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The Potential for Improved Affordability and Energy Efficiency in Panelized Housing

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ABSTRACT

This paper reviews a study of benefits and costs associated with modifying one panelized housing manufacturer's methods in favor of techniques designed to reduce energy use and construction costs, while improving quality and productivity. Three options were considered for improving the performance of wall panel construction: (1) pre-insulated, strapped walls; (2) foam-core walls; and (3) longer panels that incorporate optimum value engineering (OVE) and advanced sealing techniques. The longer panel option was selected for a detailed analysis that included consideration of energy benefits, material costs, labor costs and productivity, changes in manufacturing procedures, material flow through the plant, site delivery and erection, and other factors that would influence the value of the option. Although the analysis indicated significant production cost and eventual consumer energy savings resulting from modification of the product line, plant layout and dealer marketing barriers prevented the manufacturer from adopting all the techniques recommended.

INTRODUCTION

This paper summarizes the results of an evaluative study of options for improving the energy efficiency of factory-built housing components. This study was completed under phase 1 of the New York State Energy Authority's Innovative Energy-Efficient Building Components and Construction program. Participants in the study were a panelized home manufacturer, a construction industry consulting firm, and university researchers.

The panelized home manufacturer is listed by *Automated Builder* as the eighth largest panelizer/pre-cutter in the U.S. with gross sales of about $24 million (1990) on an annual volume of about 300 homes (Carlson 1990). It has two plants and a network of 130 dealers. (The phase 1 evaluation was conducted in cooperation with personnel of one of the plants.) The manufacturer produces building components, including wall panels, trusses, and joists and delivers other materials necessary to make the building envelope weathertight (e.g., windows, insulation, doors, sheathing products, etc.). The building package includes all materials needed to erect the structural and thermal envelope, excluding the foundation.

Current framing practice for exterior wall panels is the use of 2-in. by 6-in. studs, placed 16 inches on center with built-up headers over doors and windows consisting of triple 2-in. by 8-in. dimension lumber. (Although placement of the studs at 24 inches on center would be structurally sufficient, the manufacturer acknowledged local dealer and consumer resistance to the practice.) The wall panels rarely exceed 16 feet in length. Exterior sheathing is attached to the panels in the plant and is typically 7/16-inch oriented strandboard. Other products, such as insulation, windows, doors, and finishes, are installed at the building site. In addition to producing wall panels, the manufacturer pre-engineers roof trusses. Components are provided for a range of commercial and residential building types, although housing represents the majority of product sales.

In the residential market, the manufacturer offers a wide range of standard models. Many buyers, however, prefer to modify a standard product or, quite commonly, provide a custom design. In the latter case, the manufacturer will develop a new set of panel and working drawings and provide design and engineering assistance to the home buyer.

The independent dealer network handles most sales, and erection of the package is subcontracted to local builders not affiliated with the manufacturer. This indirect linkage between manufacturer and builder impedes the implementation of new methods of construction. Consequently, any change in the manufacturer's erection procedures—developed through this or similar efforts—would unreliably depend on the voluntary participation of diverse and numerous builders. For this reason, the technologies described herein require only minor changes in the method of product erection.

TECHNOLOGY ASSESSMENT AND SELECTION

Three variations on the manufacturer's standard wall-framing procedures were proposed for evaluation: (1) strapped walls, (2) foam-core walls, and (3) lengthened and gasketed walls applying principles of optimum value engineering. These technologies are in current use, although mainly by low-volume, cutting-edge home builders and manufacturers. As a preliminary step in quantifying benefits and costs to the manufacturer associated with adopting one

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or more of these approaches, the project team and manufacturing staff were challenged with having to describe changes necessary to adapt the techniques for factory fabrication.

