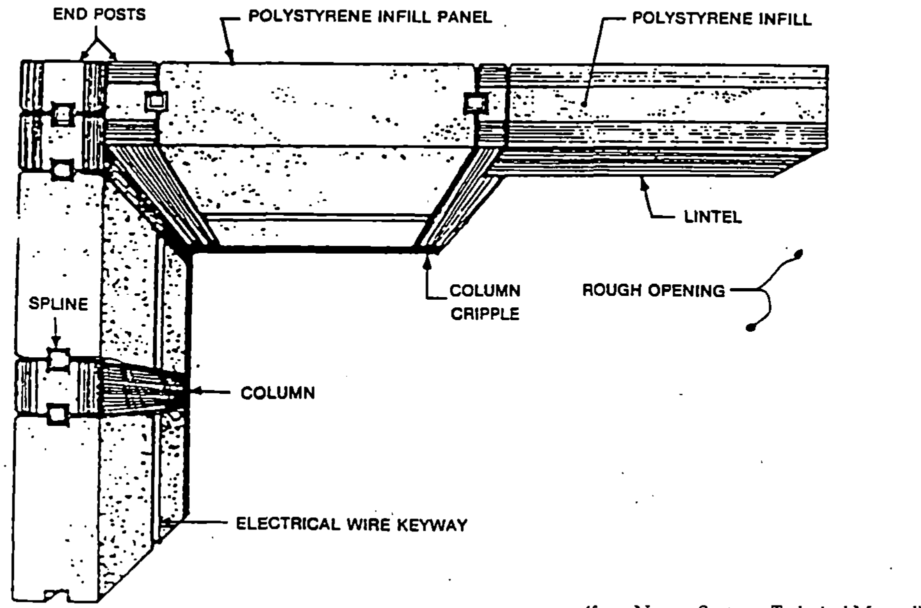


(from the International Conference of Building Officials Report No. 4639, June, 1991)



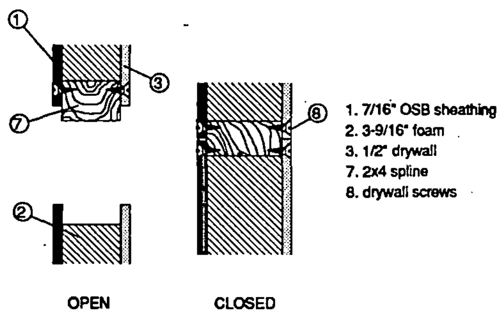
R-Control Double Spline System, AFM Corp.

Figure 3.6 Unsheathed Structural Panel System with Thermal Break (USP) (3.1)

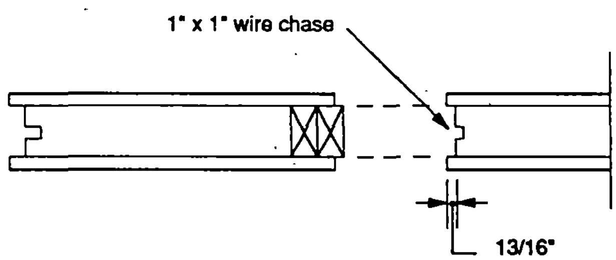


(from Nascor Systems Technical Manual)

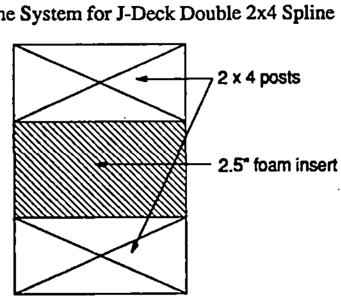
Figure 3.7 Structural Sandwich Panels (SSP) (2.0) Joints



Single 2x Spline Detail for Atlas Industries Panel



Double 2x Spline System for J-Deck Double 2x4 Spline



Laminated Thermally Broken Spline

(from Energy Design Update, Foam-Core Panels & Building Systems, 1992)

Figure 3.8 Unsheathed Structural Panel System with Thermal Break and Air Space (3.2) (from Insul-Wall)

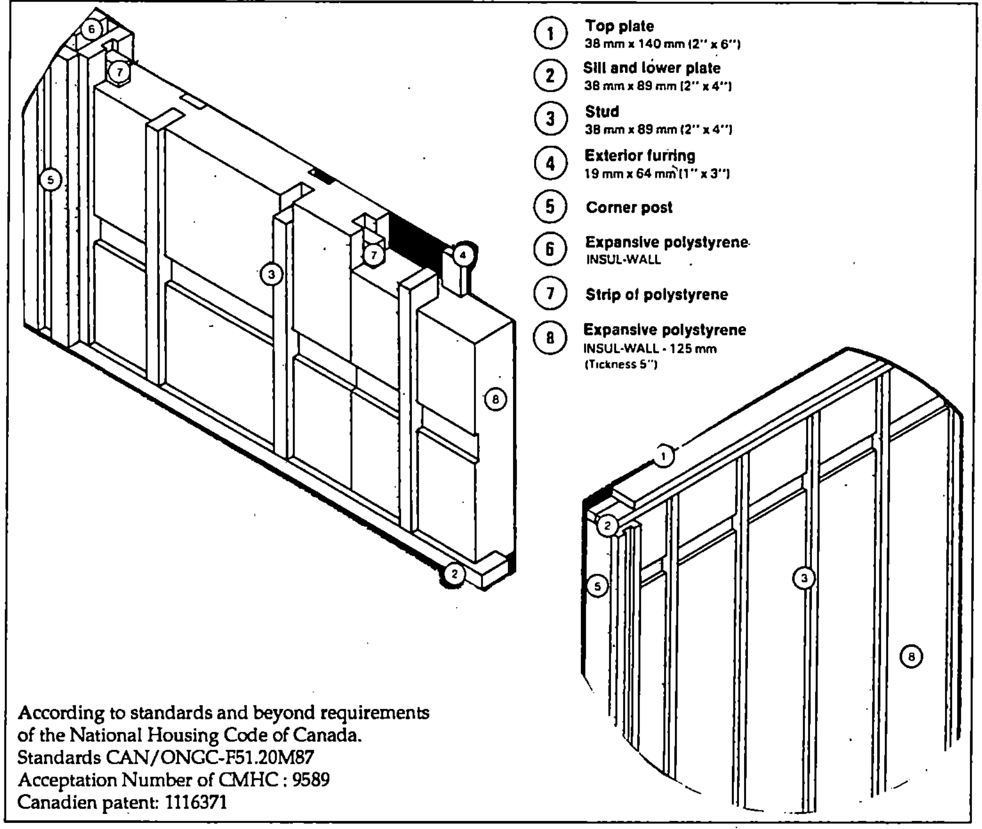
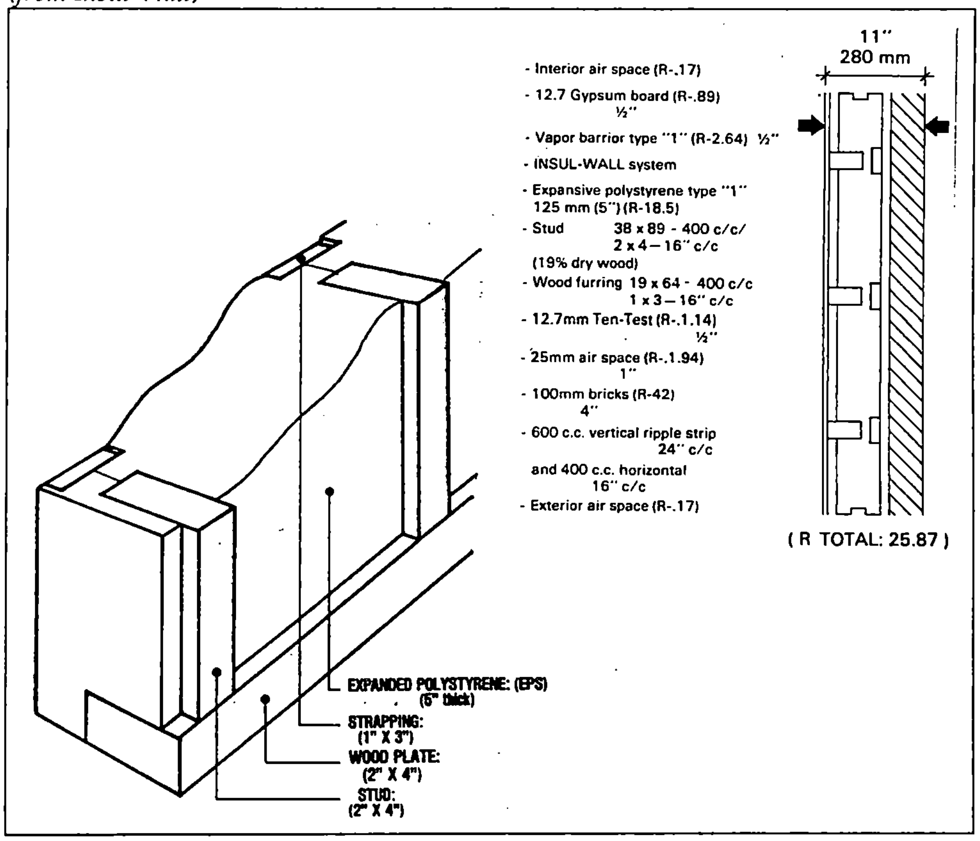


Figure 3.9 Unsheathed Structural Panel System with Thermal Break and Air Space (3.2) (from Insul-Wall)



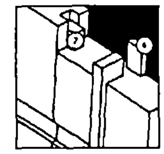


Figure 3.10 Unfaced Structural Panel System without Thermal Break, with Air Space (3.3) (Solar Wall from Superblock Brochure)

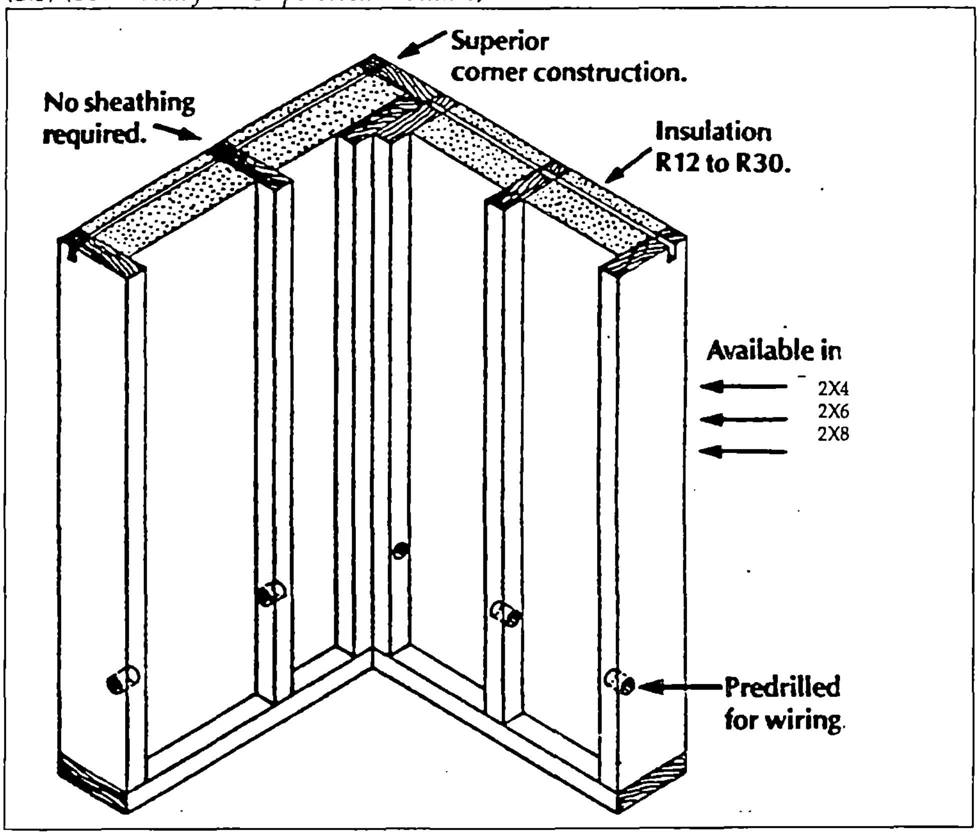
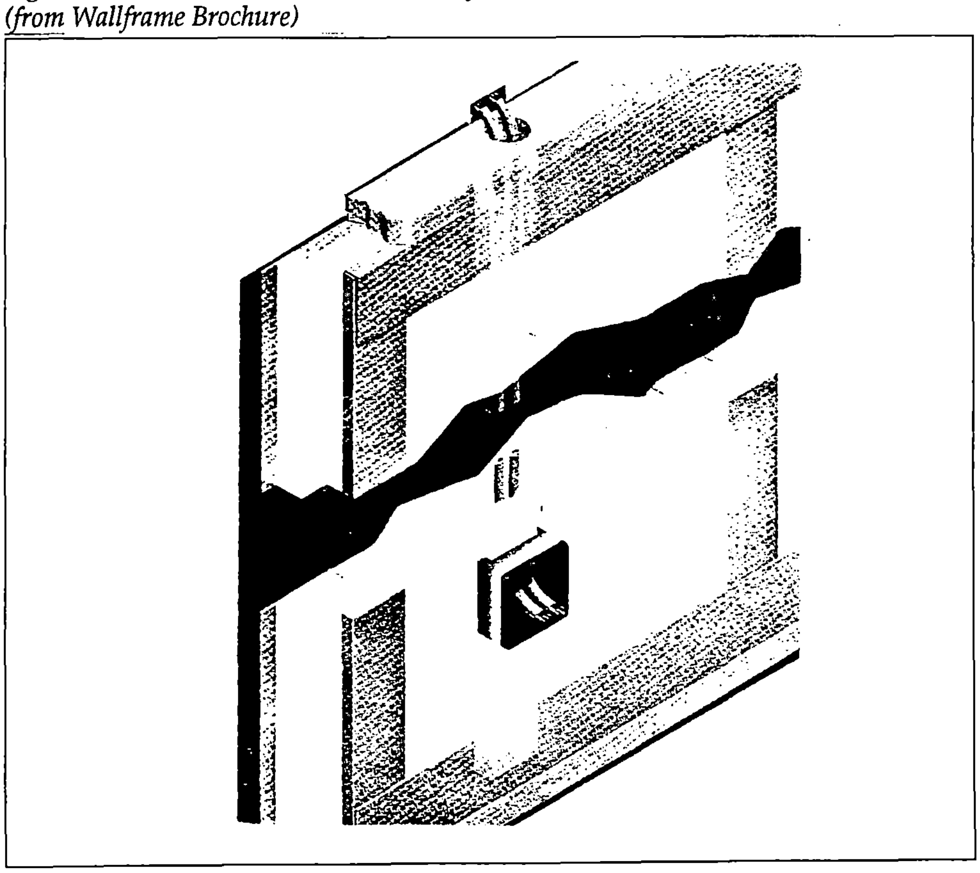


Figure 3.11 Unsheathed Structual Panel System with Metal Frame (3.4) (from Wallframe Brochure)



● 3.2. ANALYSIS AND EVALUATION OF PANEL SYSTEMS

Ultimately, the potential for any building material, product or process to be implemented successfully depends on its ability to gain acceptance from the home builders. The homebuilding industry, however, has been traditionally reluctant to accommodate change, particularly when it involves an innovative product or method [7]. Although prefabricated panel systems have been around for many years, they are still perceived by the average builder as a new method of construction. Because of the industry's special characteristics, the study of any prefabricated building system should be undertaken from the builder's perspective. Any evaluation must be conducted in comparison with conventional, stick-build methods, which represent the current state of the industry and the materials, processes and products which are likely to be accepted readily. In this context, there are several characteristics of the homebuilding industry which merit some discussion, as they will form a basis for setting up the requirements of a prefabricated system, and subsequently the criteria for its evaluation.

3.2.1. Prefabrication and the North American Homebuilding Industry

The organizational structures which characterize the construction industry are considered to be among the most complex. In the housing sector, the building process has evolved into a concise, unique system of operation which has been streamlined over the years and has locked itself out of the general industrial framework. The introduction of change into this established process is difficult but possible. There are several aspects about the industry which need to be taken into consideration.

To begin with, most of the organizations involved in the production and delivery of housing are small, localized, often family-owned operations. In Quebec, 90% of all construction companies have 5 or less employees on the permanent payroll [4][6]. The resulting vulnerability to economic cycles has led to cautious assessment and possible rejection of unfamiliar products and techniques. Furthermore, it has forced the builders to reduce continuing overhead to a minimum, thus discouraging large capital investment and assembly of large central staff [11]. Consequently, every possible management, administrative and design role is often being assumed by the individual builder.

This small-scale attempt at integration has evolved into a "closed system" of operation, whereby an inner circle of communication develops between the builder, the subcontractors and, occasionally, the user [12]. The system is a tightly-knit, interdependent arrangement of resources with well-established operational procedures and simplified lines of communication. Within this closed system, most, if not all of the construction work is subcontracted, and there is a tendency for the builder to work repeatedly with the same team of subcontractors. An informal working relationship is formed with steady pricing practices and working standards, which simplify the lines of communication even further. A builder may therefore be reluctant to force acceptance of a new system or product on a subcontractor for fear of losing him. Similarly, a builder may prefer to maintain contact with a long-time supplier to ensure reduced pricing privileges.

In single-family housing, the construction process becomes streamlined to the point where the need for detailed working drawings is diluted, since each of the team members knows his part of the work quite well. The result is a highly efficient operational standard, which carries through to the product. The units produced by an individual builder are usually very similar in plan, construction methods and materials with stylistic differences which can be integrated without changing the basic product. An architect's assistance is no longer required, with the builder opting instead for the cheaper services of an independent or in-house technician. Design decisions are often carried out by the builder, sometimes through informal verbal communication. Technical information or advice is derived directly from the product manufacturers, who design components to fit unobtrusively into the routine sequence of tasks. The general reluctance of homebuilders to accept change appears to be based on a fear of disrupting this process and complicating the traditional routine.

The problem is amplified by the very nature of the market. The purchase of a home represents the largest single personal investment an individual is likely to make in a lifetime. The decision to buy one particular home is influenced by a variety of factors including culture, personal taste and popular trend. For first-time buyers, the potential resale value of the home is also of major concern, and therefore so is the house's mass-appeal. The home builder is then faced with the need to consider the preferences and aspirations of a speculative home buyer. An innovative product may be rejected if it is felt that these aspirations will be compromised, even though the builder may be personally convinced that the product itself is superior.

Requirements for Acceptance by Builders

When viewed from the builders' perspective, there are several requirements which must be met if any prefabricated system is to gain widespread acceptance. The need to respect the economic self-interest of the builder is of primary importance. Any product that does not, in one way or another, increase the return on investment for the builder runs a high risk of being rejected. This potential can be increased either directly through a reduction of material, labor and overhead costs, or indirectly by providing a product which is more marketable than what the builder is currently offering. The fact that a product is new or innovative is not in itself a reason to expect an increase in sales volume, unless it is perceived by the consumer as being of superior quality relative to the price.

There are several aspects which will contribute to the product's marketability, namely affordability, attractiveness, energy efficiency and ability to customize. The degree to which the building systems, materials and components can influence these requirements will vary from product to product. For obvious reasons, the units' selling price is the most important factor in this regard, particularly for first-time buyers. In addition to the system's material, labor and overhead costs, its ability to enable the buyers to participate in the construction process may also affect the units affordability. This is particularly true for finishing operations, which are among the most labor-intensive of the construction processes and which can account for up to 30% of total costs. By enabling the consumer to assume these tasks, the final selling price of the units could be reduced significantly.

Because the units' attractiveness is largely a function of personal taste and priority, the contractor's ability to offer a range of options to the prospective buyer is an important marketing tool. The ease with which a unit can be adapted to meet particular demands, both during the manufacturing and construction phases, is therefore a critical factor in the decision to adopt a method or product. In a recent survey of 107 builders and architects conducted by the Structural Insulated Panel Association, the most commonly cited reason why respondents might not use structural insulated panels was the concern about design limitations [14]. During the occupancy phase, the ability for the buyer to customize the dwelling, be it through modification or decoration, is also a primary consideration. Any method which will inhibit or restrict this freedom will be interpreted as a deficiency, regardless of the technical quality which may be gained.

Another important requirement is ensuring that the product or method does not disrupt the builder's existing operational efficiency and simplified lines of communication. The traditional construction process consists of a sequence of work packages of fairly narrow scope. The tasks of any one particular trade are well defined, and the work of one affects the performance of the other. Innovation may occur within any one of these, but its acceptance is hindered if it involves more than one trade, or if the change in one trade affects the work of another. If we divide the house into its physical building elements, a hierarchical arrangement of systems (envelope), subsystems (walls), components (windows) and materials (glass) would result. The larger the element, the greater the operational and physical interdependence between trades. Therefore, the effect of changing an element lower in the scale (e.g. glass material) is less than it would be on an element higher up in the hierarchy (e.g. window unit, wall system), making it more susceptible to change. Innovation in the bigger systems stands a better chance of being accepted if it comes as a complete package which includes both material and labour, and therefore does not rely on the disposition of the other trades to accept the change.

The established routine of working with very simple construction documents should also be acknowledged. Because there is usually an absence of professional advice, any written or verbal communication relating to the innovation should be presented is brief, concise form with clear cost implications. Practical, bottom-line information will take priority over technical jargon and detailed product specifications. Simplicity in design, assembly and communication is essential.

Other Requirements

In addition to those aspects which will directly affect the likelihood of the builders accepting the product, there is also a need to provide an adequate living accommodation. There are three general requirements in this respect: habitability, maintainability and safety.

The requirement for habitability addresses the interior building environment as it is controlled by the building envelope. The house's visual environment, thermal comfort, acoustic privacy and air quality are of interest in this regard. Maintainability can be evaluated at three levels: general cleaning or seasonal maintenance, repair or replacement of finishing materials, components and fixtures, and long term maintenance over the building's life cycle. Safety issues focus on the possibility of collapse, ease of burglary and damage from calamity (strong wind, rain or fire).

Finally, there are two other considerations which must be addressed: accessibility and sustainability. The unit's accessibility deals with its ability to accommodate occupants with a physical, hearing or visual impairment, as well as hypersensitive occupants. A sustainable design needs to address the depletion of natural resources and other damage to the environment.

3.2.2. Evaluation and Selection of Panel Systems

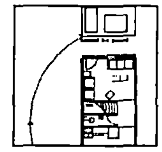
A method for evaluating prefabricated panel systems was developed to assess the adequacy and suitability of the options available, and to provide guidance for future development by identifying the strong points, weaknesses and incompatibilities of certain items which may require revision and improvement. The evaluation model consists of two sets of attributes which are correlated, weighted and quantified for a particular application.

In the first place, a set of 28 attributes was defined (based on the discussion in the previous section) which characterize the performance requirements for a prefabricated panel system. Evaluation criteria were then generated from these requirements, and each of them was rated on a scale of 1 (very poor) to 5 (excellent). A total of 30 criteria were rated, grouped into 6 general categories: environmental qualities, technical performance, durability, flexibility/adaptability, ease of assembly and craftsmanship. A weighting factor ranging from 1 (not important) to 5 (very important) was attributed to each of the criteria to reflect its importance for a particular application (design, housing type, location, climate, etc.). The system with the highest total weighted score represents the best solution for that particular context. Because of the stated intention to provide a product that was suitable for exportation and practical in its ability to gain acceptance from the average builder, the requirements were drafted with special attention given to these two factors. A summary and details of the evaluation are found in Appendix C.

All of the prefabricated panel systems received higher scores than the conventional construction methods in their total weighted average. Generally, the prefabricated wall panels received exceptional ratings in the criteria related to technical performance and craftsmanship. Characteristics related to the environment and durability were found to be fairly equal among the systems evaluated. The only drawbacks to the use of prefabricated panel systems were found in their flexibility relative to conventional construction, particularly for on-site modifications, and in their disruption of the builders' traditional operational routines, which may hinder their acceptance into the market.

While the ratings for the different panel types varied significantly for some of the criteria, the resulting total scores differed by a narrow margin. In light of the sensitivity of the relative scores to minor changes in the ratings of either evaluation criteria or importance factors, it was decided to proceed with the adaptation of the Grow Home without restricting the analysis to one specific panel system. The adaptation process and the cost analysis were therefore carried out using all except for one of the systems evaluated. Based on the evaluation, the unsheathed structural panels with metal frames were omitted from further analysis because they were considered to be more appropriate for commercial construction. Because the type of core material in the structural sandwich panel has very little effect on the adaptation process, all three variations of sandwich panels were not considered separately.

4. DESIGN ADAPTATION



In the next phase of the study, design alternatives were developed to optimize the prefabrication process, based largely on information from manufacturers and builders which was gathered from interviews. The purpose of these interviews and consultations is to acquire information on processing and assembly operations, to ascertain what conditions are most favourable to the average builder (in terms of accepting to use prefabricated panel systems), and to determine how the costs can be best reduced through design modifications.

A framework for the industrialization of the Grow Home was developed by adapting the unit's design to make it more suitable to the fabrication process. The exercise was intended to establish a guide as to how the design for a specific housing type may be structured to be built using standard components without any significant compromise in its flexibility. The standardization of prefabricated components would help achieve economies of scale and, ultimately, enhance the unit's affordability. It would also introduce the possibility of mass producing the components and keeping an inventory of parts which could be used for a variety of plan options. A flexible design would enable the builder to offer a range of designs, thereby improving the unit's marketability. While the Grow Home was used as a case study in the standardization process, the approach used could be applied to other housing types.

The house's design was adapted to address several issues simultaneously. While environmental considerations were accounted for in the evaluation of the panel systems, the unit's cost, quality, marketability and accessibility were taken into account during the design process. Specifically, modifications to the Grow Home, in both semi-detached and rowhouse versions, were carried out to fulfil 4 main objectives:

1. Reduce costs by exploiting the advantages of prefabricated panel systems to their full potential
2. Refine the design to suit buyers' needs and preferences more closely
3. Improve technical quality through modification of assembly process
4. Modify unit design for accessibility

● 4.1 METHODOLOGY

The adaptation of the Grow Home for industrialization was carried out in three stages. In the first stage, a working model was selected. The model was based on four variations of the Grow Home concept which were built and sold in the Montreal area. The construction of the units had been monitored, their builders interviewed, and their occupants surveyed.

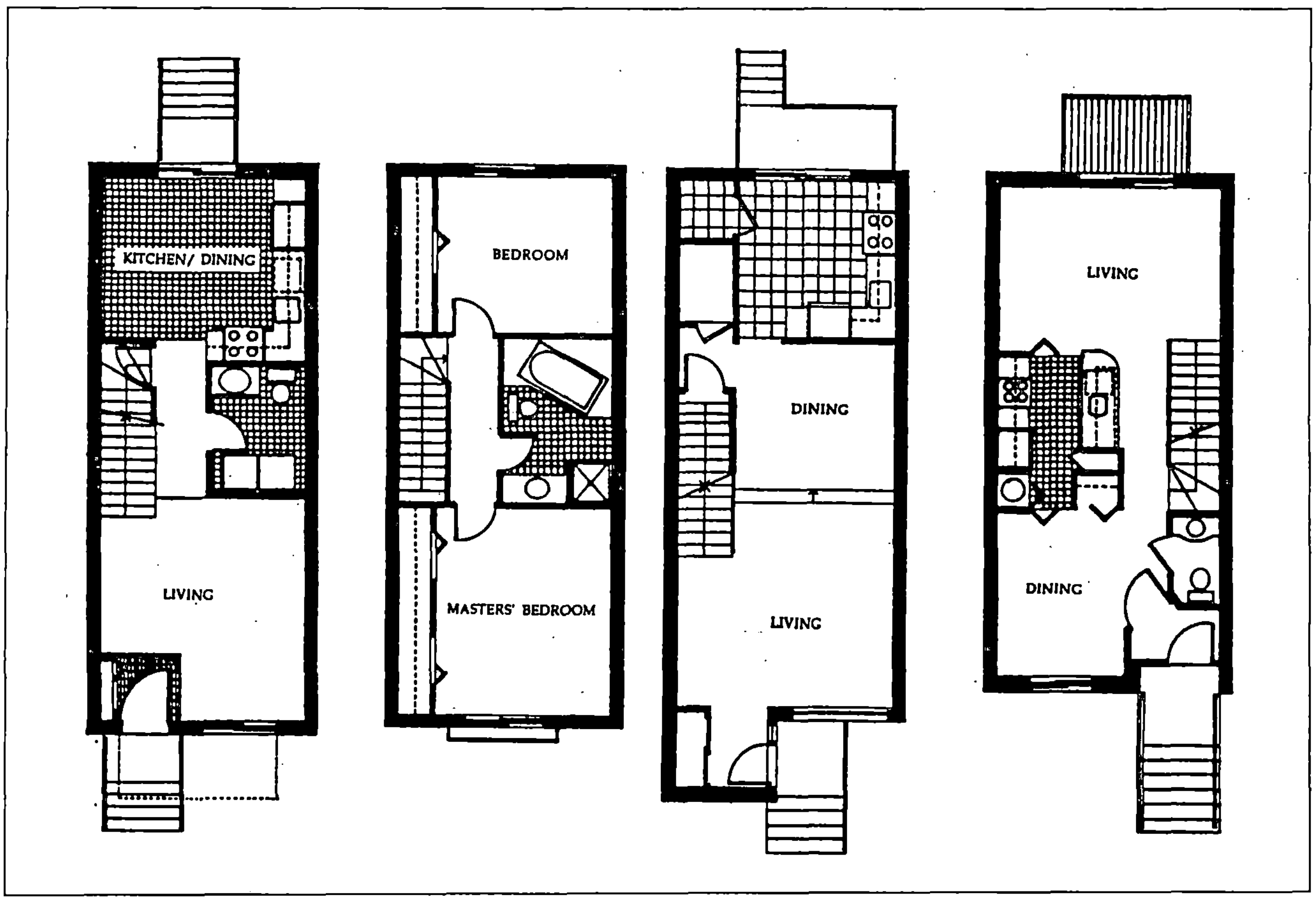
In the second stage, a set of criteria was established to guide the design optimization process. Guidelines were drafted in three areas: architectural design, which responded to the occupant's expressed preferences and aspirations; modular standardization, which addressed the prefabrication process itself, and technical factors, which were aimed at improving the quality of the products by exploiting the strengths and eliminating the weaknesses for each type of panel system.

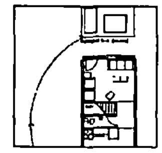
Finally, the design of the model units was optimized to conform to the architectural, modular and technical design criteria. The process was carried out for six types of panel systems simultaneously. The number of options which could be generated for the interior layout using the four model plans were considered to be sufficient in providing selection and flexibility to meet the demands of a range of prospective buyers. Possibilities for making the units accessible to the physically impaired were also investigated.

● 4.2. BASIC FLOOR PLANS

The variety of Grow Home-type projects built demonstrated the need to provide a flexible design. Although most of the projects were very similar in layout, no two projects were the same. Every builder made changes to the floor plan in response to the demands of the local buyer. Often, these changes were made spontaneously on site, simply by word-of-mouth.

Figure 4.1 : Built Plan Variations





Although various modifications to the floor plans were developed by the contractors, the general layout of the units was fairly consistent, falling into one of three general forms. The first (and most popular) was an open plan, with the stair along the side of the unit and the kitchen in the back. The second had a kitchen in the middle of the unit, separating the dining area in the front from the living area in the back, and the third consisted of a bathroom core in the centre of the unit to separate the two spaces, usually with the living area in the front. Figure 4.1 illustrates examples of these arrangements. Because of their success in the market, these layouts were used as a starting point for the optimization process. For added diversity, the design of the original Grow Home demonstration was added to the basic floor plans.

● 4.3. DESIGN CRITERIA

Prior to any design modification, a set of criteria was generated to guide the design process. These were aimed at optimizing the architectural, modular and technical design of the unit. They were based on feedback acquired from four major sources:

1. Results of a post-occupancy evaluation of Grow Home - type projects built in the Montreal area
2. Interviews and discussions carried out with representatives of the panel manufacturers
3. Results of the evaluation of prefabricated panel systems carried out in the first part of this study
4. CSA Standard for Barrier - Free Design (CAN/CSA -B651-M90)

4.3.1. Architectural Design

Architectural design modifications were derived mainly from the results of a post-occupancy evaluation of 196 Grow Home-type units built in the Montreal area between February 1991 and January 1992. There were four sections of the study that were of interest. First, the levels of satisfaction expressed with each of 11 unit attributes and 10 interior spaces were used as a relative guide to identify those areas which may require improvement. Although the levels of satisfaction expressed with each of the parameters were high, there were a few areas which could benefit from modification. The variations in satisfaction between the occupants of different unit designs were taken into consideration.

In a second section, the occupants' expressed preferences at the time of purchase were taken as indicators of the general aspirations of the local market. While many of the preferences were found to be adequately addressed by the units, the need to provide options such as a garage, basement and a third bedroom were revealed.

In the third part of the study, the reasons for purchasing the unit were investigated to determine what aspects of the built units were most helpful in attracting buyers, and which ones caused concern at the time of purchase. In addition to the price, which was the most frequently-mentioned reason for the purchase and which forms a premise for this study, there were several other features of the units that were found to be significant in attracting the buyers. Finally, the occupants were asked to suggest general improvements which could be made to the units. In these last two cases, the results of the survey corresponded closely with the occupant's levels of satisfaction and expressed preferences. The results of the survey for the four areas of investigation are shown in figures 4.2 and 4.3. The guidelines generated from these results (in order of importance) are as follows:

Improvements
- Ensure that the quality of finishes is not compromised
- Redesign entrance area for functional and privacy reasons
- Provide a superior level of soundproofing between units
- Improve kitchen layout for more functional use; increase size
- Increase the amount of storage space on the first and second floors
- Eliminate physical restrictions which compromise the unit's flexibility

Refinements
- Level of natural lighting
- Cross ventilation
- Living Room
- Dining Room
- Washroom (first floor)
- Washer/Dryer location

Figure 4.2 : Occupant Satisfaction With Unit Characteristics and Interior Spaces

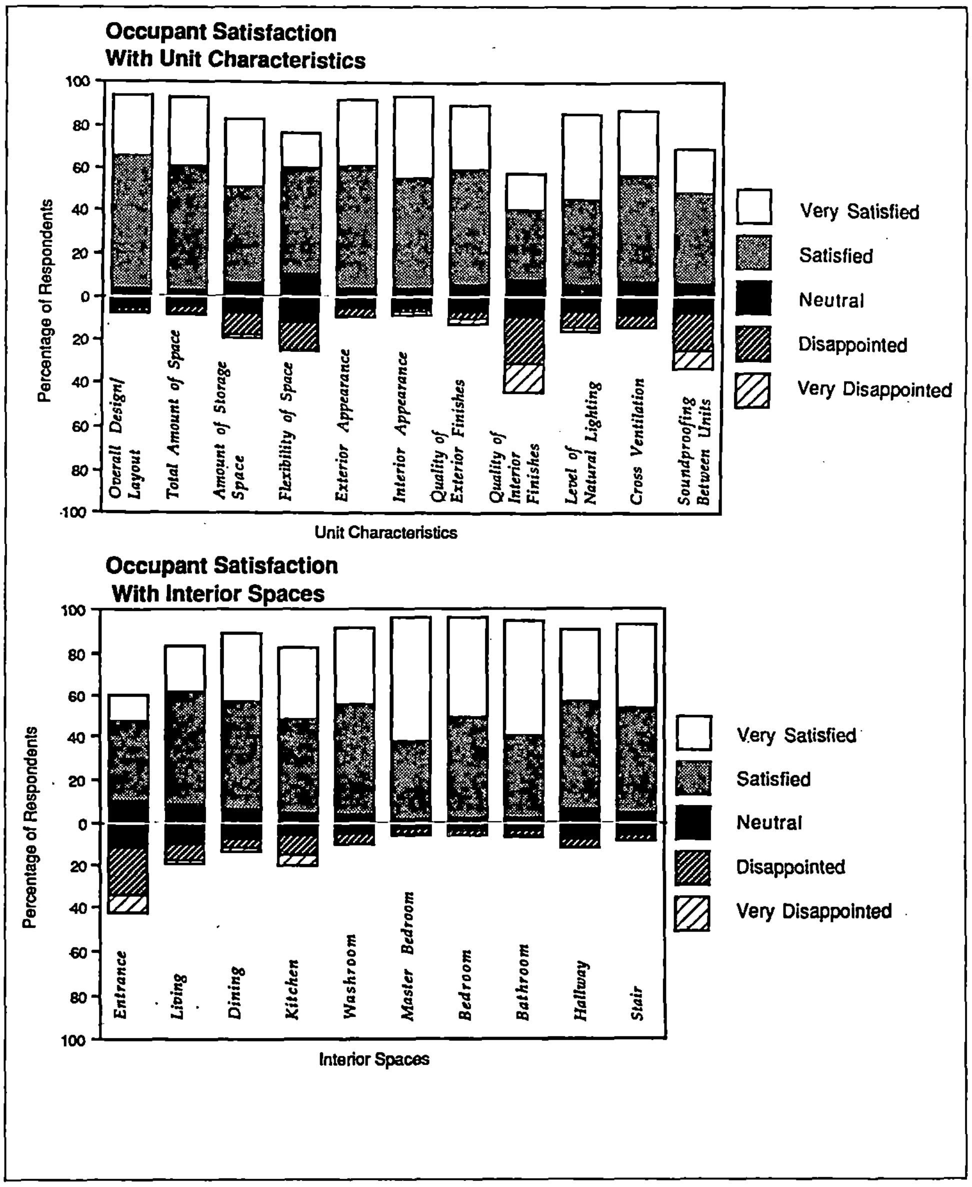


Figure 4.3 : Results of Occupant Survey

Buyers' Preferences and Desired Features

IMPORTANT FEATURES DESIRED IN A NEW HOME [1]	(%)
Second/big bathroom	9.5
Large/private backyard	7.7
Sufficient storage	6.7
Natural lighting	6.4
Basement	5.8
Garage	4.3
Second/big bedrooms	4.0
Open plan	4.0
Sufficient amount of total space	3.7
Functional kitchen	3.7
Two storeys	3.7
Private parking	3.4
Quality of interior finishes	3.1
Good location/neighbourhood	3.1

PREFERRED NUMBER OF BEDROOMS [2]	(%)
One bedroom	0.5
Two bedrooms	54.6
Three bedrooms	43.8
Four bedrooms	0.5
More than four bedrooms	0.5

SPECIFICALLY LOOKING FOR A NEWLY BUILT HOUSE [2]	(%)
	58.5

PREFERRED LOCATION [3]	(Ave)
City center	1.4
Ten minutes from city center	2.9
Suburb	4.1
Small town	3.3
Country	2.9

PREFERRED TYPE OF DWELLING [4]	(Ave)
Single-family detached	3.5
Semi-detached	2.6
Townhouse	2.5
Condominium apartment	1.4

1. *Most frequently mentioned attributes; percentage based on 327 entries*
2. *Based on percentage of respondents*
3. *Average priority on a scale of 1-5*
4. *Average priority on a scale of 1-4*

Reasons for Purchase

IMPORTANCE OF SELECTED FEATURES [1]	(Ave)
Exterior appearance	3.9
Interior layout	4.5
Price	4.8
Investment potential	4.0
Private outdoor space	4.1
Private parking space	3.9

APPEALING FEATURES [2]	(%)
Price	17.8
General layout	9.7
Total amount of space	8.3
Location/environment	6.3
Usable basement	4.7
Second/large bathroom	4.0
Open plan	3.8
Cottage style/two storeys	3.8
Natural lighting	3.6
Second/large bedroom	3.1

1. *Respondents' average on a scale of 1 (not important at all) to 5 (extremely important)*
2. *By percentage; 290 most frequently mentioned items out of 444 entries.*

Suggested Improvements

PROPOSED CHANGE	(%)
Add kitchen storage	14.4
Modify entrance	10.1
Wider unit (16')	8.6
Modify kitchen plan	8.3
More windows/natural light	5.5
Add/modify storage space	4.0
More land	4.0
Modify parking layout	3.7

Based on percentage; 327 entries

No Change Required
- Overall design/layout
- Total amount of space
- Exterior appearance
- Interior appearance
- Quality of exterior finishes
- All rooms on second floor:
  Bathroom
  Master Bedroom
  Bedroom
  Hallway
  Stair

Features to be kept
- Two floors
- Second/big bathroom on the second floor
- Potential for Do-It-Yourself
- Usable basement (natural light)

Options to be Provided
- Unit with a third bedroom
- Unit with a garage
- Unit with a larger width (16')
- Accessible unit

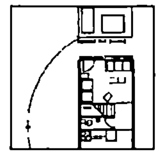
4.3.2 Modular Design

Design modifications made to suit the prefabrication process were based on modularization of the house and standardization of components. The fabricators of six different panel systems were interviewed and probed on methods to improve efficiency in design and assembly for their particular system. Most of the them acknowledged the fact that their panel systems are usually slightly more expensive than conventional construction for single family detached, custom-built housing. The biggest potential for cost reduction could materialize only with economies of scale - volume, standardization and repetition. All fabricators felt that a design like the Grow Home could be built at a lower cost with prefabricated wall panels than with conventional construction because of its simplicity.

