EMERGING NONWOOD BUILDING MATERIALS IN RESIDENTIAL CONSTRUCTION

HENRY SPELTER

ABSTRACT

The residential and low-rise building markets in Canada and the United States have been traditionally dominated by frame-style wood construction. Recent fluctuations in timber markets, however, have contributed to an upsurge in the volatility and level of lumber prices, which has stimulated interest among builders in alternative building materials. This report describes the development of steel, concrete, and sandwich panel wall systems, and compares their costs to that of wood-frame construction. In-place cost comparisons suggest that at this time wood systems continue to offer the most economical method of construction. However, lifetime cost savings can favor nonwood systems, so their attractiveness depends on an individual's payback expectation.

This paper reviews some alternatives to low-rise wood construction appearing on the market in Canada and the United States. In these countries, wood has traditionally been the favored material for low-rise structures (1,7,12). However, many novel products and systems have appeared within the past decade (11,13,14). Wood prices have also risen, eroding some of the cost advantage of wood relative to other materials **(Fig. 1).** In past episodes of sharply rising wood prices, builders also looked at wood substitutes (6), but once wood prices fell, their interest waned and the normal pattern of material use continued. In the recent period of wood market price volatility, producers of other materials are again bidding for a greater share of the residential and low-rise construction markets.

The main competitors for softwood lumber are concrete, steel, and plastic. One component of the competitiveness of products that is measurable and comparable is their installed cost. This component is examined here, along with some other ramifications of building with alternative products.

DESCRIPTION OF WALL SYSTEMS

STEEL SYSTEMS

Lightweight galvanized steel studs are widely used in high-rise and commercial construction. These materials have been offered as a homebuilding alternative for many decades, but they have made few inroads until recently (13). Among nonwood alternatives, steel studs replicate wood frame the closest and are regarded as the easiest materials for builders to adapt to. However, the use of steel as a one-for-one replacement for wood does not take optimal advantage of the material's strength. There is also an absence of standardized framing procedures and their incorporation into major building codes. Presently, a builder who wants to use steel systems in load-bearing assemblies would need engineering analysis and approval, which can add several thousand dollars to the cost. Steel also has high thermal conductivity, which can reduce a wall's insulating value by 50 percent relative to wood. Several modifications of the steel stud system have been advanced to improve its thermal performance, mostly along the lines of reducing the area of steel/sheathing contact. However, measured R-value improvements have been on the order of only 6 to 15 percent, relative to the standard C-section steel stud.

For interior, non-load-bearing walls, steel studs can be made half as light as load-bearing studs, thereby reducing their cost. With no thermal or load-bearing ramifications, a one-for-one replacement of wood by steel is more directly a question of relative cost. Consequently, many builders have switched to using steel.

CONCRETE SYSTEMS

A full description of the many new concrete wall systems is not possible here; Vanderwerf and Munsell (14) provide a more complete description of these systems. Concrete is widely used in residential structures for slabs and foundations. However, as wood prices have risen, many concrete-based systems have been offered as alternatives for above-grade walls as well. This change in emphasis may accelerate if the use of shallow, frost-protected foundations in cold climates, as recently endorsed by the Council of American Building Officials' (CABO), leads to greater use of slab foundations.

The author is an Economist, USDA Forest Serv., Forest Products Laboratory, One Gifford Pinchot Dr., Madison, WI 53705-2398. This paper was received for publication in August 1995. Reprint No. 8403.
©Forest Products Society 1996.
Forest Prod. J. 46(7/8):29-36.

Traditionally, the structural advantages of reinforced concrete were offset by disadvantages in appearance, thermal insulation, and moisture absorbance. The developers of contemporary systems claim to have addressed these shortcomings. New concrete wall systems can be placed into three basic categories: 1) poured concrete; 2) concrete block; and 3) precast concrete panels.

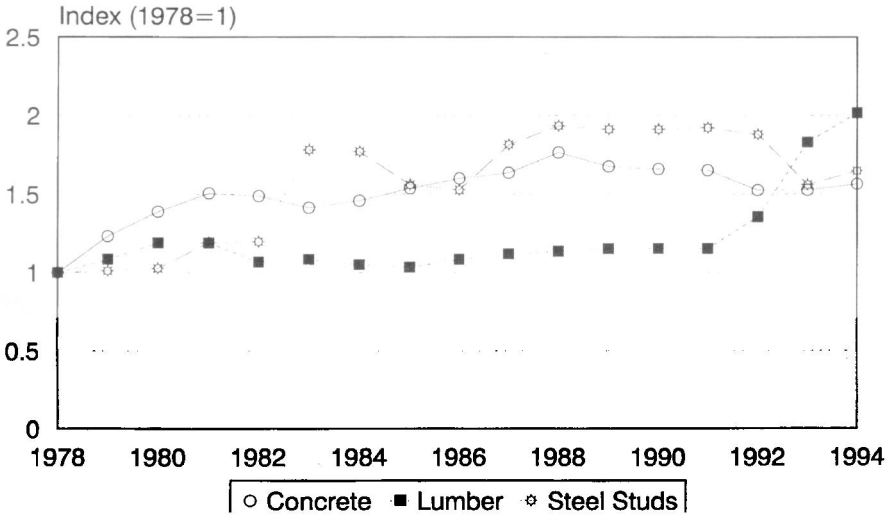

Figure 1. — Concrete, lumber, and steel stud prices, 1978-1994 (8).