Strapped Wall

A construction method familiar to many Canadian home builders but not widely used in the United States, strapped walls differ from typical wood-framed walls in that the insulation and air/vapor retarder systems are not interrupted with components of mechanical systems (CHBA 1989). For an energy-efficient home, the first layer of the wall is framed with 2-by-6s, 24 inches on center. This section of the assembly is insulated with fiberglass batts and covered with a continuous air/vapor retarder of 4- to 6-mil polyethylene. Then, 2-by-2s are installed horizontally on the face of this component, 24 inches on center. The chases formed by these 2-by-2s are used for electrical wires and boxes and water supply pipes. The technical and economic viability of strapped walls has been demonstrated in site-built homes, particularly in custom home markets. A high degree of energy efficiency is achieved with this procedure because of the lack of insulation voids that are typically created when mechanical components are installed in exterior walls. But because of the additional labor required at building sites, the technology is expensive. By introducing this as an innovation to the product line, however, little additional cost would be incurred. Currently, insulation and air/vapor retarders are added at the building site, at a labor cost higher than that of the manufacturer's factory workers. Savings realized by having these steps performed in the factory would more than offset the additional cost of 2-by-2 strapping.

From a factory manufacturing standpoint, the principal disadvantage of strapped wall construction is the need to fasten materials to both sides of the structural frame. Since exterior sheathing is applied in the plant, the panel must be turned over to install the insulation and the batten strips, an operation requiring a significant amount of additional handling and a considerable capital outlay for hardware. Further, since strapped walls call for the insulation and vapor retarder to be installed before the battens are attached, there is also the concern that these materials might be damaged during the truck loading and unloading operations. For these reasons, the manufacturer decided to exclude strapped walls from further consideration.

Foam-Core Panels

The second option discussed was the use of foam-core panels. This technology is used throughout the U.S. mainly by small- to medium-volume manufacturers and builders. While there are perhaps only a few thousand foam-core homes built each year, the numbers are growing, and, while the costs tend to be slightly higher than those for conventional frame building, there are several clear and compelling advantages to this type of construction. Foam-core walls consist of a sandwich panel type of construction that is highly energy-efficient and can significantly reduce labor erection time. Because foam-core panels are typically built in large sections cut to precise tolerances and are often assembled with the aid of large tools that are difficult to transport, a factory environment is essential to their manufacture. Foam-core panels are manufactured with thin and rigid outer and inner skins, which, when laminated to a foam insulation core, have a high structural strength that far exceeds that of conventional wood frame construction.

Benefits of foam-core construction include simplicity and speed of erection. In many instances, a finished plywood panel (e.g., T1-11) is used as the exterior face of the wall panel and gypsum board or oriented strandboard (OSB) as the interior surface. Site finish time is, therefore, minimal when compared to site building practices. The panels are erected with interlocking spline joints that are easy to caulk and offer a very tight barrier against infiltration. The insulation used for the core is either expanded polystyrene (EPS) or urethane, products that have higher per-inch R-values than does fiberglass. Of the two alternatives, EPS is more advantageous, since the first cost tends to be lower per unit of R-value than urethane and there is no perceptible degradation of R-value over time. In general, foam-core walls have a slightly higher material first cost than stick-built with fiberglass but, as noted, a lower installation cost.

The manufacturer's involvement with foam-core panels could take two forms: install a separate production line dedicated to manufacturing the panels (initially as a parallel operation to the frame panelization line) or purchase panels from another vendor at wholesale. The former option was rejected by the manufacturer due to the high capital cost involved and the uncertain nature of the market for foam-core products. Purchasing panels, both for walls and ceilings, was of greater interest, partly because it decreased the amount of value-added work for the factory. Another advantage of foam-core ceiling panels is their clear-span capability, which eliminates the need for truss-like interstitial supports. The open space in the attic can then be marketed as potential living space. The manufacturer expressed concern, however, that market conservatism and the need to retrain the independent contractors would pose formidable economic and administrative barriers and for these reasons removed the foam-core approach from consideration for wall construction.