Some of the recommendations offered were common to all types of prefabricated wall systems:

- Keep the house plan simple and rectangular; checks and corners add to the cost of prefabrication
- Design to minimize on-site labour and material handling
- Maximize panel size/minimize number
- Keep panels simple (rectangular) to reduce production costs
- Minimize the number of openings in a panel, since they are labour intensive
- Although the size of openings makes no difference in the cost of the panel (once a shop table is set for an opening, the amount of labour involved is the same for all sizes), keeping these at a standard height will improve efficiency i.e. it is easier to work with standard headers
- Dimension openings to accommodate standard window/door sizes (custom-built windows would increase costs)

In other instances, the recommendations varied from one manufacturer to another. Representatives from the manufacturers of unsheathed structural panel systems



gave similar advice as those from conventional panel systems. The structural panel systems, however, had different cost-saving strategies.

Unsheathed and conventional panel systems rely on a series of columns or studs for structural support. Most of the representatives from these companies suggested that unnecessary columns in the panels should be avoided. Keeping panel lengths at 600 mm increments and positioning windows to fit between these could lead to savings in material and labour, since no extra support would have to be integrated into the panel. One manufacturer (who was the only one to have columns spaced at 400 mm) claimed that this would make no difference in the cost of his system, since the window openings needed to be reinforced anyhow. If an opening could not be centered on a 600 mm module, then attempts should be made to align one side with a column. The use of unsheathed structural panels for roof systems was not recommended by any of the manufacturers, who proposed that while this type of construction was possible, it would only complicate both the manufacturing and assembly process, and is usually more expensive than conventional construction.

Because structural sandwich panels are cut from sheets rather than built from columns or studs, the recommendations for these systems differed somewhat from the conventional and unsheathed panel systems. It was recommended, for instance, that panels be dimensioned to 1200 mm increments (standard widths for most sheathing materials) to avoid cutting and material wastage. If this could not be avoided, then an attempt should be made to end the panel with a 600 mm section, so that the remaining half-sheet could be used on a similar or opposite panel. There were no restrictions on the size or location of openings, other than ensuring that an adequate width be left between the side of an opening and the end of the panel, generally in the area of 300 mm.

In most cases, the cost-cutting recommendations from one manufacturer did not restrict those of another. It was therefore possible to design panels which could address all of the above-mentioned criteria simultaneously.

4.3.3. Technical Design

The evaluation of prefabricated wall systems that was conducted in the first part of this study revealed certain strong points and weaknesses of specific systems. The design guidelines that follow are aimed at improving the technical performance of the home through minor modifications. Some of the points have become standard practice for some of the manufacturers interviewed. While these would have no effect on the configuration of the wall panels, they are likely to affect the overall performance of the building and are therefore worth mentioning.

Unsheathed structural and conventional panels:

- Install caulking bead/backer rod under, over and between wall plates to improve the air leakage characteristics of the envelope
- Install 12.7 mm fiberboard sheathing on unsheathed structural panels to improve acoustic performance
- Diagonal strapping for unsheathed structural panels should be anchored to top and bottom plates and not to wall studs/columns
- Although not technically required, sheathing membranes and vapour barriers should be installed on the exterior and interior of unsheathed structural wall panels, respectively, for added performance at a relatively insignificant cost

- Where a panel runs parallel to floor joists, a second joist should be installed close to the header joist to facilitate nailing of the wall panel (accessible only from the interior) and to improve structural performance (avoid nailing only through floor sheathing).

Structural sandwich panels:

- Openings should be cut in the factory, since they require unconventional skills and tools. Although some of the system's flexibility would be compromised, the simplification and reduction of on-site labour could lead to savings, while modifications to the openings would still be possible.

● 4.4. DESIGN PROCESS

The design process was aimed at providing sufficient flexibility for the builder and economies of scale for the manufacturer by generating a wide range of options for the dwelling using a small number of simple, standard components. This would enable mass prefabrication of components without the need to finalize the design. Modifications to the interior layout could then be made on-site simply by adding or replacing components.

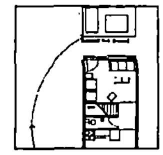
The design process evolved from the inside out, starting with a general, basic analysis of the overall modular dimensions of the dwelling, followed by more specific configurations of the interior plan and ending with the exterior walls. This sequence was considered to be most suitable, since the flexibility and applicability of standard exterior prefabricated walls depends largely on the interior plan. Four aspects of the house were examined:

1. General dimensions
2. Stair configuration and orientation
3. Interior partitions
4. Exterior walls

A CAD software was used as a design tool. Because the design process involved the manipulation of standard components within established modules, the use of a computer provided an efficient method of generating and testing alternatives. The process was intended to provide a general framework for the eventual possible industrialization of the Grow Home and its variations. The study could, for example, be used as a basis for software development which could monitor the production and distribution of an inventory of parts. The data contained therein may also be put to use in a user-friendly graphic package to be used by the prospective buyer in laying out his unit and selecting finishes. While there are several possibilities for how the data could be used, the scope of this study was limited to generating a framework for standardization which could be further articulated for any of several applications.

4.4.1. General Dimensions

The first stage of standardization dealt with the overall unit configuration and its dimensions. The units were broken up into three sections at each floor: a central or core area, which is smaller than the others and accommodates the stairs, and the front and back sections, one bigger than the other to accommodate different functions, both at the ground and upper levels (figure 4.4 a). The options were categorized according to the major function of the core space at the ground level.

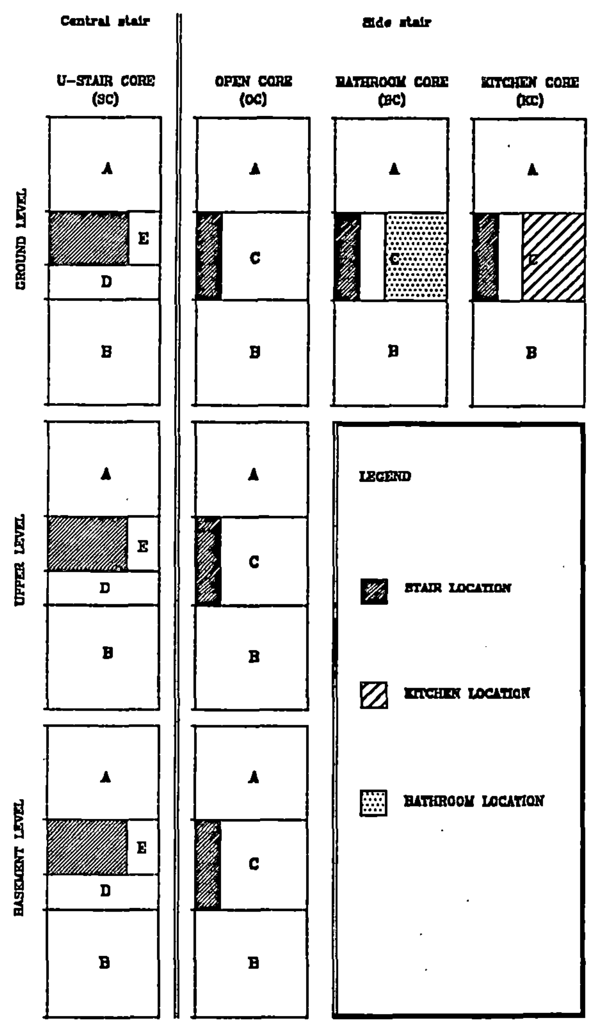


Any area which is illustrated as empty or is designated as an "open" space can accommodate more than one function.

Four basic arrangements for the interior spaces were generated for the ground floor based on the starting plans described previously and the original Grow Home layout. These include units with a stair core (SC), an open core (OC), a bathroom core (BC) and a kitchen core (KC). For the basement and upper floors, the number of arrangement is limited by the types of rooms which are found at these levels. Only the first two options (SC,OC) apply to these plans.

At the ground floor, the larger module (A) is generally intended to accommodate either a living space or a combined kitchen/dining area. The smaller modules (B and C) are sufficient for dining rooms, kitchens or bathrooms. At the upper level, all of the modules can be used to accommodate either a bedroom, den, play area or bathroom. The design appears to be most efficient when the central module (C) is used for the bathroom while the larger of the remaining two (A,B) is designated the master bedroom.

Figure 4.4a : Segmentation of Floor Plans

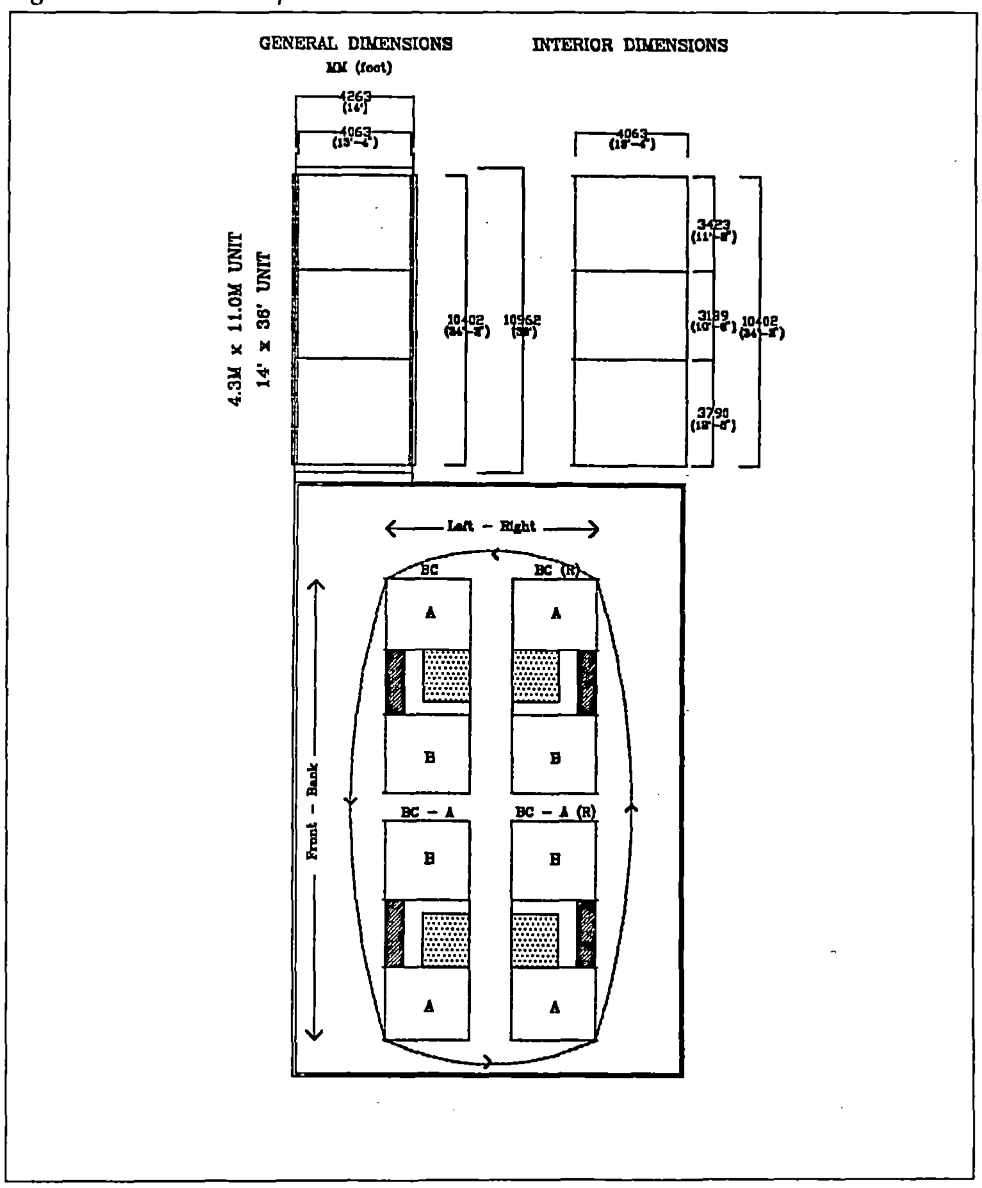


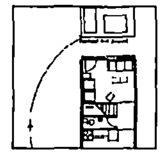
The modular dimensions were based on the feedback from the post-occupancy evaluation. Because the size of the rooms was not really an issue in the occupant survey, these dimensions were similar to those of the built units. The kitchen section was increased slightly in response to some disappointment expressed with this area.

The basement layout was analyzed to the same extent as that of the other floors because of evidence from the occupant survey that it is an important part of the dwelling. There are several possibilities for how the basement space can be used. Generally, these could include any one or a combination of storage, garage, workshop, laundry room, bathroom, playroom, study/den or bedroom. The basement would be eliminated altogether for accessible units.

In addition to providing a framework for analysis, the divisions of space into three segments may also be seen as modules for a prefabricated floor system, which would add to the units' flexibility. In cases where a more defined or articulated

Figure 4.4b : Reversed Options





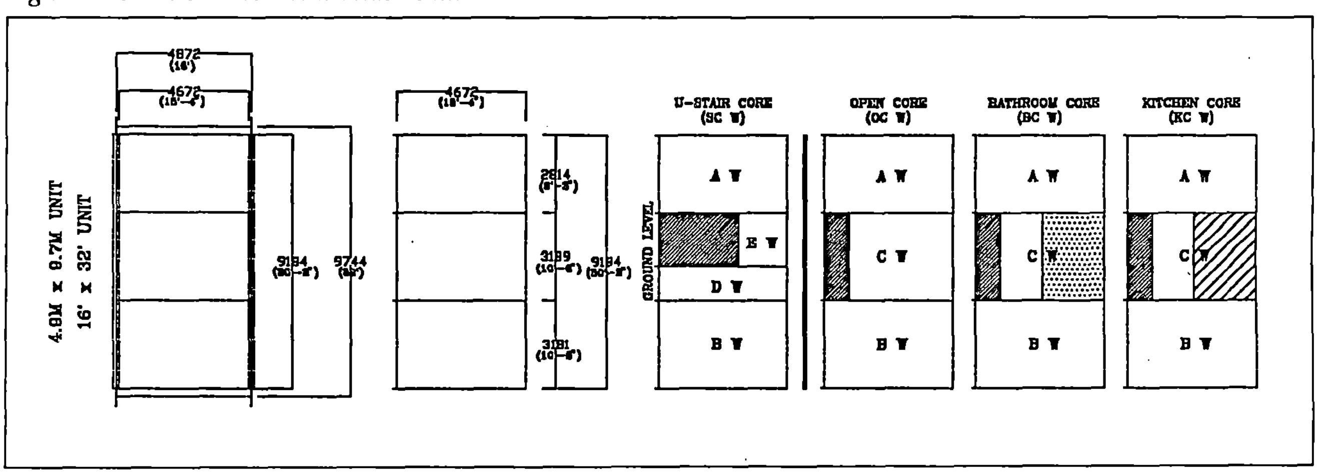
space is preferred, for example, a change in level at the panel interface can be accommodated by checking the foundation wall and/or building up that section of the wall.

The manner in which the units are grouped, as well as their setting, will affect the possible use of a space as well as the quality of light which it is likely to have. Depending on the context in which the units are built, there may be a preference for a particular orientation. Builders may prefer to have bathroom cores back to back on adjoining units, buyers may want south-facing kitchens, and the addition of a window to the side wall of an end unit may require that a reversed floor plan be used. Figure 4.4 b shows four alternatives which could be generated by reversing the units either front to back, left to right, or both. Reversing the unit front to back, for example, will dictate whether the larger module will face the front or back of the house. At the upper level, this will determine where the master bedroom is located. At the ground level, it makes it possible to enter the unit either through the kitchen or the living area.

Although the configuration and orientation of the plan can change the appearance of the units, both singularly and as a group, including all four versions of a floor plan in the analysis would only confuse the process. As such, the analysis will consider only the basic options shown in figure 4.4a. It should be kept in mind, however, that a reversal of the unit in either direction could also be accommodated in most cases without significant change to the required standard components.

In response to the expressed desire for a wider unit from 14 % of the respondents in the occupant survey, a fifth option was proposed (figure 4.4 c). A 4.9 x 9.7 meter unit could be arranged in any of the four layouts that were drawn for the 4.3 meter model. Although the analysis concentrates on 4.3 meter units, it should be mentioned that the 4.9 meter version may be more suitable for some applications. The most important advantage of the 4.9 meter width is its ability to adapt more

Figure 4.4c : Alternative with Wider Unit



easily for accessible design. A wider unit could also accommodate a vestibule more comfortably, although the proportions of the rooms will change.

4.4.2. Stair Configuration and Orientation

In a narrow and simple unit such as the Grow Home, many aspects of the interior layout will depend on the stairs. The size, type, configuration, orientation and location of the stairs will affect everything from the size of the rooms to the general appearance and functional layout of the spaces. The ability of the contractor to offer a variety of options and to make on the spot changes will therefore depend on the type of stairs he/she has committed to.

The construction of a staircase is usually more labour intensive than other framing tasks. Once built, it is not easily changed, particularly if the modification involves a different-sized opening in the floor. Prefabricating the stair would enable several options to be offered for the same standard opening in the floor, and on-site changes to the layout could be made by either reversing or replacing the stair modules. In light of this potential for increased flexibility and standardization of parts, the stairs in the units were examined as an integral part of the prefabricated component system. Figure 4.5 illustrates three modules for each type of stair. The clear opening in the floor required for the stairs could be accommodated by a central floor panel. Given a standard opening, several combinations of modules could be used. The only place where the stairs are permitted to go off these limits is in the basement, where it would not disrupt the placement of any prefabricated component, and can provide a more efficient use of space.

The stair characteristics can influence the design of the interior space in several ways. To begin with, the size of the stairs will determine the size of the spaces surrounding it, particularly in small houses. The width of the stairs was established at 914 mm and 1500 mm for accessible units. These were perceived as the minimum practical limits, considering the space restrictions in a narrow-front rowhouse and the need to accommodate mechanical lifts in the accessible units. The type of stair (U-shaped or straight) will determine the possibility of having an open-concept plan, while its placement will affect the size of rooms which can be found at either end. Both of these have already been determined by the division of the interior spaces into three distinct modules.

Some of the implications of the stairs' configuration and orientation with respect to the interior layout of the units are illustrated in figure 4.6. Although many other options are possible, these diagrams serve to illustrate how the stair affects the potential for space usage and, ultimately, adaptability of the space. In general, the orientation of the stairs (direction - up or down) will dictate whether or not the unit can accommodate a garage in the basement. The method of arrival (with winders or straight) will affect several aspects of the layout. Architecturally, the provision of winders enables the end of the stairs to be finished with either a railing or a partition, which will affect the general appearance of the space, since an extra portion of wall can be used for furniture or decorative elements.

Functionally, winders make for a more efficient use of space, eliminating the requirement for a separate landing. A straight stair with a landing, on the other hand, provides a safer access from the ground floor to the basement (where a door is likely to be installed) as well as a more private access to the bathroom. The area which is least affected by the stairs is the second floor, where a reversal of the stairs (from front to back and vice versa) will determine whether the bigger room (usually the master bedroom) will be located on the front or the back of the unit. Arrival at the second floor level is shown with winders to maximize space-use efficiency. In the case of accessible units, a straight landing would be maintained.

Figure 4.5 : Options for Stair Configurations and Prefabricated Modules

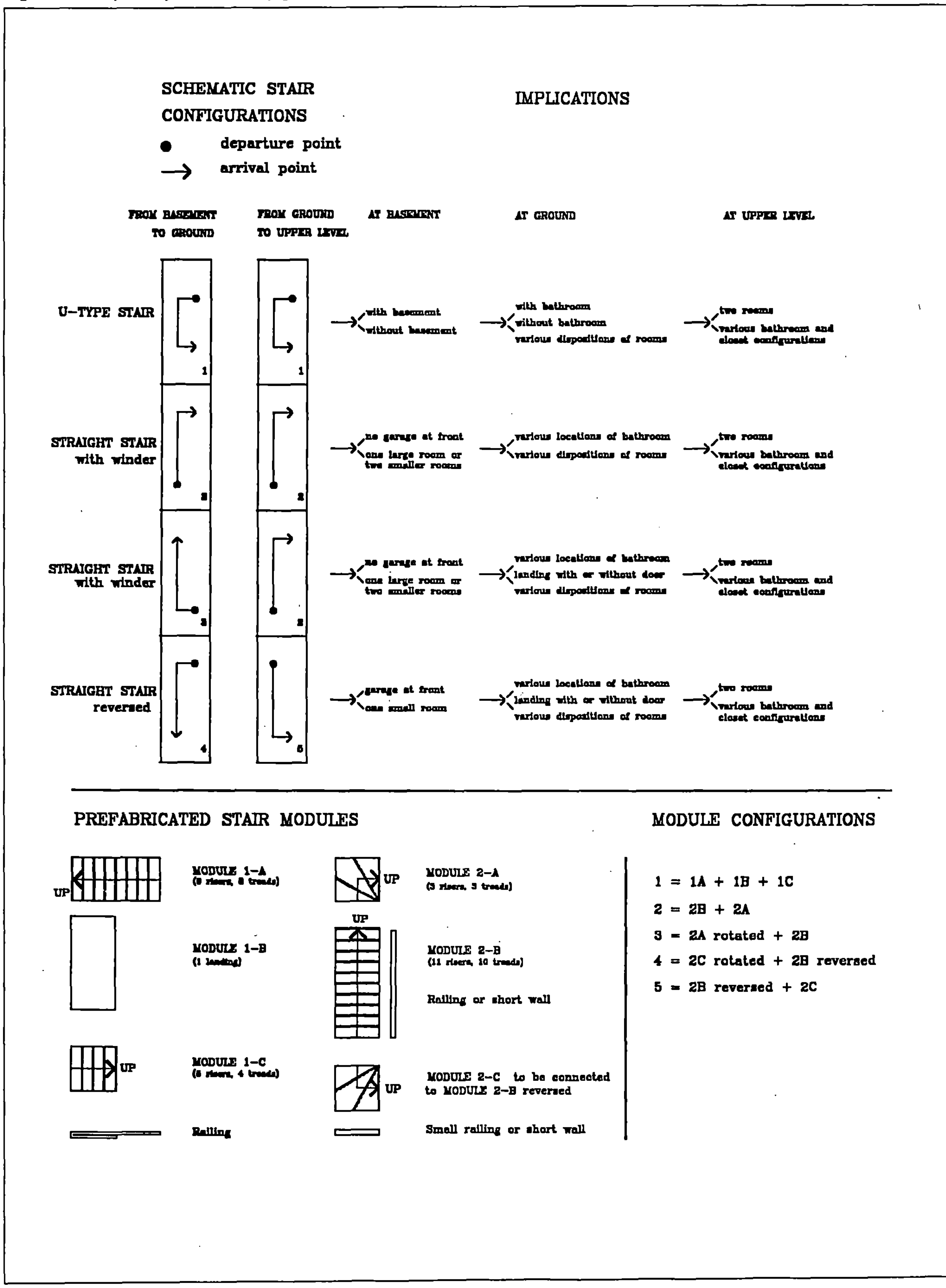
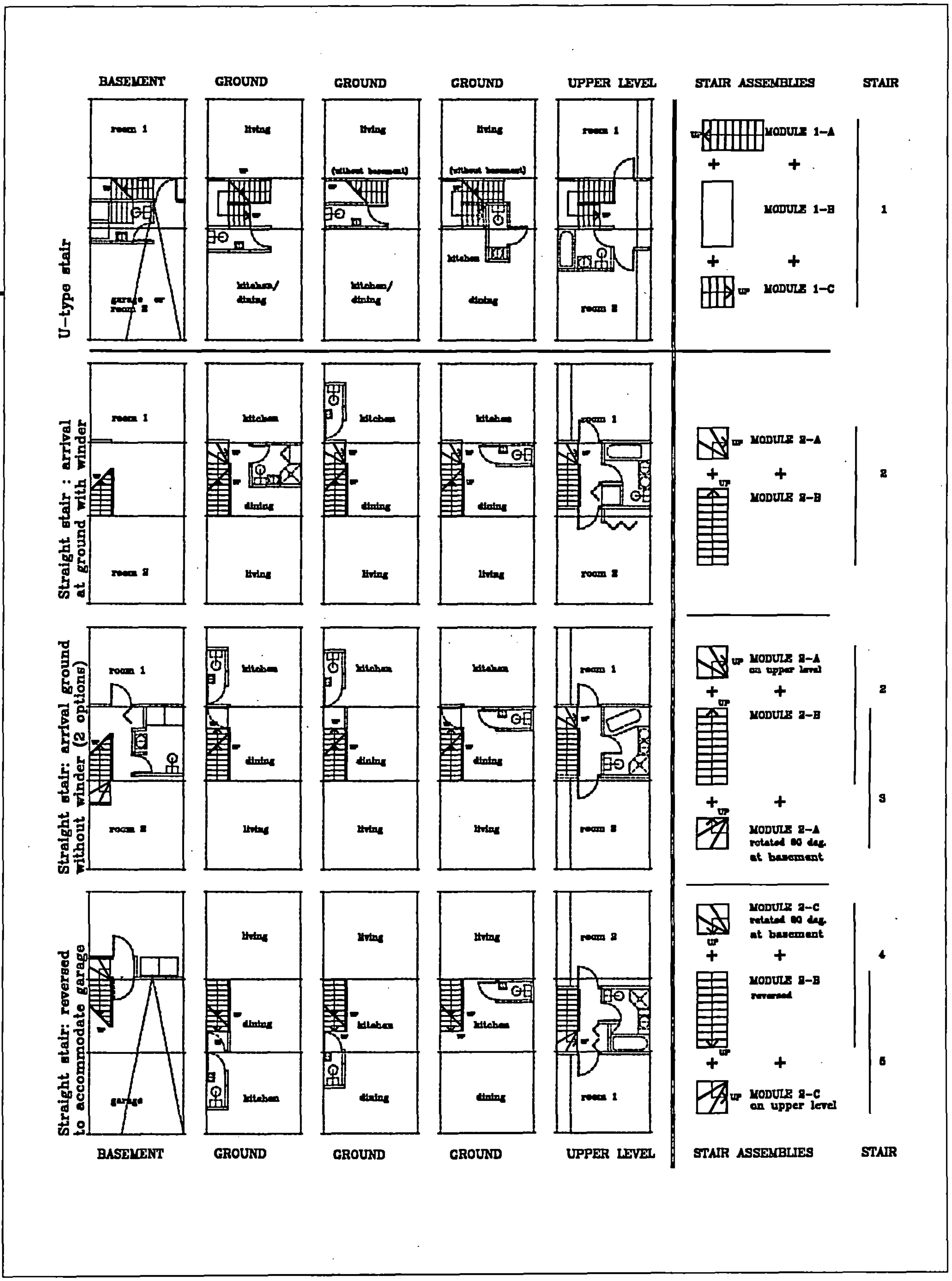
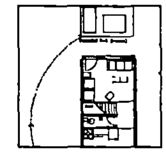


Figure 4.6 : Effect of Stairs on Options for Interior Layout



4.4.3. Interior Partitions



Most of the Grow Home builders which were interviewed felt that the offer of options, particularly in the bathrooms and kitchens, were helpful in attracting buyers. Furthermore, the post-occupancy evaluation clearly demonstrated that these rooms were of primary importance to the prospective buyers. The units' entrance and the amount of storage space, on the other hand, were areas of concern for some of the occupants, as was the location of the washer and dryer. In a small house like the Grow Home, these rooms account for most, if not all, of the interior partitions of the dwelling.

Interior partitions and finishes are also of interest in that they represent about 30% of construction costs. These costs could potentially be reduced by transferring them either to the buyer (by providing unfinished or partially finished units) or to the fabricator. The latter would require that the exterior wall panels be delivered as closed systems (with the gypsum wallboard installed) and/or that the interior partitions be economically prefabricated, delivered and installed.

Because of the small size of the units, the amount of framing required for the interior partitions is minimal. Any attempt at reducing costs by prefabricating the interior partitions should be aimed at achieving a high degree of standardization while maintaining sufficient flexibility for the builder and simplified assembly for the buyer. This could be achieved through the use of small, easy-to-handle components which could be assembled into a variety of configurations, either during construction or after occupancy.

Several options were developed for the unit's bathrooms and entrances using three standard partitions: 614 mm, 914 mm and 2020 mm. Although the assembly of small partitions in series may require more framing members than a continuous one, the increased flexibility, speed of assembly and standardization may lead to economies of scale which might offset the added material costs. Figure 4.7 illustrates how 15 different bathroom configurations could be built for the basement, ground and upper levels using the same standard partitions. The alternatives include options for large tubs, double sinks, separate showers, linen closets and washer/dryer placement. Similarly, figure 4.8 illustrates 6 possibilities for the entrance to the unit with alternative closet locations. The entrance may be fully opened, semi private or fully enclosed as a vestibule. In either case, the configurations illustrated represent only some of the options which are possible with the modular partitions. The dashed lines in figure 4.8 represent larger vestibules which would be suitable for accessible units.

It should be mentioned that the kitchen space was not examined to the same extent as the other rooms due to the high level of prefabrication which already exists with the kitchen cabinets. Once a space has been designated as a kitchen, there are many options for counter and cabinet design using standard components. For the purpose of this exercise, the provision of spaces dimensioned to one-foot increments and accounting for refrigerator and range widths was considered to be sufficient in accommodating standard sections of kitchen cabinets.

Figure 4.7 : Optional Bathroom Configurations Using Standard Partitions

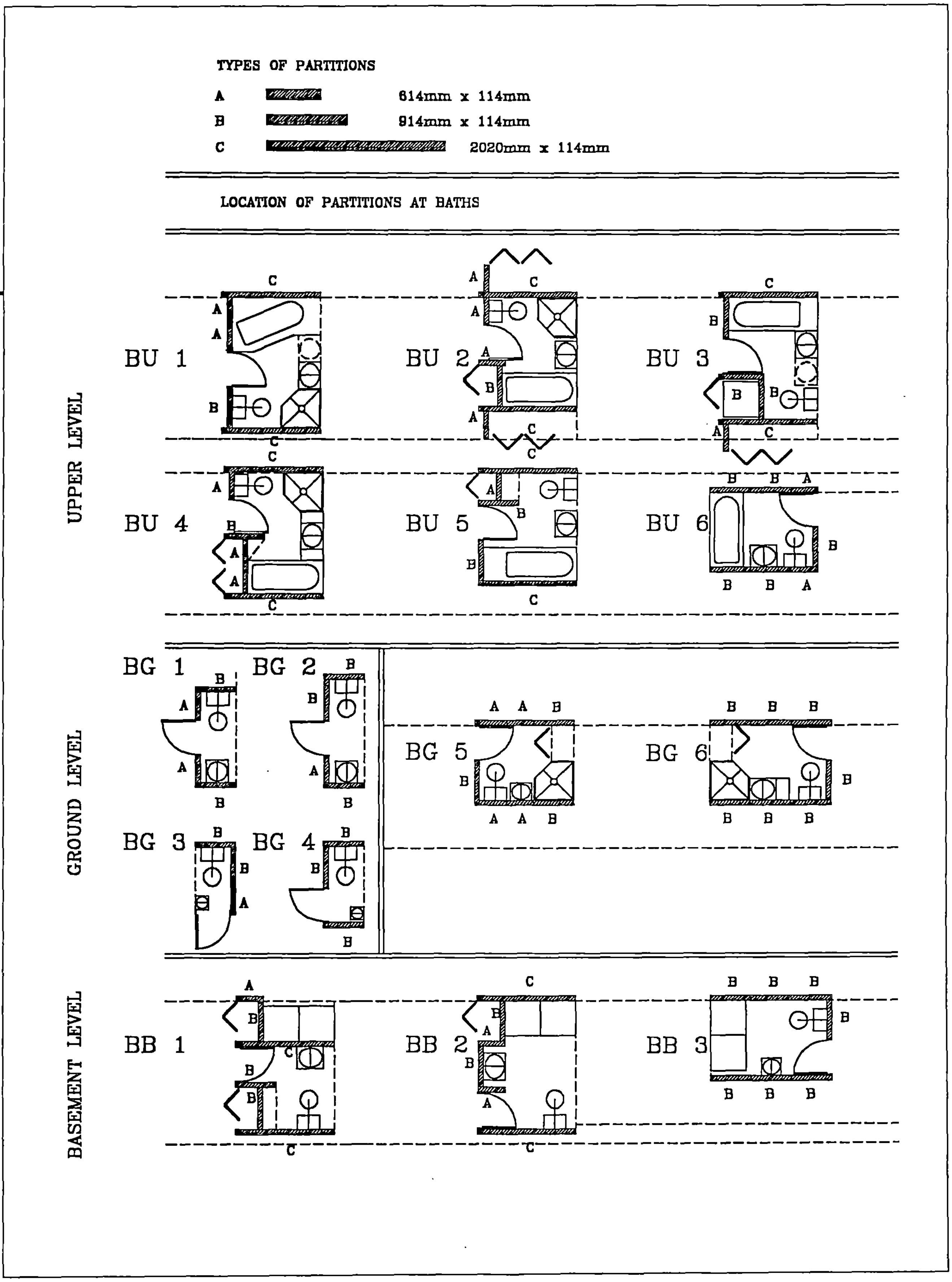
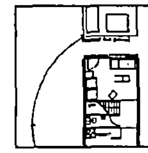


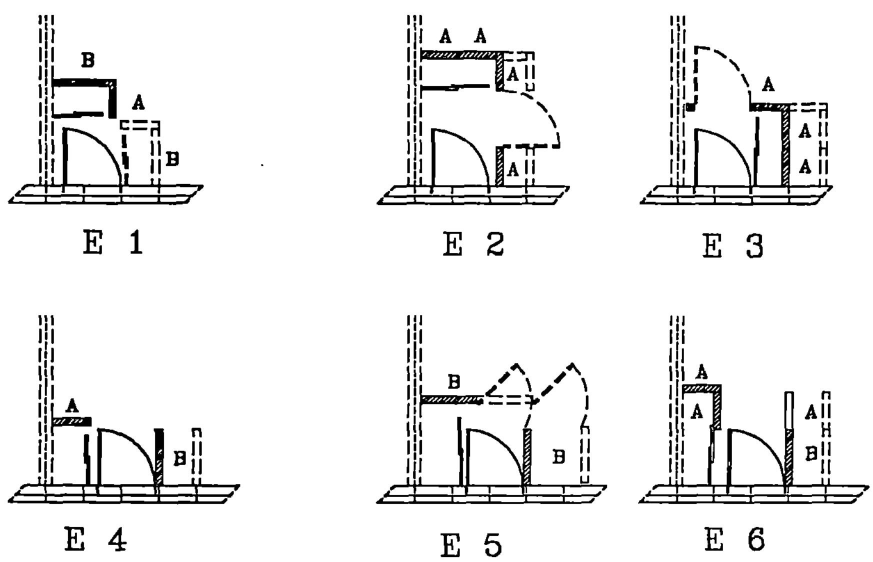
Figure 4.8 : Optional Entrance Configurations Using Standard Partitions



TYPES OF PARTITIONS

A		614mm x 114mm
B		914mm x 114mm
C		2020mm x 114mm

LOCATION OF PARTITIONS AT ENTRANCES



Possibilities for Interior Layout

Once the stairs, bathrooms and entrances have been standardized, a variety of possibilities for the interior layout of the dwelling can be generated by treating these as modules in themselves. Some of the options which could be achieved by moving and replacing the bathroom and entrance modules are shown schematically in figure 4.9. Examples of how these diagrams translate into floor plans are given in figures 4.10, 4.11 and 4.12 for the ground, basement and upper levels, respectively.