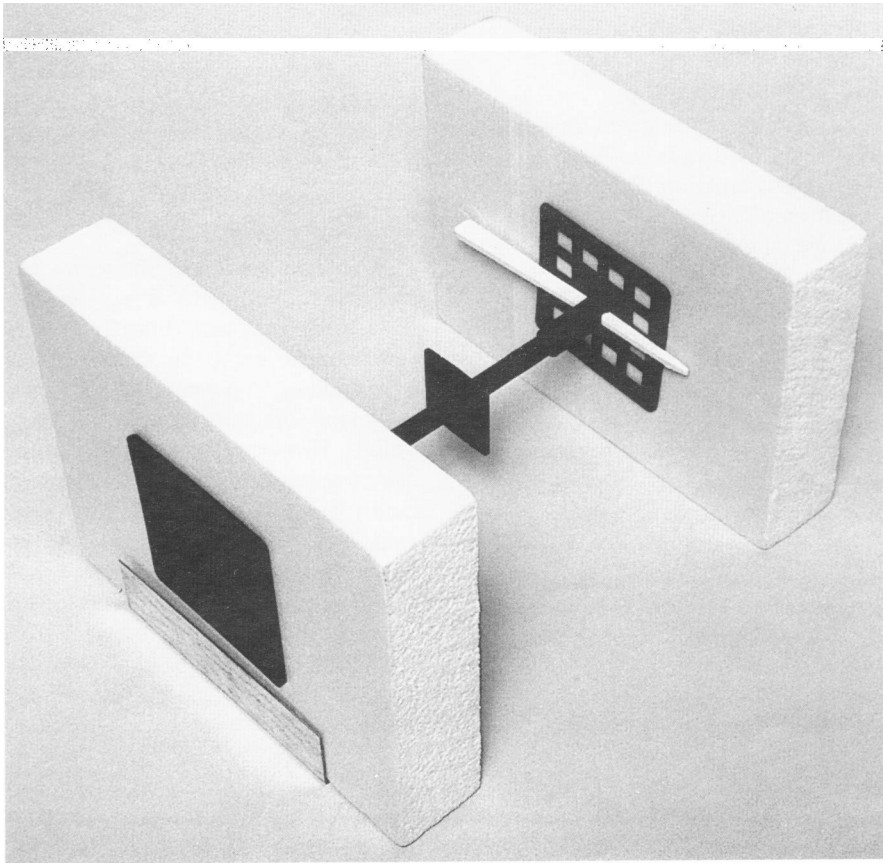

Figure 2. — Elements of insulated concrete form: channel guide, adjustable plastic tie, and polystyrene sheets.

Poured concrete walls. — Conventional poured concrete walls require extensive form work that has to be erected on-site, kept in-place for several days while the concrete cures, and then disassembled, cleaned, and stored for future use. If the wall is to be upgraded to livable area, further work is required to insulate, waterproof, and finish it. New poured concrete wall systems shortcut this process by the use of rigid, plastic foam form work that is left permanently in place. The foam contains the concrete during the pour and provides insulation for the wall thereafter. These new systems fall into two classes based on the type of concrete structure Case monolithic slabs and post-and-beam grids.

Monolithic slab walls differ from conventionally cast-in-place (CIP) walls chiefly in the use of polystyrene forms held together by plastic ties **(Fig. 2)** instead of plywood held together by metal ties. Because plastic ties are noncorrosive, they do not react with concrete. Plastic reduces thermal bridging because of its lower conductivity. The large pads on the tie ends can also double as embedded studs to which screws for exterior or interior facings or 'furring can be attached.

Although the density of the polystyrene sheets used as forms is higher than that of polystyrene sheathing, foam is nevertheless weaker than plywood used in conventional forms. Consequently, considerable bracing may be required to prevent the pressure of the concrete from breaking or bending the foam **(Fig. 3).** Thus, the pouring of the concrete is the most critical step in the process. If the concrete is poured too quickly or allowed to fall from too high a distance, the chance of bulging or breakage increases. Several systems are available with various tie spacings: 5, 8, 12, and 16 inches. (See **Table 1** for SI conversion factors.) Generally, the greater the number of ties used, the less bracing the manufacturers recommend.

A standard crew needs about 2 to 3 days to erect, brace, and pour a simple 8-foot poured concrete wall for a typical home. Cutouts for doors and windows in a more complicated layout will extend the schedule because lumber or metal pieces must be cut and secured to openings **(Fig.4).** An advantage of the R-20 concrete shell is the minimization of seams, gaps, or thermal bridges that com-

promise the insulation value. Damp-proofing above grade is not needed, but the polystyrene needs to be sided promptly to prevent degradation by sunlight. The strength of the structure can be adjusted to withstand local earthquake or wind loads through appropriate steel rod reinforcement.