Lengthened, Gasketed, OVE Walls

The third technology considered was optimum value engineered (OVE) long-wall panels sealed with high-quality, long-life gaskets. OVE is "a procedure of comparing alternative materials and methods to determine the least costly combination that will result in an acceptable product" (HUD 1979). For example, practices common to OVE include modular dimensioning, coordination of framing materials with standard dimensions and with each other, and the coordination of openings with framing members. Use of OVE principles results in reduced construction costs through a methodical and integrated building process.

An additional way in which efficiency of constructing wall assemblies can be greatly improved is by increasing their length in the factory. In Sweden, for example, most housing manufacturers now produce large wall sections of about 32 feet in length that are installed at the building site with a crane. The large components minimize the number of joints in the envelope, providing a highly energy-efficient building skin. In addition, the small number of large components allows the homes to be made weathertight in one day.

The energy efficiency of these wall components can be further improved with the addition of gasket sealing around wall panel perimeters. Now common in Scandinavian factory-built homes, this use of gaskets results in a high degree of airtightness not achievable through common reliance on standard caulking techniques. In addition, considerable savings in building materials can be realized through the incorporation of principles derived from optimum value engineering (OVE), particularly those associated with a more efficient use of lumber. Savings realized through reliance on OVE principles would contribute to affordability improvements. According to research results from the National Association of Home Builders, adoption of OVE would result in one extra home for every 10 produced using current practices (HUD 1979).

In addition to evaluating changes to the construction and length of wall components, the installation of windows at the factory was examined, a technique that by itself could result in substantial labor savings per house. Changes to labor training procedures—both in the factory and at the site—and modifications to the trucks used to transport panels were also evaluated.

Most Scandinavian panel manufacturers install the insulation and fenestration in the panels during the fabrication process, and many close the wall with gypsum board or similar material prior to shipping. When the closed wall panel is placed on the floor or foundation at the site, only a final finish (e.g., painting) is needed. Panels with electric service frequently have factory-installed conduit, simplifying the field operations. Among the advantages of this approach are the following: most of the critical steps in the construction process are performed in the plant under controlled conditions; field installation time is minimized, reducing exposure to the elements and abbreviating total installation time; and some technical advances can only practically be applied in the factory. (An example of the latter is the installation of windows in the wall panels. Techniques were developed by Swedish companies for framing and sealing the windows in less than 10 minutes. Installing windows at the site typically takes substantially longer, and the quality of the seals is lower.)

The manufacturer's staff directed the research team to perform a detailed evaluation of this option with the exception that only the frame and sheathing would be factory-assembled (representing no change in material use relative to current practice). One of the manufacturer's objections to emulating the Scandinavian practice of factory installation of windows, doors, insulation, and vapor retarders in the panels is the need to ship these panels vertically, rather than stacked horizontally, as is current practice. Also, contrary to the research team's preconceptions, the manufacturer cited previous experience in not deriving a net economic benefit as the amount of value-added in the plant is increased. (This would tend to argue against the strapped wall option as well.) In addition, a large part of the savings is realized at the point of erection through reduced site labor, a factor that the manufacturer is not positioned to use easily to advantage. The team analyzed the long-wall option as modified using the manufacturer's standard home model as the basis for comparison.

ANALYSIS OF WALL PANELS

Existing Panels

Table 1 summarizes the salient characteristics of the 13 wall panels that currently compose the manufacturer's standard model. Column 1 contains the identifying labels assigned by the manufacturer to the panels. Columns 2 and 3 list the panel length and area dimensions, respectively. All panels in this model are 7 feet, 8½ inches in height. Column 4 provides the sum of the costs for framing and sheathing materials expressed freight on board (f.o.b.) at the plant. This value does not include the labor cost for assembly or other markups, such as overhead, delivery, profit, etc. Therefore, the costs to the home buyer would be considerably higher.

The weight of the open, uninsulated panel is listed in column 5. The range of weights, from just over 200 pounds to slightly less than 500 pounds, suggests the type and capacity of lifting mechanisms needed to move the panels around the plant and unload and install the panels at the site. Finally, column 6 provides a computation of the panel U_w-value, which is an area-weighted average of all the panels.