It is important to note that not all stair, bath or entrance configurations are applicable to every layout. As mentioned earlier, the orientation, type and location of stairs will affect the applicability of options for the other modules. The compatibility of stairs, bathroom and entrance modules with respect to the general layout is shown in figure 4.13. Generally, the flexibility is greatest at the ground level. Because the level of occupant satisfaction with the spaces on the second floor was found to be relatively high, the general arrangement of this floor was not altered. Aside from the selection of a bathroom, the flexibility of the upper floor was limited to the configuration of the two bedrooms, which could be changed by relocating the closets.

Figure 4.9 : Schematic Layout of Plans

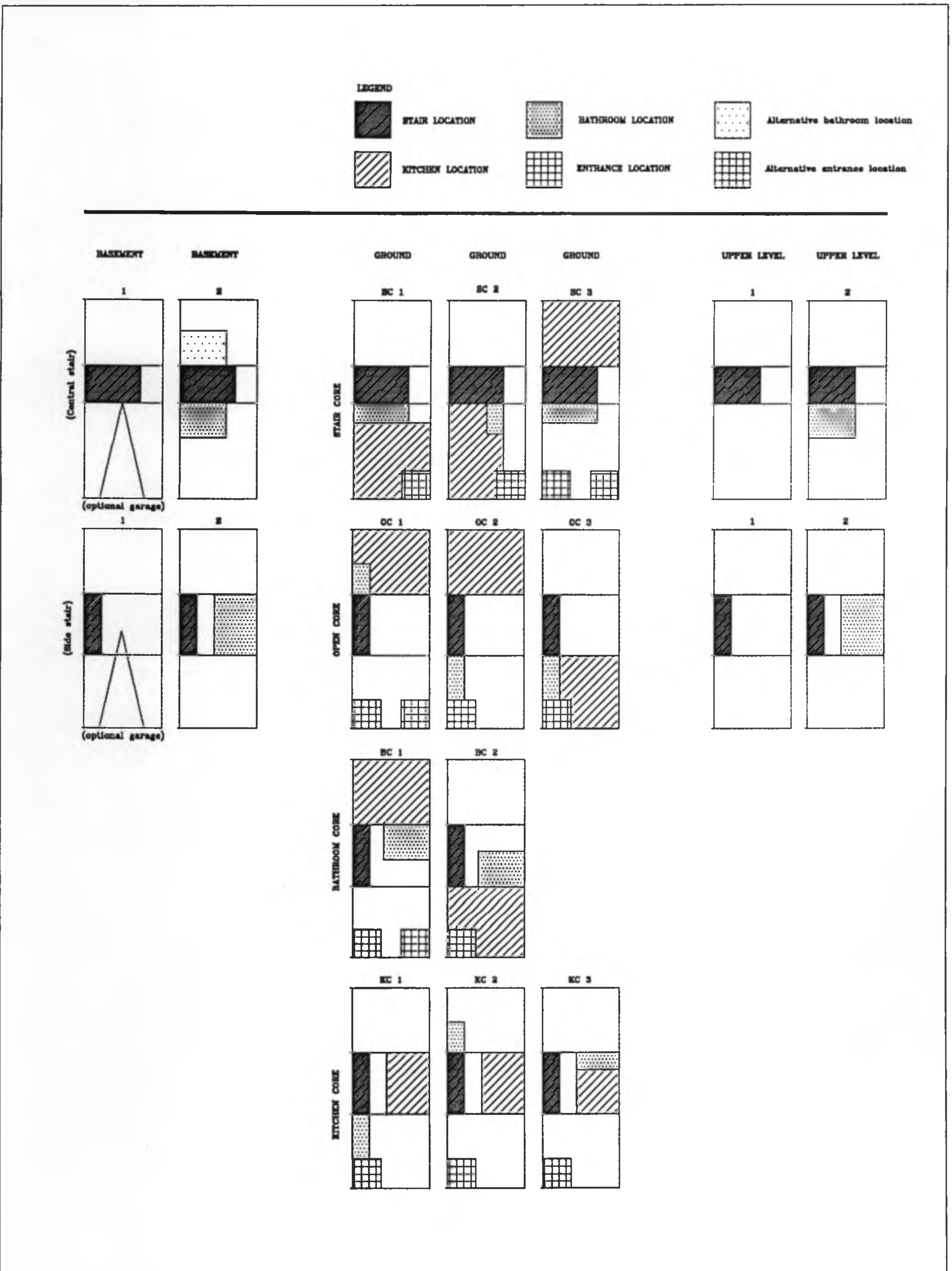


Figure 4.10 : Location of Partitions at Ground

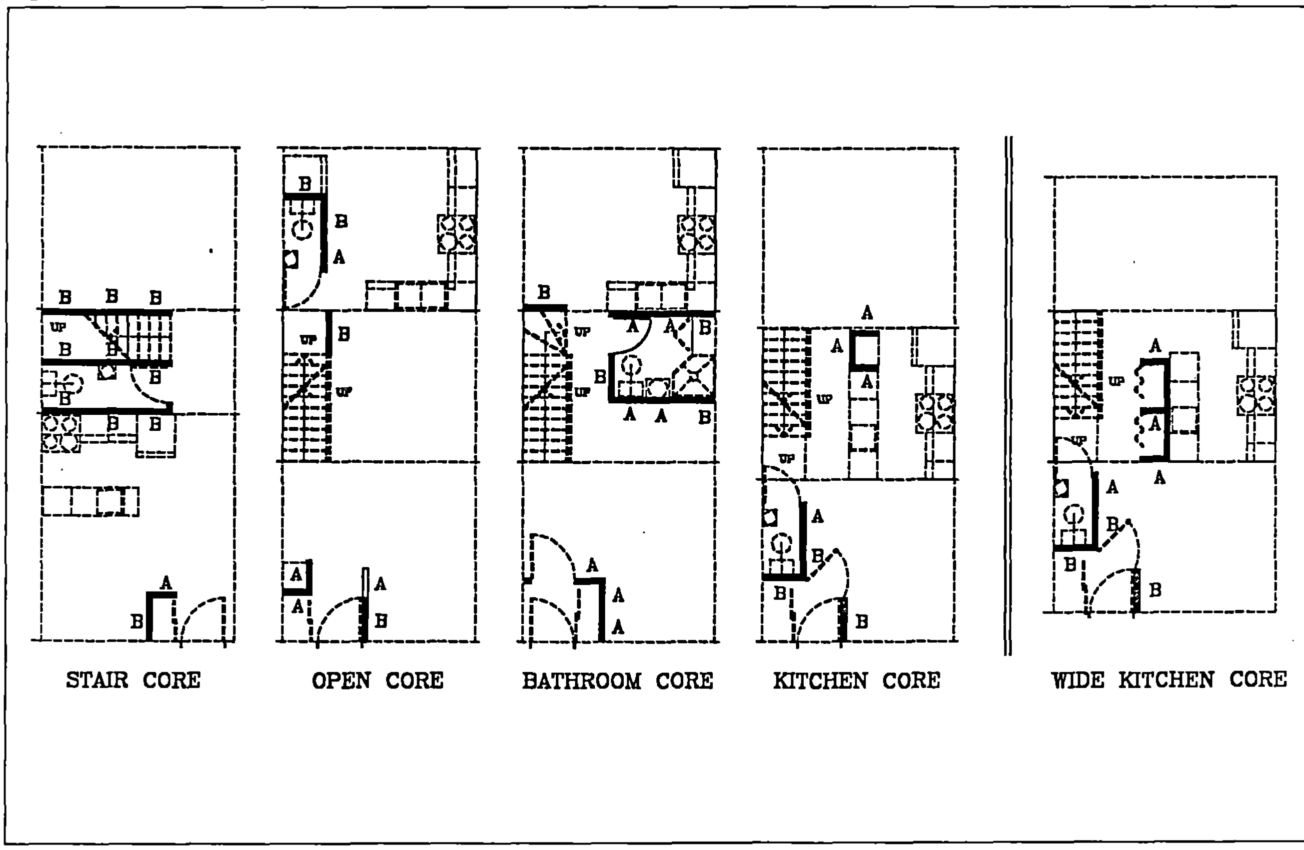


Figure 4.11 : Location of Partitions at Basement

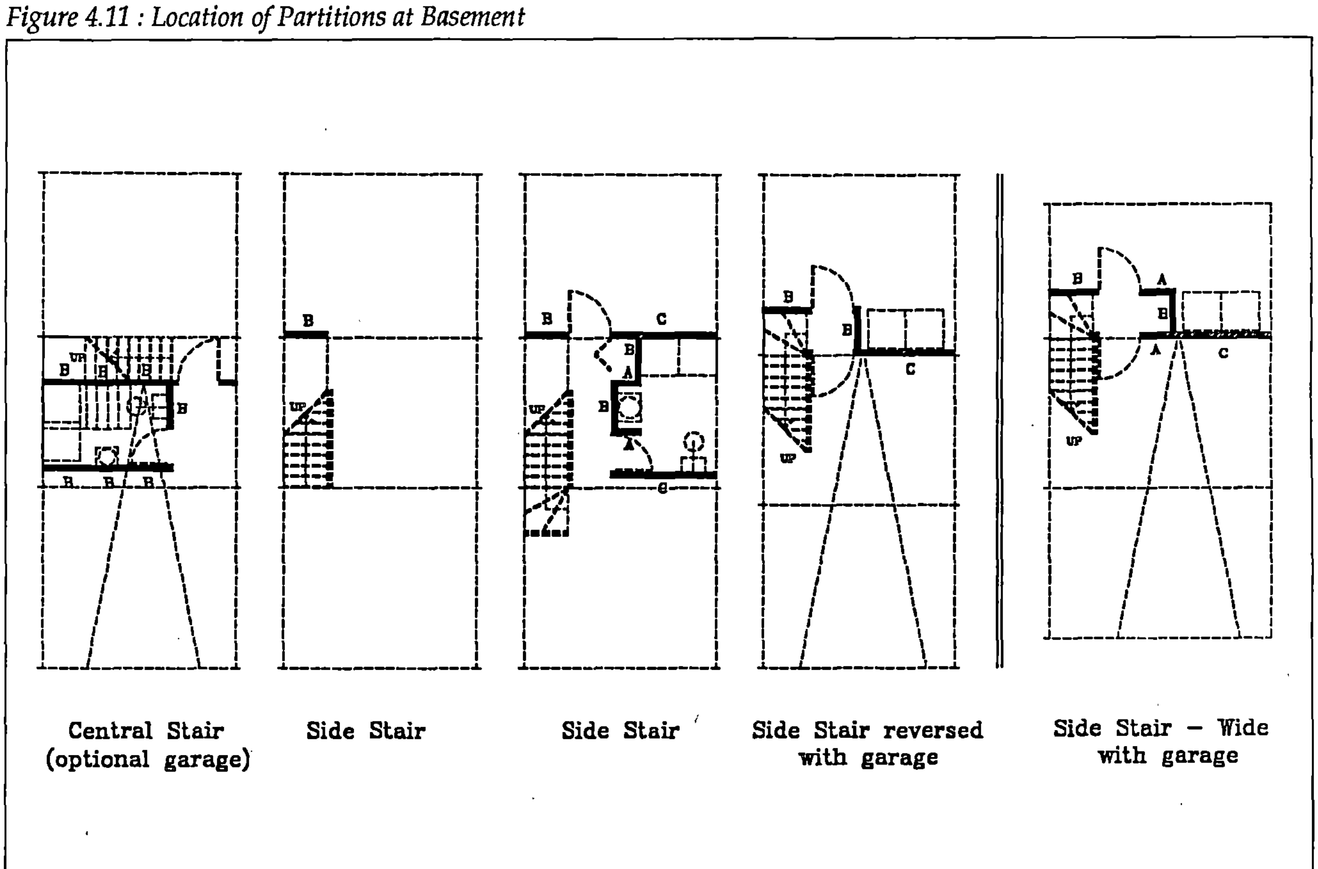


Figure 4.12 : Location of Partitions on Upper Level

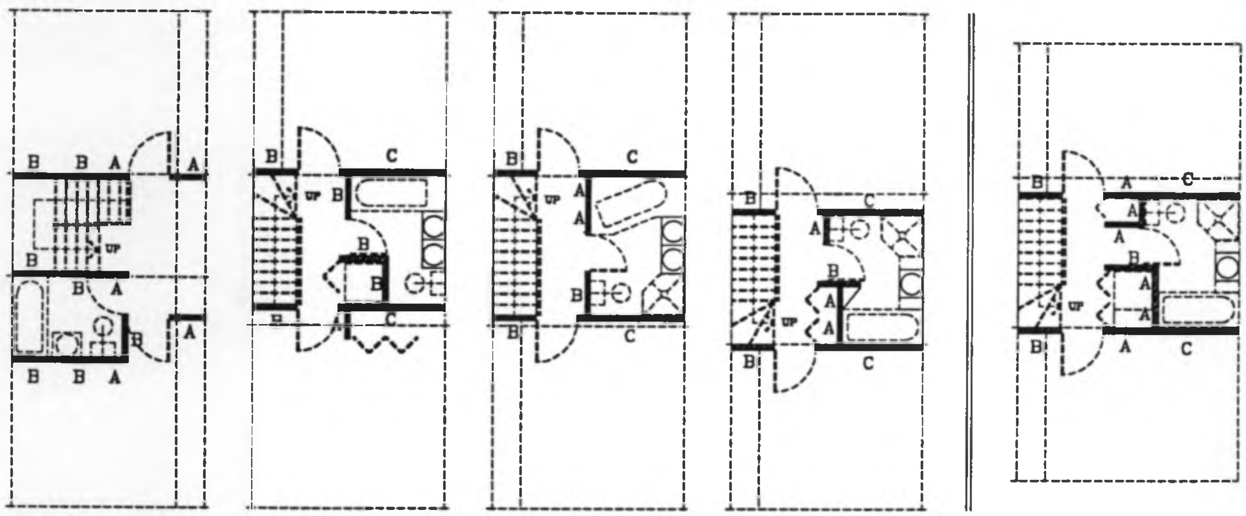


Figure 4.13 : Applicability of Entrance, Washroom and Stair Configurations to Optional Floor Plans

	BASEMENT LEVEL				GROUND LEVEL											UPPER LEVEL			
	Central Stair		Side Stair		Central Stair			Side Stair								Central Stair		Side Stair	
	1	2	1	2	SC1	SC2	SC3	OC1	OC2	OC3	BC1	BC2	KC1	KC2	KC3	1	2	1	2
Entrance																			
Type E-1					•	•	•	•	•	•	•	•	•	•	•				
Type E-2					•	•	•	•	—	—	•	•	—	•	•				
Type E-3					•	•	•	•	—	—	•	•	—	•	•				
Type E-4					•	•	•	•	—	—	•	•	—	•	•				
Type E-5					•	•	•	•	•	•	•	•	•	•	•				
Type E-6					•	•	•	•	—	—	•	•	—	•	•				
Washroom																			
Type BB-1	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	—	—	N/A	N/A	N/A	N/A	—	N/A	—
Type BB-2	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	• [1]	• [1]	N/A	N/A	N/A	N/A	•	N/A	•
Type BB-3	N/A	•	N/A	—	•	—	•	N/A	N/A	N/A	• [2]	• [2]	N/A	N/A	N/A	N/A	•	N/A	• [2]
Type BG-1	• [3]	•	• [3]	•	—	•	NR	NR	NR	NR	N/A	N/A	NR	NR	NR	• [3]	—	• [3]	—
Type BG-2	• [3]	•	• [3]	•	—	•	NR	NR	NR	NR	N/A	N/A	NR	NR	NR	• [3]	—	• [3]	—
Type BG-3	• [3]	•	• [3]	•	•	—	•	•	•	•	N/A	N/A	•	•	•	• [3]	—	• [3]	—
Type BG-4	• [3]	•	• [3]	•	—	•	NR	NR	NR	NR	N/A	N/A	NR	NR	NR	• [3]	•	• [3]	•
Type BG-5	N/A	•	N/A	•	NR	NR	NR	N/A	N/A	N/A	•	•	N/A	N/A	N/A	N/A	•	N/A	•
Type BG-6	N/A	•	N/A	—	•	•	•	N/A	N/A	N/A	• [2]	• [2]	N/A	N/A	N/A	N/A	NR	N/A	• [2]
Type BU-1	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	—	—	N/A	N/A	N/A	N/A	NR	N/A	•
Type BU-2	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	—	—	N/A	N/A	N/A	N/A	NR	N/A	•
Type BU-3	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	—	—	N/A	N/A	N/A	N/A	NR	N/A	•
Type BU-4	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	—	—	N/A	N/A	N/A	N/A	NR	N/A	•
Type BU-5	N/A	•	N/A	•	—	—	—	N/A	N/A	N/A	•	•	N/A	N/A	N/A	N/A	NR	N/A	•
Type BU-6	N/A	•	N/A	•	•	—	•	N/A	N/A	N/A	•	•	N/A	N/A	N/A	N/A	•	N/A	•
Stair	From Basement				Arrival at Ground											Arrival at Upper			
Type-1	—	—	N/A	N/A	•	•	•	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	•	•	N/A	N/A
Type-2	N/A	N/A	•	•	N/A	N/A	N/A	•	—	—	•	•	—	•	•	N/A	N/A	•	•
Type-3	N/A	N/A	•	•	N/A	N/A	N/A	•	•	•	•	•	•	•	•	N/A	N/A	—	—
Type-4	N/A	N/A	•	•	N/A	N/A	N/A	•	•	•	•	•	•	•	•	N/A	N/A	—	—
Type-5	N/A	N/A	•	•	N/A	N/A	N/A	•	•	•	•	•	•	•	•	N/A	N/A	•	•

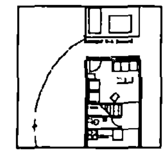
Notes:

[1] May be used, but does not result in an efficient use of space

[2] May be used if rotated; door and partition to be switched

[3] Small baths may be used in the open configuration

Legend:
- • Possible
- — NOT Possible
- NR - Not Recommended
- N/A - Not Applicable



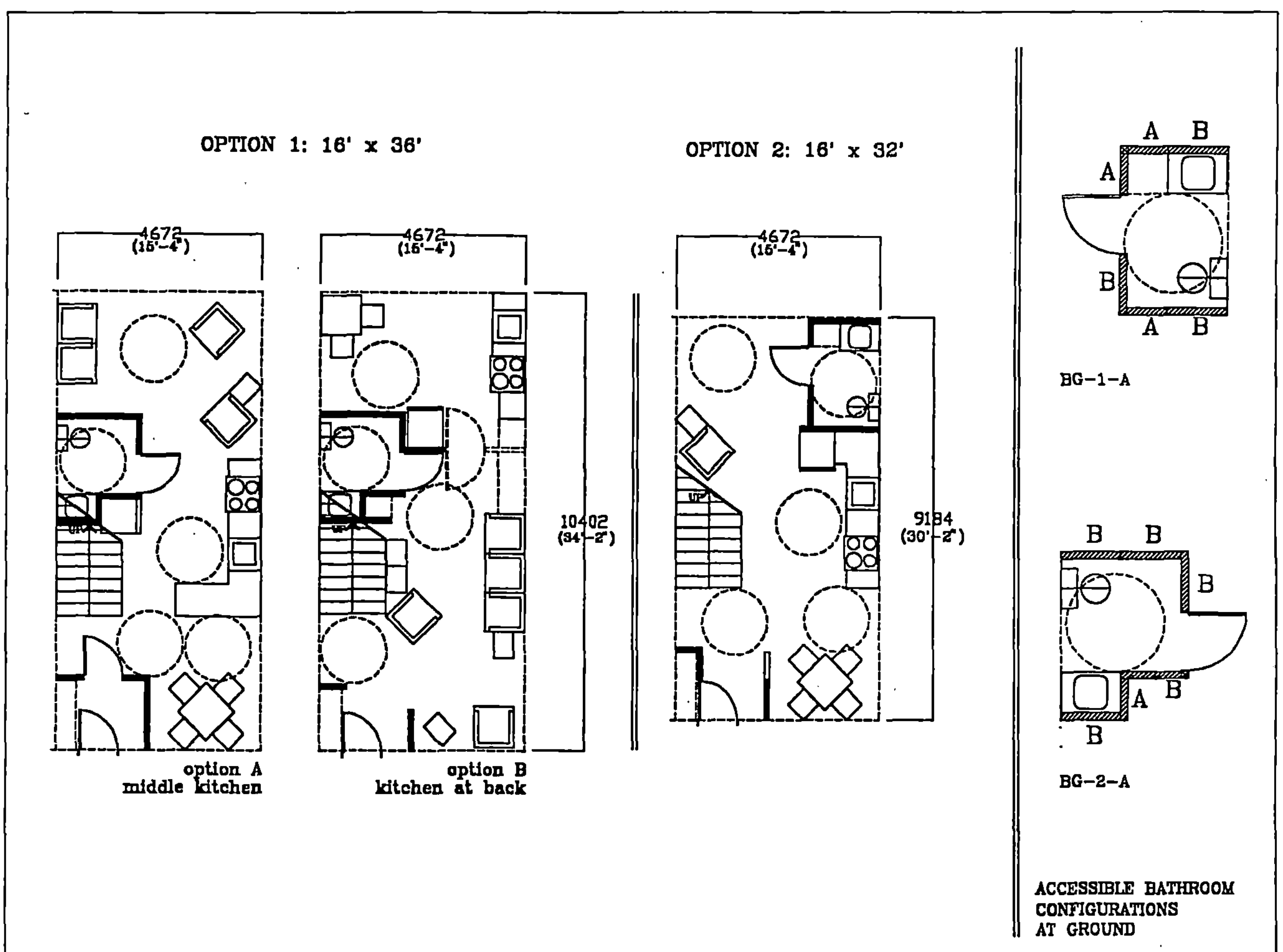
It should also be mentioned that the variations possible for interior modification are not restricted to the options illustrated here. The possibilities, particularly those involving minor (often on-site) changes to the interior are numerous.

4.4.4. Accessible Units

The possibility of providing a unit which is accessible to the physically impaired within the constraints of the Grow Home configuration was examined. Two alternatives were explored for units on two levels units with mechanical lifts (figures 4.14, 4.15). Both alternatives make use of the standard interior partitions for the bathroom and entrance configurations. The first of these is 108 square meters (4.9 x 11 m), with two options for the ground floor: one with kitchen in the centre and another with the kitchen in the back. Both options are shown with washrooms on the ground floor, although these can be eliminated if a larger living space is desired. The upper floor has a bedroom at the front of the unit and either a second bedroom or a den at the back.

The second alternative is smaller with 95 square meters of living area (4.9 x 9.7 m). The ground floor is open with a kitchen in the centre, and the upper floor accommodates a bedroom and a smaller reading/sitting area. In both cases, the bathrooms on the upper level may be reversed to be accessed from different rooms.

Figure 4.14 : Accessible Units, Ground Level

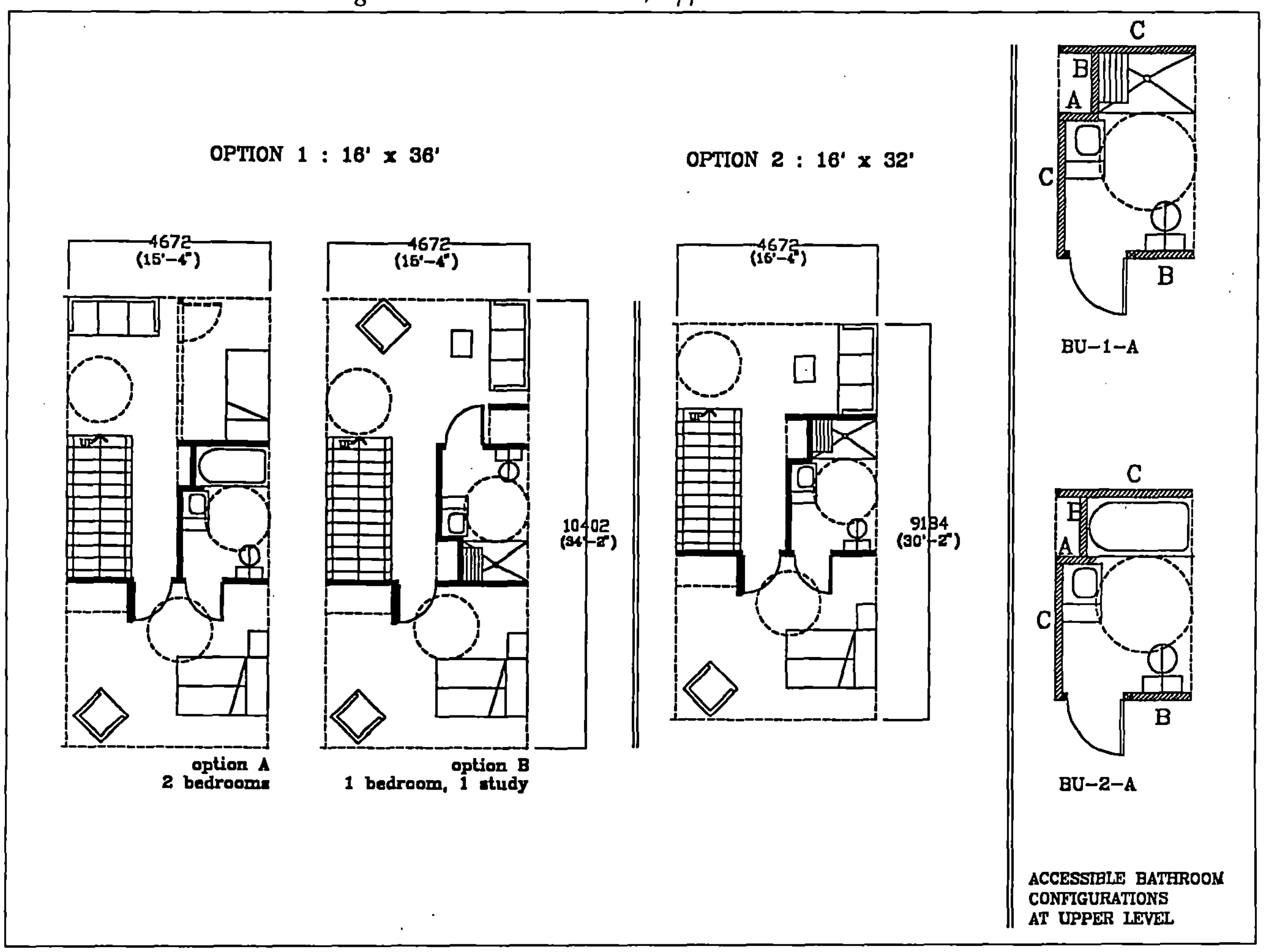


As was the case with the 4.3 meter units, these options represent only some of the possibilities which could be generated using standard modules for entrances and bathrooms. More in-depth studies aimed at adapting and transforming the standard plans would provide a more extensive selection of accessible units.

4.4.5. Exterior Walls

The design of standard exterior wall panels was aimed at accommodating the range of options generated for the interior layout while addressing the cost-saving recommendations put forth by the fabricators. The latter included the use of larger panels, and simple, standard-sized openings located between the structural members of the wall system where possible. All panels were configured according to these recommendations (figure 4.16). The width of the openings was limited to

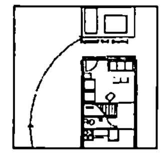
Figure 4.15 : Accessible Units, Upper Level



two options to fit the 600 mm stud spacing, while their height was kept standard to accommodate a 38 x 235 mm header. Their depth could vary more easily, since it does not affect the efficiency of the prefabrication process.

Nine panel configurations were proposed in all: six for the front and back elevations (figure 4.17) and three for the side walls of the end units (figure 4.18). Rowhouse versions of the home could be built with anywhere from two to four panels, while

Figure 4.16 : Standardization of Openings in Panels



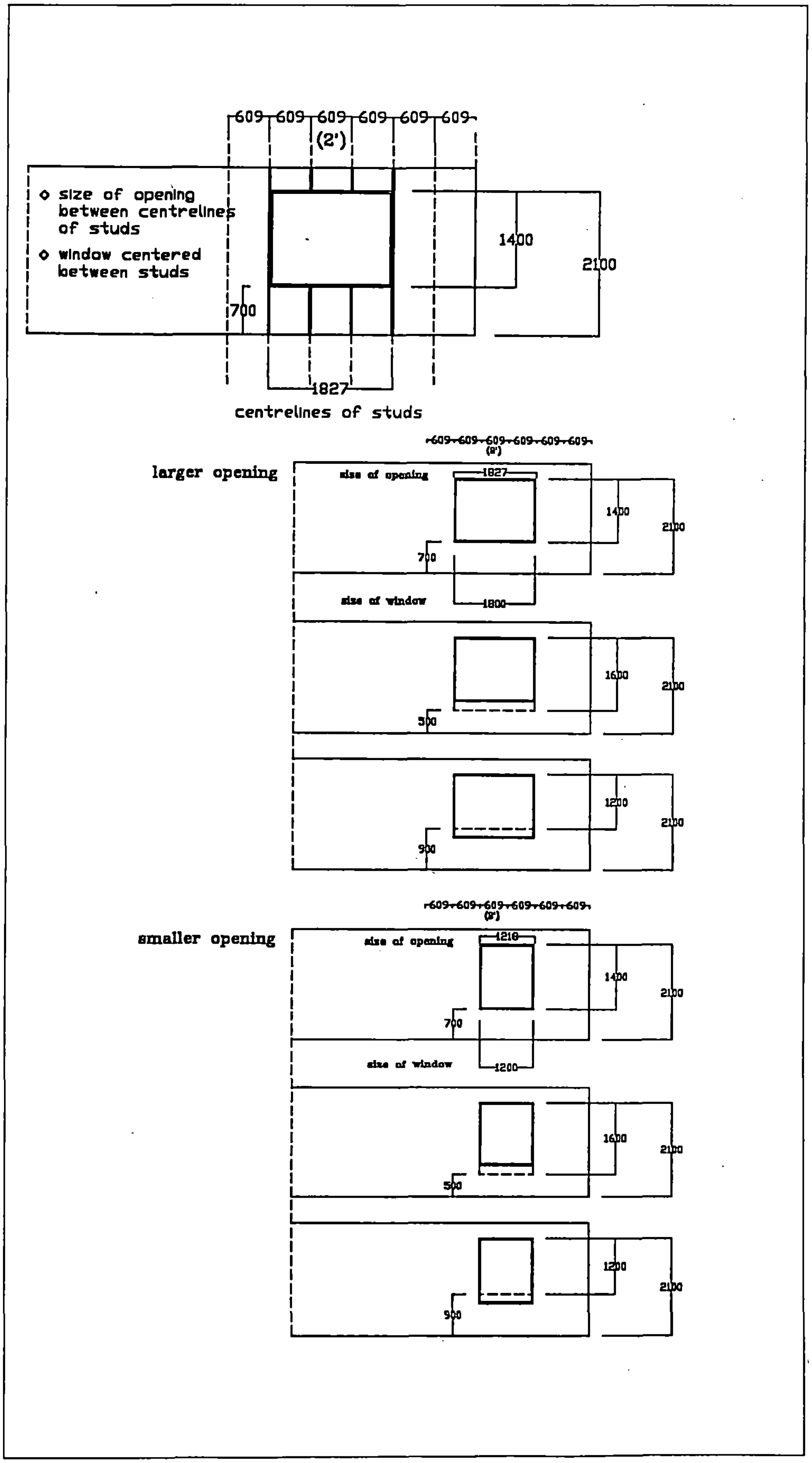
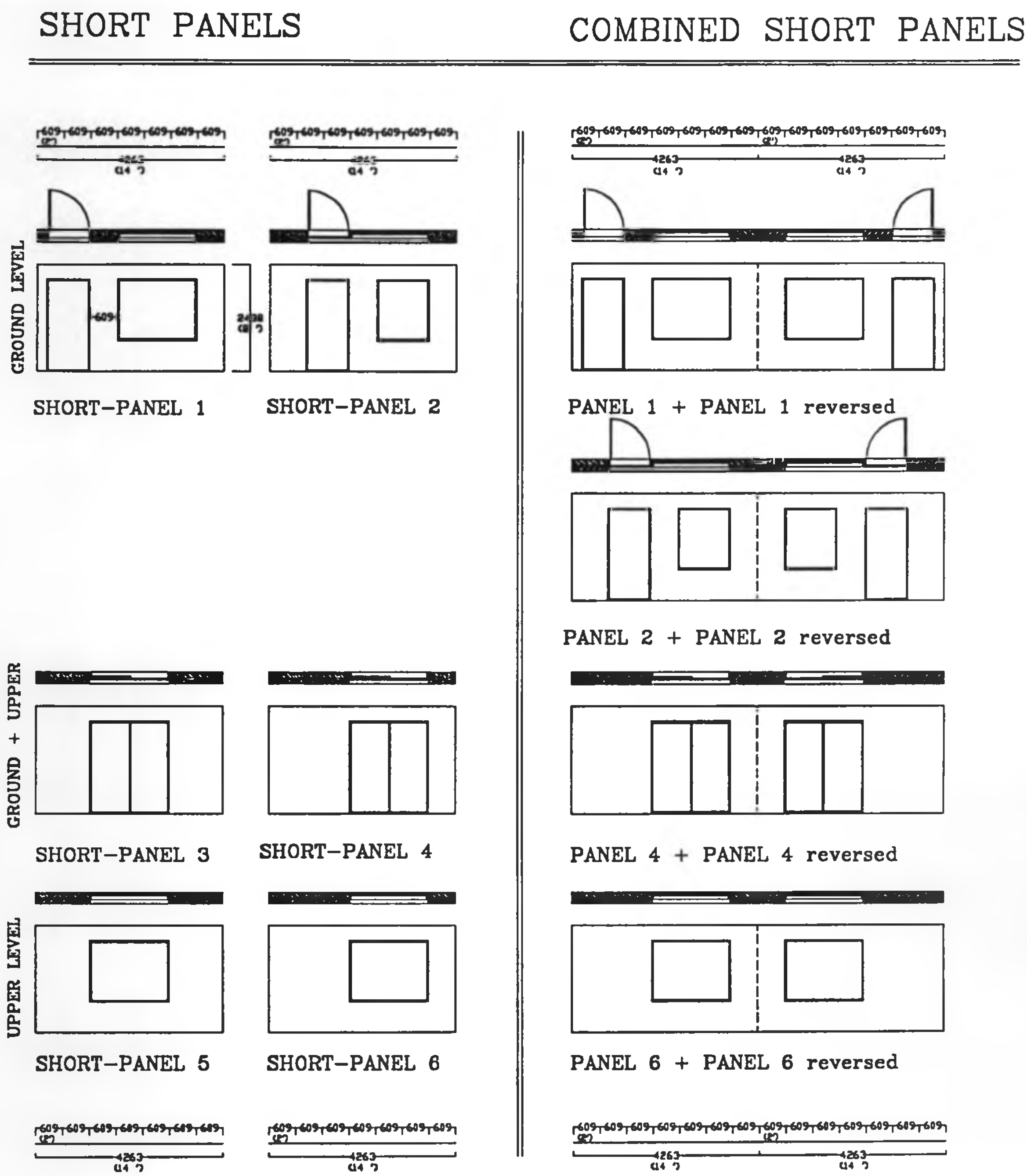


Figure 4.17 : Front and Back Wall Panels



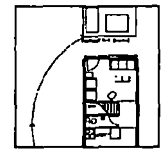
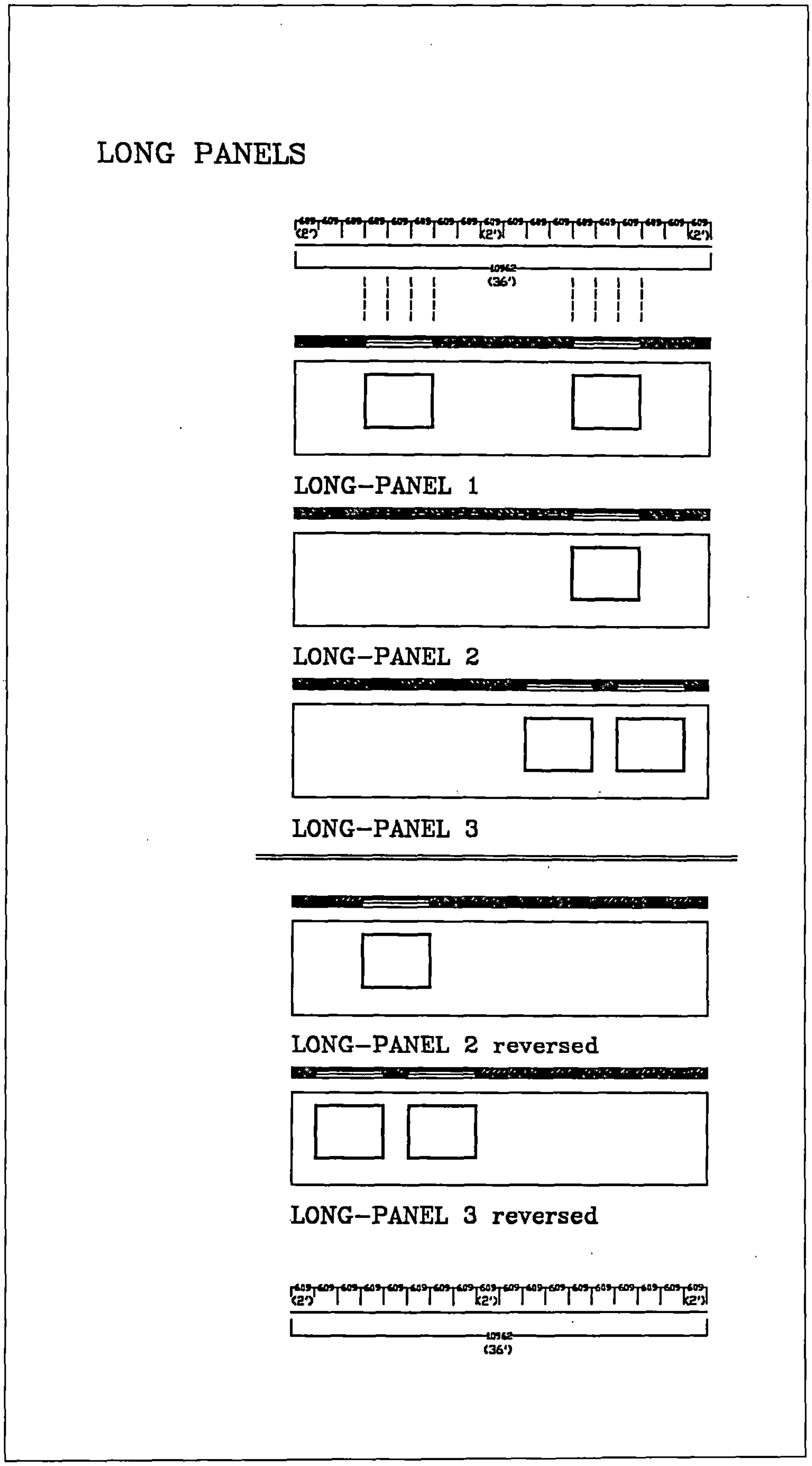


Figure 4.18 : End Wall Panels



semi-detached or end units would require 3 to 6. The compatibility of the panels to the floor plans in shown in figure 4.19.