The other type of poured concrete wall system is called post-and-beam because only certain vertical and horizontal cavities of the form work are fully filled. In some systems, concrete is poured throughout the wall, but less concrete is poured between the columns and beams, creating a honeycomb pattern. These systems economize on concrete while leaving additional spaces for more insulation. To obtain satisfactory concrete flow into the horizontal cavities, highly fluid concrete (with a higher cement content or the addition of water or plasticizers) and small-sized aggregate (no greater than 3/4 in.) are needed. Originally developed in Europe, several of these systems are now available in North America. Some use interlocking blocks with crenelated edges; others use plank-shaped units with slots into which the ties are placed. The blocks/planks are light and require no mortar, but builders often spray an adhesive on the mating surfaces for extra reinforcement during the pour.

Concrete blocks. — In addition to the usual cement, sand, and gravel, concrete blocks are made with several other ingredients to lower the weight and density of the blocks, increase their thermal insulative qualities, or add color. Many new concrete block types are basically variations of the traditional concrete block. Others represent more radical departures from concrete masonry.

The more conventional systems involve combinations of standard concrete blocks and insulation, from within the block or on either side of the block wall. If insulated on the inside of the wall, wood or metal furring strips are used to create cavities into which fiberglass or polystyrene is placed. If insulated from within the block, loose or foamed insulation or polystyrene inserts are placed in the block cavities. Alternatively, if the blocks are insulated on the outside of the wall, foam is attached to the exterior. This last approach maximizes the mass available on the inside of the wall to act as a thermal buffer. It is also easier to prevent thermal bridging with insulation placed on the surface. Some of these block systems are laid dry and surface-bonded with fiberglass mesh reinforcing; others are mortared and reinforced in the conventional way. Sealers or stucco provide moisture resistance. For walls not insulated from the outside, appearance can be enhanced by using colored concrete and/or blocks with a roughened, split-rock-like face.

A more basic redesign of the concrete block involves changing the makeup of the block itself. One product uses a combination of cement, fine sand, and expanded polystyrene (EPS) beads. While the beads lower the compressive strength of the concrete blocks compared with that of standard concrete, they create a lighter, more insulated block that is easier to cut, drill, and shape.

Alternatively, a European company has introduced to the United States a lightweight block in which a matrix of cement, lime, water, and finely ground sand is mixed with an aluminum-based expansion agent. The chemical reacts with the cement to produce air bubbles, which, by the time the product hardens in

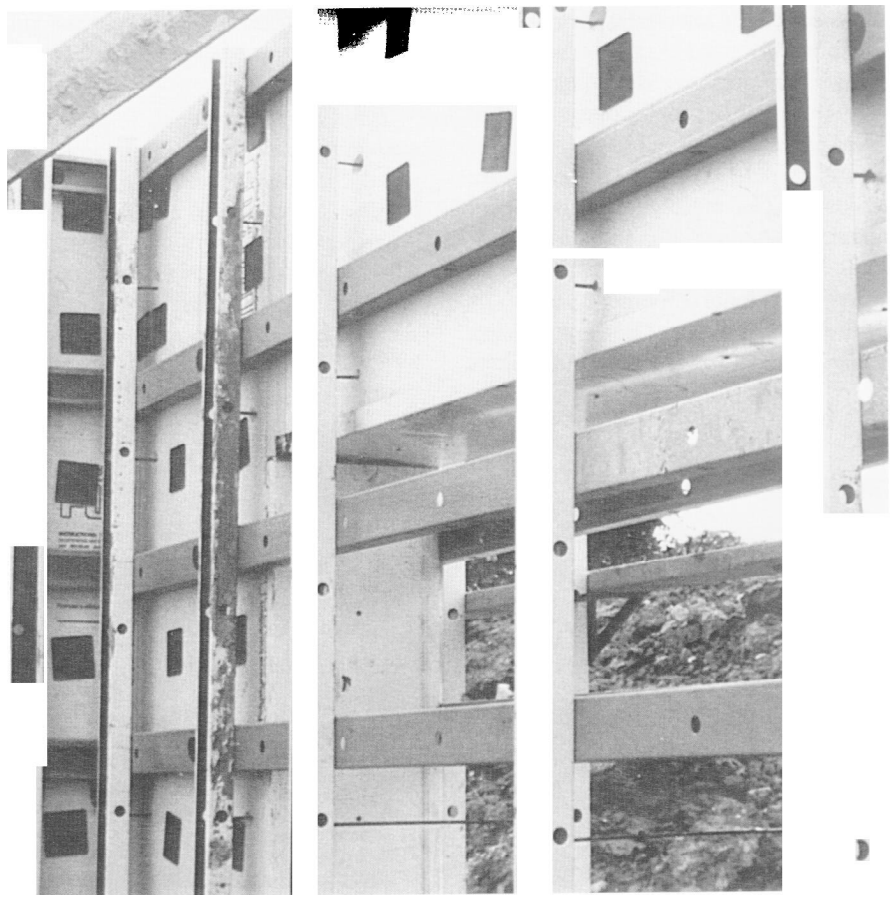

Figure 3. — Metal bracing for insulated concrete forms.

TABLE 1. — SI conversion factors.