Modified Panels

The physical, thermal, and cost characteristics of the proposed long-wall panels are provided in Table 2. The original design was based on a 13-panel scheme that is reduced to eight panels in the proposal. Column 1 of Table 2 provides a numerical designation for the panels. The panel characteristics are listed under columns 2 through 6 and are displayed in the same sequence as those provided in Table 1 for current panel designs.

In the proposed panel scheme, the maximum panel length is 24 feet, as compared to the current maximum of 12 feet, and the average panel lengths for the two proposed and existing schemes are 16.77 feet and 10.32 feet, respectively. The smaller number of panels and longer average

TABLE 1
Description of Current Panel Construction for Standard Model

(1) As-Built Wall Section	(2) Length (ft)	(3) Area (ft^2)	(4) Cost ($)	(5) Weight (lbs)	(6) U_w-Value
W1	5.33	44.63	27.19	223	0.062
W2	10.91	84.17	55.79	452	0.091
W3	8.12	62.64	34.55	288	0.061
W4	9.46	73.05	48.91	392	0.128
W5	10.36	79.93	50.14	404	0.121
W6	12.17	93.96	49.85	412	0.059
W7	11.71	90.37	49.11	407	0.060
W8	12.17	93.96	57.07	461	0.111
W9	12.17	93.96	58.81	475	0.112
W10	9.47	73.08	43.85	351	0.069
W11	10.36	79.93	49.60	394	0.187
W12	11.50	88.74	57.93	466	0.116
W13	12.41	103.77	59.90	486	0.066
Totals	**136.13**	**1,062.19**	**$642.70**	**5,211**	**0.096**

TABLE 2
Description of Proposed Panel Construction for Standard Model

(1) Proposed Wall Section	(2) Length (ft)	(3) Area (ft^2)	(4) Cost ($)	(5) Weight (lbs)	(6) U_w-Value
PW1	5.34	44.63	22.19	183	0.0584
PW2	14.95	115.41	53.92	454	0.766
PW3	23.89	184.45	77.04	638	0.1039
PW4	23.88	184.32	77.52	657	0.0566
PW5	24.35	187.92	80.09	664	0.1037
PW6	19.82	153.00	77.80	617	0.1235
PW7	11.50	88.74	41.31	339	0.1071
PW8	12.21	102.06	50.86	416	0.0608
Totals	**136.13**	**1,062.19**	**$480.73**	**3,968**	**0.0897**

lengths decrease the number of joints, reducing material costs and eliminating some of the thermal bridging associated with frame construction. The larger panels also engender an increase in maximum panel weight from about 500 pounds for the heaviest of the existing panels to just under 700 pounds for the largest of the proposed panels. Allowances will need to be made in plant layout, lifting mechanisms, loading procedures, and site installation for these larger, heavier panels.

The major change in plant layout would include the addition of a framing table (longer than the current table) that can accommodate a 24-foot panel and also provide for framing at 24 inches on center. Pre-cut studs are currently stored along one side of the framing table. With a longer table, stud storage may be needed on both sides of the framing table or at both ends. In addition to the space requirement of a larger framing table is the need for space to maneuver and store panels up to 24 feet in length. The clear space required to rotate, reverse, align, and otherwise maneuver long-wall panels on the framing table and suspended from a crane would have to be taken from other factory operations (not examined in this study). As a result, current storage space, often a critical need due to normal changes in production scheduling, will be in even greater demand. Existing cranes have a one-half-ton capacity, which is adequate for the increased panel weight. However, the current practice of point-load lifting would be unsatisfactory for some panels. Such panels would require the use of a spreader bar. The increased panel length would also sacrifice some truck-loading flexibility because fewer panel sizes are available to organize a tightly packed load.