Panels for the 4.9 meter versions of the design would be the same general configuration, with the extra 600 mm added either between the window and the door (to accommodate some of the vestibules), at the end of the panel, or with one foot added to either end (for panels with central openings).

The biggest challenge in standardizing the exterior wall panels is keeping their number at a minimum while providing a pleasant and functional interior for each of the layouts which could be generated. There are two basic ways of reducing the number of standard panels. The first is to design them so that they could be rotated to suit the layouts of both the fronts and backs, left or right sides of the same or different units. The second approach is somewhat more restrictive, and deals with making the panels reversible. In this case, panels could be shifted from front to back or from side to side without the need to change their orientation. This would require that the panel be symmetrical about its cross section - a quality which is characteristic only of structural sandwich panels. Unsheathed structural panels could not be reversed, since they are either equipped with pre-cut electrical chases or designed with an air space to accommodate electrical wiring, which gives the panels a definite interior and exterior side.

Figure 4.19 : Applicability of Panels to Floor Plan Options

	GROUND LEVEL																						UPPER LEVEL							
	Central Stair						Side Stair																Central Stair				Side Stair			
	SC1		SC2		SC3		OC1		OC2		OC3		BC1		BC2		KC1		KC2		KC3		Option 1		Option 2		Option 1		Option 2	
Short Panels	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B
Type S-1	—	•	—	•	•	• [3]	•	—	•	—	•	•	•	—	•	•	•	•	•	•	•	•	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]
Type S-1 Reversed	•	•	•	•	•	—	•	—	—	•	—	•	•	•	—	•	•	•	—	•	—	•	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]
Type S-2	—	• [2]	—	• [2]	•	• [3]	•	• [3]	•	•	•	•	•	•	•	•	•	•	•	•	•	•	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]
Type S-2 Reversed	•	• [2]	•	• [2]	•	•	•	•	—	•	—	•	•	•	—	•	•	•	—	•	—	•	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]	• [1]
Type S-3	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	•	•	•	•	•	•	•	•
Type S-4	N/A	•	N/A	•	N/A	• [3]	N/A	• [3]	N/A	• [3]	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	N/A	•	•	•	•	•	•	•	•	• [1]
Type S-4 Reversed	N/A	•	N/A	•	N/A	•	N/A	• [3]	N/A	• [3]	N/A	•	N/A	• [3]	N/A	•	N/A	•	N/A	•	N/A	•	•	•	•	•	•	•	•	•
Type S-5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	•	•	•	•	•	•	•	•
Type S-6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	•	•	•	•	•	•	•	•
Type S-6 Reversed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	•	•	•	•	•	•	•	•

	GROUND LEVEL																						UPPER LEVEL							
	Central Stair						Side Stair																Central Stair				Side Stair			
	SC1		SC2		SC3		OC1		OC2		OC3		BC1		BC2		KC1		KC2		KC3		Option 1		Option 2		Option 1		Option 2	
Long Panels	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Type L-1	• [4]	•	• [4]	•	•	•	—	—	—	—	—	—	•	—	•	—	•	•	—	•	—	•	—	—	—	—	—	—	—	—
Type L-2	• [4]	•	• [4]	•	•	•	•	—	—	—	—	•	•	—	•	•	—	•	•	•	•	•	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]
Type L-2 Reversed	•	•	•	•	• [4]	•	—	•	• [4]	•	•	—	• [4]	•	•	—	•	•	—	•	•	•	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]	• [6]
Type L-3	—	•	—	•	—	•	—	—	—	—	—	•	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Type L-3 Reversed	—	• [3]	—	• [3]	—	• [3]	—	• [5]	—	•	—	—	—	• [5]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Notes:
[1] Depends on room layout and closet location
[2] Depends on room layout
[3] Possible ONLY with narrow window or door
[4] Height of window adjusted to counter height
[5] Depends on entrance location
[6] Depends on room designation (bedroom or study)

Legend:
• Possible
— NOT Possible
NR - Not Recommended
N/A Not Applicable

In figures 4.20 and 4.21, the reversibility and rotation of panels is illustrated for the short (front and back) and long (end) panels, respectively. In either case, the reversibility and rotation of the panel is facilitated if the windows are centered. Figures 4.22, 4:23 and 4.24 illustrate some of the plan options which could be assembled using various modules for entrance, bathroom and stairs. The number of partitions and panels required for a particular design are shown in figure 4.25.

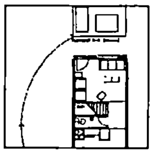


Figure 4.20 : Rotation and Reversibility of Short Walls Panels

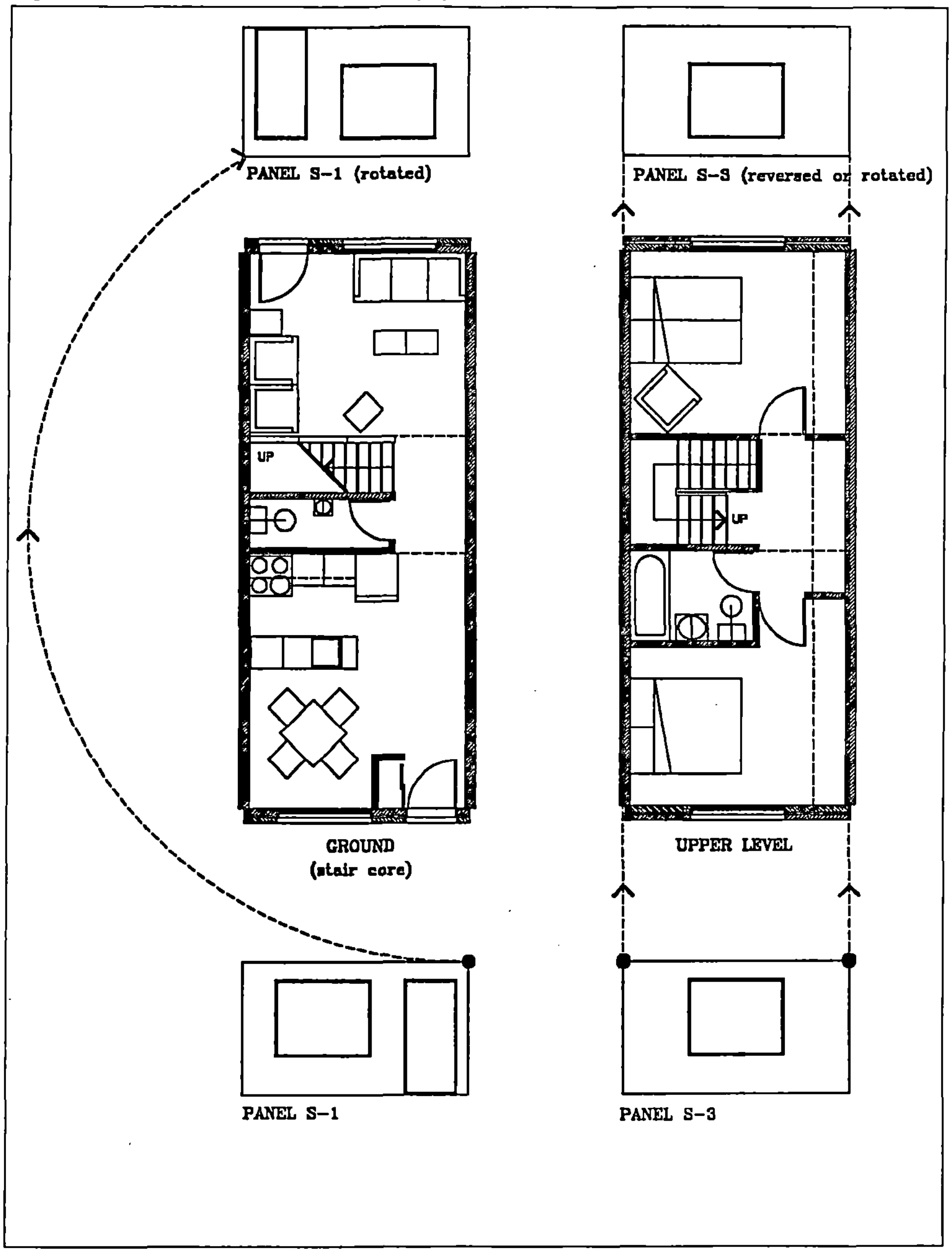


Figure 4.21 : Rotation and Reversibility of Long Wall Panels

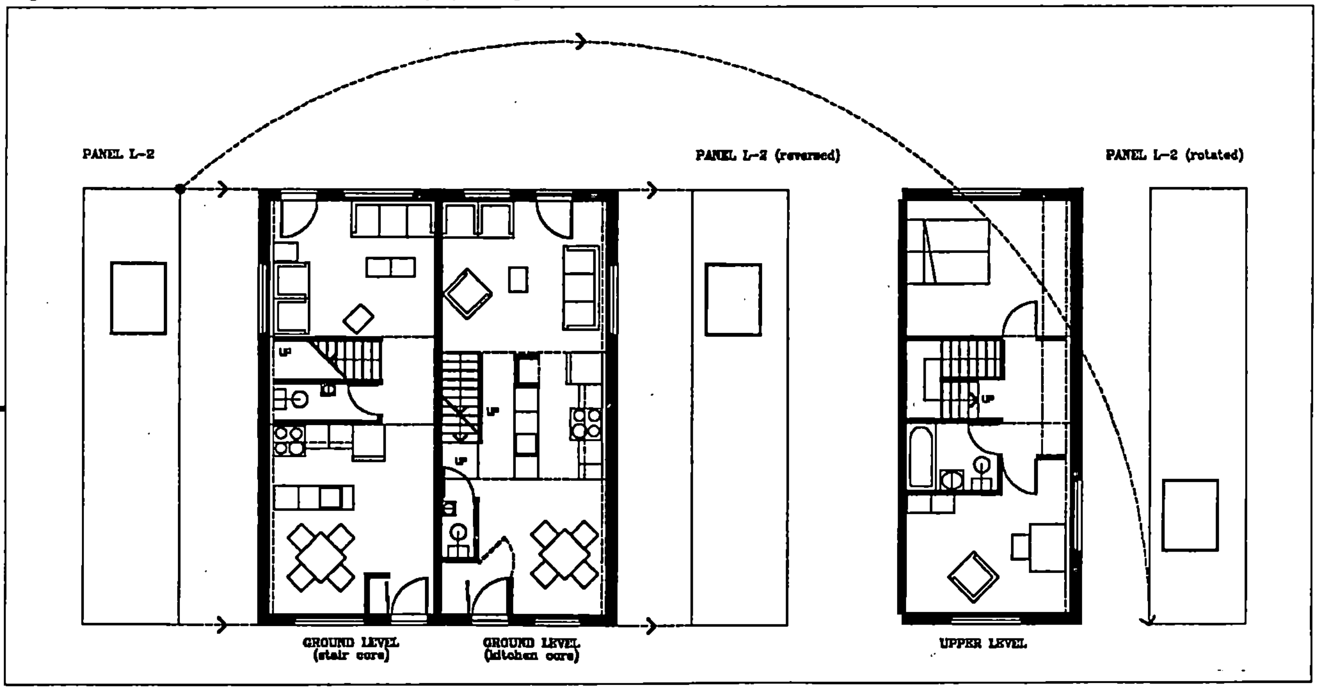


Figure 4.22 : Sample Ground Level Arrangements Using Standard Components

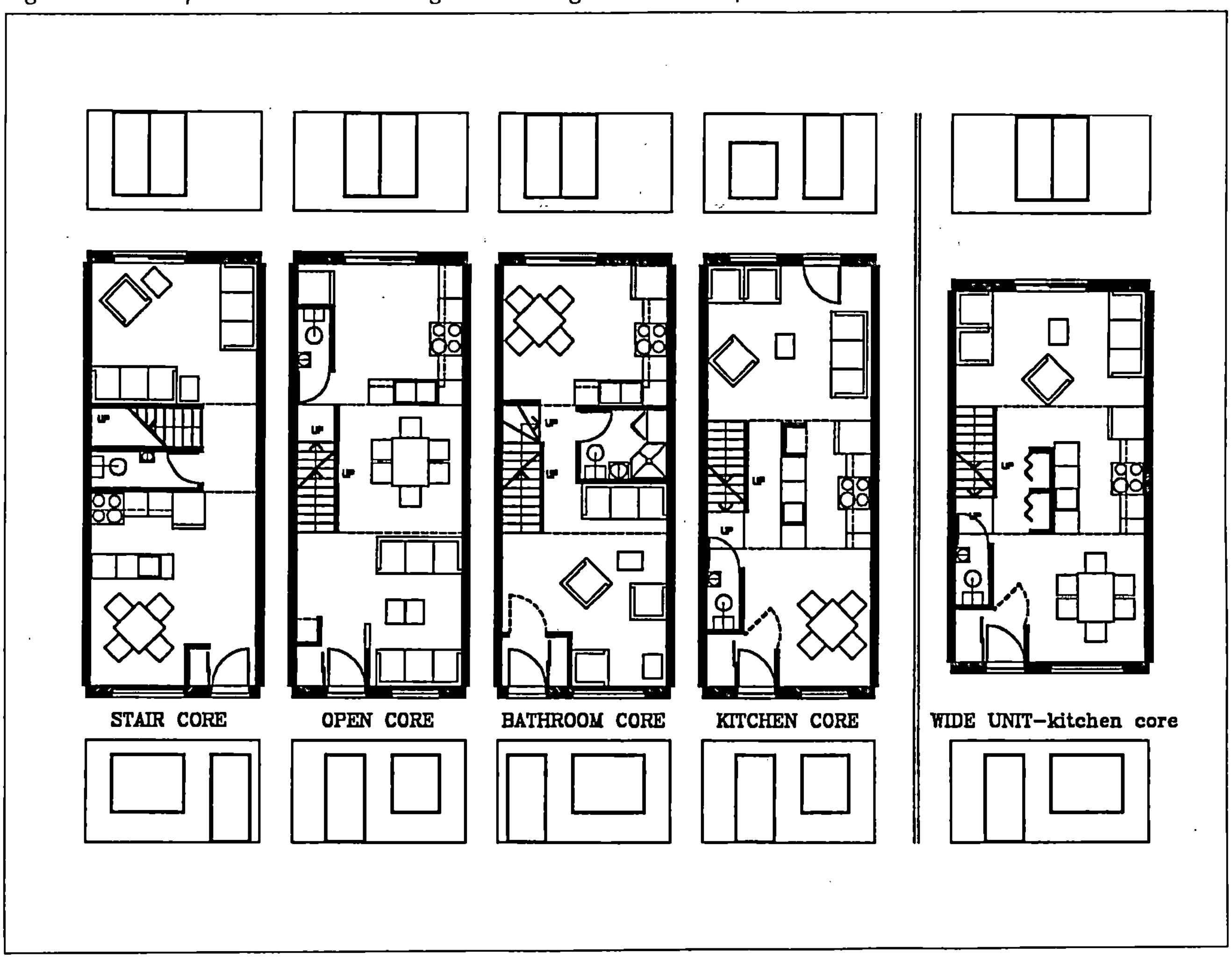


Figure 4.23 : Sample Basement Level Arrangements Using Standard Components

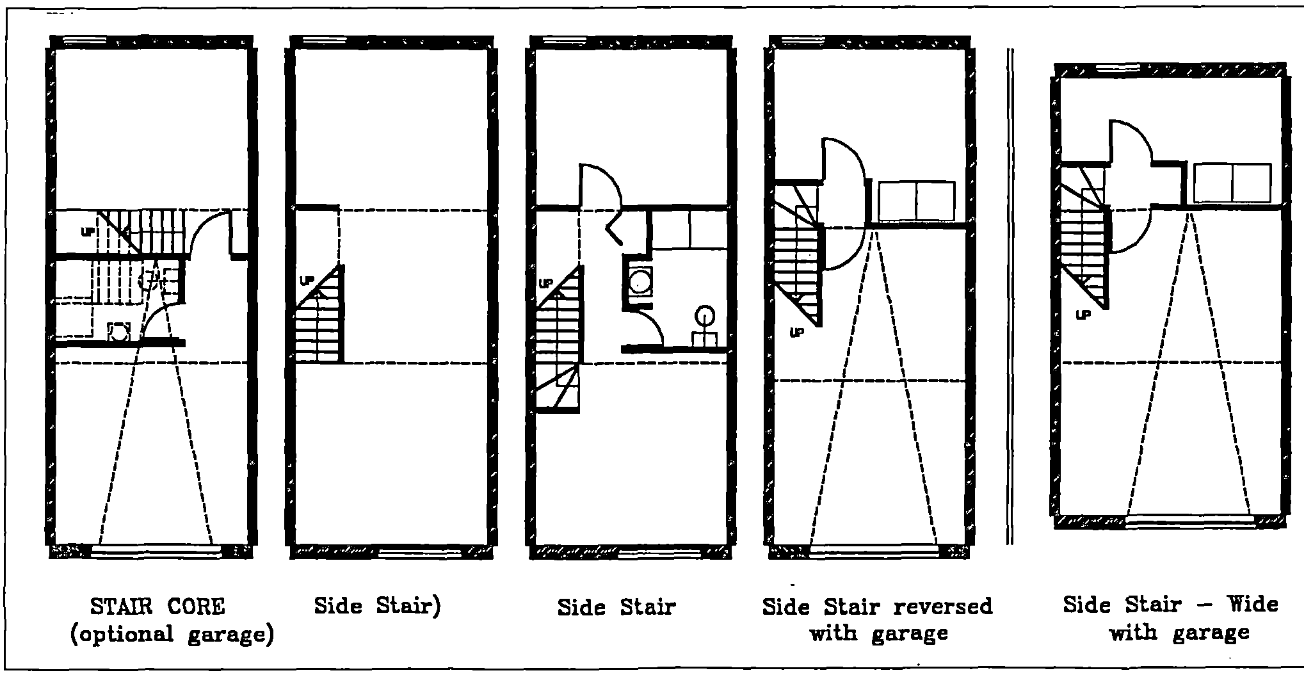


Figure 4.24 : Sample Upper Level Arrangements Using Standard Components

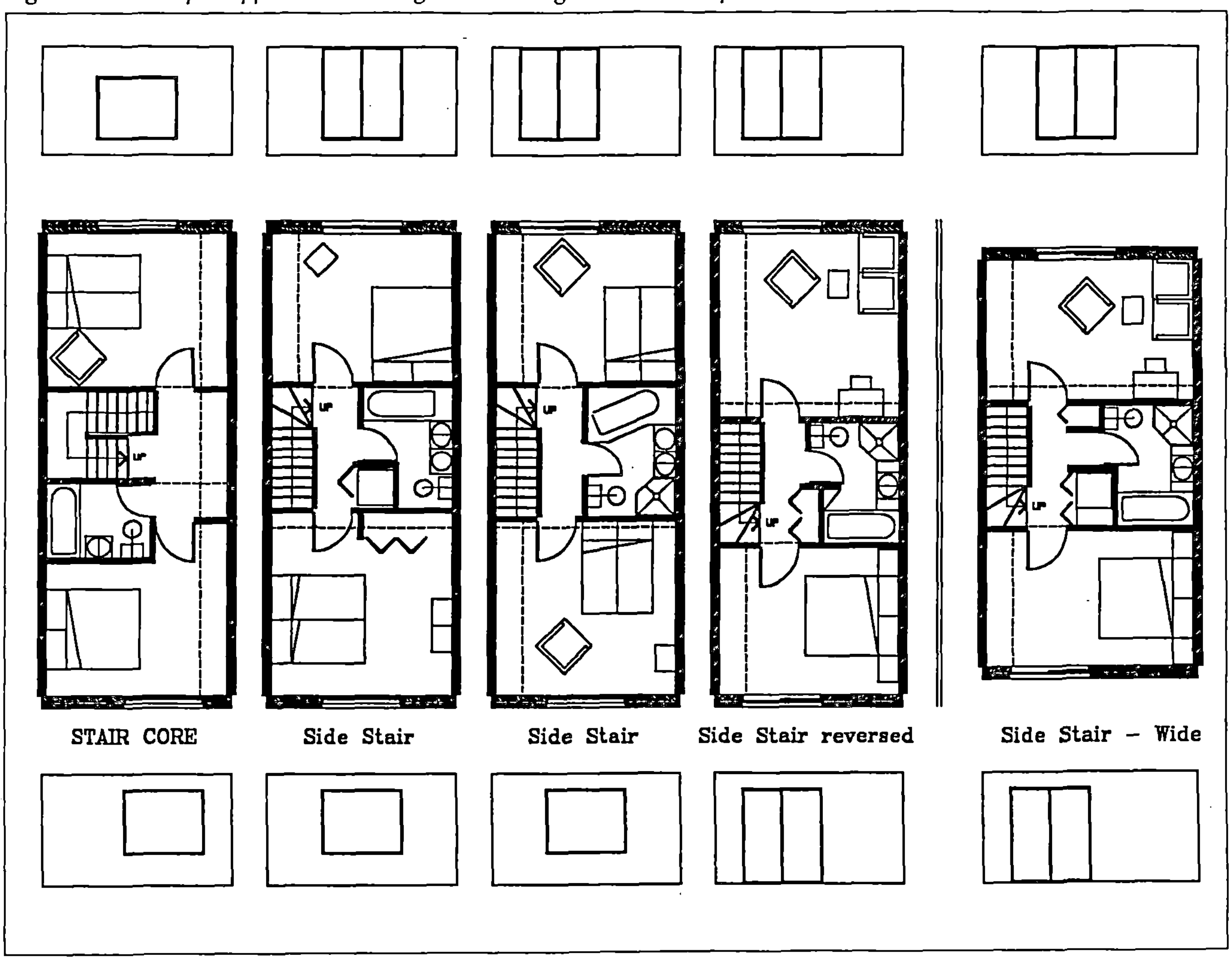
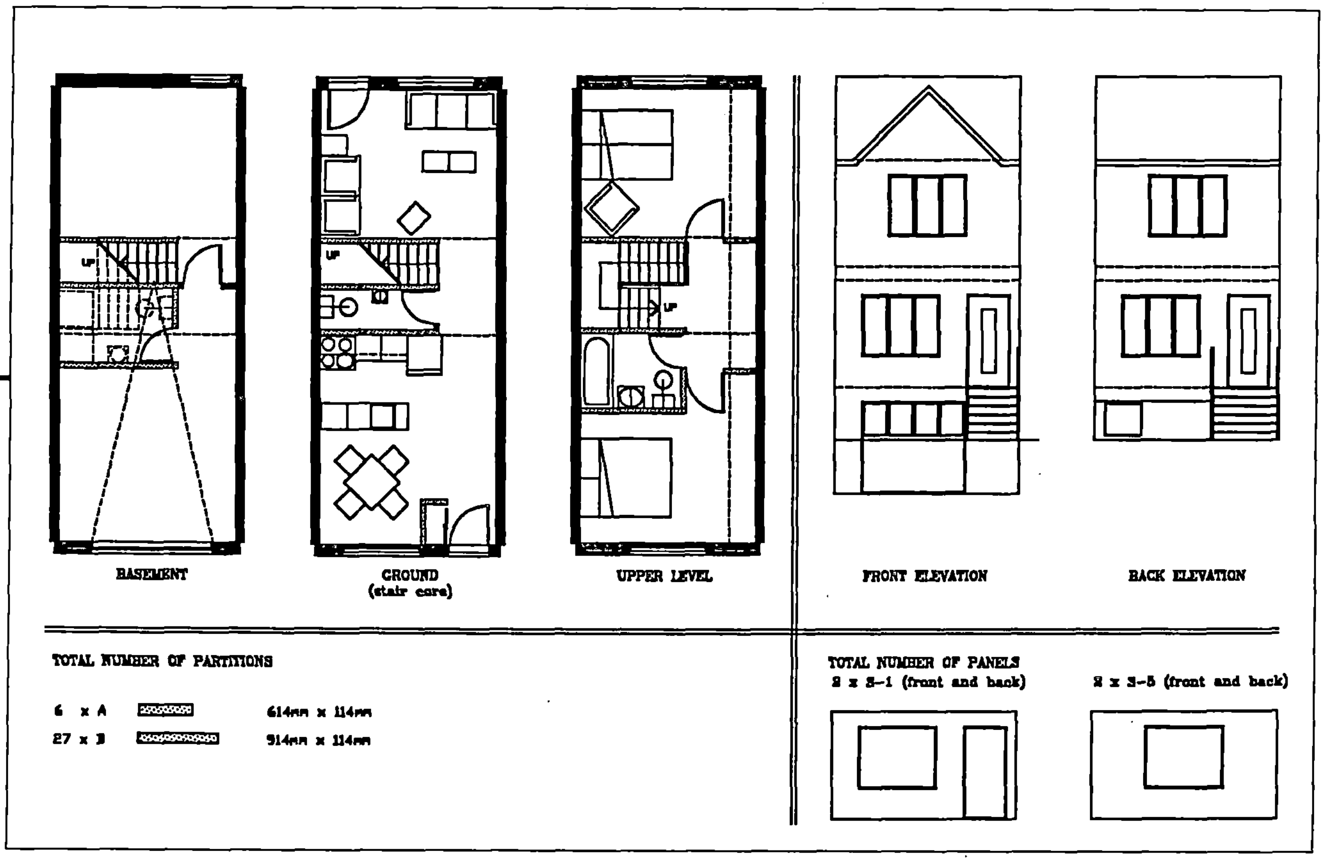


Figure 4.25 : Components Required For Sample Plan and Elevation



Most of the fabricators suggested the use of full length side panels to minimize on-site labour. In instances where the transportation/lifting costs are critical, however, the construction of smaller panels which can be lifted by a 2 or 3-man crew may be favourable. The division of space into 3 segments which took place in the first stage of analysis could be used as a guideline for dimensioning smaller panels. The use of panels dimensioned to 600 mm increments may reduce cutting and material wastage. While the cost estimates in the next section are based on full-length end panels, the design of smaller panels leaves more room for standardization and, more importantly, flexibility, as was demonstrated with the standardization of interior partitions. One further advantage of working with smaller components is the possibility of selling a do-it yourself kit of parts, to be assembled entirely by the homeowner. The reduction of weight and bulk would not only simplify the assembly, but would reduce any intimidation caused by the need of cranes or special lifting equipment.

5. COST ANALYSIS

$1,842	$1,423	$1,84
$2,017	$1,489	$2,01
$2,310	$1,349	$2,31
$4,434	$3,462	$4,43
$2,271	$1,330	$2,27
$2,646	$1,973	$2,64
$2,271	$1,330	$2,27
$2,271	$1,330	$2,27

Costs for both conventional construction and prefabricated panel systems were estimated to determine whether significant savings could be achieved with prefabrication using adapted versions of the Grow Home. The possibility of integrating other prefabricated components available from the panel manufacturers was also investigated, as were transportation costs.

● 5.1. METHODOLOGY

One of the plan options developed in the previous section was selected as a basis for acquiring cost estimates. It was assumed that individual cost estimates for each of the plans developed would not be necessary, since there is no significant difference between the designs which could affect the comparison. The unit chosen was the open-core model with the kitchen in the back (Appendix D). Variations of this model accounted for some 80% of the units sold in the Montreal area, and continue to be the most popular options for the contractors. The unit is a semi-detached version of the Grow Home, measuring 4.3 x 11 meters, with an unfinished basement. Features include a brick exterior (two floors in the front, one floor on the side and back), a finished upper floor with two bedrooms and a second bathroom, and a balcony on the second floor.

The model plan was submitted to an independent party for an elemental cost estimate using conventional construction techniques. This estimate was then compared with values obtained from the builders of 7 Grow Home projects in Montreal to assess any discrepancies. Adjustments were made as required, and the estimate was used as a basis for comparison with the prefabricated systems.

This same plan was distributed to each of the five panel manufacturers for cost estimates of their systems, and to one other manufacturer specializing in prefabricated floor system. Fabricators were asked to submit costs for the following items:

Material (wall panels)
Labour (estimated site labour required)
Electrical (estimated increase or decrease in electrical work)
Transportation requirements and associated costs

Costs for 1, 10 and 30 units were requested. Other prefabricated elements available from the manufacturers were also investigated, including prefabricated roofs, floors, basements, partitions and stairs. The cost of "added value" panel systems was also requested, whereby sheathing, siding, gypsum wallboard and electrical wiring are installed or supplied by the manufacturer.

● 5.2 CONVENTIONAL CONSTRUCTION

Estimates received for some of the prefabricated systems include material other than that which is part of the panel. Other estimates included only a portion of the wall, and extra on-site labour is required to complete the envelope. In order to provide an appropriate framework for comparison to prefabricated systems, the cost estimate for conventional construction was broken down by element rather than by trade, with each element further subdivided by labour and material. The cost data was entered in cells on a spreadsheet software, where individual values for conventional construction could easily be replaced with the estimates for prefabricated components. This format would also enable adjustments to be made to material and/or labour rates depending on the location of the project. The labour component is reflective of the potential savings which could be achieved by allowing the buyer to do some of the work.

The estimated costs were compared to those obtained from 7 builders who completed Grow Home type projects in Montreal between February 1991 and January 1992. The cost of building the model unit with conventional construction was estimated at $57,720, as compared to an average of $45,020 from the 7 builders. This discrepancy can accounted for by considering three main factors: quantity discounts obtained by the builders, rise in material costs over a 12-month period and the use of a semi-detached unit for the model (most of the builders had built rowhouses in groups of 4 to 8). The difference adds up as follows:

Estimate	$57,720
10% quantity discount	- $5,772
	$51,948
5% material costs (5% x $30,796)	- $1,540
	$50,408
allowance for end unit	- $3,000
	$47,408

For conventional construction, it is generally accepted that a discount of 10% on material and labour can be obtained with as little as 10 units, although this figure does not increase substantially with additional units. This is supported by data obtained from the builders, all of whom reported having received discounts of 10% despite the fact that the number of units under construction ranged from 12 to 78 units. Costs per unit for both 10 and 30 units were therefore estimated at $51,948.

It should be mentioned that these costs do not represent the least expensive option for building the unit, but are rather indicative of the type of construction which was common in the built projects. Replacing a few materials, such as the brick exterior and windows, can significantly lower construction costs. Replacing the brick with aluminum siding, for instance, can reduce the price by approximately $2,250. Similarly, replacing the aluminum-clad wood windows with vinyl sliding units can lead to additional savings in the area of $1,000. While material replacements as such are worthwhile considering for cost reduction, they do not normally affect the cost of the building's structure, and are therefore of no importance in the cost comparison with prefabricated panel systems.