English unit	Conversion factor	SI unit
Inch (in.)	25.4	Millimeter (mm)
Foot (ft.)	0.305	Meter (m)
Board foot (BF)	2.359×10^3	Cubic meter (m^3)
Cubic yard ($yd.^3$)	0.765	Cubic meter (m^3)
Pound (lb.)	0.454	Kilogram (kg)
Pound-force/inch (lb./in.)	6.894	Kilopascal (kPa)
British thermal unit (BTU)	1.055×10^3	Joule (J)

about 4 hours, constitute 80 percent of the volume. The material is then wire cut into precisely sized blocks that are transported into a pressurized chamber for 8 to 10 hours of further conditioning. The finished precast autoclaved aerated concrete (PAAC) blocks are nearly twice the size of conventional masonry units, but weigh about the same, offer an insulating value of R-1.1 per inch, and can be worked with conventional carpentry tools. A $21 million factory, capable of producing enough blocks for about 10,000 homes annually, is being built in Georgia to supply the southeast United States market, which currently is being supplied by imports.

Precast concrete panels. — Panelized wall systems were also originally targeted for foundations, but they have emerged above ground as their manufacturers saw this opportunity. These systems are among the lowest cost concrete systems. They consist of monolithic slabs with a solid concrete face, backed by concrete or steel studs, between which polystyrene or fiberglass insulation is placed. The panels are lifted into place by a crane and bolted to one another, after which the seams are sealed to prevent moisture penetration. Stucco is the usual external finish, but nailed or screwed sidings can also be fastened to the concrete with furring strips.

Figure 4. — Door-opening detail for insulated concrete form wall.

Sandwich panel systems

The development of sandwich panels goes back to basic research conducted at the Forest Products Laboratory in the 1930s (11). The modern manifestation of the sandwich panel employs insulating foam, usually polystyrene, for the core, and two sheets of structural panels, usually oriented strandboard (OSB), for the skins **(Fig. 5).** Variations for the sake of economy can include siding-grade plywood exterior skins and load-bearing, fiber-reinforced interior gypsum board. The cores of the panels are recessed to allow for the placing of wood stiffeners along the sides and connecting plates along the top and bottom. Panel dimensions are usually 4 by 8 feet, although larger sizes can also be specified. When erected, the stiffness and strength of the assembly is at least as great as that of frame construction, but less wood is required and the structure is enclosed in a nearly seamless thermal envelope.

Economic evaluation

Cost effects of using different building materials can be placed into three orders: direct building expenses, lifetime operating costs, and other considerations, such as appearance, environmental health, and survivability from catastrophe. For the builder or consumer, direct building expenses are the easiest to calculate because they can be determined from known material and labor needs. Lifetime operating costs associated with differing maintenance, insurance, heating, and cooling expenses are less certain because they depend on a stream of unknown future prices, building operation, construction quality, and type of heating and cooling equipment used. Nevertheless, with the periodic energy crises of the last few decades, lifetime operating costs have assumed greater importance in building codes and buyer concerns. The importance of the other considerations that constitute third-order cost effects depends more upon personal preference and motivation and is not directly quantifiable. Accordingly, the focus here is to characterize first- and second-order effects.

A direct comparison of alternative system costs is meaningful only if assemblies are reasonably similar in performance. For this study, the main criterion selected was the thermal resistance of an assembly. The reference used was a wall with a resistance rating of approximately R-20. Such an insulation level is more appropriate for cold climates, but would offer an advantage in hot climates as well, where cooling loads are high. Reinforcement to resist high wind loads was also assumed.

In a wood-framed structure, an R-value of 20 can be achieved by using nominal 2 by 6 stud framing with l-inch-thick polystyrene sheathing and 5.5 inches of fiberglass. The polystyrene-fiberglass section has an approximate R-value of 24 and constitutes about 85 percent of the wall surface if the stud spacing is 16 inches. The polystyrene-wood (studs and plates) section has an R-value of about 12 and makes up the remaining 15 percent (this ignores fenestration and door openings, which would increase the framed fraction and reduce the insulated cavity fraction). The weighted average of these sections is 22, or 22.5 if 2-foot centers are used. Other elements include an interior vapor barrier, comer bracing, and metal strapping on every stud, plus drywall and vinyl siding. Installation times and material costs were obtained from the 1994 Means Building Construction Cost Data manual (8). For labor costs, a total expense (wages and fringe benefits) of $15 per hour was assumed.