Comparative Analysis of Construction Process Modification

The theoretical impact of the proposed panel configuration compared with existing practice is illustrated in Table 3. Based solely on the aspects listed in this table, the

TABLE 3
Comparison of Proposed Panel Construction with Existing Practice[1]

	Material Cost ($)	Labor Cost[2] ($)	Total Cost ($)	Fabrication Time (hrs)[3]	Energy Cost ($/yr)[4]	Weight (lb)
As-Built	643.00	19.92	663.00	1.29	303.00	5,211
Proposed	481.00	13.60	495.00	0.878	226.00	3.972
Savings	$162.00 (25%)	$6.32 (32%)	$168.00 (25%)	0.41 (32%)	$77.00 (25%)	1,239 (24%)

[1]Based on the standard model.
[2]Two workers @ $7.75/hr; framing table only.
[3]Framing and erection time only.
[4]Attributable to wall-finished wall panels and air infiltration only.

lengthened and gasketed OVE long-wall option provides an array of substantive benefits. Both the material and labor costs are lower with this alternative. The material savings are estimated to be $162, a 25% reduction. Labor costs are reduced by $6.32, a 32% savings over existing practice. These figures include direct costs to the manufacturer; potential savings to the home buyer would be multiples of these values.

As implied by the labor savings, plant fabrication and site placement time of panels is also reduced from 1.975 hours per unit for framing and erection to 1.30 hours, a 34% reduction. Due to the difficulty in characterizing and quantifying how labor is affected by procedural and material changes, this is a rough approximation based on the manufacturer's experience, which the research team hopes to verify in a proposed demonstration. The reduction in energy cost is due to two factors: (1) the decrease in the overall U-value associated with the elimination of some of the framing members, and (2) the reduction in the wall-related infiltration, a consequence of using gaskets on all the panel seams and decreasing the total seam length. Occupant energy costs assignable only to the walls are expected to drop about $77 or 25% for this relatively small home (one story, 960 ft^2).

The energy savings from the wall panel changes were derived from two sources: (1) the change in the U-value for the wall from removing wood and installing fiberglass and (2) the reduction in infiltration losses resulting from gasket sealing. The effective leakage area method (ASHRAE 1989) was used for the infiltration calculations.

A final factor that is partly reflected in the material savings is the reduction in the total weight of the structure of about 1,239 pounds or 24% of the original cumulative panel weights. Further investigation is warranted to determine whether collateral savings are possible through modifications in the structural design of the foundation.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of the lengthened and gasketed OVE long-wall option demonstrated advantages of substantial dollar savings in labor and materials and energy savings for buyers. In addition, this option would require minimal contractor retraining and factory retooling. The smaller number of panels required for the house under study and their longer lengths decrease the number of joints. A reduction in the number of studs from the use of OVE decreases costs for materials and also results in energy savings from reduced thermal bridging.

The results of this analysis were presented to the manufacturer, and a meeting was held to discuss implications. In spite of the savings potential from longer panels, company personnel do not feel that this option can be implemented because of concerns related to site handling under conditions of high wind. This is currently an installation issue with panels as they are presently sized. Dealer resistance to longer panels is likely and would pose obstacles to implementation of this option.

Gasket sealing of the panels was considered to be a viable option and will be implemented in upgraded energy-efficient models. Installation procedures will include factory placement of vertical gaskets on panel edges and site placement of horizontal gaskets on panel bottoms. There is some concern about potential damage that may be caused to the gaskets during truck loading and unloading, but employee training in the factory and at building sites should overcome any problems in this regard.

The manufacturer recognizes the considerable advantages to be gained from use of OVE building techniques and will consider this option further. Serious resistance from dealers and buyers is expected because of a lack of understanding of this method of construction. To overcome these obstacles, an awareness campaign would have to be conducted that would be targeted to both groups. The campaign would need to stress OVE principles, construction strength, and cost savings. Employees in the factory would also be targeted for a training program in this method.

While not all recommendations of this study will be implemented immediately by the manufacturer, the initial step of gasket sealing may increase awareness of factory employees, dealers, and site contractors of building methods to increase energy efficiency, which may lead to further efficiency increases in the future.

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