Elemental Cost Estimate
Conventional Construction

Code	Description	Unit	Quantity	Unit Cost Material	Unit Cost Labour	Unit Cost Total	Total Cost Material	Total Cost Labour	Total	(%)
2	SITEWORK						$440	$1288	$1729	(3.0%)
2.1	Preparation						$87	$589	$676	(1.2%)
2.1.1	Excavation	cu.m.	108.50	$0.00	$4.66	$4.66	$0	$506	$506	
2.1.2	Drainage	m.	21.10	$4.13	$3.95	$8.08	$87	$83	$170	
2.2	Backfill						$353	$699	$1053	(1.8%)
2.2.1	Under Slab	cu.m.	12.90	$12.23	$17.50	$29.73	$158	$226	$384	
2.2.2	Drainage	cu.m.	1.90	$22.00	$6.12	$28.12	$42	$12	$53	
2.2.3	General	cu.m.	26.40	$5.82	$17.50	$23.32	$154	$462	$616	
3	CONCRETE						$2560	$2736	$6296	(10.9%)
3.1	Footings						$578	$554	$1132	(2.0%)
3.1.1	Concrete	cu.m.	6.03	$82.30	$31.45	$113.75	$496	$190	$686	
3.1.2	Formwork	sq.m.	18.20	$4.50	$20.00	$24.50	$82	$364	$446	
3.2	Walls						$1839	$1424	$3263	(5.7%)
3.2.1	Concrete	cu.m.	11.70	$82.30	$16.72	$99.02	$963	$196	$1159	
3.2.2	Rebars	ton	0.07	$622.00	$500.00	$1122.00	$43	$35	$77	
3.2.2	Formwork	sq.m.	70.20	$11.87	$17.00	$28.87	$833	$1193	$2027	
3.3	Slab						$142	$759	$901	(1.6%)
3.3.1	Concrete	sq.m.	43.00	$1.90	$11.60	$13.50	$82	$499	$581	
3.3.2	Mesh	sq.m.	43.00	$1.41	$1.95	$3.36	$61	$84	$144	
3.3.3	Finish	sq.m.	43.00	$0.00	$4.10	$4.10	$0	$176	$176	
3.4	Prefab								$1000	(1.7%)
3.4.1	Front stairs	unit	1.00			$600.00	(90%)	(10%)	$600	
3.4.2	Rear stairs	unit	1.00			$400.00	(90%)	(10%)	$400	
4	MASONRY						$2015	$3249	$5263	(9.1%)
4.1	Brick Masonry						$1310	$2425	$3735	(6.5%)
4.1.1	Front wall	sq.m.	16.20	$24.44	$45.24	$69.68	$396	$733	$1129	
4.1.2	Side wall	sq.m.	28.40	$24.44	$45.24	$69.68	$694	$1285	$1979	
4.1.3	Rear wall	sq.m.	9.00	$24.44	$45.24	$69.68	$220	$407	$627	
4.2	Accessories						$17	$40	$56	(0.1%)
4.2.1	Flashing	m.	20.00	$0.83	$1.98	$2.81	$17	$40	$56	
4.3	Block masonry						$688	$784	$1472	(2.6%)
4.3.1	Mitoyen wall	sq.m.	25.20	$27.30	$31.13	$58.43	$688	$784	$1472	
5	METALS						$169	$1025	$1194	(2.1%)
5.1	Railings						$169	$1025	$1194	(2.1%)
5.1.1	Front stairs	m.	4.30	$9.43	$57.26	$66.69	$41	$246	$287	
5.1.2	Rear stairs	m.	7.70	$9.43	$57.26	$66.69	$73	$441	$514	
5.1.3	Balcony	m.	5.90	$9.43	$57.26	$66.69	$56	$338	$393	

Elemental Cost Estimate
Conventional Construction (cont'd)

Code	Description	Unit	Quantity	Unit Cost Material	Unit Cost Labour	Unit Cost Total	Total Cost Material	Total Cost Labour	Total	(%)
6	WOOD AND PLASTICS						$7764	$4700	$12464	(21.6%)
6.1	Wood structure						$5699	$3797	$9496	(16.5%)
6.1.1	Walls (2x6)						$1456	$808	$2264	(3.9%)
6.1.1.1	Side wall	m.	276.00	$2.10	$1.10	$3.20	$580	$304	$883	
6.1.1.2	Front wall	m.	146.00	$2.10	$1.10	$3.20	$307	$161	$467	
6.1.1.3	Rear wall	m.	110.00	$2.10	$1.10	$3.20	$231	$121	$352	
6.1.1.4	Mitoyen wall	m.	240.00	$1.41	$0.93	$2.34	$338	$223	$562	
6.1.2	Floor (2x10)						$1636	$584	$2220	(3.8%)
6.1.2.1	First floor	m.	220.50	$3.50	$1.25	$4.75	$772	$276	$1047	
6.1.2.2	Second floor	m.	220.50	$3.50	$1.25	$4.75	$772	$276	$1047	
6.1.2.3	Balcony	m.	26.40	$3.50	$1.25	$4.75	$92	$33	$125	
6.1.3	Roof						$463	$208	$671	(1.2%)
6.1.3.1	Trusses	unit	8.00	$57.93	$26.00	$83.93	$463	$208	$671	
6.1.4	Interiors						$285	$188	$473	(0.8%)
6.1.4.1	Partitions (2x4)	m.	202.00	$1.41	$0.93	$2.34	$285	$188	$473	
6.1.5	Stairways						$173	$477	$650	
6.1.5.1	Stringers	m.	13.40	$3.50	$8.00	$11.50	$47	$107	$154	
6.1.5.2	Treads	m.	28.40	$2.16	$10.00	$12.16	$61	$284	$345	
6.1.5.3	Low walls	m.	46.00	$1.41	$1.86	$3.27	$65	$86	$150	
6.2	Sheathing						$1232	$1096	$2327	(4.0%)
6.2.1	Walls (1/2)	sq.m.	107.00	$4.92	$4.37	$9.29	$526	$468	$994	
6.2.2	Floors (5/8)	sq.m.	84.70	$5.03	$4.37	$9.40	$426	$370	$796	
6.2.3	Roof (5/8)	sq.m.	55.50	$5.03	$4.65	$9.68	$279	$258	$537	
6.3	Furring						$455	$436	$891	(1.5%)
6.3.1	Basement (2x4)	m.	168.00	$1.41	$0.93	$2.34	$237	$156	$393	
6.3.2	Siding (1x3)	m.	131.40	$0.67	$1.42	$2.09	$88	$187	$275	
6.3.3	Basement mit(2x3)	m.	100.00	$1.30	$0.93	$2.23	$130	$93	$223	
6.4	Woodworking						$2065	$903	$2968	(5.1%)
6.4.1	Built inst						$1435	$403	$1838	(3.2%)
6.4.1.1	Kitch cab/wall	m.	5.50	$133.00	$22.73	$155.73	$732	$125	$857	
6.4.1.2	Kitch cab/floor	m.	3.20	$146.50	$77.55	$224.05	$469	$248	$717	
6.4.1.3	Vanity	unit	1.00	$235.00	$30.00	$265.00	$235	$30	$265	
6.4.2	Handrails						$52	$128	$180	(0.3%)
6.4.2.1	Stair	m.	12.50	$4.13	$10.27	$14.40	$52	$128	$180	
6.4.3	Trim						$524	$314	$838	(1.5%)
6.4.3.1	Baseboard	m.	68.70	$3.94	$3.27	$7.21	$271	$225	$495	
6.4.3.2	Door frames	unit	4.00	$63.25	$22.45	$85.70	$253	$90	$343	
6.4.4	Shelves						$54	$57	$111	(0.2%)
6.4.4.1	Closets	m.	7.30	$7.42	$7.80	$15.22	$54	$57	$111	

Elemental Cost Estimate
Conventional Construction (cont'd)

Code	Description	Unit	Quantity	Unit Cost Material	Unit Cost Labour	Unit Cost Total	Total Cost Material	Total Cost Labour	Total	(%)
7	WEATHERPROOFING						$2950	$2148	$5098	(8.8%)
7.1	Roofing						$336	$310	$646	(1.1%)
7.1.1	Shingles	sq.m.	55.50	$5.33	$5.19	$10.52	$296	$288	$584	
7.1.2	Felt	sq.m.	55.50	$0.72	$0.40	$1.12	$40	$22	$62	
7.1.3	Sheet metal						$367	$390	$757	(1.3%)
7.1.3.1	Flashing	m.	29.50	$1.80	$7.25	$9.05	$53	$214	$267	
7.1.3.2	Soffits	sq.m.	11.60	$5.50	$12.15	$17.65	$64	$141	$205	
7.1.4	Balcony floor	unit	1.00	$250.00	$35.00	$285.00	$250	$35	$285	
7.2	Dampproofing						$82	$163	$245	(0.4%)
7.2.1	Foundation coating	sq.m.	35.10	$2.35	$4.64	$6.99	$82	$163	$245	
7.3	Vapour barrier						$82	$156	$238	(0.4%)
7.3.1	Walls	sq.m.	107.00	$0.36	$0.69	$1.05	$39	$74	$112	
7.3.2	Ceiling	sq.m.	43.00	$0.36	$0.75	$1.11	$15	$32	$48	
7.3.3	Slab	sq.m.	43.00	$0.36	$0.60	$0.96	$15	$26	$41	
7.3.4	Basement	sq.m.	35.10	$0.36	$0.69	$1.05	$13	$24	$37	
7.4	Air barrier						$132	$73	$204	(0.4%)
7.4.1	Membrane	sq.m.	107.00	$1.23	$0.68	$1.91	$132	$73	$204	
7.5	Thermal insulation						$1064	$406	$1471	(2.5%)
7.5.1	Walls	sq.m.	107.00	$4.64	$1.91	$6.55	$496	$204	$701	
7.5.2	Basement	sq.m.	35.10	$3.00	$1.29	$4.29	$105	$45	$151	
7.5.3	Roof	sq.m.	43.00	$7.24	$2.13	$9.37	$311	$92	$403	
7.5.4	Mitoyen	sq.m.	50.40	$3.00	$1.29	$4.29	$151	$65	$216	
7.6	Siding						$887	$650	$1537	(2.7%)
7.6.1	Rear wall	sq.m.	12.40	$13.65	$10.00	$23.65	$169	$124	$293	
7.6.2	Side wall	sq.m.	52.60	$13.65	$10.00	$23.65	$718	$526	$1244	
8	DOORS AND WINDOWS						$4334	$1533	$5867	(10.2%)
8.1	Doors						$1307	$700	$2007	(3.5%)
8.1.1	Exterior	unit	1.00	$235.00	$35.00	$270.00	$235	$35	$270	
8.1.2	Interior	unit	4.00	$33.00	$29.00	$62.00	$132	$116	$248	
8.1.3	Wardrobe 1000	unit	7.00	$108.00	$61.00	$169.00	$756	$427	$1183	
8.1.4	Wardrobe 300	unit	2.00	$92.00	$61.00	$153.00	$184	$122	$306	
8.2	Windows						$3027	$833	$3860	(6.7%)
8.2.1	Casement 180/160	unit	2.00	$582.00	$119.00	$701.00	$1164	$238	$1402	
8.2.2	Casement 180/140	unit	1.00	$360.00	$119.00	$479.00	$360	$119	$479	
8.2.3	Sliding 180	unit	1.00	$189.00	$119.00	$308.00	$189	$119	$308	
8.2.4	Sliding 90	unit	1.00	$126.00	$119.00	$245.00	$126	$119	$245	
8.2.5	Patio	unit	2.00	$594.00	$119.00	$713.00	$1188	$238	$1426	

Elemental Cost Estimate
Conventional Construction (cont'd)

Code	Description	Unit	Quantity	Unit Cost Material	Unit Cost Labour	Unit Cost Total	Total Cost Material	Total Cost Labour	Total	(%)
9	FINISHES						$5339	$6719	$12057	(20.9%)
9.1	Wallboard						$1389	$2468	$3858	(6.7%)
9.1.1	Walls	sq.m.	107.00	$3.14	$5.32	$8.46	$336	$569	$905	
9.1.2	Partitions	sq.m.	91.00	$3.14	$5.32	$8.46	$286	$484	$770	
9.1.3	Ceilings	sq.m.	83.40	$3.14	$6.69	$9.83	$262	$558	$820	
9.1.4	Basement	sq.m.	60.30	$3.14	$5.32	$8.46	$189	$321	$510	
9.1.5	Mitoyen	sq.m.	100.8	$3.14	$5.32	$8.46	$317	$536	$853	
9.2	Tiling						$730	$543	$1273	(2.2%)
9.2.1	Floor	sq.m.	8.70	$43.00	$31.90	$74.90	$374	$278	$652	
9.2.2	Base	m.	12.50	$14.25	$11.06	$25.31	$178	$138	$316	
9.2.3	Wall	sq.m.	5.50	$32.30	$23.07	$55.37	$178	$127	$305	
9.3	Paint						$862	$2660	$3523	(6.1%)
9.3.1	Walls & partitions	sq.m.	281.40	$1.91	$4.64	$6.55	$537	$1306	$1843	
9.3.2	Ceilings	sq.m.	83.40	$2.39	$5.65	$8.04	$199	$471	$671	
9.3.3	Doors & frames	sq.m.	17.20	$1.83	$10.83	$12.66	$31	$186	$218	
9.3.4	Baseboards	m.	68.70	$1.37	$10.15	$11.52	$94	$697	$791	
9.4	Carpet						$772	$307	$1079	(1.9%)
9.4.1	Rooms	sq.m.	33.40	$15.17	$5.00	$20.17	$507	$167	$674	
9.4.2	Stairs	sq.m.	14.00	$18.96	$10.00	$28.96	$265	$140	$405	
9.5	Vinyl						$169	$67	$236	(0.4%)
9.5.1	Kitchen	sq.m.	13.00	$12.97	$5.19	$18.16	$169	$67	$236	
9.6	Parquet						$1416	$673	$2089	(3.6%)
9.6.1	Living	sq.m.	26.35	$53.75	$25.53	$79.28	$1416	$673	$2089	
15	MECHANICAL	sub					(60%)	(40%)	$4500	(7.8%)
16	ELECTRICAL	sub					(50%)	(50%)	$3250	(5.6%)
	TOTAL						$30,796	$26,923	$57,719	(100.0%)

$1,842	$1,423	$1,84
$2,017	$1,489	$2,01
$2,310	$1,349	$2,31
$4,434	$3,462	$4,43
$2,271	$1,330	$2,27
$2,646	$1,973	$2,64
$2,271	$1,330	$2,27
$2,271	$1,330	$2,27

● 5.3 PREFABRICATED SYSTEMS

Cost estimates were received for eight types of panels. Two of these were "added value" variations of standard panel systems, one of which had the interior finish pre-installed, and the other with both interior and exterior finishes forming part of the wall system. Four manufacturers submitted estimates for floor systems (three conventional and one proprietary), and two estimates for interior partitions were received. The effect of prefabricated assembly on the cost of electrical and plumbing installation was considered by the manufacturers to be negligeable, with the sole exception of structural sandwich panels, where the labour costs were increased by 5% for electrical wiring. Labour rates were assumed to be $85/hr for a 3-man crew consisting of one framer and two helpers. The costs do not include land, infrastructure, contractor's overhead and profit. All costs are for November 1992. Transportation costs were for the Montreal area.

5.3.1. Equivalent Values of Prefabricated Components

Figure 5.1 compares the costs of various prefabricated components to their equivalent value in conventional construction. For the purpose of analysis, transportation costs were separated from the component costs and prorated for each system according to volume. It was found that the use of prefabricated wall systems could represent savings ranging from 9% for one type of unsheathed structural panel to 54% for open sheathed panel systems. When viewed from this perspective, it is evident that the economic benefits of prefabrication can be realized, although they are likely to have little impact on the overall cost of the unit. Considering that in a case like the Grow Home, the exterior wall components (including interior and aluminum siding) account for about 14% ($8,000) of the total cost of the unit, the resulting savings which could be achieved by prefabricating the envelope were significant.

The costs for the dividing wall were separated from the other walls because of the particular requirements of this wall with respect to noise and fire. Regulations concerning the materials and construction of the dividing wall may vary from one municipality to another. Although some of the prefabricated panel systems have been tested for fire resistance, many of them may encounter obstacles in gaining approval from municipal authorities. By treating these walls as separate components, the cost implications of having to build them using alternative methods are easier to evaluate.

The savings which resulted with the use of prefabricated exterior walls were not evident in the case of the dividing wall, except for open sheathed-type panels. Despite its relatively long dimension, this wall is a fairly simple element in that there are no openings or irregularities. The site labour component for the dividing wall is relatively small, requiring very little cutting or fitting. The sound and fire resistance characteristics required are usually achieved through multiple layers of gypsum wallboard, batt insulation and resilient furring channels. The air-tight qualities of prefabricated panel systems which use unconventional construction methods may be excessive for what would otherwise be a simple structure. Cost differences ranged from savings of 10-34% for open sheathed panels to increases of 54% for one type of unsheathed structural panel.

The prefabrication of floors and partitions was also found to be competitive with conventional construction methods, although estimates were highly variable for identical assemblies. Estimates for floor systems were received from four manufacturers, 3 of which used conventional construction methods (2 panels and 1

Figure 5.1 : Cost Comparison Between Prefabricated Components and Their Equivalent Value in Convetional Construction

Equivalent Values of Prefabricated Components

	Value in Conventional Construction			Cost of Prefabricated Construction [1]			Cost Difference per Unit [1]			Cost Difference Total [1]			Partial Transp. Costs	
	Material	Labour	Total	Material	Labour	Total	1 Unit	10Units	30Units	1 Unit	10Units	30Units	Costs	
EXTERIOR WALLS														
1.1. OSP/38x140mm w/OSB sheathing	$1,842	$1,423	$3,265	$1,190	$325	$1,515	-$1,750	-$1,454	-$1,454	-$1,750	-$14,538	-$43,614	$260	
1.2. OSP/38x89 mm w/XEPS sheathing	$2,017	$1,489	$3,506	$1,605	$325	$1,930	-$1,576	-$1,264	-$1,264	-$1,576	-$12,640	-$37,920	$260	
2.1. SSP/OSB both sides	$2,310	$1,349	$3,659	$4,630	$255	$4,885	$1,226	$1,592	$615	$1,226	$15,919	$18,447	$280	[2]
2.1.a. SSP/added value	$4,434	$3,462	$7,896	$5,628	$255	$5,883	-$2,013	-$1,223	-$2,400	-$2,013	-$12,234	-$72,000	$280	[2],[3]
3.1. USP/ no air space	$2,271	$1,330	$3,601	$2,304	$64	$2,368	-$1,233	-$991	-$1,110	-$1,233	-$9,913	-$33,291	$75	
3.1.a. USP/ no air space/added value	$2,646	$1,973	$4,619	$2,560	$64	$2,624	-$1,995	-$1,664	-$1,796	-$1,995	-$16,643	-$53,865	$75	
3.2. USP/thermal break & air space	$2,271	$1,330	$3,601	$2,675	$300	$2,975	-$626	-$427	-$501	-$626	-$4,266	-$15,028	$190	
3.3. USP/no thermal break; air space	$2,271	$1,330	$3,601	$3,072	$215	$3,287	-$314	-$118	-$118	-$314	-$1,183	-$3,548	$320	
DIVIDING WALLS														
Conventional - 2 x 4	$339	$223	$562	$321	$185	$506	-$56	-$10	-$10	-$56	-$99	-$298	$140	
	$497	$491	$988	$612	$36	$648	-$340	-$274	-$306	-$340	-$2,736	-$9,180	$25	
	$497	$491	$988	$710	$170	$880	-$108	-$57	-$79	-$108	-$567	-$2,362	$70	
2.1. SSP/OSB both sides	$648	$526	$1,174	$1,399	$150	$1,549	$375	$492	$183	$375	$4,924	$5,478	$95	[2],[4]
2.1.b. SSP/added value	$807	$794	$1,601	$1,740	$150	$1,890	$289	$449	$71	$289	$4,491	$2,133	$95	[2],[4]
3.1. USP/ no air space	$648	$556	$1,204	$1,296	$36	$1,332	$128	$182	$115	$128	$1,818	$3,456	$25	
3.2. USP/thermal break & air space	$648	$556	$1,204	$1,290	$170	$1,460	$256	$298	$261	$256	$2,976	$7,832	$100	
3.3. USP/no thermal break; air space	$648	$556	$1,204	$1,728	$125	$1,853	$649	$677	$677	$649	$6,767	$20,302	$180	
FLOORS														
Conventional	$1,970	$922	$2,892	$2,439	$635	$3,074	$182	$410	$410	$182	$4,097	$12,292	$100	[5]
	$1,970	$922	$2,892	$1,714	$504	$2,218	-$674	-$496	-$607	-$674	-$4,957	-$18,198	$30	
	$1,970	$922	$2,892	$2,342	$470	$2,812	-$80	$57	-$13	-$80	$574	-$388	$100	
V-type joist systems	$1,970	$922	$2,892	$2,200	$300	$2,500	-$392	-$303	-$503	-$392	-$3,028	-$15,084	$20	[5]
PARTITONS														
Conventional	$285	$188	$473	$240	$85	$325	-$148	-$107	-$107	-$148	-$1,072	-$3,216	$100	
	$571	$672	$1,243	$582	$24	$666	-$577	-$486	-$519	-$577	-$4,860	-$15,579	$20	

[1] Transportation not included; discounts of 10% for 10 or more units for conventional construction assumed
[2] System costs include 5% extra labour for electrical wiring
[3] Price compared to conventional wall with aluminum siding
[4] Based on single wall between units
[5] Pre-cut construction

Legend:
OSP: Oriented Strand Board
SSP: Open Sheathed Panels
USP: Unsheathed Structural Panles
OSB: Oriented Strand Board

Figure 5.1: Cost Comparison Between Prefabricated Components and Their Equivalent Value in Conventional Construction

$1,842	$1,423	$1,84
$2,017	$1,489	$2,01
$2,310	$1,349	$2,31
$4,434	$3,462	$4,43
$2,271	$1,330	$2,27
$2,646	$1,973	$2,64
$2,271	$1,330	$2,27
$2,271	$1,330	$2,27

pre-cut) and another using a proprietary floor system to be assembled on site (V-type joist systems). When transportation costs are included in the estimate, only two of these systems were found to provide savings. One estimate for prefabricated floor panels (using conventional construction methods) and the proprietary floor system provided savings of 23% and 14%, respectively. Two submissions were received for interior partitions using prefabricated panels, one which included only the frame and another with the drywall installed. Both were less expensive than conventionally-built partitions, with savings of 31% and 46% of their equivalent value.

Estimates were also received for basements and roofs using structural sandwich panels. When properly installed, these systems are capable of providing dry, comfortable and energy - efficient basements. The high-cost of water-resistant wood products, however, results in costs which are slightly above those for a conventional concrete basement, in the order of $1,300. This difference becomes negligeable at a production volume of 30 or more units. Considering that these basements are less expensive to finish and heat, their use may provide an attractive alternative for the home buyer.

A similar situation was found for the roof system, which resulted in cost increases of $900 per unit. Despite its higher costs, the use of a structural sandwich panel roof system may be worth considering due to its potential to reclaim the attic. With slopes of 6:12, a 2.4 meter clearance could be achieved in an 11 meter unit. Assuming that 40% of this space is usable for occupancy, an additional 19 square meters of floor space could be added to a house like the Grow Home. The cost of adding an extra floor and stair or access hatch will also have to be considered. Alternatively, the structural sandwich panel roof system may be a simple and effective way of building cathedral ceilings.

One case where prefabrication could increase flexibility is with the stairs. The prefabrication of modules as described in the previous section could facilitate changes on site and reduce installation time while providing a higher quality product in terms of strength and rigidity. The cost estimate received from one of the manufacturers was not found to be competitive with conventional construction. Acceptance by builders, however, may not be hindered significantly since the stairs represent a relatively small cost, estimated at approximately $500.

5.3.2. Exterior Wall Panel Systems

While the use of prefabricated wall panels represents substantial savings when compared to their equivalent value in conventional construction, reductions to the total cost of the unit are nevertheless minor, ranging from 1 to 3%. Construction costs using several types of exterior wall panel systems are summarized in figure 5.2. As far as material and labour are concerned, all of the exterior wall panels were found to be competitively priced with conventional construction, with the exception of standard structural panel systems (oriented strand board on both sides of the panel), which added close to $1,200 to the cost of the unit. The highest potential for cost reduction was found for the "added value" versions of structural sandwich panels and unsheathed structural panels, with savings in the range of $2,000 per unit. Open sheathed panel systems provided the second highest savings over conventional construction, with average reductions of $1,660 per unit. Savings for unsheathed structural panels ranged from $300 to $1,200 per unit. Most of these savings, however, are minor once the transportation costs are considered. With average transportation and handling costs of over $450, some of the savings were converted to cost overruns. The savings of these systems may also be easily offset

Figure 5.2 : Cost Breakdown Using Prefabricated Exterior Wall Panels

Cost Breakdown Using Prefabricated Exterior Wall Panels/Semi-Detached Unit

	Conventional	Open Sheathed Panels		Structural Sandwich Panels		Unsheathed Structural Panels			
	Construction	38 x 140 mm	38 x 89 mm	Expanded Polystyrene Core		w/ TB-w/o AS		w/TB-w/AS	w/o TB-w/AS
				Standard	Value Added[1]	Standard	Value added		
2 SITEWORK									
2.1 Preparation	$676	$676	$676	$676	$676	$676	$676	$676	$676
2.2 Backfill	$1,053	$1,053	$1,053	$1,053	$1,053	$1,053	$1,053	$1,053	$1,053
3 CONCRETE									
3.1 Footings	$1,132	$1,132	$1,132	$1,132	$1,132	$1,132	$1,132	$1,132	$1,132
3.2 Walls	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263
3.3 Slab	$901	$901	$901	$901	$901	$901	$901	$901	$901
3.4 Prefab	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
4 MASONRY									
4.1 Brick Masonry	$3,735	$3,735	$3,735	$3,735	$0	$3,735	$3,735	$3,735	$3,735
4.2 Accessories	$56	$56	$56	$56	$56	$56	$56	$56	$56
4.3 Block masonry	$1,472	$1,472	$1,472	$1,472	$1,472	$1,472	$1,472	$1,472	$1,472
5 METALS									
5.1 Railings	$1,194	$1,194	$1,194	$1,194	$1,194	$1,194	$1,194	$1,194	$1,194
6 WOOD AND PLASTICS									
6.1 Wood structure	$9,497	$6,437	$6,437	$6,801	$6,526	$6,801	$6,801	$6,801	$6,801
6.4 Woodworking	$2,968	$2,968	$2,968	$2,968	$2,968	$2,968	$2,968	$2,968	$2,968
7 WEATHERPROOFING									
7.1 Roofing/Sheet metal	$1,403	$1,403	$1,403	$1,403	$1,403	$1,403	$1,403	$1,403	$1,403
7.2 Dampproofing	$245	$245	$245	$245	$245	$245	$245	$245	$245
7.3 Vapour barrier	$238	$238	$238	$126	$126	$238	$126	$238	$238
7.4 Air barrier	$204	$0	$0	$0	$0	$0	$0	$0	$0
7.5 Thermal insulation	$1,471	$1,471	$1,230	$770	$770	$770	$770	$770	$770
7.6 Siding	$1,537	$1,537	$1,537	$1,537	$0	$1,537	$1,537	$1,537	$1,537
8 DOORS AND WINDOWS									
8.1 Doors	$2,007	$2,007	$2,007	$2,007	$2,007	$2,007	$2,007	$2,007	$2,007
8.2 Windows	$3,860	$3,860	$3,860	$3,860	$3,860	$3,860	$3,860	$3,860	$3,860
9 FINISHES									
9.1 Wallboard	$3,858	$3,858	$3,858	$3,858	$2,953	$3,858	$2,953	$3,858	$3,858
9.2 Tiling	$1,273	$1,273	$1,273	$1,273	$1,273	$1,273	$1,273	$1,273	$1,273
9.3 Paint	$3,523	$3,523	$3,523	$3,523	$3,523	$3,523	$3,523	$3,523	$3,523
9.4 Carpet	$1,079	$1,079	$1,079	$1,079	$1,079	$1,079	$1,079	$1,079	$1,079
9.5 Vinyl	$236	$236	$236	$236	$236	$236	$236	$236	$236
9.6 Parquet	$2,089	$2,089	$2,089	$2,089	$2,089	$2,089	$2,089	$2,089	$2,089
15 MECHANICAL	$4,500	$4,500	$4,500	$4,500	$4,500	$4,500	$4,500	$4,500	$4,500
16 ELECTRICAL	$3,250	$3,250	$3,250	$3,305	$3,305	$3,250	$3,250	$3,250	$3,250
17 *SYSTEM*		*$1,515*	*$1,930*	*$4,885*	*$5,883*	*$2,368*	*$2,624*	*$2,975*	*$3,287*
SUB-TOTAL		$55,971	$56,145	$58,947	$53,493	$56,487	$55,726	$57,094	$57,406
TRANSPORTATION [2]		$600	$600	$500	$500	$150	$150	$470	$500
TOTAL [3]	$57,720	$56,571	$56,745	$59,447	$53,993	$56,637	$55,876	$57,564	$57,906
Total / Square Meter [4]	$617	$604	$606	$635	$577	$605	$597	$615	$619
10 UNITS	$51,948	$51,095	$51,285	$54,041	$49,232	$51,032	$50,360	$51,991	$52,330
30 UNITS	$51,948	$51,095	$51,285	$53,064	$48,055	$50,902	$50,217	$51,917	$52,330

[1] Contains Innearseal Siding; compared (more appropriately) to a home with aluminum siding, estimated at $55,503.
[4] Based on 93.6 sq. m. (basement not included)
[2] Transportation costs are for delivery to the Montreal area
[3] Total costs do NOT include: land, infrastructure, tax, contractor's overhead and profit

$1,842	$1,423	$1,84
$2,017	$1,489	$2,01
$2,310	$1,349	$2,31
$4,434	$3,462	$4,43
$2,271	$1,330	$2,27
$2,646	$1,973	$2,64
$2,271	$1,330	$2,27
$2,271	$1,330	$2,27

by simple alterations, particularly for panels which do not use conventional construction methods. The decision to add an air barrier or fiberboard sheathing (for sound insulation) on the exterior, for instance, may offset the savings in the system.

Costs for 10 and 30 units were calculated assuming a 10% discount for conventional construction and using individual discounts submitted by each of the manufacturers. In most cases, there was no cost advantage to building multiple units, since discounts for prefabricated systems were usually equal to or less than those for conventional construction. The structural panel systems were the only products which provided higher discounts (20%) for orders of 30 or more units. Bigger economies might be possible with orders of 100 units or more.

5.3.3. Combined Systems

One way of maximizing possible savings is by combining cost-effective components and eliminating those which are uncompetitive. In figure 5.3, the most advantageous combination of prefabricated components was chosen for each of the manufacturers. Where costs submitted for prefabricated floors were not found to be economical for one particular manufacturer, the proprietary floor system was used. It is seen that the savings (shown in brackets) are more substantial when combined systems are used. The addition of the proprietary prefabricated floor system alone in most cases increased the total savings by $15,000 for 30 units. Similarly, the prefabrication of conventional partitions provided additional savings of $3,000 and $15,000 for two of the manufacturers, and the prefabrication of a conventional dividing wall, which was found to be feasible for 3 of the manufacturers, increased the savings by up to $9,200 for 30 units.

Estimates which combined "added value" wall panels with other components revealed savings ranging from $2,400 per unit for sandwich panels to $3,600 for unsheathed systems. With transportation costs included, these savings are reduced to $1,900 and $3,400, respectively. Similar savings were found with open sheathed panel systems, which resulted in cost reductions of $2,300 for material and labour and $1,700 with delivery included. Savings on material and labour with the basic unsheathed panels were lower, ranging from $700 to $1,100 per unit.

The increased savings that were achieved with combined systems may provide some incentive for builders, particularly when compounded for multiple units. In quantities of 30 units or more, savings of up to $95,000 for unsheathed panel systems with "added value" could be achieved, representing cost reductions of 6% of the total cost of the unit. Open sheathed panel systems provided economies of $44,000, while structural sandwich panels with integrated wood exterior finishes were priced $72,000 lower when compared to homes finished with aluminum siding. With the exception of the unsheathed structural panels with no air space, the proprietary floor system was included in all of the combined systems.

Figure 5.3 : Cost Breakdown Using Combined Prefabricated Components

Cost Breakdown Using Combined Prefabricated Components/Semi Detached Unit

	Conventional Construction	Open Sheathed Panels 38 x 140 mm		Structural Sandwich Panels/EPS Core		Unsheathed Structural Panels					
				Value Added [1]		w/ TB-w/o AS Value added		w/TB-w/AS		w/o TB-w/AS	
2 SITEWORK											
2.1 Preparation	$676	$676		$676		$676		$676		$676	
2.2 Backfill	$1,053	$1,053		$1,053		$1,053		$1,053		$1,053	
3 CONCRETE											
3.1 Footings	$1,132	$1,132		$1,132		$1,132		$1,132		$1,132	
3.2 Walls	$3,263	$3,263		$3,263		$3,263		$3,263		$3,263	
3.3 Slab	$901	$901		$901		$901		$901		$901	
3.4 Prefab	$1,000	$1,000		$1,000		$1,000		$1,000		$1,000	
4 MASONRY											
4.1 Brick Masonry	$3,735	$3,735		$0	($3,735)	$3,735		$3,735		$3,735	
4.2 Accessories	$56	$56		$56		$56		$56		$56	
4.3 Block masonry	$1,472	$1,472		$1,472		$1,472		$1,472		$1,472	
5 METALS											
5.1 Railings	$1,194	$1,194		$1,194		$1,194		$1,194		$1,194	
6 WOOD AND PLASTICS											
6.1 Wood structure	$9,497	$2,510	($6,987)	$3,634	($5,863)	$2,875	($6,622)	$3,347	($6,150)	$3,909	($5,588)
6.4 Woodworking	$2,968	$2,968		$2,968		$2,968		$2,968		$2,968	
7 WEATHERPROOFING											
7.1 Roofing/Sheet metal	$1,403	$1,403		$1,403		$1,403		$1,403		$1,403	
7.2 Dampproofing	$245	$245		$245		$245		$245		$245	
7.3 Vapour barrier	$238	$238		$126	($112)	$126	($112)	$238		$238	
7.4 Air barrier	$204	$0	($204)	$0	($204)	$0	($204)	$0	($204)	$0	($204)
7.5 Thermal insulation	$1,471	$1,471		$770	($701)	$770	($701)	$770	($701)	$770	($701)
7.6 Siding	$1,537	$1,537		$0	($1,537)	$1,537		$1,537		$1,537	
8 DOORS AND WINDOWS											
8.1 Doors	$2,007	$2,007		$2,007		$2,007		$2,007		$2,007	
8.2 Windows	$3,860	$3,860		$3,860		$3,860		$3,860		$3,860	
9 FINISHES											
9.1 Wallboard	$3,858	$3,858		$2,953	($905)	$1,757	($2,101)	$3,432	($426)	$3,858	
9.2 Tiling	$1,273	$1,273		$1,273		$1,273		$1,273		$1,273	
9.3 Paint	$3,523	$3,523		$3,523		$3,523		$3,523		$3,523	
9.4 Carpet	$1,079	$1,079		$1,079		$1,079		$1,079		$1,079	
9.5 Vinyl	$236	$236		$236		$236		$236		$236	
9.6 Parquet	$2,089	$2,089		$2,089		$2,089		$2,089		$2,089	
15 MECHANICAL	$4,500	$4,500		$4,500		$4,500		$4,500		$4,500	
16 ELECTRICAL	$3,250	$3,250		$3,305	-($55)	$3,250		$3,250		$3,250	
17 COMBINED SYSTEM		*$4,846*		*$8,383*		*$6,156*		*$6,355*		*$5,787*	
SUB-TOTAL		$55,375	($2,345)	$53,101	($2,402)	$54,136	($3,584)	$56,594	($1,126)	$57,014	($706)
TRANSPORTATION [2]		$600		$500		$150		$470		$500	
TOTAL [3]	$57,720	$55,975	($1,745)	$53,601	($1,902)	$54,286	($3,434)	$57,064	($656)	$57,514	($206)
Total / Square Meter [4]	$617	$598		$573		$580		$610		$614	
TOTAL-10 UNITS	$519,480	$506,743	($12,737)	$509,218	($10,262)	$491,034	($28,446)	$516,319	($3,161)	$520,269	-($789)
TOTAL-30 UNITS	$1,558,440	$1,514,228	($44,212)	#######	($72,084)	#######	($95,322)	#######	($18,373)	#######	($3,632)

[1] Contains Innearseal Siding; compared (more appropriately) to a home with aluminum siding, estimated at $55,503.
[2] Transportation costs are for delivery to the Montreal area
[3] Total costs do NOT include: land, infrastructure, tax, contractor's overhead and profit
[4] Based on 93.6 sq. m. (basement not included)
( ) Cost reduction

$1,842	$1,423	$1,84
$2,017	$1,489	$2,01
$2,310	$1,349	$2,31
$4,434	$3,462	$4,43
$2,271	$1,330	$2,27
$2,646	$1,973	$2,64
$2,271	$1,330	$2,27
$2,271	$1,330	$2,27

5.3.4. Comments on Specific Systems

Open Sheathed Panel Systems

Prefabricated systems using conventional construction methods were consistently found to provide the highest percentage of savings over their equivalent value using stick-build methods. Most of the savings were sufficient to accommodate transportation costs. The use of basic construction materials and standard assembly procedures appears to be one of the reasons why these systems are competitive. The prefabrication process is relatively uncomplicated, since no special cutting, gluing or fitting is required, as is the case when rigid foams or plastics are used. Discounts offered for multiple units, however, were the lowest at 2% for 10 or more units.

As the materials and fabrication process become more sophisticated, the price for the system becomes less competitive. This was seen in the higher prices for unsheathed and sandwich panels. The same features which give these systems superior performance potential also increase production costs. The panels' exceptional resistance to air and heat flow is achieved by virtue of its continuous and rigid sheathing and/or insulation. The additional material costs and more complex fabrication processes often reduce the savings to marginal amounts.

Structural Sandwich Panel Systems

The cost of standard structural sandwich panels consisting of two layers of oriented strand board glued to an expanded polystyrene core were found to be higher than those of conventional construction, although the modified "added value" systems provided substantial savings. A panel consisting of Innearseal exterior sheathing and FiberBond wallboard for the interior was found to provide savings of 25% when compared to traditional wood frame walls with aluminum siding. While the use of recycled, fiber-reinforced paper products may be attractive from an environmental perspective, the unproven track record of these materials may hinder their acceptance into the market. These systems also provided the highest economies for volume production, with discounts of 20% when ordering 30 or more units.