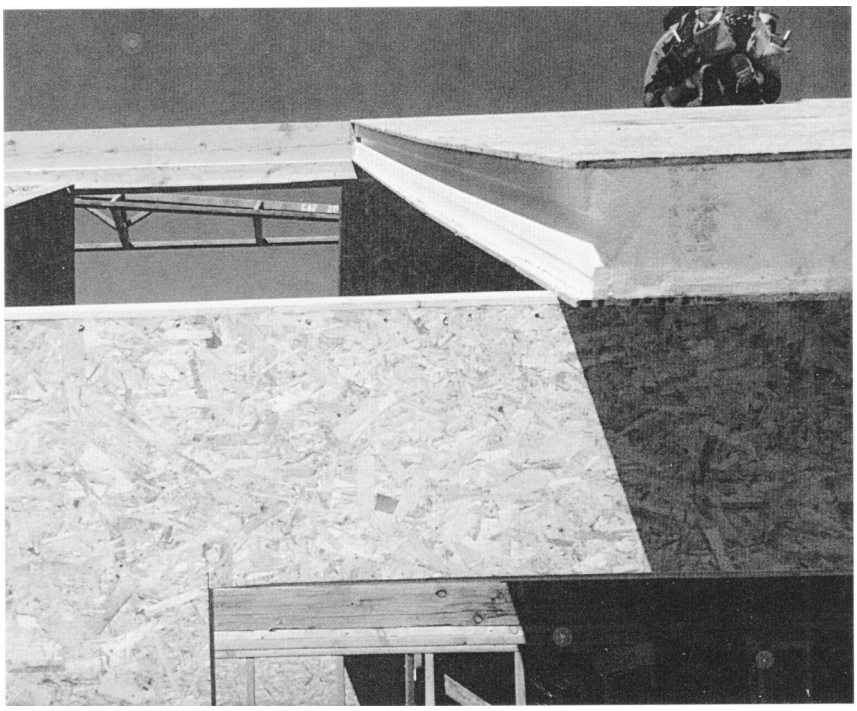

Figure 5. — Installation of insulated sandwich panel.

TABLE 2. — Estimated costs of in-place construction for various wall systems.

Wall system	Cost per 100 ft.^{2} of wall: Material	Labor cost: Time	Labor cost: Cost	Total	Total cost per 2,000 ft.^{2} of house[a]
	($)	(hr.)	($)	($)	
Wood frame					
Exterior, 16-in. spacing	287	12.2	184	471	9,265[b]
Exterior, 24-in. spacing	269	11.2	168	436	8,740[b]
Partitions, 16-in. spacing	90	5.6	84	174	--
Steel frame					
Exterior, 16-in. spacing	290	14.3	214	504	9,630[d]
Exterior, 24-in. spacing[c]	314	13.0	194	509	9,700[d]
Partitions, 16-in. spacing	77	5.7	84	164	--
Poured concrete					
Ties, 8-in. spacing	403	10.8	162	565	10,540[d]
Ties, 12-in. spacing	450	9.8	147	597	11,025[d]
Ties, 16-in. spacing	425	12.7	190	615	11,300[d]
Precast concrete	411	9.9	149	559	10,450[d]
PAAC blocks	455	15.8	236	692	12,415[d]
Sandwich panels	361	10.1	152	513	9,890[b]

[a] Multiplier is 15 for exterior walls and 12.5 for partitions.
[b] Including wood partitions.
[c] Studs spaced 2 feet apart with 3 inches of foam sheathing.
[d] Including steel partitions.

In a steel stud wall, the thermal bridging of the steel sharply reduces the R-value of the assembly because heat flows through the path of least resistance, not evenly through a wall cross section, as is assumed in a parallel path calculation. For example, in a 6-inch-thick wall with nominal cavity insulation equal to R-19, it has been calculated that the thermal bridging of the steel yields an effective R-value of only 7 to 8 compared to 16 for wood frame (3). To compensate for the thermal bridging would require almost 2 inches of extra foam sheathing. An alternative is to space the load-bearing studs on 4-foot centers and employ horizontal furring on each side, using light-gage channels, to support the finishes. This enlarges the wall cavity to 8.375 inches, which, when filled with fiberglass and sheathed with 1-inch foam sheathing, gives a nominal R-value of 31. The efficiency is reduced where the studs or channels cross and create a thermal bridge, but this only occurs on about 3 percent of the wall surface compared with 11 percent in conventional, 2-foot spacing.

Poured-in-place concrete walls with permanent foam forms or foam blocks come with at least 4 inches of uninterrupted polystyrene. Together with the concrete, these meet the 20-plus R criterion. Eight-by-eight placement of l/2-inch-diameter rebar was included to meet severe wind load requirements. Prices for proprietary components and average labor needs were obtained from manufacturers. Other material costs and their installation times were obtained from estimation manuals (8,9).

Structural insulated panel walls were assumed to contain a 5.625-inch core of

TABLE 3. — Cost of various wall systems relative to cost of 16-inch-spaced wood-frame walls[a]

Wall system	Tie or frame member spacing					
	8 in.	12 in.	16 in.	24 in.	48 in.	Solid
	($)					
Wood frame	--	--	--	-525	--	--
Steel frame	--	--	--	435	365	--
Poured concrete	1,275	1,760	2,035	--	--	--
Precast concrete	--	--	--	--	--	1,185
PAAC blocks	--	--	--	--	--	3,150
Sandwich panels	--	--	--	--	625	--

[a] Based on f.o.b. lumber price of $385 per 1,000 board feet and delivered lumber price of $515 per1,000 board feet.