Unsheathed Structural Panel Systems

All three of the unsheathed structural systems investigated were found to be competitively priced with conventionally-built walls, with saving of 9% to 34%. As was the case with the sandwich panels, unsheathed panels can benefit from having the interior finish applied in the shop, which increased the savings for one type of system to 43%. The installation of electrical wiring in closed panels is not seen as a problem, since pre-cut electrical chases run along the wall at a constant height. Because of their lighter weight and slightly more conventional design, the systems appear to have a higher chance of being accepted in the market. The discounts offered for large orders were comparable to those for conventional construction, ranging from 5% for an order of 10 units to a maximum of 10% for 30 units. The cost estimates that were received for site labour indicated that these systems benefit from the most efficient assembly on site.

6. CONCLUSIONS

The purpose of this study was to examine how the Grow Home can be adapted to an industrialized method of production using prefabricated panel systems, and to determine what implications this would have in terms of quality, economy and technical performance. The project was carried out in three phases. The first phase consisted of research on systems currently available in North America, and an evaluation of options considered appropriate for the Grow Home. In the second phase, the unit's design was adapted to suit the prefabrication process and provide flexibility for the builder, and a cost estimate was carried out to determine whether significant savings could be achieved with prefabrication, using the adapted version of the Grow Home. Finally, the results of the study were analyzed and recommendations drafted based on the findings.

The survey of prefabricated panel systems revealed that there is a fairly extensive network of innovative products and ideas for any builder to choose from. While the panels were categorized into three basic groups, there were several variations on each type of system available in the market, with each manufacturer adopting a slightly different version of the system. Insulation materials, joint types and sheathing materials vary from one manufacturer to another. Information on products and services was readily available from most of the manufacturers. It is evident that any hindrance in the proliferation of use of prefabricated panel systems is not due to availability. The challenge in achieving widespread acceptance lies in meeting the builders' and buyers' needs more closely.

The evaluation of the various systems indicated that all types of prefabricated panels could provide a level of quality which is superior to that of conventional construction. While the ratings varied significantly for some of the criteria, the total scores differed by a narrow margin. Generally, prefabricated systems rated higher on criteria related to technical performance and level of craftsmanship. Characteristics related to the environment and durability were found to be fairly equal among the systems evaluated. The only drawbacks to the use of prefabricated panel systems were found in their flexibility relative to conventional construction, particularly for on-site modifications, and in their disruption of the builders' traditional operational routines, which may hinder their acceptance into the market.

Whether the superior characteristics of prefabricated systems can attract the average builder, either directly or indirectly by providing a more marketable product, remains questionable. Any product, innovative or otherwise, will gain support only when it promotes the interest the person who pays for it. In the case of residential construction, the party who eventually assumes the energy costs is not the builder, making it unlikely that the panels' superior energy efficiency in itself will attract the interest of the average builder. The ability of prefabricated systems to offer higher quality and energy efficiency for the same price or lower, however, can be an attractive and effective marketing tool for builders.

A framework for the industrialization of the Grow Home was developed in the second phase of the study by adapting the unit's design to make it more suitable to the fabrication process. The design process was aimed at providing sufficient flexibility for the builder and economies of scale for the manufacturer by generating a wide range of options for the dwelling using a small number of simple, standard components. Architectural, modular and technical design criteria were established based on feedback from manufacturers, builders, and occupants of existing Grow Home projects.

Although no prefabricated system can equal the flexibility of stick-build construction, the number of options generated for the interior plan with a limited number of standard components provided sufficient selection for interior layouts and exterior elevations. Nine panel configurations were proposed in all: six for the front and back elevations and three for the side walls of the end units. The panels could be combined in various ways to accommodate the options for interior layout. Rowhouse versions of the home could be built with anywhere from two to four panels, while semi-detached or end units would require 3 to 6. The use of small, standard interior partitions generated various configurations for entrances and bathrooms, while enabling changes to be made fairly easily on site in response to a client's request.

The potential for prefabricated systems to reduce construction costs was addressed by examining the costs of several prefabricated components, including exterior walls, floors, partitions and dividing walls. An elemental cost breakdown was drafted for labour and material using conventional construction methods, compared to actual costs submitted by 7 Grow Home builders, and used as a basis for cost comparisons between prefabricated and conventional construction. The analysis demonstrated that prefabricated panel systems can provide a competitive alternative to conventional construction. The magnitude of the savings, however, can vary significantly depending on the type of panel system, the degree of prefabrication and the component in question.

The fact that prefabricated systems using open sheathed wall panels provided the highest percentage of savings over the equivalent stick-build value demonstrates that, system for system, economies through prefabrication are possible. The total cost reductions which were achieved, however, were usually limited to 2-3%, due partly to the relatively small fraction of the unit cost which is accounted for by the building envelope. While these savings may not be sufficient to lower the selling price of the house, it was found that the savings could be as high a 6% if the number of prefabricated components is increased. The question is whether these savings in themselves provide sufficient incentive for the average builder to adopt a new or unfamiliar method of construction.

Other incentives for builders to integrate these systems into their normal, established operational routines may need to be considered. One possibility has to do with simplifying the management of construction tasks. If the prefabricated system does not interfere with the normal operational routines of the average builder, the chance of acceptance may be enhanced. This may be achieved in three ways: by enhancing the flexibility of the systems, by designing the product so that it integrates smoothly with the other operations, or by providing a complete package, whereby a product is manufactured, delivered and installed by the same party.

The lack of flexibility in prefabricated panel systems relative to conventional construction appears to be more of a problem for last-minute changes on site than it is for design. There are basically no restrictions imposed by prefabricated panel systems insofar as the unit's size and configuration is concerned, although a more complex design is inevitably accompanied by an increase in cost. Limitations in the systems' flexibility become evident on site, where any adjustment may be complicated or time consuming. The practical limitations of the system's flexibility, however, can be greatly reduced through standardization of components into smaller, more manageable units. This facilitates custom changes and increases the options available to both the builder and the buyer.

For a component to integrate smoothly with the other construction operations, it has to be small enough so that the least amount of trades are affected. In the case of prefabricated wall systems, this is not entirely possible, since just about every trade on the site will, at one point or another, have to work on some component of the envelope. One way of reducing overlapping trades is to manufacture "added value" or closed panels which require only painting after installation. It should be noted, however, that this notion of "adding value" to the panel system is more easily achieved with those systems that have some form of rigid insulation in their core, in which chases can be pre-cut to accommodate electrical wiring. Systems with batt insulation or an air space are less likely to be built this way unless conduits (or wiring) are integrated into the panel. Otherwise, the installation of electrical wiring on site may become a difficult process.

The last option provides a more tangible approach, whereby the panel manufacturer delivers and installs the envelope. If this same party could complete the structure, the construction task is simplified in that it virtually eliminates one of the trades altogether. Rather than adding to the number of parties which need to be coordinated, management for one of the trades, namely rough carpentry, could be reduced to a minimum.

This notion points towards the need for a more service-oriented industry. With a predisposition to higher quality and design aimed at achieving competitive prices, the only obstacle left in the acceptance of prefabricated wall systems is the conservative nature of the industry. Disruption of the builder's established operational routines needs to be minimized by replacing rather than adding to one of the work tasks. For the same money, a builder would not hesitate in replacing a carpenter or an electrician if higher quality work is expected. If the framing operation can be replaced entirely by the manufacturer by supplying both labour and material, the general acceptance of prefabricated systems would be accelerated.

As is the case with the introduction of any new product, the challenge lies in educating both the builder and the buyer as to the advantages of prefabricated construction. The consumer needs to be instructed on the potential energy savings which could be gained from air-tight construction. The builder needs to be made aware of the fact that prefabrication may result in less material wastage and, consequently, lower expenses for clean-up and trash removal. The faster assembly process could translate into savings in overhead and financing costs. Construction delays due to poor weather conditions could be reduced, and the possibility of vandalism and theft is decreased since the envelope can be closed in a matter of hours. Specialized labour requirements are reduced, as are warranty commitments, which are passed onto the manufacturer. Emphasis needs to be placed on how the construction task can be simplified, and, consequently, the managerial burden relieved.

7. RECOMMENDATIONS FOR FURTHER STUDY

The analysis and conclusions generated in this study were of a preliminary nature and oriented to a specific type of housing. A more in-depth examination of the issues analyzed and extension of the evaluation and design process to other forms of housing would be helpful in determining the broader implications of industrialized housing. The development of more alternatives for accessible units, for instance, would establish the suitability of prefabricated components for different markets, as would refinements to the systems for healthy and sustainable construction.

The evaluation, adaptation and cost estimates which were conducted revealed several aspects of industrialized housing which can benefit from a more comprehensive and detailed investigation. The recommendations which follow represent efforts which could be undertaken by academia, industry and government in four general areas:

1. Survey and analysis of transportation and lifting requirements for various locations, components and housing types
2. Research efforts aimed at assessing the actual cost implications of prefabricated construction, including those associated indirect factors affecting project delivery
3. Development of products, software and services to suit the builders' and buyers' needs more closely
4. Marketing studies aimed at identifying the potential of prefabricated construction and promoting its benefits

● 7.1 TRANSPORTATION AND LIFTING CONSIDERATIONS

It was evident from the cost analysis that transportation and lifting costs associated with the delivery of prefabricated systems can be significant, and in some cases capable of reversing potential savings to cost increases. In light of the critical nature of this component, it would be helpful to determine the exact implications of transportation and lifting costs, particularly in the context of long-distance delivery, as would be the case for export. Two aspects which merit investigation are the type of transportation/lifting arrangement used and physical characteristics of the prefabricated components.

Transportation and Lifting Arrangement

The possibilities for transportation and assembly of prefabricated components will vary depending on both the manufacturer and the product. In addition to the actual transportation distance, costs will depend on the equipment used, number of trips required, number of homes built as well as on the party who assumes the delivery. Most of the manufacturers interviewed provided delivery services on specially-equipped trucks. The panels are normally delivered and lifted into position in two separate trips — the first at completion of the first floor platform, and the second upon completion of the second floor. This approach has the advantage of eliminating the need to store the product on site, and therefore reducing the possibility of damage due to exposure and vandalism. It also eliminates the cost of hiring an independent crane. For a small project consisting of one or two homes, however, the delivery in two trips may not be cost-effective, particularly when longer distances are involved. Alternatively, the components may be delivered by an independent party who will deposit the panels on site, leaving the responsibility for storage and lifting to the contractor. The availability of larger trucks from independent transportation companies may reduce the number of trips required, and may be cost-effective for larger projects in remote locations.

Component Optimization

The cost implications of transporting and assembling a prefabricated house are not only dependent on distance and equipment, but also on the product. In the case of prefabricated wall panels, the size, weight and configuration of the individual components will affect the packing efficiency for a given size of truck, the capacity of crane required, the size of crew needed as well as the construction time. Whereas smaller, standardized panels may increase on-site flexibility, production efficiency and lifting requirements (possibly eliminating the need for a crane altogether), they require more installation time and/or on-site crew size. A study aimed at optimizing these product characteristics for various locations and panel types may be a worthwhile investment.

The optimal solution for both transportation arrangement and product design will vary depending on the location of the project. Availability and cost of labour, material and equipment will differ from one location to another. A study aimed at optimizing costs associated with transportation and assembly of prefabricated components should be undertaken for various locations in Québec, Canada and abroad.

● 7.2 INDIRECT COST SAVINGS

The study concluded that cost savings over conventional construction methods are possible with prefabricated construction. While the cost analysis concentrated on labour and material, there are several indirect factors which can further improve the cost equation for the builder and, ultimately, for the consumer which were not accounted for. There are three main factors that may lower costs for the builder which were not quantified: construction time, material wastage, and after-sale service requirements.

Decrease in Construction Time

One of the biggest advantages of prefabricated construction is its ability to substantially reduce on-site construction time. In the case of the Grow Home, time estimates for installation of wall panels were approximately 4 hours per unit. While the savings achieved by reducing the need for specialized on-site labour are obvious, there are various other savings which can be significant which are not normally accounted for. Overhead, financing, and supervision costs are reduced when the construction period is shortened.

Reduction in Material Wastage

The fact that the unit is closed within a short period of time reduces delays due to bad weather. The probability of vandalism and theft is reduced because there is less material stored on site, and the cost of replacing materials damaged by inadequate storage and exposure is also reduced. Because there is less material wastage, the cost of clearing and removing debris is lowered. Considering that the construction of an average house produces some 2.5 tons of waste (25% of which is dimensional lumber and an additional 15% manufactured wood products), the savings could be substantial, particularly in large developments.

After-Sale Service Requirements

One other factor which needs to be considered is the potential savings from less after-sale service. The assembly of components under controlled conditions ensures that the materials are dry, clean and straight, resulting in a higher general level of craftsmanship. Consequently, the possibility of cracking, bending or warping of interior finishes caused by shrinking lumber is reduced, along with the need for repairs and adjustments after occupancy.

An assessment of costs associated with these factors would provide a more realistic estimate of the potential savings, as well as a more convincing argument for the builder.

● 7.3 DEVELOPMENT OF PRODUCTS, SOFTWARE AND SERVICES

7.3.1 Product Development

Although the advantages of prefabricated construction are clear, there are some benefits of the panel systems evaluated which could be enhanced to suit the builders' and buyers' needs more closely, and, consequently, accelerate widespread acceptance. Increasing both the degree and scope of prefabrication appear to be a starting point in achieving these goals.

Degree of Prefabrication

One area which merits investigation is the possibility of expanding the degree of prefabrication on panel systems. Possibilities for cost reductions were found to be highest when "added value" systems were used, since a larger fraction of the envelope (and therefore building costs) were prefabricated. It is evident that an effective way of enhancing the potential savings is by increasing the content of the panel. This may include the integration of interior and/or exterior finishes, and electrical and/or plumbing services. While some of the manufacturers interviewed provided some leeway in this respect, the selection of exterior finishes available to the buyer remained fairly limited. A more sophisticated range of finishes would increase the marketability of the product, making the apparent preference for brick exteriors less of an obstacle in the proliferation prefabricated homes.

Scope of Prefabricated Components

One of the difficulties in reducing the total cost of the unit has to do with the fairly limited scope of prefabricated wall panels. While most panel systems can, in one form or another provide savings for the wall components, they are usually less competitive when applied to basements, roofs or even dividing walls. The need for developing cost-effective prefabricated alternatives for subsystems other than the exterior walls is evident. The industry could benefit, for instance, from efforts aimed at designing prefabricated walls with superior fire and sound resistance, preferably single walls, which could replace the conventional double-wall construction which is commonly in use for dividing walls. Similarly, efforts in the development of cost-effective floors and partitions for residential construction could provide a more complete package for the builder. The design of smaller, standardized modular sections, similar to what was generated in the second part of this study, could increase flexibility and facilitate last-minute, on-site modifications in response to a client's request, rendering the product more marketable. This type of development would be especially useful in the renovation of existing buildings.

Aside from increasing the potential cost savings for the builder, by increasing the degree and scope of prefabrication will also simplify the management and coordination task. Interference caused by overlapping electrical, plumbing, carpentry and finishing trades, for instance, will be reduced, making any disruption to the builders' established operational routines less pronounced.

7.3.2 Software Development

The standardization of materials and components which characterizes the industrialization process provides a suitable basis for computer-aided design, production, construction and marketing. Software development could provide efficient tools for several functions:

- Optimize resource efficiency (labour and material) for prefabrication of components
- Monitor production and distribution of an inventory of materials and prefabricated components
- Cost estimation, including transportation and handling
- Interactive graphic software to be used by the prospective buyer in laying out his unit and selecting finishes

Integrated systems capable of performing two or more of these tasks would be especially useful. With the proliferation of portable and laptop computers, the use of this software could be used as a marketing tool. Builders, buyers and suppliers could be introduced to and allowed to work with the design of the units, making the appearance and cost implications of their decisions readily available either in the factory, the builders' office, the buyers' residence or on the construction site for last-minute changes.

7.3.3 Increase Range of Services

As mentioned earlier, the provision of a subsystem as a complete package, which minimizes disruption to a builder's traditional operational routines and simplifies coordination, stands a better chance of being accepted by builders. While increasing the scope and degree of prefabrication and providing readily available, computer-aided services is a step in the right direction, the need for a broader range of services cannot be dismissed. The provision of transportation, lifting, installation, labour, training and inspection by the manufacturer, as well as warranties and a commitment to after-sale servicing can be an attractive incentive for the builder debating whether or not to adopt a new method of construction. Replacing a trade (rather than adding one) and simplifying the construction task appear to be objectives worth aiming for in the promotion of any prefabricated component, subsystem or system.

● 7.4 MARKETING STUDIES

From a larger perspective, the industry could benefit from marketing efforts aimed at assessing the potential for specific types of prefabricated assemblies in the North American context and at promoting their benefits. In addition to those factors mentioned earlier, the potential for prefabricated housing in any given location will depend on a variety of architectural, technical, practical and legal considerations. Local tastes, cultures, trends and income averages will influence the design, appearance and cost range which are most marketable. The number, size and operational characteristics of the builders and suppliers will affect their disposition to adopt prefabricated systems. Municipal bylaws and building codes will determine the acceptability of various systems for local construction. Climatic and geographic characteristics will govern the technical requirements of the systems.

An assessment of these parameters could produce valuable guidance for development by identifying he strengths, weaknesses and incompatibilities of a particular prefabricated system in any given context. Products could then be modified to suit the specific market requirements.

Finally, there is a need for promotional efforts to educate builders and buyers as to the advantages of prefabricated construction, and to create a positive atmosphere around industrialized housing in general and prefabricated subsystems in particular. With a predisposition to higher quality, better energy efficiency and a potential for competitive pricing, the prospects appear to be promising.

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CONTRIBUTING MANUFACTURERS

Modulex Inc.
3090 Wilfred Hamel Blvd.
Québec, Québec
G1P 2J1
Tel.: (418) 681-0133

Uni-Structurx (Thermapan)
P.O. Box 132
Beaconsfield, Québec
H9W 5T7
Tel.: (514) 426-3276

Les Maisons Claude Bouchard (Nascor)
234 de Normandie
Boucherville, Québec
J4B 7T5
Tel.: 523-2805

Dunfab Inc. (Insul-Wall)
663 Road 139
Roxton Pond, Québec
J0E 1Z0
Tel.: (514) 372-0008

Breuers and Associates (Super-Lock)
No. 201 - 20559 Fraser Valley
Langley, B.C.
V3A 4G3
Tel.: (604) 533-4476

Les Systèmes V-Joist
50, rue Pacific
Bromont, Québec
J0E 1L0
Tel.: (514) 534-4031

APPENDIX A
LIST OF MANUFACTURERS

ABC Custom Cedar Homes, Inc., Sonoma, CA
Acorn Structures, Concord, MA (*)
Active Homes Corp., Marlette, MI
Advance Energy Technologies, Clifton Park, NY (**)
Advance Foam Plastics, Inc., Denver, CO
Advanced Building Systems Inc., Lawrenceville, NJ
Affordable Luxury Homes, Inc., Markle, IN
AFM Corporation, Shorewood, MN (*)
Ahern Enterprises, Inc., Campti, LA
Air Lock Log Company, Inc., Las Vegas, NM
Alchem Inc., Anchorage, Alaksa (**)
ALH Building Systems, Markle, IN (*)
Aliquot, Ltd., Metamora, IL (**)
Allied Foam Products, Onc., Gainesville, GA
American Dream Homes, Springfield, MA
American Standard Building Systems, Martinsville, VA
Amwood Homes, Beloit, WI
Andrews Building Systems, Inc., Longmont, CO (**)
APC International, Auburn, WA (*)
Archimede 2000 Inc., Anjou, PQ (*)
Armstrong Lumber Company, Inc., Auburn, WA CO (**)
Artery Organization, The, Fredericksburg, VA
Atlas Industries, Ayer, MA (*)
Barden & Robeson Corporation, Middleport, NY (*)
Barna Log Systems, Jim, Oneida, TN
Baticube, Chicoutimi, PQ (***)
Bâtisseurs Associés Ltée., Saint-Adelphe, PQ (*)
Bay Wood Homes, Inc., Bay City, MI
Beaver Homes & Cottages, Nepean, ONT (**)
Beaver Mountain Log Homes, Inc., Hancock, NY
Bellevue Builders Supply, Schenectady, NY
Bentley Construction, Travelers, SC
Berkshire Construction Co., Inc., Falls Village, CT (**)
Best Panel Homes, Hamilton, OH
Bétonnière Lemyre Ltée., Drummondville, PQ (**)
Big Sky Insulations, Inc., Belgrade, MT
H.W. Blackstock Co., Seattle, WA
Blink Lumber Co., Marne, MI (**)
Branch River Foam Plastics, Inc., Smithfield, RI
Brentwood Log Homes, Murfreesboro, TN
Brown-Graves Co., Akron, OH
Buerman Homes Inc., Cold Spring, MN
Building Contractors Inc., Benton Harbor, MI
BYC Homes, Ltd., Gloucester, ONT (***)
C & S Cal-Walls, El Paso, TX
California Pre-Cut Homes, Danville, NC
Carolina Builders Corporation, Raleigh, NC
Carolina Model Home Corporation, Fayetteville, NC
Cavco Homes, Inc., Cavetown, MD
Cedar Mark Homes, Bellevue, WA
Cedarridge Buildings, Springfield, MO
Century Homes, Lawrence, KS
Century Insulations Mfg. Co., Union, MS
Chapman Homes, Dothan, AL
Charpentec Inc., Québec, PQ (**)
Chase Barlow Lumber, Louisville, KY (**)
Cheim Pre-Fab Homes, San Jose, CA
Chopp & Co., Waldorf, MD
Christiansen Building Comp. Div., Oconomowoc, WI
Citation Homes, Spirit Lake, IA (**)
ClarkLite, Colombus, Oh (**)
Coastal Structures, Inc., South Portland, MA (***)
Component Building Systems, Inc., Newville, PA
Component Division, Memphis, TN
Compu-Tech Lumber Co., Fairfield, CA
Concept 2000 Homes, Dittmer, MO (*)
Construction Concepts P-3000, Matane, PQ (*)
Contour Products, Inc., Wichita, KS
Corat Building Systems, Miami, FL
Crawford Manufactured Homes Ltd., Aldersyde, AB
Crenshaw, Co., Gardena, CA
Crestmanor Homes, Inc., Martinsburg, VA
Custom Craft, Windsor, NY
Davidson Industries Inc., Indianapolis, IN (**)
D.B.S., Monkton, MD
Deck House Inc., Acton, MA (*)
Deltec Homes, Asheville, NC
Design America Corporation, Perrysburg, OH
Dessen Homes, Vancouver, WA
Deville Homes, Canton, OH
Diamond Point Lumber, Delanson, NY
Diversified Homes, Columbia, MD
Drake Industries, Cleveland, OH
Dunfab, Roxton Pond, PQ (*)
Dura-Built Homes, Inc., Montgomery, AL
East Coast Homes, Mifflintown, PA
Eight Builders Associated, Inc., Fayetteville, NC
Endeavor Homes, Bakersfield, CA
Endure-A-Lifetime Products, Inc., Miami, FL
Enercept, Inc., Watertown, SD (*)
Enviro Buildings, Inc., Quincy, IL (*)
Fairfield Homes, Culpepper, VA

Fermes de Toit des Laurentides, Mont Laurier, PQ (**)
First Colony Homes, Calverton, VA
Fischer Corporation, Louisville, KY (*)
Flanders Bldg. Supply, Inc., Essex Junction, VT (**)
Fleetwood Homes, Inc., Worthington, MN (*)
Foam Laminates of Vermont, Hinesburg, VT (*)
Foam Products Corporation, Maryland Heights, MO (*)
Forest Maid Homes, Great Barrington, MA
Fox Ridge Homes, Brentwood, TN (*)
Futurebilt Structural Insulated Panels, Wimberley, TX (*)
Gastineau Log Homes, Inc., New Bloomfield, MO
3-C General Construction, Limoges, ONT (***)
Gentry Homes Ltd., Waipahu, HI
Geodesic Domes & Homes, Whitehouse, TX

Golden Key Homes, Howard County, MD
Goscobec, Rivière du Loup, PQ (**)
Green Island Homes, Green Island, NY (**)
Green Mountain Homes, Royalton, VT (**)
Habitations Quélord Ltée.,
Saint-Léonard-de-Portneuf, PQ (**)
Harmony Exchange, Inc., Boone, NC (*)
Hartl Haus, Merced, CA
Harvest Homes, Inc., Delanson, NY (*)
Hearthstone Homes, Dandridge, TN
Helikon Design, Cavetown, MD
Heritage Building Products, Murray, UT
Heritage Homes of New England, Westfield, MA (**)
Heritage Homes of Thomasville, Inc., Thomasville, NC
Hess Home Builders, Lancaster, PA
HP PAnels, Inc., Chicago, IL (**)
Home MFG. & Supply Co., Sioux Falls, SD
Homecraft Corp., South Hill, VA
Homes America Corporation, Huntington, MD
Industries Fermco, Saint-Adelphe, PQ
Industries Pre-Fab Silmar, Inc., Grand-Mère, PQ (***)
Iso-Sand Inc., Granby, PQ (*)
Insulated Building systems, Inc., Sterling, VA
Insu-Kor, Inc., Elkhart, IN (**)
Insul-Wall, Ltd., Dartmouth, NS (*)
International Building Concepts, Kamloops, C.-B. (**)
International Building Systems, Portland, OR
J-Deck Building Systems, Columbus, OH (**)
Kingman Homes, Inc., Mount Vernon, OH
Kingsberry Homes, Inc., Fort Payne, AL
Korwall Industries, Inc., Arlington, TX (*)
Latham Lumber Sales, Roseville, CA
L.C.H. Mid-West, Inc., Mt. Clemens, MI
Lena Builders Inc., Eleroy, IL
Les Habitations Techniques H.C. Ltée.,
Saint-Joseph-de-Beauce, PQ (*)
Lincoln Logs Ltd., Chestertown, NY
Lindal Cedar Homes, Seattle, WA
Logangate Homes, Youngstown, OH
Log Cabin Homes Inc., Rocky Mount, NC
Log Homes of America, Centreville, AL
Lowe's of Florida, Sanford, FL
L.T.S. Inc., Worthington, OH (**)
Manufactured Homes, Inc., Marshall, MI
Marine Industries, Inc., Kentwood, MI
Mid-America Industries, Inc., Mead, NE
Midwest Panel Systems, Blissfield, MI (*)
Miles Homes Inc., Minneapolis, MN
Miron Lumber Co., Poughkeepsie, NY
Mitchell Company, The, Mobile, AL
Model Log Homes, Gallatin Gateway, MT
Modern Home & Equipment Co., Mobile, AL
Modular Energy Systems, Inc., Mesa, AZ (**)
Modulex Inc., Québec, PQ (*)
M.T. Inc., Sabana Seca, PR
Mur-Ext Inc., Lafontaine, PQ (**)
The Murus Company, Mansfield, PA (*)
MV Hinson, Memphis, TN
Nascor, Inc., Calgary, Alberta (*)
National Building Systems, Effingham, IL (*)
National Homes Corp., Thomson, GA
National Partisians, Hialeah, FL
Nelson Homes, Bakersfield, CA
New England Homes, Inc., Greenland, NH (*)
New England Log Homes, Hamden, CT
New Pioneer Log Homes, Inc., Weippe, ID
Newtrend, Inc., Colorado Springs, CO
Newtowne Group, Inc., Dublin, OH
Nickerson Homes, Orleans, MA
North American Panel Systems, Inc., Westmoreland, NH (*)
Northern Counties, Inc., Upperville, VA
Northern Homes, Inc., Glen Falls, NY (**)
Northern Log Homes, Groton, VT
NV Ryan, Columbia, MD
O'Connor Company, E.R., Fullerton, CA
O'Connor Lumber, Westfield, MA
Ohio Valley Homes, Inc., Evansville, IN
Ontario Panelization, ONT (**)
Orange Blossom Hill, Lady Lake, IL
Oregon Dome, Inc., Eugene, OR
Pacemaker Plastics Co., Inc., Newcomerstown, OH
Pacesetter Building Systems, Modesto, CA
Pacific Allied Products, Ltd., Ewa Beach, HI
Pacific Buildings, Inc., Evansville, IN
Pacific Component Homes, Inc., Seattle, WA
Pacific Homes, Langley, BC (*)
Pacific Modern Homes, Inc., Elk Grove, CA
Pageant Homes, Holt, MI
Pan Adobe International Ltd., Richmond, BC
Panel Building Systems, Inc., Greenville, PA (**)
Panel Tech, Inc., Madisonville, TN
Panel Technology Building Systems, Inc.,
Fort Myers, FL (**)
Pease Company, Hamilton, OH
Permabilt Manufactured Homes, Inc., Marshall, MI
Perma-R Products, Inc., Johnson City, TN (**)
Person & Person, Inc., Sumner, WA
F.S. Plummer Co., Inc., Gorham, ME (**)
Poly-Core Manufacturing, Inc., Crystal, MI
Poly-Foam Inc., Lester Prairie, MN
Pond Hill Homes, Blairsville, PA (*)
Porter Inc., W.H., Holland, MI (**)
Poulin & Dumais, Beauport, PQ
Prairies Homes, Pottstown, PA
Pre-Engineered Housing, McLean, VA
Prince Homes Inc., Princeville, PQ (**)
Produit PBM Ltée., Saint-Pierre-de-Lamy, PQ (**)
Prowswood, Inc., Salt Lake City, UT
Purnell, Inc., Ocean City, MD
RADVA Corporation, Radford, VA (*)

Randall Phillips Builders Inc., Nashville, TN
Raphael Building System, Anaheim, CA
Ray-Core, Inc., Lock Haven, PA (*)
Real American Housing Corp., Phoenix, AZ
Real Log Homes, Hartland, VT
Reasor Corporation, Charleston, IL
Remarc, Inc., Holderness, NH (*)
Riverbend Timber Framing, Blissfield, MI
Rocklin Lumber, Rocklin, CA
Robert Coulombe, Inc., Lauzon, PQ (***)
Ronning Ent. Home Supply Co., Sioux Falls, SD
Ryan Homes, Inc., Pittsburg, PA
Rycenga Homes, Inc., Spring Lake, MI (**)
Ryland Group, Columbia, MD (**)
Saco Homes, Timonium, MD
Scan-American Enterprises, Canon City, CO
Seth Lumber Co., Inc., Lincolnton, NC
Silver Companies, Fredericksburg, VA
Smith Inc., A.J., Nashville, TN
Soli-Cor, Inc., Oilville, VA (*)
Southern Cross Lumber Co., Hazelwood, MO
Southern Cypress Log Homes, Lenoir City, TN
Standard Homes Co., Olathe, KS
Sterling Custom Homes Corp., Wausau, WI
Stimpert Enterprises, Sleepy Eye, MN
St. Mary's Precision Homes, Inc., St. Mary's, PA
Stress Panel Manufacturing, Inc., Pittsburg, KS (*)
Structural Panels Inc., Oldsman, FL (**)
Structural Systems Inc., Gaithersburg, MD
Structure Noram Inc., Saint-Luc, PQ
Structures Equerres, Thurso, PQ (***)
Structures Laprise Inc., Montmagny, PQ (**)
Sturdy-Built Manufacturing, East Freedom, PA
Summey Bldg. Systems, Dallas, NC
Sunburst Homes, N.Adams, MA (**)
Sunlight Homes, Bernalillo, NM (*)
Super Lock Ltd., Langley, BC (*)
Surfast Industries Inc., Morin Heights, PQ (*)
Système Nascor Inc., Sainte-Marie, PQ
Tech Built Homes, Inc., N. Dartsmouth, MA (**)
Technologies Thermomat Intl., Longueuil, PQ (***)
Temo, Inc., Mt. Clemens, MI (**)
Thermal Foams, Inc., Buffalo, NY
Thermal Shell Homes, Las Vegas, NV (**)
Thermapan Industries, Inc., Fonthill, ONT (*)
Timberpeg Pacific, Reno, NV
Timber Truss Housing Systems, Inc., Salem, VA
Titan Unlimited, Orlando, FL
T J Contractors, Inc., Jacksonville, FL (**)
Today's Building Systems, Newark, OH
Toll Brothers, Inc., Morrisville, PA
Topsider Homes, Yadkinville, NC
Traditional Management, Hanover, NH
Triangle Lumber Company, Quakerston, PA
Tri-State Homes, Inc., Mercier, WI
Tylander Systems Inc., Hobe Sound, FL
Unified Corporation, Columbia, VA (**)
Uni-Structurx Inc., Beaconsfield, PQ (*)
United Building Systems, Lexington, KY
United Development, Wheeling, IL
United Industries Company, Inc., Bentonville, AR (**)
Universal Manufacturing Corp., Camden, OH
Valley Homes of Connecticut, Inc., Newington, CT
Vanguard Homes, Inc., San Diego, CA
Vaughn & Sons, Inc., San Antonio, TX
Ventury Homes, Bowmanville, ONT (**)
Vermont Stresskin Panels, Cambridge, VT (**)
Viceroy Homes Ltd., Scarborough, ONT
Wallframe of Southern California, Inc., Sun Valley, CA (*)
Wallup Industries, Inc., Ormond Beach, FL
Walnut Custom Homes, Walnut, IL
Ward Component Systems, Rockville, MD
Wausau Homes, Inc., Wausau, WI (*)
West Coast Mills, Inc., Chehalis, WA
Western Insulfoam, Kent, WA
Western Log Homes, Hamilton, MT
Westland Modular Homes, Hastings, NE
Whispering Pines Log Homes, Verndale, MN
Wick Homes, Mazomanie, WI
Wickes Shelter Systems, Atlanta, GA
Winchester Homes, Baltimore, MD
Windsor Homes, Madison, WI
Wisconsin EPS, Inc., Fond du Lac, WI
Wing Manufacturing, Inc., Latrobe, PA (**)
Winter Panel Corporation, Brattleboro, VT (*)
Woodmaster Foundations, Inc., Prescott, WI
Woodward Lumber Company, Las Cruces, NM
Yankee Barn Homes, Inc., Grantham, NH (**)
Ziner Lumber Company, J., Agincourt, ONT

*	Response received
**	Response received/not applicable to single-family residential construction
***	Out of business or telephone service disconnected

RESPONSES RECEIVED (*)

OPEN SHEATHED PANELS (conventional)

Acorn Structures Inc., Concord, MA
Barden Homes, Middleport, NY
Deck House Inc., Acton, MA
Harvest Homes, Delanson, NY
Les Habitations techniques H.C. Ltée., Saint-Joseph-de-Beauce, PQ
Modulex, Québec, PQ
New England Homes, Greenland, NH
Pacific Homes, Langley, Colombie-Britannique
Wausau Homes, Inc., Wausau, WI

STRUCTURAL SANDWICH PANELS

AFM Corporation, Excelsior, MN
APC International, Auburn, WA
Archimede 2000 Inc., Anjou, PQ
Atlas Industries, Ayer, MA
Concept 2000 Homes, Dittmer, MO
Enercept Inc., Watertown, SD
Enviro-Buildings Inc., Quincy, IL
Fischer Corporation, Louisville, KY
Foam Laminates of Vermont, Hinesburg, VT
Foam Products Corporation, Maryland Heights, MO
Futurbilt, Wimberly, TX
Harmony Exchange, Inc., Boone, NC

Iso-Sand Inc., Granby, PQ
Korwall Industries Inc., Arlington TX
Midwest Panel Systems, Blissfield, MI
North American Panel Systems Inc., Westmoreland, NH
Pond Hill Homes, Blairsville, PA
RADVA Corporation, Radford, VA
Remarc Inc., Holderness, NH
Soli-Cor Inc., Oilville, VA
Stress Panel Manufacturing Inc., Pittsburg, KS
Sunlight Homes, Bernalillo, NM
The Murus Company, Mansfield, PA
Thermapan Industries, Fonthill, Ontario
Unistructrx, Beaconsfield, PQ
Winter Panel Corporation, Brattleboro, VT

UNSHEATHED STRUCTURAL PANELS

Dunfab, Roxton Pond, PQ
Insul Wall Ltd., Dartmouth, Nova Scotia
Nascor Inc., Calgary, Alberta
Super Lock Ltd., Langley, Colombie-Britannique
Wallframe Inc., Sun Valley, CA

STRESSED-SKIN PANELS

ALH Building Systems, Markle, IN
Bâtisseurs Associés, Saint-Adelphe, PQ
Construction Concepts P-3000, Matane, PQ
Enercept Inc., Watertown, SD (Foundations)
Surfast Industries Inc., Morin Heights, PQ

NOT APPLICABLE FOR RESIDENTIAL USE (**)

Beaver Homes and Cottages, Nepean, ONT
Berkshire Construction Co. Inc., Falls Village, CT
Bétonnière Lemyre Ltée., Drummondville, PQ
Blink Lumber Co., Marne, MI
Chase Barlow Lumber, Louisville, KY
ClarkLite, Columbus, OH
Davidson Industries Inc., Indianapolis, IN
Fermes de Toit des Laurentides, Mont-Laurier, PQ
Flanders Building Supply Inc., Essex Junction, VT
Tech Built Homes, Inc., N. Dartsmouth, MA

OUT OF BUSINESS OR
TELEPHONE SERVICE DISCONNECTED (***)

Bâticube, Chicoutimi, PQ
BYC Homes Ltd., Gloucester, ONT
Coastal Structures, Inc., South Portland, ME
3-C General Construction, Limoges, ONT
Industries Pre-Fab Silmar Inc., Grand-Mère, PQ
Robert Coulombe Inc., Lauzon, PQ
Structures Equerres, Thurso, PQ
Technologies Thermomat Intl., Longueuil, PQ

APPENDIX B
LIST OF QUÉBEC MANUFACTURERS

PREFABRICATED HOMES/WALL/FLOOR SYSTEMS

Archimède 2000 Inc., Anjou
Baticube, Chicoutimi
Bâtisseurs Associés Ltée., Saint-Adelphe
Bétonnière Lemyre Ltée., Drummondville
Charpenter Inc., Québec
Construction Concepts P-3000, Matane
Dunfab, Roxton Pond
Fermes de Toit des Laurentides, Mont-Laurier
Goscobec, Rivière du Loup
Habitations Quélord Ltée., Saint-Léonard-de-Portneuf
Industries Fermco, Saint-Adelphe
Industries Pre-Fab Silmar Inc., Grand-Mère
Iso-Sand Inc., Granby
Les Habitations Technique H.C. Ltée., Saint-Joseph-de-Beauce
Modulex, Inc., Québec
Mur-Ext Inc., Lafontaine
Poulin & Dumais, Beauport
Prince Homes Inc., Princeville
Produit PBM Ltée., Saint-Pierre-de-Lamy
Robert Coulombe, Inc., Lauzon
Structure Noram Inc., Saint-Luc
Structures Equerres, Thurso
Structures Laprise Inc., Montmagny
Surfast Industries Inc., Morin Heights
Système Nascor Inc., Sainte-Marie
Technologies Thermomat Intl., Longueuil
Uni-Structurx Inc., Beaconsfield

WINDOW MANUFACTURERS

Afpec Inc., Saint-Eustache
Alumibois Inc., Alma
Aluminium Atlanta Inc., Saint-Léonard
Aluminium Fenebel (1989) Inc., Montréal-Nord
Aluminium J.L. (1989) Inc., Saint-Hubert
Aluminium M.G.S. Inc., Montréal-Nord
Armoires Garland Inc. (Les), Saint-Rémi
Atelier de la Crapaudière Inc., Saint-Léon-de-Standon
Atelier de Matane Inc., Matane
Ateliers Chouinard Inc. (Les), Saint-Pamphile
Aubrie Menuiserie Générale (Ernest), Verchères
Aucoin Inc. (Edmond), Saint-Boniface-Shawinigan
Bastille & Fils Inc. (E.), Pohénégamouk
Beco Inc., Warwick
Boissonneault & Bisson Inc., Rouyn-Noranda
Bolduc & Grégoire Inc., Cowansville
Bonneville Portes et Fenêtres; Div. Groupe Bocenor (BF) Inc., Sainte-Marie
Brouillette Inc. (Gaston), Cap-de-la-Madeleine
Caya (1982) Inc. (Thomas), Notre-Dame-du-Bon-Conseil
Centre du Chassis R.N. Inc. (Le), Lauzon
Charlebois & Fils Ltée., Lachute
Charron (1975) Ltée. (J.B.), Sainte-Thérèse
Chomedey Aluminium Ltée., Laval
Compagnie Lucien Leboeuf Ltée. (La), Bécancour
Compagnie Shalwin Ltée. (La), Shawinigan-Sud
Compagnie Zimmcor (La), Lachine
Duval & Gilbert Inc., Montréal
Entreprises A.M. (Saint-Tite) Inc., Saint-Tite
Entreprises C. & L. Caruso & Fils Inc., Montréal-Nord
Entreprises C. Levesque Ltée (Les), Saint-Jude
Entreprises Chartre Ltée. (Les), Malartic
Entreprises Dalcourt & Roussel Inc. (Les), Saint-Léonard
Entreprises Marchand (1979) (Les), Sainte-Catherine
Entreprises Tessier & Frère Inc., Saint-Césaire
Entreprises Windoors Inc. (Les). Montréal-Nord
Fabelta Aluminium Inc., Manseau
Fantastique Aluminium Ltée., LaSalle
Fenebec Inc., Saint-Joseph-de-Beauce
Fenestral Inc., Dolbeau
Fene-Tech Inc., Amqui
Fenêtres & Rénovations Maki Inc., Maniwaki
Fenêtres AGM Inc. (Les), Hébertville-Station
Fenêtres Dominic Inc. (Les), Saint-Bruno-de-Montarville
Fenêtres Elite Inc. (Les), Saint-Gilles
Fenêtres Gaspésiennes Inc. (Les), Sainte-Anne-des-Monts
Fenêtres Mirabel Inc. (Les), Saint-Antoine
Fenêtres Montmagny Inc., Saint-François-de-la-Rivière
Fenêtres P.E. Ouelet Inc. (Les), Notre-Dame-des-Lourdes
Fenêtres Polyco Ltée., Jonquière
Fenêtres Réjean Tremblay Inc. (Les), Métabetchouan
Fenêtres Select Inc., Sainte-Thérèse
Fenêtres Saint-Jean Inc. (Les), Saint-Jean-sur-Richelieu
Flamand Inc. (Donald), Saint-Apollinaire
Foyer Canadien (1986) Inc. (Le), Amqui
Gestion Yvon Boilard Inc., Saint-Ferréol-les-Neiges
Gingras & Fils (1974) Ltée. (Jos), Saint-Damasse
Girard & Fils Inc. (Gilles), Saint-Felix-de-Valois
G.I.T. Aluminium Ltée., Saint-Léonard
Goulet & Fils Ltée. (Treffle), Saint-Joseph-de-Beauce

Groupe Laurendeau Tardif Inc., Montmagny
Industries Guay Inc. (Les), Delisle
Industries Prime Ltée. (Les), Lachine
Industries Unik Ltée. (Les), Saint-Agapit
Isothermiques Solarcan Ltée., Boucherville
Lajoie & Fils Inc. (J.G.), Saint-Bruno-de-Montarville
Lepage Inc. (Alphonse), Rivière-du-Loup
Maisonneuve Aluminium Inc., Montréal
Marcoux & Frères Enr., Coaticook
Martin (1984) Inc. (L.), Rivière-du-Loup
Menuiserie Albert, Le Gardeur
Matériaux de construction Castonguay Inc., Dégelis
Menuiserie Bélisle Inc., Saint-Jean-de-Dieu
Menuiserie des Pins (L.F.) Ltée., Notre-Dame-des-Pins
Menuiserie générale Roberval Enr., Roberval
Meubles du Québec Inspiration XIXe Ltée. (Les), Sainte-Agathe-des-Monts
Milette Inc. (Gérard), Saint-Boniface-de-Shawinigan
Mineault Inc. (Théo), Angers
Mongrain & Frères Ltée., Shawinigan
Multiver Ltée., Vanier
Murphy Enr., Beauharnois
Nadeau Enr. (D.), Saint-Léon-de-Standon
Naud Inc. (Pierre), Sainte-Thècle
Ouvertures St-Boniface Inc. (Les), Saint-Boniface-de-Shawinigan
Paquin Inc. (E.), Piedmont
Portes & Chassis Eddy Boulet Inc., Tracy
Portes & Chassis Giguère & Fils Inc., Château-Richer
Portes & Chassis J.C. Coulombe Inc., Saint-Thomas
Portes & Fenêtres Abritek Inc., Saint-Georges
Portes & Fenêtres de Beauce (1979) Ltée., Saint-Benoit-Labre
Portes & Fenêtres Isolco Inc., Sainte-Foy
Portes & Fenêtres Isothermic Inc., Thetford Mines
Portes & Fenêtres Leblanc Inc., Saint-Athanase
Portes & Fenêtres L.G.C. Inc., Chicoutimi
Portes & Fenêtres Québec, Québec
Portes & Fenêtres Yvon Lambert Enr., Notre-Dame-du-Mont-Carmel
Portes Modernes Inc., Boisbriand
Prodomo Inc., Montréal-Est
Produits Chantecler Inc., Saint-Apolinaire
Produits A.B.P. Inc., Montréal
Produits Aéro Inc. (Les), Laval
Produits d'Aluminium Admiral Inc., Montréal
Produits d'Aluminium Allied Inc. (Les), Montréal
Produits d'Aluminium Wilton Ltée. (Les), Saint-Léonard
Produits de bâtiment Alcan, Div. d'Alcan Aluminium Ltée., Anjou
Produits S.U.M. Inc (Les), Mont-Laurier
R. Laflamme & Frères Inc., Saint-Apolinaire
Rénovation en aluminium ASA Inc., Saint-Léonard
Roberge & Fils Inc., La Sarre
Robert & Robert Ltée., Saint-François-Xavier-de-Québec
Solarco Inc., Notre-Dame-des-Pins
Solaris Québec Inc., L'Ange-Gardien
Thibault Inc. (P.E.), Beauharnois
Toiturex Inc., Saint-Bruno
Vaillancourt & fils Ltée. (R.), Drummondville
Varin & Fils Ltée. (Hervé), Sainte-Julienne
Veillette & Deschênes Ltée., Chicoutimi
Vertec Enr., Div de 2427-9861 Québec Inc., Saint-Bruno
Vinyline Québec Enr., Div. de 2542-1983 Québec Inc., Saint-Romuald
Vitrerie Bourgeois Inc., Granby
Vitrerie de la Lanaudière Inc., Saint-Thomas
Vitrerie Ferme-Neuve Inc., Ferme-Neuve
Vitrerie Nominingue Inc., Lac Nominingue
Vitrerie Norcristal (1982) Inc., Sept-Îles

MANUFACTURED STRUCTURAL WOOD PRODUCTS

Adam Lumber Inc., Waterloo
Ateliers Ferjan Inc. (Les), L'Assomption
Bolduco Inc., Val-Alain
Brouillette & Frères Inc., Drummondville
Chevrons Dionne Inc., Saint-Pacôme
Chevrons du Bas Saint-Laurent Inc. (Les), Rimouski
Chevrons RBR Inc. (Les), Saints-Anges
Chevrons Richelieu Inc. (Les), Sainte-Victoire-de-Sorel
Chevrons Rivard (1980) Inc. (Les), Granby
Clyvamor Ltée., Saint-Georges-Est
Compagnie des Fermes Clermont Lessard inc. (La), Saint-Joseph-de-Beauce
Construction Concept P-3000 Inc., Matane
Cote Inc. (Gaston), Sherbrooke
Cote (1981) Inc. (Gilles), Chicoutimi
Dionne & Fils (1988) Ltée., Drummondville
Ébénisterie T. & L. Gagnon Inc., Sept-Iles
Ébénisteries Gaspésiennes Inc. (Les), Maria
Enterprises Chartre Ltée., Malartic
Entreprises Chartre Ltée., Malartic
Fecteau & Fils Inc. (Wilfrid), Saint-Benoît-Labre
Fermes de Toit des Laurentides Inc., Mont-Laurier
Fermes de Toit Hurtubise Inc., Notre-Dame-de-Pontmain
Fermes de Toit J.P.C. Enr. (Les), Lac-des-Écorces
Fermes de Toit Lac des Écorces Inc., Lac-des-Écorces
Fermes de Toit Montmagny Inc., Montmagny
Forget (1979) Inc. (Claude), Saint-Jovite
Freneco (1988) Ltée., Notre-Dame-de-Portneuf
Habitations Quelord Inc., Saint-Léonard-de-Portneuf
Industries Fremco Ltée. (Les), Saint-Adelphe
Industries Jager Inc., Blainville
Kefor Structures Ltée., Sainte-Anne-des-Plaines
Lépine & Lépine Inc., Sainte-Anne-des-Plaines
MacMillan Bloedel, Lasalle
Matériaux Laurier Inc., Laurier Station
Menuiserie Bélisle Inc., Saint-Jean-de-Dieu
Menuiserie Côte-Nord (Baie-Comeau) Inc., Baie-Comeau
Menuiserie Syrica Ltée., Lorrainville
Moisan Inc., Beauport
Pignons du Québec Inc. (Les), Mascouche
Poutrelles du Québec Ltée., Mascouche
Poutrelles modernes Ltée., Saint-Ephrem-de-Beauce
Produits Chantecler Inc., Gatineau
Produits PBM Ltée. (Les), Saint-Pierre-de-Lamy
Riopel Inc. (Jean), Chertsey
Romaro 2000 Ltée, Saint-Victor
Sofab (1984) Ltée., Lavaltrie
Structures de l'Outaouais (Les), Gatineau
Structures Le Tau Ltée., Saint-Jean-sur-Richelieu
Structures Paquet (1990) Inc., Montréal
Structures R.H. Inc., Thurso
Toits Fermetec Ltée. (Les), Terrebonne

Toiture Mauricienne (1982) Inc., Sainte-Marthe-du-Cap
Toitures Blanco (1984) Inc. (Les), Sainte-Foy
Toitures Deslongchamps Inc., Laurentides
Trusses Dufresne Inc. (Les), Arthabaska
Toitures Laferte, Drummondville
Toitures régionales Inc. (Les), Delisle
Toiturex Inc., Saint-Bruno

APPENDIX C EVALUATION OF PANEL SYSTEMS

Evaluation Methodology

A method for evaluating prefabricated panel systems was developed to assess the adequacy and suitability of the options available, and to provide guidance for future development by identifying the weaknesses and incompatibilities of certain items which may require revision and improvement. Several factors were taken into consideration:

- The method should be general enough so that it could be applied to a variety of building types and sizes
- It should be flexible enough to be modified, expanded or refined easily as new knowledge becomes available or other parameters need to be added
- In addition to the technical and physical characteristics of the system, the procedure should account for the obstacles which are likely to be encountered as a result of the industry's practical and conventional operational routines.

The model consists of two sets of attributes which are correlated, weighted and quantified for a particular application. After a set of requirements is drafted, evaluation criteria are generated from these requirements, and each of them is rated. The total weighted score is tabulated for each alternative, and the system with the highest score represents the system which offers the best solution for that particular problem. Because of the stated intention to provide a product that was suitable for exportation and practical in its ability to gain acceptance from the average builder, the requirements were drafted with special attention given to these two factors.

System Requirements

A total of 28 attributes that characterize the performance requirements for a prefabricated panel system were defined and categorized into 9 groups. The requirements were derived from the findings of previous studies dealing with buyers' preferences [8] , guidelines set out by the sponsors (SHQ, CMHC), and general experience with builders of Grow Home-type projects. They were selected to reflect the physical, practical and marketable qualities which are desired. The importance or nature of these requirements may vary from region to region. The analysis of requirements was oriented towards the Québec housing market, and many of the desired qualities were derived from an evaluation of existing projects in Montreal. They are also relate principally to the affordable housing market, particularly first-time buyers.

Evaluation Criteria

Once the requirements were defined, a set of quantifiable or qualifiable evaluation criteria was generated which would be used to select a panel system. Each of the criteria may represent one or more of the requirements, and each requirement is supported by one or more evaluation criteria. Seven general categories totalling 34 attributes were generated. The system requirements, evaluation criteria and the correlation between the two are shown in figure C1. Three levels of correlation were used: strong, medium and weak.

Rating Parameters

The panel systems are evaluated by rating each of the criteria on a scale of 1 (poor) to 5 (excellent). The parameters for the rating vary from one attribute to another. Evaluations were based on either one of three parameters: empirical calculation, test results or analysis. Rating scales were either based on relative performance, absolute parameters or on the ability to fulfil code requirements. In some cases, the criterion is rated at multiple levels of detail e.g. wall, joints, materials to ensure that all aspects of the product be considered.

The score for each criterion is multiplied by a weight factor from 1 (not important) to 5 (very important) which reflects the importance of that particular attribute for a specific application (design, housing type, location, climate, etc.). The total scores for the panel systems are then summarized, with the highest weighted score representing the most suitable alternative.

It should be mentioned that the sets of attributes included in the evaluation matrices are by no means exhaustive. Attributes dealing with architectural design and planning are not included because they go beyond the scope of this study. Additions to include these considerations, however, could be made readily for a more comprehensive and integrative approach to building evaluation. The model, for example, can eventually be expanded to include layout characteristics (proxemics, ergonomics and convenience). At a practical level, the manufacturer's background, reliability and warranty programs may be added to the list of system requirements. In figure C1, the unit's attractiveness was accounted for under "visual environment".

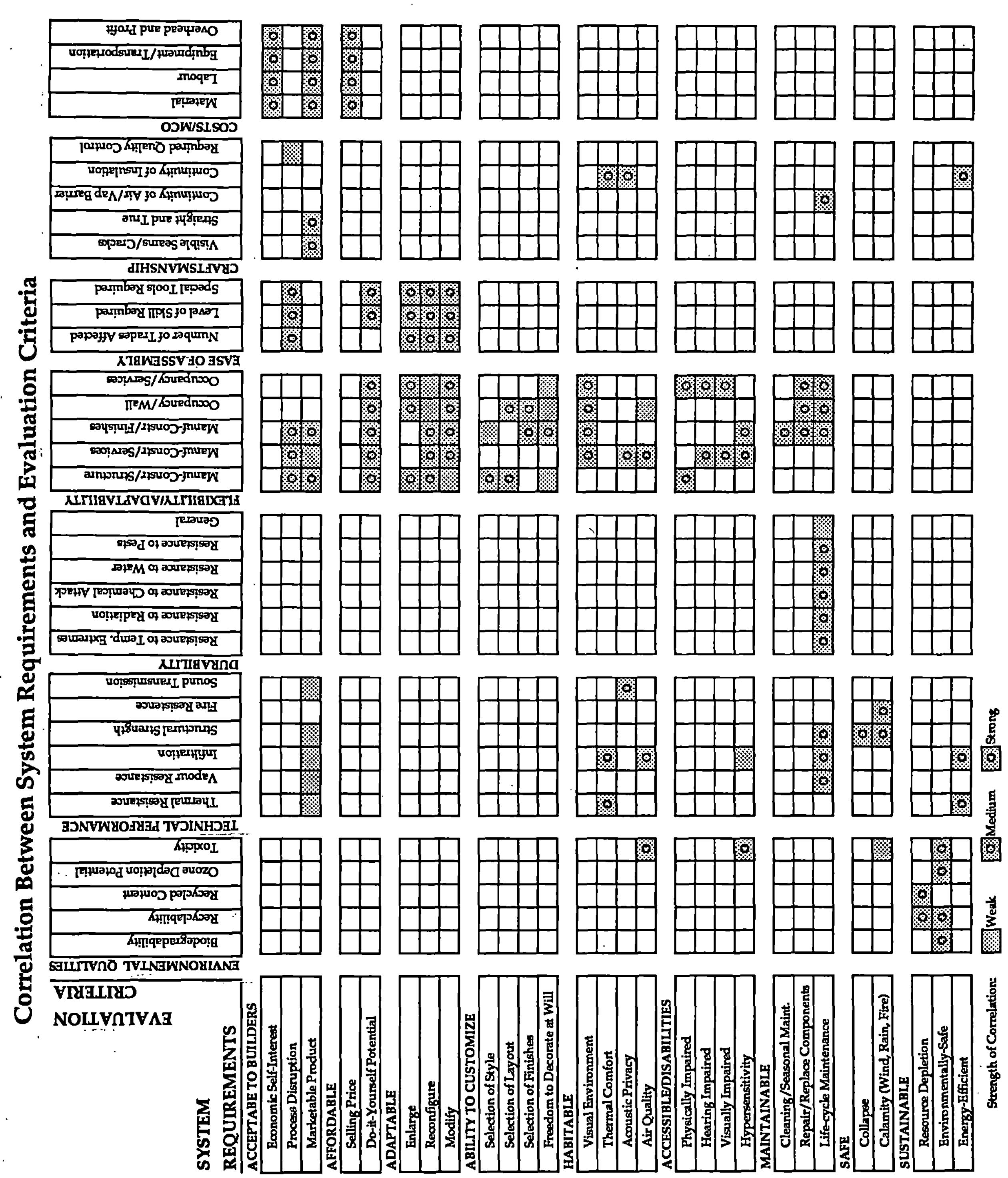
Evaluation of Panel Systems

What follows is a brief discussion on the findings of the evaluation for each category of criteria. The ratings for each of the criteria are compiled in figure C2, and evaluation tables are found at the end of this appendix.

It should be mentioned that the results of the evaluation should be interpreted with caution. It is evident that minor modifications, either in the design or the assembly of the panels, can significantly affect the ratings on several points. The addition of sheathing material to the open structural panels, for instance, can improve its acoustic, thermal and structural performance, while the addition of a vapour barrier to any of the systems will improve their vapour transmission performance at a minimal cost.

The scores found in figure C2 reflect the suitability of the panel systems for a particular application, as defined by the importance factors attributed to each of the 30 evaluation criteria. A change in the regulatory environment, climate, housing type, geographical location or builders' operational characteristics (disposition to try new products) may generate different results. Furthermore, the cost figures

Figure C1 : Correlation Between System Requirements and Evaluation Criteria



which would be used in the assessment of the systems may vary significantly with the design of the unit and the location of the manufacturer. As such, the figures are not to be taken as absolute ratings, but as relative indicators in a specific context.

Environmental Qualities

The panel systems' composition was evaluated in terms of its environmental qualities. Five characteristics were examined: biodegradability, recyclability, recycled content, ozone depletion potential and toxicity under normal operating conditions.

The ratings for these characteristics were highly dependent on the ratio of wood and wood products to foam and insulation in the panel systems. Biodegradability ratings were highest in those systems with the highest wood content, namely conventional construction, conventional panel systems and structural sandwich panels. Recycling potential was assessed in terms of the ease with which the materials could be recovered and/or recycled, and whether or not a process or a market exists for this purpose. It was affected primarily by the type and amount of foam insulation in the panel. The structural sandwich panel with an extruded polystyrene (XEPS) core was rated slightly higher than the other panels in this category, since it can be recovered and reused more easily. Waferboard or oriented strand board products make more efficient use of natural resources, and have a potential for using recycled materials. Products with this type of sheathing therefore rated higher than the others.

The ozone depletion potential was not a problem for any of the panels evaluated. Although the CFC's used in the production of XEPS is extremely harmful to the environment, substitute blowing agents such as HCFC-141b are finding their way into the market. The ozone depletion potential with the new blowing agents is reduced by about 95%. Those panels containing urethane scored lowest in this regard. Finally, the ratings for toxicity in normal use were fairly consistent from panel to panel, with no one system displaying exceptionally good or poor qualities.

Technical Performance

There were six aspects of the panels' technical performance that were evaluated: Thermal resistance, vapour resistance, infiltration potential, structural stability, fire performance and airborne sound transmission. Because of the variability of the figures found in the manufacturers' literature, empirical calculations were carried out where possible to provide an unbiased comparison. In other cases, averages from several manufacturers of a specific type of panel system were used. Some types of systems had insufficient data on which to base the evaluation. In these cases, data considered reliable from similar types of systems was used.

Several types of joints were taken into account in the evaluation of thermal resistance, as were the spacing and thickness of the structural members. In general, the foam-core sandwich panel systems, particularly those with polyurethane or isocyanurate foam, provided the best insulation for a given thickness, due partly to their continuous thermal break across the joints. Conventional construction and open sheathed panels rated lowest, due to the lower thermal resistance of batt insulation and thermal bridging caused by the framing members. The effect of the wall's thermal resistance, particularly in rowhouses, is not critical. Infiltration, poor workmanship and low quality windows may result in more energy loss than that caused by low thermal resistance of the wall. As such, the thermal resistance of the walls was given a importance factor of 4.

Figure C2 : *Evaluation of Prefabricated Panel Systems/Summary*

Evaluation of Prefabricated Panel Systems/Summary

	F	Conventional Construction		Open Sheathed Panels						Structural Sandwich Panels							
				w/OSB Shthng		w/XEPS Shthng				w/MEPS		w/XEPS		w/PUR/ISO			
		RTG	RTG•F	RTG	RTG•F	RTG	RTG•F	A	A•F	RTG	RTG•F	RTG	RTG•F	RTG	RTG•F	A	A•F
ENVIRONMENTAL QUALITIES		16.5	61.5	16.5	61.5	13.5	53	15	57	17.5	65	18.5	67.5	15.5	57	17	63
Biodegradability	(2)	4	8	4	8	2	4	3	6	4	8	4	8	4	8	4	8
Recyclability	(2)	2	4	2	4	2	4	2	4	2.5	5	3	6	2	4	3	5
Recycled Content	(4)	3	12	3	12	2.5	10	3	11	3	12	4	16	3	12	3	13
Ozone Depletion Potential	(5)	4.5	22.5	4.5	22.5	4	20	4	21	5	25	4.5	22.5	3	15	4	21
Toxicity	(5)	3	15	3	15	3	15	3	15	3	15	3	15	3.5	18	3	16
TECHNICAL PERFORMANCE		13.1	50.2	13.6	52.7	13.3	52.5	13	53	23.2	88.8	25.2	95.8	26.5	101	25	95
Thermal Resistance	(4)	1	4	1	4	2	8	2	6	3	12	4	16	5	20	4	16
Vapour Resistance	(3)	1	3	1	3	1	3	1	3	4	12	5	15	5	15	5	14
Infiltration	(5)	1.8	9	2.3	11.5	2.3	11.5	2	12	5	25	5	25	5	25	5	25
Structural Strength	(3)	3	9	3	9	2	6	3	8	5	15	5	15	5	15	5	15
Fire Resistence	(4)	3.3	13.2	3.3	13.2	3	12	3	13	2.7	10.8	2.7	10.8	3	12	3	11
Sound Transmission	(4)	3	12	3	12	3	12	3	12	3.5	14	3.5	14	3.5	14	4	14
DURABILITY		22	66	23	70	20	65	22	68	18	60	18	63	19	65	18	63
Resistance to Temp. Extremes	(5)	4	20	4	20	3	15	4	18	3	15	3	15	3	15	3	15
Resistance to Radiation	(2)	5	10	5	10	3	6	4	8	4	8	3	6	4	8	4	7
Resistance to Chemical Attack	(1)	5	5	5	5	4	4	5	5	3	3	3	3	3	3	3	3
Resistance to Water	(5)	2	10	2	10	3	15	3	13	4	20	5	25	5	25	5	23
Resistance to Pests	(3)	3	9	3	9	3	9	3	9	2	6	2	6	2	6	2	6
General	(4)	3	12	4	16	4	16	4	16	2	8	2	8	2	8	2	8
FLEXIBILITY/ADAPTABILITY		23	99	21	89	21	89	21	89	14.3	62.9	14.3	62.9	14.3	63	14	63
Manuf-Constr/Structure	(5)	5	25	3	15	3	15	3	15	4	20	4	20	4	20	4	20
Manuf-Constr/Services	(5)	5	25	5	25	5	25	5	25	2	10	2	10	2	10	2	10
Manuf-Constr/Finishes	(5)	5	25	5	25	5	25	5	25	4	20	4	20	4	20	4	20
Occupancy/Wall	(3)	4	12	4	12	4	12	4	12	2.3	6.9	2.3	6.9	2.3	7	2	7
Occupancy/Services	(3)	4	12	4	12	4	12	4	12	2	6	2	6	2	6	2	6
EASE OF ASSEMBLY*		15	50	12	40	12	40	12	40	5	16	5	16	5	16	5	16
Number of Trades Affected	(4)	5	20	4	16	4	16	4	16	1	4	1	4	1	4	1	4
Level of Skill Required	(4)	5	20	4	16	4	16	4	16	2	8	2	8	2	8	2	8
Special Tools Required	(2)	5	10	4	8	4	8	4	8	2	4	2	4	2	4	2	4
CRAFTSMANSHIP		9	33	17	61	18	66	18	64	20	80	20	80	19	77	20	79
Visible Seams/Cracks	(3)	3	9	4	12	4	12	4	12	3	9	3	9	3	9	3	9
Straight and True	(3)	1	3	4	12	4	12	4	12	5	15	5	15	5	15	5	15
Continuity of Air/Vap Barrier	(5)	1	5	3	15	3	15	3	15	5	25	5	25	5	25	5	25
Continuity of Insulation	(5)	2	10	2	10	3	15	3	13	5	25	5	25	5	25	5	23
Required Quality Control	(3)	2	6	4	12	4	12	4	12	2	6	2	6	1	3	2	5
TOTAL SCORE		99		103		98		100		98		101		99		99	
WEIGHTED TOTAL			360		374		366		370		373		385		378		379

	F	Unsheathed Structural Panels									
		w/TB		w/T B & AS		w/o TB; w/AS		w/MF			
		RTG	RTG•F	RTG	RTG•F	RTG	RTG•F	RTG	RTG•F	A	A•F
ENVIRONMENTAL QUALITIES		14	54	14	54	14	54	14	54	14	54
Biodegradability	(2)	3	6	3	6	3	6	3	6	3	6
Recyclability	(2)	2	4	2	4	2	4	2	4	2	4
Recycled Content	(4)	1	4	1	4	1	4	1	4	1	4
Ozone Depletion Potential	(5)	5	25	5	25	5	25	5	25	5	25
Toxicity	(5)	3	15	3	15	3	15	3	15	3	15
TECHNICAL PERFORMANCE		17.8	70	17.8	70	18.3	71.5	19.8	78	18	72
Thermal Resistance	(4)	2	8	2	8	2	8	3	12	2	9
Vapour Resistance	(3)	3	9	3	9	3	9	3	9	3	9
Infiltration	(5)	4.3	21.5	4.3	21.5	4.3	21.5	4.8	24	4	22
Structural Strength	(3)	2.5	7.5	2.5	7.5	3	9	3	9	3	8
Fire Resistence	(4)	2	8	2	8	2	8	2	8	2	8
Sound Transmission	(4)	4	16	4	16	4	16	4	16	4	16
DURABILITY		21	70	21	70	21	70	21	70	21	70
Resistance to Temp. Extremes	(5)	3	15	3	15	3	15	3	15	3	15
Resistance to Radiation	(2)	5	10	5	10	5	10	5	10	5	10
Resistance to Chemical Attack	(1)	3	3	3	3	3	3	3	3	3	3
Resistance to Water	(5)	4	20	4	20	4	20	4	20	4	20
Resistance to Pests	(3)	2	6	2	6	2	6	2	6	2	6
General	(4)	4	16	4	16	4	16	4	16	4	16
FLEXIBILITY/ADAPTABILITY		16.7	70.1	17.7	75.1	19	81	14.3	58.9	17	71
Manuf-Constr/Structure	(5)	2	10	2	10	3	15	2	10	2	11
Manuf-Constr/Services	(5)	3	15	4	20	4	20	3	15	4	18
Manuf-Constr/Finishes	(5)	5	25	5	25	5	25	3	15	5	23
Occupancy/Wall	(3)	3.7	11.1	3.7	11.1	4	12	3.3	9.9	4	11
Occupancy/Services	(3)	3	9	3	9	3	9	3	9	3	9
EASE OF ASSEMBLY*		8	26	9	30	9	30	8	26	9	28
Number of Trades Affected	(4)	2	8	3	12	3	12	2	8	3	10
Level of Skill Required	(4)	3	12	3	12	3	12	3	12	3	12
Special Tools Required	(2)	3	6	3	6	3	6	3	6	3	6
CRAFTSMANSHIP		20	78	20	78	19	71	20	78	20	76
Visible Seams/Cracks	(3)	4	12	4	12	4	12	4	12	4	12
Straight and True	(3)	4	12	4	12	4	12	4	12	4	12
Continuity of Air/Vap Barrier	(5)	4	20	4	20	4	20	4	20	4	20
Continuity of Insulation	(5)	5	25	5	25	3	15	5	25	5	23
Required Quality Control	(3)	3	9	3	9	4	12	3	9	3	10
TOTAL SCORE		98		100		100		97		99	
WEIGHTED TOTAL			368		377		378		365		372

Legend: OSB-Oriented Strand Board; MEPS-Expanded Polystyrene; XEPS-Extruded Polystyrene; PUR-Polyurethane; ISO-Polyisocyanurate; TB-Thermal Break; AS-Air Space; MF-Metal Frame; F-Importance Factor, from1 (not important) to 5(very important); RTG-Rating, from 1 (very poor) to 5 (excellent); A-Average

* Criteria related to ease of assembly are rated with respect to the expected disruption to traditional operational routines on the construction site

A similar situation exists with the evaluation of vapour resistance of the wall section, where structural sandwich panels rated highest, followed by the structural unsheathed panels, and finally by the open sheathed panels. The assessment was based on the merits of the panel system itself, with the interior vapour barrier assumed damaged or ineffective. The location of the vapour-resistant materials was taken into consideration for the assessment. The presence of a fairly resistant sheathing material on the exterior, for instance, was not taken as an advantage, since it may act as a vapour trap. This criterion may change depending on location. In hot, humid climates, the migration of water vapour across the wall section is reversed. Again, the importance of this characteristic was considered to be relatively low (3), since infiltration through gaps and joints can do more harm in terms of moisture migration than diffusion through the wall section.

A qualitative assessment of infiltration potential was conducted by taking into account two parameters: quality of the joint design and length of exposed seams or joints found in the assembled envelope. Four points of infiltration were accounted for: joint between the insulation and the structure, joint between two panels, joint between panels and floors and/or roofs, and openings in the wall created by electrical and/or plumbing fixtures. Infiltration losses at the window/wall joint depend mostly on installation practices, and were not considered to be reflective of the panel quality. The tightest assemblies were estimated to be the structural sandwich panels, for two main reasons: their exceptionally well-fitted joint systems and the possibility of extending the exterior skin below the floor level, allowing for a continuous barrier across the end of the floor section. The structural unsheathed panels were second, due to their tight friction-fit joints and the ability to accommodate electrical boxes without interrupting the continuity of the insulation.

Fire and sound resistance ratings (important for the dividing wall assembly) were based on their ability to fulfil minimum code requirements. Toxic fume emissions were taken into consideration for fire resistance, given the high number of systems with foam insulation. The results of this evaluation as well as those of the sound transmission yielded a fairly even distribution of ratings, with conventional systems offering a slight advantage in fire performance and the unsheathed structural panels doing the same for sound transmission. All the systems were all above the code requirements for structural resistance, with the sandwich panels scoring highest. The importance factor of the latter would be increased from its present value of 3 for earthquake or hurricane - prone areas.

Durability

The panels' resistance to five elements was rated to determine the durability of the systems: temperature extremes, solar radiation, chemical attack, water damage and insect or rodent infestation. A sixth, general category was included to account for specific defects which may occur in some of the panels. The durability for some of the panels containing rigid foam insulation was difficult to assess due to the lack of reliable data on the systems' track record. Therefore, the ratings were based on the resistance of the individual materials which make up the panels under the assumption of direct exposure.

The most reliable panel systems appear to be the unsheathed structural panels, followed closely by the open sheathed panels. Among the questionable characteristics of structural sandwich panels was a susceptibility for these systems to ridge at the joints because of inadequate allowance for thermal expansion, and the relatively high level of quality control required to prevent delamination.

Flexibility and Adaptability

In the evaluation of the systems' flexibility, three phases of the project life-cycle were taken into consideration: manufacturing, assembly and occupancy. The first of these will determine the design constraints which are applicable to a panel system. The second phase, construction, represents the extent to which last-minute changes could be made on-site in response to individual requests for modifications. Flexibility in the occupancy phase determines the ease with which various components can be inspected and accessed for repair or replacement. It also reflects the adaptability of the space by rating how easily plumbing and electrical conduits can be accessed and redirected.

The most flexible panel system overall was the open sheathed panel, followed by the structural sandwich panel. Although the unsheathed structural panel systems offer greater flexibility during the manufacturing phase, they are not easily modifiable on site. The structural sandwich panels offer the highest flexibility on site, since openings can be cut in the panels at any time with relatively little reconstruction required. Although the size of the opening is limited by the panel size and the cutting operation may be more difficult, it is the only panel system which can have openings cut into it at any location even after the wall has been erected.

The biggest drawback of the structural sandwich panel is its flexibility after occupancy. Inspection and repair of the insulation, which is a critical structural component in these types of panels, is difficult if not impossible, even if all finishes are removed. Furthermore, the ability to hang heavy objects or accessories which require structural support, such as grab bars, may be restricted, particularly after occupancy.

Ease of Assembly

The panel systems' ease of assembly was evaluated to reflect the practical complexity of the system. The sophistication of design was accounted for only insofar as it affected the builder's ability to erect the structure. In other words, a complex panel design would not rate lower than a simple one unless it hindered the assembly process. Three aspects regarding the assembly process were evaluated. First, the number of building trades that are affected by the system (with respect to traditional stick-build methods) was determined to reflect the extent to which the average builder's established operational routines will be disrupted. Second, the level of skill required for various tasks was rated to reflect the difficulty of assembly and the amount of training that would be required. Finally, the need for special tools was ascertained for three basic operations: lifting, cutting and fastening. In all three cases, a rating of 4 represents equality with stick-build methods of construction.

In all cases, the structural sandwich panels were found to have the lowest rating, and the unsheathed structural panel systems came in second to last. The open sheathed panels, which use conventional construction techniques, provided the simplest assembly of the prefabricated panel systems due to their use of familiar products, materials and construction methods.

It should be mentioned that these ratings represent the probability of a contractor accepting the system, and not the efficiency with which the system could be erected. Once a builder has decided to use one of the systems and provide whatever training is required, the operational efficiency of the construction task may improve relative to the traditional construction methods.