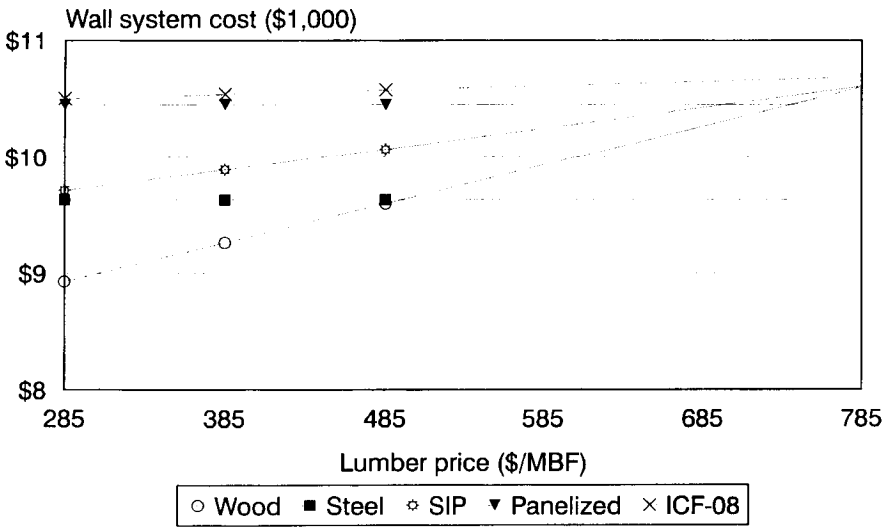

Figure 6. — Wall system costs as a function of lumber prices. SIP is structural insulated panel; ICF-08 is insulated concrete form with 8-inch tie spacing.

bead board, with an R-value in excess of 20, sandwiched between two 3/8-inch sheets of OSB. Cost estimates included the caulking of all seams and the application of strapping for wind resistance. A panel cost of $2 per square foot was selected as representative of many producers' quotes.

Estimated costs of in-place construction for various wall systems are given in **Table 2.**

FIRST-ORDER EFFECTS: DIRECT IN-PLACE COSTS

Wood frame. — Including waste, a 100-ft.^{2} 2 by 6 wall, placed on 16-inch centers, requires 153 board feet of lumber for the studs, blocking, bracing, and top and bottom plates. Total installation of all materials, including drywall and siding, takes about 12.2 hours of labor. These inputs translate to about $471, which drops to $436 if studs are spaced every 2 feet **(Table 2).** For interior walls, costs are $174 per 100 ft.^{2} These costs are based on free on board (f.o.b.) lumber costs of $385 per 1,000 board feet.

Steel frame. — A combination steel stud/channel framed wall with 48-inch spacing requires approximately 131 pounds of steel compared to 101 pounds for a wall with 24-inch spacing. The stud/channel system also requires more fiberglass but less polystyrene. Its overall costs are slightly lower than those of a similarly insulated wall constructed from a conventional layout. Total installation of all materials requires about 14.3 hours, based on Means Company labor estimates for lightweight steel erection. These figures translate to about $504 per 100 ft.^{2}, which rises to $509 if studs are spaced every 2 feet with 3 inches of foam sheathing **(Table 2).**

Poured concrete. — Estimates for stay-in-place poured concrete walls are based on 8-inch-thick walls composed of 4 inches of concrete and 4 inches of foam. Concrete requirements are 1.23 yd.^{3}/100 ft.^{2} Costs vary according to tie spacing. For a system with 8-inch tie spacing, total labor for field-erected forms is estimated at 10.8 hours. Total costs of the finished wall are estimated at $565 **(Table 2).** For the systems with 12- and 16-inch tie spacing, total costs are $597 and $615, respectively. The cost differentials are primarily due to different tie and bracing requirements. Differences in tie weight also contribute to the variations in costs. Tie weight (strength), spacing, and wall bracing are variables for which different manufacturers have arrived at different solutions and in which cost and form strength are the tradeoffs.

Precast concrete. — Precast concrete panelized wall systems cost between $4 and $4.75/ft.^{2} This includes the cost of lifting and securing the panels in place and sealing the seams. The panel face is slightly roughened to hold stucco without requiring wire mesh. Total costs, including interior drywall, are estimated at $559 per 100 ft.^{2} **(Table 2).**

PAAC blocks. — Materials for building walls with precast, autoclave, aerated concrete (PAAC) blocks cost about $455 **(Table 2).** At $4.67 per unit, the cost of a PAAC block is about 2-1/2 times as great as that of an equivalent common concrete block. However, less labor is required to install and finish PAAC blocks, and they provide insulation and structure in one package. Total labor, using the finishes assumed for the other systems, is about 16 hours and the total cost is $692.

Insulated sandwich panels.— The total cost of building a wall from structural insulated sandwich panels is $513 per 100 ft.^{2} of wall **(Table 2).** Lower labor costs are offset by higher material prices to yield slightly higher in-place costs compared to wood frame.

Summary of first-order cost effects.— The following summary is qualified by the caveat that the estimates cover only one specific simplified design, with prices based on national averages that vary locally and on labor estimates that vary with the skill and experience of crews. Among wall systems with roughly comparable amounts of insulation and uplift resistance, construction costs for nonwood walls generally exceeded costs for wood-frame walls, based on prices and wages that prevailed in early 1994. Steel and insulated panel wall costs were

closest to those for wood-frame walls for an average 2,000-ft.^{2} house, exceeding wood by $365 to $625 **(Table 3).** Using insulated-foam poured-concrete walls resulted in increased costs of from $1,275 to $2,035; panelized concrete systems were $1,185 higher. Construction with PAAC blocks was the most costly.

To equalize the costs of a wood-frame exterior/interior wall with those of steel, prices for lumber would need to increase to about $500 per 1,000 board feet (f.o.b. mill); even higher prices would be needed to exceed the costs of construction with concrete **(Fig. 6).** However, the $1,000 to $3,000 additional expense is not large when viewed in the context of the $150,000 cost of a typical new home. If additional benefits can be gained from using alternative systems, then the added up-front cost may be justified. To examine that, we need to consider second-order cost effects that occur over a structure's lifetime.