Craftsmanship

The systems' craftsmanship was evaluated in terms of its potential to achieve consistent quality from application to application. Three aspects of workmanship were evaluated: the number of seams and cracks (which reflects the probability of failure occurring at a later date due to infiltration), the probability of the systems being built straight and plumb, and the continuity of the vapour barrier and thermal insulation. Furthermore, the complexity of the manufacturing process in terms of required quality control was evaluated to reflect the probability of receiving inadequately assembled panels.

The panel systems which offer the highest potential for good craftsmanship are the structural sandwich panels. These panels are likely to achieve high levels of workmanship due to the continuous sheathing and tight joints, particularly with the double spline variation. The critical nature of the lamination process, however, requires a relatively high level of quality control, especially for polyurethane (PUR) and isocyanurate (ISO) foams. Unsheathed structural panels rated close to the structural sandwich panels, due to the fact that they are assembled using simple techniques (some make no use of adhesives) to provide continuous thermal breaks and adequate air barriers. Stick-build methods were rated lowest due to the high variability of craftsmanship and susceptibility of materials to damage from inadequate site storage.

Types of Panel Systems

Generally, all of the panel systems evaluated rated higher than conventional construction. The strong points and drawbacks vary from system to system. Open sheathed panel systems, for instance, have three main advantages: flexibility, durability and easy assembly. Given the importance of being able to provide custom design, the ability of these systems to lend themselves to last-minute modifications more easily and to provide serviceable structures after occupancy resulted in a favourable rating. Although structural modifications on site are limited, the installation of electrical and plumbing services remains highly flexible. The inverse is true for the sandwich panels, which can easily be modified structurally but provide little leeway for the arbitrary placement of lighting and plumbing fixtures. After occupancy, modifications in this regard do not appear to be any easier.

The open sheathed panel's slightly higher durability ratings are not as much due to the materials' ability to resist deterioration as they are to the panel's ability to retain its structural integrity. Because of their lack of dependance on the insulation material for structural stability, temperature variations, rodents (which have been known to burrow through rigid foams) and chemicals have less of a damaging potential on open sheathed panels. While their susceptibility to moisture problems remains higher than that of other systems, these panels benefit from the fact that the interior of the wall can be relatively easily be inspected and repaired.

Finally, the open sheathed panel's ease of assembly is a major asset for these systems. Although the idea of erecting panels rather than studs is not a familiar one for most builders, the use of standard components and construction methods facilitates both the assembly process and the probability of acceptance. While the assembly of the sandwich panels themselves provides a simple, straightforward process, the integration of electrical services remains a problem.

The structural sandwich panels were found to be technically superior for most of the aspects evaluated. Exceptional joint designs and panel-to-panel interface surfaced as the primary advantage of these systems. It is conceivable that these systems would receive higher ratings in other, more demanding applications. In the case of a narrow-front rowhouse, the heat losses through the wall sections are less critical than they would be in other types of housing, somewhat reducing the effect of these advantages on the panel's total score.

The unsheathed structural panels appear to provide adequate performance in all respects, but benefit from few extraordinary characteristics. Their biggest advantage is that they can overcome the inadequate workmanship which is often found in conventional construction without resorting to very unfamiliar building techniques. The use of expanded polystyrene foam between the "studs" significantly improves the performance of the wall in that area which is a key failure point in conventionally-built walls: discontinuous insulation and vapour barrier caused by improper site installation.

Table 1 : Material Charateristics

		RATINGS								
		Biodegradability			Recyclability			Recycled Content		
		Shthg	Core	Panel	Shthg	Core	Panel	Shthg	Core	Panel
0	Conventional Construction	5	3	4.0	3	1	2.0	5	1	3.0
1	Open Sheathed Panels									
1.1	• w/ OSB Sheathing	5	3	4.0	3	1	2.0	5	1	3.0
1.2	• w/ XEPS Sheathing	1	3	2.0	3	1	2.0	3	1	2.5
2	Structural Sandwich Panels									
2.1	• w/MEPS Core	5	3*	4.0	3	2	2.5	5	1	3.0
2.2	• w/XEPS Core	5	3*	4.0	3	3	3.0	5	3	4.0
2.3	• w/PUR/ISO Core	5	3*	4.0	3	1	2.0	5	1	3.0
3	Unsheathed Structural Panels									
3.1	• w/Thermal Break	SNR	3	3.0	SNR	2	2.0	SNR	1	1.0
3.2	• w/Thermal Break & Air Space	SNR	3	3.0	SNR	2	2.0	SNR	1	1.0
3.3	• w/o Thermal Break; w/Air Space	SNR	3	3.0	SNR	2	2.0	SNR	1	1.0
3.4	• w/Metal frame	SNR	3	3.0	SNR	2	2.0	SNR	1	1.0

Rating Scale:
Based of percentage of biodegradable material [1]:
1. Not biodegradable
3. Partially biodegradable
5. biodegradable

* Includes interior sheathing

SNR: Sheathing Not Required

Rating Scale:
Based on the potential for reusing the material [2]:
1. 0%; no potential
2. some potential exists, no market, no process
3. some potential exists, market exists, no process
4. Partially recyclable; secondary applications
5. Fully recyclable; same type of application

Rating Scale:
Based on potential to fabricate using recycled materials:
1. 0%; all virgin raw material
3. Some recycled content is possible
5. 100% recycled content is possible

		RATINGS					
		Ozone Depletion			Toxicity (in use)		
		Shthg	Core	Panel	Shthg	Core	Panel
0	Conventional Construction	5	4	4.5	3	3	3.0
1	Open Sheathed Panels						
1.1	• w/ OSB Sheathing	5	4	4.5	3	3	3.0
1.2	• w/ XEPS Sheathing	4**	4	4.0	3	3	3.0
2	Structural Sandwich Panels						
2.1	• w/MEPS Core	5	5	5.0	3	3	3.0
2.2	• w/XEPS Core	5	4**	4.5	3	3	3.0
2.3	• w/PUR/ISO Core	5	2	3.0	3	4	3.5
3	Unsheathed Structural Panels						
3.1	• w/Thermal Break	SNR	5	5.0	SNR	3	3.0
3.2	• w/Thermal Break & Air Space	SNR	5	5.0	SNR	3	3.0
3.3	• w/o Thermal Break; w/Air Space	SNR	5	5.0	SNR	3	3.0
3.4	• w/Metal frame	SNR	5	5.0	SNR	3	3.0

Rating Scale:
Based on use of harmful material in manufacturing:
1. Extremely harmful (CFC's)
2. Very harmful
3. Somewhat harmful (HCFC's)
4. Slightly harmful (uses CFC/HCFC substitute)
5. Not harmful

** May vary from 1 to 4; highest performance is assumed

Rating Scale:
Based of potential health risk in daily use [3]:
1. Health risk determined
2. Health risk possible
3. Contains small amounts of unhealthy components [4]
4. Healthy environment probable
5. Healthy environment determined

Notes:

[1] The percentage of wood content in the cores of conventional and unfaced strucural systems is taken as equal to that on interior facing of structural sandwich panels

[2] Accounts for a) ability to recover material in recyclable form, b) whether or not a market for the recycled product currently exists, and c) whether a recovery/recycling process is currently under way

[3] health risks in a fire are accounted for in "Fire Resistance"

[4] Includes adhesives; accounted for as part of the "core" material

Table 2 : Thermal Resistance of Wall Sections

		RSI							
		Material						Total	RATING
		Int Shthng	Ins/Core	(%)	Frme/Jts	(%)	Ext Shthng	(Panel)	
0	Conventional Construction	N/A	3.332	(87%)	1.212	(13%)	0.121	3.177	1
1	Open Sheathed Panels								
1.1	• w/ OSB Sheathing	N/A	3.332	(87%)	1.212	(13%)	0.121	3.177	1
1.2	• w/ XEPS Sheathing	N/A	2.286	(87%)	0.866	(13%)	1.319	3.420	2
2	Structural Sandwich Panels								
2.1	• w/MEPS Core	0.121	3.738	(89%)	3.236	(11%)	0.121	3.925	3
2.2	• w/XEPS Core	0.121	4.858	(89%)	4.100	(11%)	0.121	5.017	4
2.3	• w/PUR/ISO Core	0.121	6.986	(89%)	5.741	(11%)	0.121	7.091	5
3	Unsheathed Structural Panels								
3.1	• w/Thermal Break	N/A	3.738	(86%)	2.367	(14%)	SNR	3.546	2
3.2	• w/Thermal Break & Air Space	N/A	3.551	(86%)	2.367	(14%)	SNR	3.385	2
3.3	• w/o Thermal Break; w/Air Space	N/A	3.647	(86%)	1.212	(14%)	SNR	3.306	2
3.4	• w/Metal frame	N/A	3.738	(100%)	Negl.		SNR	3.738	3

Material	l	RSI
Foams:		
MEPS	140	3.738
	127	3.391
	108	2.884
	64	1.709
XEPS	140	4.858
	108	3.748
	64	2.221
	38	1.319
PUR/ISO	140	6.986
	108	5.389
	64	3.194
Batt:		
	140	3.332
	90	2.286
Wood		
S-P-F	140	1.212
	100	0.866
	38	0.329
OSB	16	0.176
	11	0.121
Air Space	13	0.160

THERMAL RESISTANCES OF MATERIALS (1/k)	(1/k)
Foam: Expanded polystyrene, molded beads (MEPS); 16kg/cu.m.	(26.7)
Expanded polystyrene, extruded (XEPS)	(34.7)
Cellular polyisocyanurate (ISO) w/gas-impermeable facers *	(49.9)
Batt Insulat approx. 90 mm	(25.4)
approx. 140-165 mm	(23.8)
Wood: Spruce, Pine, Fir (S-P-F) @ 12% moisture content	(8.7)
Oriented strand board or waferboard	(11.0)
Air Space, 13mm. w/ E=0.82; temp diff 16.7, mean temp. 10	(0.16)

Type of Joint	RSI			Total
	(%)	Splines	Core	(Joint)
Conventional	(13%)	N/A	1.212	1.212
Single 2X Lumber	(6%)	N/A	1.212	1.212
Double 2X Lumber	(9%)	N/A	1.212	1.212
Double Thin Spline				
w/ MEPS Core	(11%)	0.352	2.884	3.236
w/ XEPS Core	(11%)	0.352	3.748	4.100
w/ XEPS Core	(11%)	0.352	5.389	5.741
Thermally Broken/ Laminated				
w/ MEPS Core	(10%)	0.658	1.709	2.367
w/ XEPS Core	(10%)	0.658	2.221	2.879
w/ XEPS Core	(10%)	0.658	3.194	3.852

Rating Scale: Relative performance

* RSI value may be reduced by 12% to 23% for polyurethane or for gas-permeable or no facing material
• Based on that part of the wall consisting of the frame, insulation and sheathing; cladding and interior finishes are not included (unless they form an integral part of the system);
  Calculated for 140 mm wide wall
• Double thin spline joints assumed in the calculation of RSI in structural sandwich panels; thermally Broken/Laminated joints are assumed for unfaced panels
• Total RSI value in structural sandwich panels may be reduced by as much as 7% with other types of joints

N/A: Not applicable
NSR: Sheathing Not Required
(%): Percentage of wall area
RSI: Resistance; K•sq.m./W
k: Conductivity W/(sq.m.•K)
l: Thickness; mm
E: Effective Emittance

Source:ASHRAE Fundamentals,1989

• Thermal drift in foam insulation accounted for in "Durability"
• Heat losses from joints accounted for in "Infiltration"
• Variability of RSI value with temperature is accounted for under "durability"

Table 3 : Vapor Resistance of Wall Section and Infiltration

VAPOUR RESISTANCE

		PERMEANCE/RESISTANCE								RATING
		Material						Total		
		Int Shthng		Ins/Core		Ext Shthng		(Panel)		
		P	R	P	R	P	R	R	M	
0	Conventional Construction	N/A		1750	0.00057	23	0.04297	0.04354	23	1
1	Open Sheathed Panels									
1.1	• w/ OSB Sheathing	N/A		1750	0.00057	23	0.04297	0.04354	23	1
1.2	• w/ XEPS Sheathing	N/A		2450	0.00041	45	0.02235	0.02276	44	1
2	Structural Sandwich Panels									
2.1	• w/MEPS Core	23	0.04297	40	0.02478	23	0.04297	0.11072	9	4
2.2	• w/XEPS Core	23	0.04297	12	0.08235	23	0.04297	0.16829	6	5
2.3	• w/PUR/ISO Core	23	0.04297	10	0.09722	23	0.04297	0.18316	5	5
3	Unsheathed Structural Panels									
3.1	• w/Thermal Break	N/A		40	0.02478	SNR		0.02478	40	3
3.2	• w/Thermal Break & Air Space	N/A		44	0.02248	SNR		0.02248	44	3
3.3	• w/o Thermal Break; w/Air Space	N/A		44	0.02248	SNR		0.02248	44	3
3.4	• w/Metal frame	N/A		40	0.02478	SNR		0.02478	40	3

Material	1	Permeance
Foams:		
MEPS	140	40.357
	127	44.488
XEPS	140	12.143
	38	44.737
PUR/ISO	140	10.286
Batt:		
	140	1750
	100	2450
Wood:		
OSB	11	23.273
Air Space	13	13385

- Based on potential to resist vapour migration without an interior vapour barrier (assumed damaged or ineffective)
- Rating accounts for sequence of materials and probability of entrapped vapour

PERMEABILITY OF MATERIALS	P
Foam: Expanded polystyrene, molded beads (MEPS); 16 kg/cu.m.	
Average (varies from 2.9 to 8.4)	5.65
Expanded polystyrene, extruded (XEPS)	1.70
Expanded Polyurethane/R-11 blown(PUR);	
Average (varies from .58 to 2.3)	1.44
Mineral Wool (unprotected)	245
Wood: Oriented strand board or waferboard *	0.26
Air (still)	174

Rating Scale: Relative Performance

- Based on that part of the wall consisting of the frame, insulation and sheathing; cladding and interior finishes are not included (unless they form an integral part of the system);
- Calculated for 140 mm wide wall
- Vapour migration through joints are accounted for in "Infiltration"

N/A: Not Applicable
SNR: Sheathing Not Required
Permeance: ng/(Pa•s•sq.m)
Permeability (P): ng/(Pa•s•sq.m.)
l: Thickness, in mm
Resistance: (Pa•s•sq.m)/ng
Source: ASHRAE Fundamentals, 1989
* Permeance for oriented strand board assumed to be equal to that of plywood (douglas fir; exterior glue)

INFILTRATION

		Infiltration Potential				AVE
		Insul/Struct	Panel/Panel	Panel/Flrs/Rfs	Openings	RATING
0	Conventional Construction	2	2	2	1	1.75
1	Open Sheathed Panels	2	3	2	2	2.25
2	Structural Sandwich Panels	5	5	5	5	5
3	Unsheathed Structural Panels					
3.1	• w/Thermal Break	4	4	4	5	4.25
3.2	• w/Thermal Break & Air Space	4	4	4	5	4.25
3.3	• w/o Thermal Break; w/Air Space	4	4	4	5	4.25
3.4	• w/Metal frame	5	5	4	5	4.75

- Based on potential to resist air/vapour migration without an interior vapour barrier (assumed damaged or ineffective)
- Rated as a function of both joint quality and amount of joints present in the system

Rating Scale (joint locations):
1. Very Poor
2. Poor
3. Fair
4. Good
5. Excellent

Rating Scale (total rating):
Relative performance

- Best potential is assumed; probability of achieving tight joint is accounted for under "Craftsmanship"

Table 4 : Structural Strength, Fire Resistance, Sound Transmission and Craftsmanship

		STRENGTH			FIRE				SOUND		
		Ratings			Ratings				STC		
		Axial	Flex	TOT	FRR	Tox/S	Tox/C	TOT	Single	Double	RTG
0	Conventional Construction	3	3	3.0	3	4	3	3.3	36 to 54 *	50-63 *	3
1	Open Sheathed Panels										
1.1	• w/ OSB Sheathing	3	3	3.0	3	4	3	3.3	36 to 54 *	50-63 *	3
1.2	• w/ XEPS Sheathing	2	2	2.0	N/A	3	3	3.0	N/A	N/A	N/A
2	Structural Sandwich Panels										
2.1	• w/MEPS Core	5	5	5.0	1	4	3	2.7	39	No	
2.2	• w/XEPS Core	5	5	5.0	1	4	3	2.7	to	data	3.5
2.3	• w/PUR/ISO Core	5	5	5.0	1	4	4	3.0	41*	available	
3	Unsheathed Structural Panels										
3.1	• w/Thermal Break	3	2	2.5	1	N/A	3	2.0	37	51	
3.2	• w/Thermal Break & Air Space	3	2	2.5	1	N/A	3	2.0	to	to	4
3.3	• w/o Thermal Break; w/Air Space	3	3	3.0	1	N/A	3	2.0	51	57	
3.4	• w/Metal frame	3	3	3.0	1	N/A	3	2.0	*	*	

Rating Scale:

Relative Performance

Notes:

[1] Flame spread ratings and smoke developed classifications were not included since the effect of these on occupant safety depends largely on the finishing materials used; code requirements are surpassed

[2] Depends highly on workmanship; probability of achieving quality is accounted for in "craftsmanship"

Rating Scale (FRR):

Based on requirements to achieve 1-hr Fire Resistance Rating (on fire-exposed side):

1. 2x 15.9 mm Type X gyps brd
2. 2x12.7 mm gyps brd
3. 1x 15.9 mm Type X gyps brd
4. 1x 12.7 mm gyps brd
5. as is

Rating Scale (Toxicity):

Based on safety risk posed to the occupants in a fire by the sheathing (S) and core (C)[1]:

1. Unhealthy risk determined
2. Unhealthy risk possible
3. Maintains integrity at 167 F
4. Maintains integrity at 800-850F
5. No health risks expected

Rating Scale:

Based on requirements to achieve a 50 STC Rating[2]:

1. Double wall + modification
2. Double wall
3. Single wall/modified
4. Single wall/ slight variation
5. Single wall-as is

"Modified" implies the use of unconventional elements ex. resilient bars

"Variation" implies either a thicker wall section or alternative wall type (available as option in prefabricated wall panels)

* Using 90 mm partition

CRAFTSMANSHIP

		Assembly				Manufacture
		S&C	S &T	VB/AB	INS	QC
0	Conventional Construction	3	1	1	2	2
1	Open Sheathed Panels					
1.1	• w/ OSB Sheathing	4	4	3	2	4
1.2	• w/ XEPS Sheathing	4	4	3	3	4
2	Structural Sandwich Panels					
2.1	• w/MEPS Core	3	5	5	5	2
2.2	• w/XEPS Core					
2.3	• w/PUR/ISO Core	3	5	5	5	1
3	Unsheathed Structural Panels					
3.1	• w/Thermal Break	4	4	4	5	3
3.2	• w/Thermal Break & Air Space					
3.3	• w/o Thermal Break; w/Air Space	4	4	4	3	4
3.4	• w/Metal frame	4	4	4	5	3

Legend:

S & C: Seams and Cracks

S & T: Straight and True

VB/AB: Continuilty of air barrier and vapour barrier

INS: Continuilty of Insulation

QC: Required quality control

Rating Scale:

1. Very Poor
2. Poor
3. Fair
4. Good
5. Excellent

Table 5 : Product Durability and Flexibility

DURABILITY

		Ratings					
		Panels					
		Temperature	Radiation	Chemicals	Water	Pests	General
0	Conventional Construction	4	5	5	2	3	3
1	Open Sheathed Panels						
1.1	• w/ OSB Sheathing	4	5	5	2	3	4
1.2	• w/ XEPS Sheathing	3	3	4	3	3	4
2	Structural Sandwich Panels						
2.1	• w/MEPS Core	3	4	3	4	2	2
2.2	• w/XEPS Core	3	3	3	5	2	2
2.3	• w/PUR/ISO Core	3	4	3	5	2	2
3	Unsheathed Structural Panels						
3.1	• w/Thermal Break						
3.2	• w/Thermal Break & Air Space	3	5	3	4	2	4
3.3	• w/o Thermal Break; w/Air Space						
3.4	• w/Metal frame						

- Assumes exposure; based on tendency to stain, deform, delaminate, disintegrate, decay, corrode or lose performance characteristics (eg. loss of R-value in foam insulation due to low temperatures)
- General catagory includes tendency to lose performance either as a function of natural aging (eg. thermal drift) or as a consequence of deterioration of materials (eg. loss of structural strength of sandwich panels with disintegration of foam core)

Rating Scale:
1. Very Poor
2. Poor
3. Fair
4. Good
5. Excellent

FLEXIBILITY/ADAPTABILITY

MANUFACTURING/CONSTRUCTION

		Structure	Electrical	Int. Finishes
0	Conventional Construction	5	5	5
1	Open Sheathed Panels	3	5	5
2	Structural Sandwich Panels	4	2	3
3	Unsheathed Structural Panels			
3.1	• w/Thermal Break	2	3	5
3.2	• w/Thermal Break & Air Space	2	4	5
3.3	• w/o Thermal Break; w/Air Space	3	4	5
3.4	• w/Metal frame	2	3	3

Rating Scale:
Based on restrictions imposed by the system in terms of design, site modification or adaptation by occupants:
1. No Change Possible
2. Very Limited
3. Somewhat Limited
4. Few Limitations
5. No Limitations

OCCUPANCY

		Wall				Electrical
		Struct	Insul	VB	AVE	
0	Conventional Construction	4	4	4	4	4
1	Open Sheathed Panels	4	4	4	4	4
2	Structural Sandwich Panels	1	1	5	2.3	2
3	Unfaced Structural Panel Systems					
3.1	• w/Thermal Break	3	4	4	3.7	3
3.2	• w/Thermal Break & Air Space	3	4	4	3.7	3
3.3	• w/o Thermal Break; w/Air Space	4	4	4	4	3
3.4	• w/Metal frame	2	4	4	3.3	3

Table 6 : Ease of Assembly

TRADES AFFECTED

		Trade								Tot	RATING
		A	B	C	D	E	F	G	H		
0	Conventional Construction	4	4	4	4	4	4	4	4	32	**5**
1	Open Sheathed Panels	2	4	4	4	4	4	4	4.5	30.5	**4**
2	Structural Sandwich Panels	1	3	5	3	1	4	4	4.5	25.5	**1**
3	Unsheathed Structural Panels										
3.1	• w/Thermal Break	2	4	5	3	2	4	4	4.5	28.5	**2**
3.2	• w/Thermal Break & Air Space	2	4	5	3	3	4	4	4.5	29.5	**3**
3.3	• w/o Thermal Break; w/Air Space	2	4	5	3	3	4	4	4.5	29.5	**3**
3.3	• w/Metal frame	2	4	5	3	2	4	4	4.5	28.5	**2**

Trades:

- A Rough Carpentry
- B Roofing
- C Insulation/v.b inst.
- D Plumbing
- E Electrical
- F Drywall inst.
- G Finish Carpentry
- H Cleaning

Rating Scale:

1. Trade Affected Considerably
2. Trade Affected Somewhat
3. Trade Affected Slightly
4. Trade Not Affected
5. Trade Eliminated

TOOLS REQUIRED

		Operation			Tot	RTG
		Lifting	Fastening	Cutting		
0	Conventional Construction	4	4	4	12	**5**
1	Open Sheathed Panels	2	4	4	10	**4**
2	Structural Sandwich Panels	2	3	3	8	**2**
3	Unsheathed Structural Panels	2	4	4	10	**3**

Rating Scale:

1. Specialized Tools Required/ Special Training or Operator
2. Specialized Tools Required
3. Specialized Tools Helpful
4. No Additional Tools Required
5. Less Tools Required

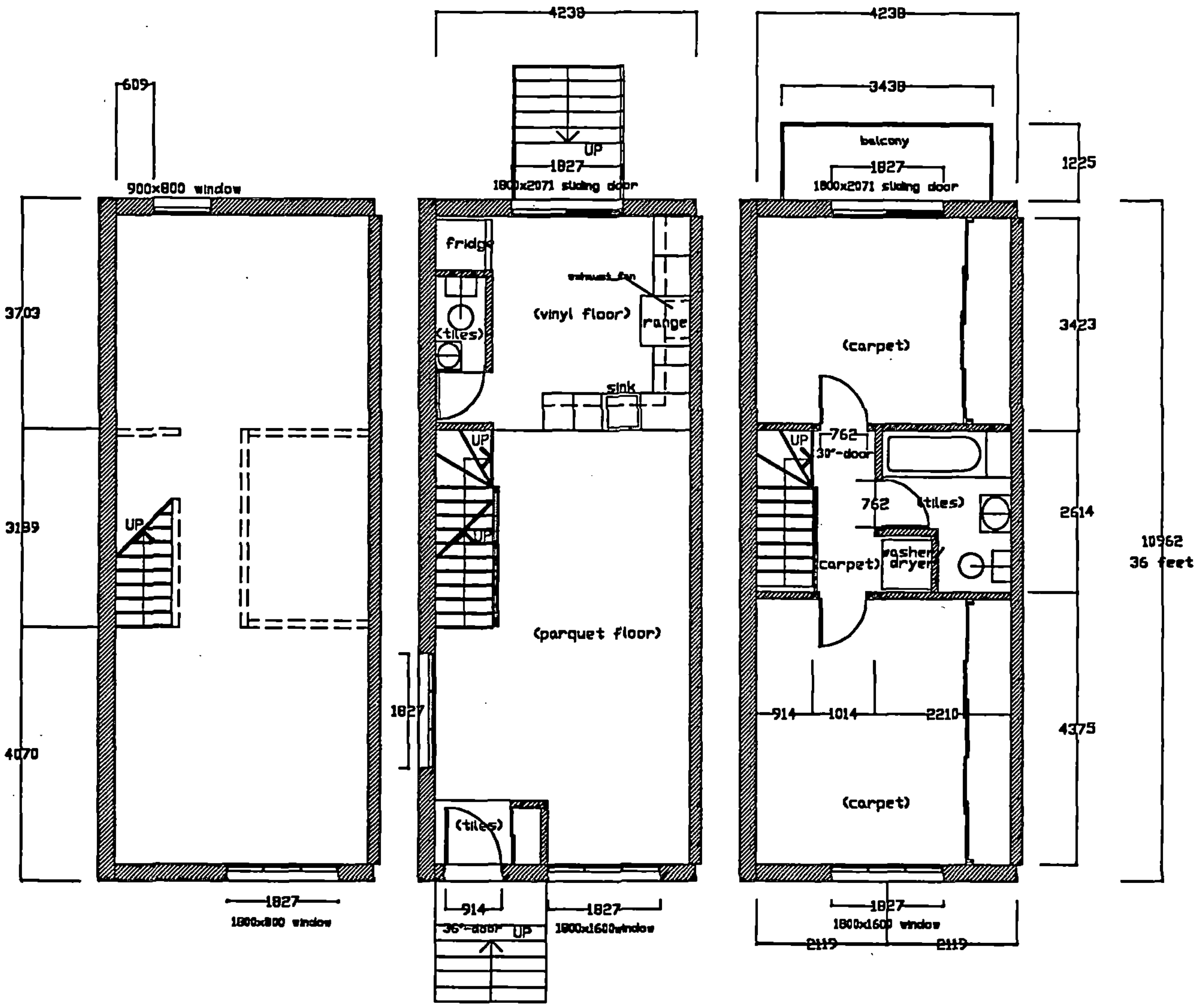
SKILL REQUIRED

		Structure			Electrical	Interior Finishes	Total	RTG
		Panels	Corners	Openings				
0	Conventional Construction	4	4	4	4	4	20	**5**
1	Open Sheathed Panels	3	3	3	4	4	17	**4**
2	Structural Sandwich Panels	2	2	1	1	4	10	**2**
3	Unsheathed Structural Panels	3	3	2	3	4	15	**3**

Rating System:

1 Training Required; Significant Difficulty
2 Training Required; Some Difficulty
3 Training Required; Minimal Difficulty
4 No Training Required; Equal Difficulty
5 No Training Required; Less Difficulty

APPENDIX D



Basement level   Ground level   Upper level

Floor Plans - Type OC / End Unit (Preliminary)	Drawn by: Paola DeGhenghi	Scale: 1: 100	Page: 1/3
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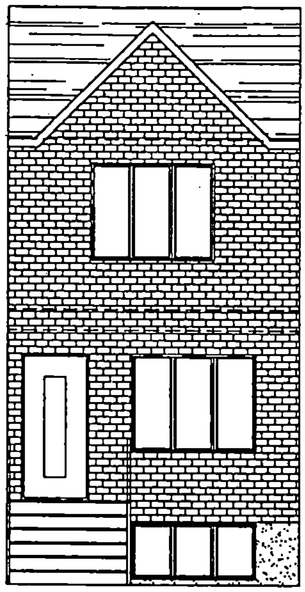
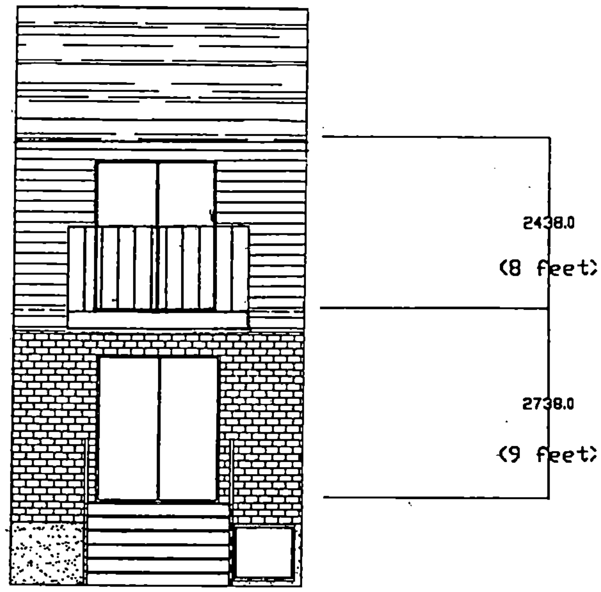
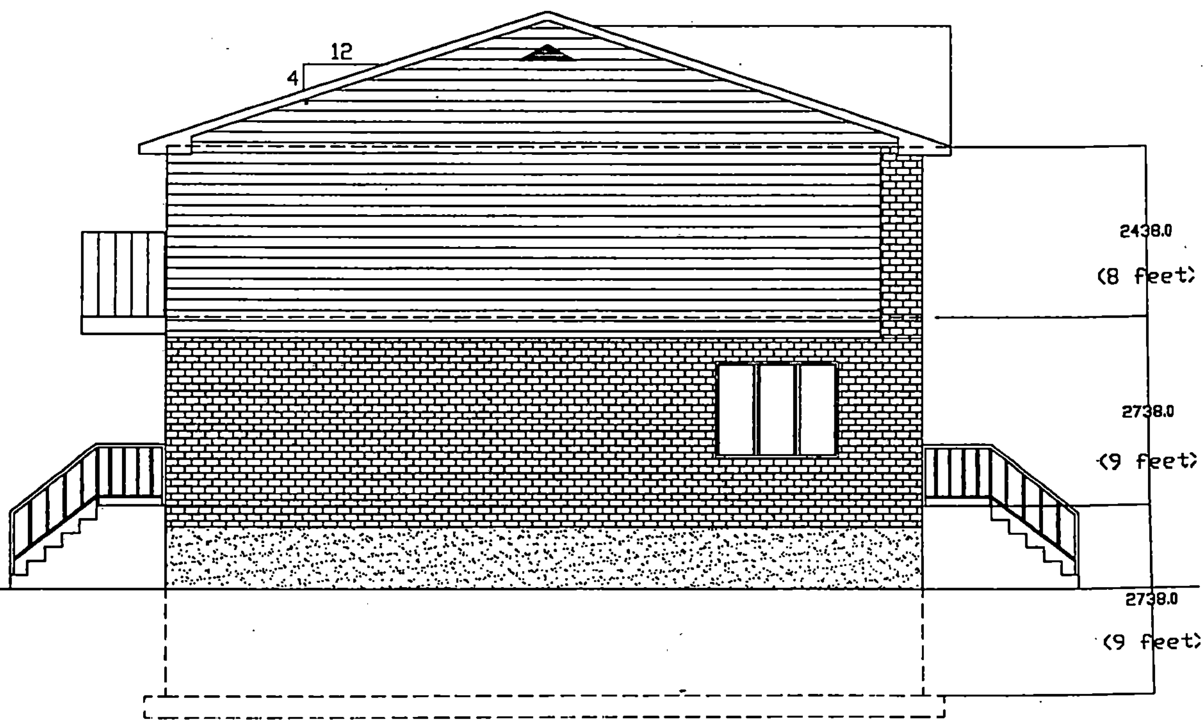


Front Elevation



Back Elevation



Side Elevation

Elevations - Type OC/End Unit (Preliminary)	Drawn by: Paola DeGhenghi	Scale: 1: 100	Page: 2/3
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Footings

- 300 x 750 mm concrete footings at 1500 mm below grade, with 38 x 89 mm continuous key at center of wall
- 100 mm PVC corrugated drainage pipe, covered with 300 mm (min.) crushed stone (19 net)

Basement Walls

- 12.7 mm gypsum wallboard
- 0.15 mm poly vapour barrier
- 38 x 89 mm studs at 400 mm o.c., with 90 mm (RSI 2.11) batt insulation (to slab)
- 13 mm air space
- 250 mm concrete wall,with 2 rebars (10M) at top and bottom
- Waterproofing to grade, 2 coats
- Cement parging above grade

Basement Floor

- 100 mm concrete slab, with mesh reinforcement (6/6 @ 150 x 150)
- 0.15 poly moisture barrier
- 3000 mm crushed stone (0 to 19)

Structure (general)

- All wood is eastern spruce, No. 2 or better

- Walls with sole and double plate at top (except in basement); double studs at openings, with 38 x 140 mm lintels. Stairs to be enclosed with 1000 mm high partition; same detail.

- Floors with 2 rows of blocking; double joists under partitions and perimeter of openings; header at perimeter with plates bolted to foundation wall. Firestops to be installed at each floor level in air space of dividing wall.

- Stairs of 32 mm pine board, round nose, supported on 38 x 235 mm wood stringers

- Balcony floor of fiberglass-costed plywood, custom made.

Exterior Walls

- 12.7 mm gypsum wallboard

+

*
- 0.15 mm poly vapour barrier
- 38 x 140 studs at 400 mm o.c., with 140 mm (RSI 3.52) batt insulation
- 12.7 mm plywood sheathing
- Spun-bonded polyolefin membrane weather barrier

+

- 19 x 64 mm furring at 400 mm o.c.
- Aluminum siding

<u>or</u>

- 25 mm air space
- 100 mm clay brick (52.75 bricks/sq.m.), with nervastral flashing at bottom

Dividing Walls

- 15.9 mm gypsum wallboard, fire rated
- 38 x 89 mm studs at 400 mm o.c., with 90 mm batt insulation
- 25 mm air space
- 12.7 mm gypsum wallboard, 2 layers
- 38 x 89 mm studs at 400 mm o.c., with 90 mm batt insulation
- 15.9 mm gypsum wallboard, fire rated

Dividing Walls (Basement)

- 12.7 mm gypsum wallboard
- 38 x 64 mm studs at 600 mm o.c., with 64 mm batt insulation
- 200 mm concrete block
- 12.7 mm gypsum wallboard, 2 layers
- 38 x 64 mm studs at 600 mm o.c., with 64 mm batt insulation
- 12.7 mm gypsum wallboard

Roof

- 12.7 mm gypsum wallboard
- 0.15 mm poly vapour barrier
- Prefabricated trusses, 600 mm o.c., sloped 4:12, with 260 mm (RSI 7.04) batt insulation
- 15.9 mm waferboarddeck
- 1 layer building paper
- Asphalt shingles

+

- Aluminum fascia, perforated aluminum soffit

Floors

- 12.7 mm gypsum wallboard

*
- 38 x 235 mm joists at 400 mm o.c.
- 15.9 mm waferboard deck

Interior Partitions

- 12.7 mm gypsum wallboard
- 38 x 89 mm studs at 600 mm o.c.
- 12.7 mm gypsum wallboard

2 coats latex paint and primer

Doors and Windows

- Exterior doors: insulated metal
- Interior doors: 35 mm hollow core, with masonite facing
- Wardrobe doors: mirrored sliding, full height (2400 mm)
- Patio doors: insulated glass; vinyl frame
- Windows: casement; aluminum-clad wood; sliding vinyl in basement.

Finishes/Furnishings

- Paint: one primer and two finish coats (latex) on all walls, ceilings, doors, trims and baseboards (except in basement)

- Floor finishes to be glued directly to subfloor

- Pine baseboard, 114 mm high

- Pine door frames (for painting) with moulding on both sides and recessed door stopper

- Wood shelves in wardrobes, 300 mm wide with pole and supports

- Kitchen cabinets and bathroom vanities of melamine over presswood core, standard product; prefabricated modular units

- Steel railings on exterior, 13 x 13 mm bars at 100 mm o.c., with flat bars at 100 and 1000 mm above deck/floor

* Specification changes according to prefabricated system

General Specifications (Preliminary)	Drawn by: ----------	Scale: ------	Page: 3/3
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