SECOND-ORDER EFFECTS: LIFETIME COSTS

Several costs of owning and operating a home are incurred on a perpetual basis. Heating and cooling, insurance, and basic maintenance costs are among the most important. Because these last as long as a structure is used, they can become important when considering how to build.

Chief among the benefits cited in favor of nonwood systems is enhanced energy efficiency. Although most structures are required to meet basic energy codes, there can be wide variation in results. Thermal bridges, breaks and tears in air barriers, unsealed sill plates, and leaks at seams or outlet boxes are some causes of reduced thermal efficiency in otherwise nominally well-insulated structures. Because many nonwood walls are erected in a continuous and seamless manner, the expectation is that such failures are reduced, allowing these structures to more fully achieve their thermal potential.

A common test of air tightness is to pressurize and repressurize a structure to reference levels and measure the air exchange rate. Such test results are referred to as air changes per hour (ACH) at 50 Pa of pressure (ACH50). In a test of homes built of PAAC blocks compared with those built with wood frame, the ACH50 value for the blocks was 2.6 compared to 7.0 for the wood frame. In similar tests on walls built with insulated panels, the panel ACH50 level was 0.55 compared to 4.88 for an "average new home" in Wisconsin, resulting in annual heating cost savings of $175 with the insulated panels.

A review of the literature lends support to such claims. A side-by-side evaluation of two homes in Kentucky (one frame, the other stressed skin) yielded ACH50 equivalent values of 5.4 for frame and 4.2 for stressed skin, which would result in an estimated energy cost savings of from 14 to 20 percent for the stressed skin home (10). Results of tests in Sweden comparing 205 wood-frame homes with 12 lightweight-concrete homes showed respective ACH50 values of 4 and 2.1 (4). Results of tests conducted by a utility company in Madison, Wis., from 1988 to 1990 showed an average ACH50 rating of 6.8 for new, predominantly wood-frame homes (5), which is similar to the 6.3 rating for nine "energy-efficient homes" found in another study (4). These data indicate substantial leakages in nominally well-insulated frame buildings. However, results from a 40-home study in Canada showed that where building standards are more rigorously applied, exceptionally low leakage values can be consistently attained with frame construction as well (4). On the whole, based on prevailing U.S. building practices, it appears that energy savings can be expected from a structure built with PAAC concrete or stressed skin panels and, by extension, with insulated concrete forms.

Potential savings from the installation of smaller heating or cooling units are another advantage that has been attributed to nonwood construction. In Wisconsin, contractors size a furnace for a building using a rule of 7.5 BTUs/ft.^{3} of space. For well-insulated structures, that size can be reduced by 20 percent. In the case of a 2,000-ft.^{2} home, effective insulation can reduce the heating unit size by about 20,000 BTUs, resulting in equipment savings of about $200. At the same time, a tight house requires an air exchange system to meet minimum fresh air requirements, Recommendations from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) cited in Standard 62-1989 (2) call for at least 0.35 air changes per hour (under unpressurized conditions roughly equivalent to ACH50 of 7.0). Since most homes, whether frame or otherwise, are designed to be at least this tight, all homes should be equipped for that rate of air exchange.

Property insurance rates also vary by building type and region. In most parts of the United States, owners of homes built of noncombustible materials may enjoy only minor insurance-related savings of from 5 to 15 percent. In Wisconsin, that translates to a typical discount of about $25 per year for a $150,000 home. In a high wind zone such as coastal Florida, however, insurance for wind damage may not be covered by normal homeowner policies and would have to be purchased separately. In the wake of recent destructive hurricanes, savings on masonry homes are about $150 per year for an average home.

Among maintenance costs, one of the greatest is the repainting of siding. Wood and stucco may need repainting every 5 to 7 years. This cost is obviated by some concrete block systems.

Lastly, in a wide swath of the United States, termite control is a periodic expense. In the South, most banks and all federally backed loans require homes to have a 5-year warranty against wood-eating insects. This makes site treatments standard procedure for most new homes. However, such treatment does not provide permanent protection, and homeowners usually enter into yearly inspection contracts, costing from $50 to $150, for long-term monitoring and treating. As long as a structure contains wood, it is vulnerable to termite attack. However, steel or masonry exterior walls lessen this risk.

These considerations imply a tradeoff between a set of relatively small but multiple cost savings and a greater but one-time-only initial outlay. One approach to weighing this tradeoff is to calculate the time needed for the recurrent savings to pay back the initial cost plus the compounding interest. First, the initial cost expands exponentially over time according to Equation **[1]:**

$$S = P\,(1 + r)^n \qquad [1]$$

where:

S = value at any future period of P invested in perpetuity at rate r

P = amount of extra expense incurred to build with a system

r = opportunity cost of money (interest-rate), in inflation-adjusted terms

n = time

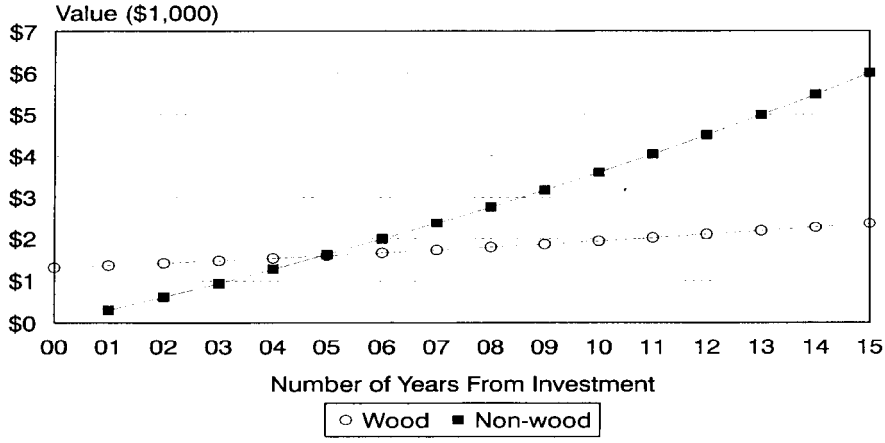

Figure 7. — Savings from wood and nonwood systems over time.

For simplicity, the same rate for borrowing as for lending is used.

The stream of uniform operating cost savings also compounds over time according to the formula:

$$S = [(1 + r)^n - 1)]p/r \qquad [2]$$

where:

p = uniform recurring savings, in constant dollars, that result from using a system

The item of interest is the value of n for which the two flows of money are equal. Equalizing Equations **[1]** and [2] and solving for n yields Equation [3], which can be solved for any set of values for P, p, and r:

$$n = [\log(p) - \log(p - rP)] / \log(1 + r) \qquad [3]$$

The real rate of return on long-term government bonds over the last decade has been approximately 4 percent. Using that value for r, we can calculate the payback period for any set of estimated building cost differentials and life-cycle savings. For example, taking the cost differential of $1,275 in **Table 3** for insulated foam-poured concrete walls with 8-inch tie spacing and assuming an annual cost savings of $300 from a location in a high wind zone (insurance savings of $150 plus $150 savings for heating/cooling costs), the payback period would be 5 years **(Fig. 7).** Therefore, if the owner's expectation of payback was greater than 5 years, then the nonwood system would be preferable on economic grounds. With a shorter payback expectation, the wood system would be preferable. Using the same life-cycle cost savings but an initial cost difference of $3,150, the payback period would be 14 years.

Conclusions

Within the past decade, a number of interesting building systems have emerged in the low-rise and housing construction markets. Their emergence has coincided with increases in wood prices that have caused builders to search for alternative materials at lower costs or more stable prices. Even at the higher prices for wood, however, wood-frame wall systems remain the lowest cost alternative in most cases if only direct in-place costs are considered. This conclusion is not universal because of localized variability in building practices and costs. For example, codes in hurricane zones require greater wall impact resistance than included in the wood-frame example, which would require additional plywood sheathing. But, in general, wood framing costs appear to be the lowest when similar assemblies are compared. Furthermore, since 1994, lumber prices have fallen while concrete and steel prices have risen, thus consolidating the status of wood as the most economical building material. However, when potential long-term savings stemming from the use of nonwood materials are factored in, they result in lower costs over time, which may justify their higher initial cost, depending on individual time preferences and planning horizons.

Literature Cited

1. Anderson, R.G. and D.B. McKeever. 1988. Wood used in new residential construction in the United States—1988. American Plywood Assoc., Tacoma, Wash.
2. American Soc. of Heating, Refrigerating, Air-conditioning Engineers. 1989. Standard 62-1989. ASHRAE, Atlanta, Ga.
3. _____. 1989. Standard 90.1. ASHRAE, Atlanta, Ga.
4. _____. 1993. ASHRAE Handbook: Fundamentals. ASHRAE, Atlanta, Ga.
5. Borski, D. 1995. Personal communication. Madison Gas and Electric Co., Madison, Wis.
6. Hoyle, R.J. 1970. Do steel studs threaten wood in home building? Forest Prod. J. 20(3):12-13.
7. McKeever, D.B. and R.G. Anderson. 1991. Wood products used for residential repair and remodeling in the United States, 1991. FPL-RB-19. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
8. Means Company. 1994. Means building construction cost data—1994. Means Company, Kingston, Mass.
9. Richardson Engineering. 1994. Rapid system: General construction estimating standards, 1994. Richardson Engineering Services, Inc., Mesa, Ariz.
10. Rudd, A. and S. Chandra. 1994. Side-by-side evaluation of a stressed-skin insulated-core panel house and a conventional stud-frame house. Prepared for Office of Building Technologies, U.S. Dept. of Energy, Washington, D.C.
11. Sherwood, G.E. and H. Spelter. 1994. Time is ripe for structural insulated panels. Automated Builder 31(10):22-23.
12. Spelter, H. and R.G. Anderson. 1985. A profile of wood use in nonresidential building construction. FPL-RB-15, USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
13. Sullivan, B. 1994. Steel framing: Thermally challenged? J. of Light Construction, March. pp. 58-60.
14. VanderWerf, P.A. and W.K. Munsell. 1995. The Portland Cement Association's guide to concrete homebuilding systems. McGraw-Hill, Inc./Portland Cement Assoc., Skokie, Ill.