The effect of panelized single family residential construction on the environment

G.Z. Brown and T.E. Peffer
Energy Studies in Buildings Laboratory, Center for Housing Innovation
Department of Architecture, University of Oregon, Eugene, Oregon, USA

Abstract

The construction of single family housing in the U.S. is growing increasingly industrialized with panelization emerging as the dominant form of industrialization. Will this trend mean that housing construction, operation, and demolition will have a greater or a reduced impact on the environment?

This paper analyzes the differences between low levels of industrialization, such as site built wood framing or open wood-frame panels, with higher levels of industrialization, such as closed wood-frame or stressed skin insulating core panels, in terms of material use, waste generation in construction, and energy use in operation. One experiment measured the energy consumption of six units of housing built using various forms of factory fabrication — open wood-frame panels, closed wood-frame panels, and stressed skin insulating core panels. The tests indicated that the more completely components are factory fabricated, the less energy a house built from these components will consume, resulting in reduced CO_2 emissions from burning fossil fuels. The units built with more industrialized panels had a more complete insulation envelope and half the air changes per hour. Another test compared conventional on site construction (wood frame) to stressed skin insulating core panel construction. Stressed skin insulating core panel construction used 5% less total wood and 50% less framing lumber, indicating the consumption of fewer trees. A similar experiment comparing the side by side construction of a wood frame house to a panelized house showed less solid sawn lumber used and less waste generated on site by the panelized house construction. A recent prototype panelized floor/foundation system showed promise as a lower cost alternative to concrete slab construction with its high embodied energy. The on-grade panel floor system has a better thermal performance than a typical slab floor, and the panels can be reused upon demolition. These examples show that high levels of industrialization can potentially result in less environmental impact from construction, operation, and demolition.

Keywords: energy, environment, industrialized housing, material use, panels

1. The current state of industrialized housing in the U.S.

Valued at $179 billion in 1994, the housing industry in the United States has an enormous impact on the economy and environment. The 1.6 million housing units constructed in 1995 (about 1 million of which are single family) consumed large quantities of raw materials and energy, and represent future demand for resources for operation and demolition [1].

1.1 Types of industrialized housing

Over the past 40 years, the production of houses has increasingly included more industrialized components and processes, ranging from dimensional lumber and prefabricated walls to completely prefabricated homes.

Data collected on industrialized housing is divided into four groups: HUD Code, Modular, Panelized, and Production built housing. Houses completely built in the factory are considered the most industrialized and those built primarily on site are least industrialized. The most industrialized type of housing is HUD Code housing, which is built to a preemptive national code. A *HUD Code* house, a movable or mobile dwelling constructed for year-round living, consists of one, two or more manufactured units each towed on its own chassis, and connected on site. *Modular* housing is built from self-supporting, three-dimensional house sections intended to be assembled as whole houses. *Panelized* houses are built from manufactured roof, floor and wall panels designed for assembly after delivery to a site. The least industrialized are *production built* houses, the mass production of whole houses "in situ" that employs rationalized and integrated management, scheduling, and production processes, as well as factory-made components. Rather than the house built in the factory and moved to the site, the building site is the factory, which becomes an open-air assembly line of walls, floor or other building components [2].

1.2 Market share of industrialized housing

The last decade of industrialized housing production shows the growing strength of the *more* industrialized modes of housing. From 1985 to 1995, HUD Code, modular, and panel producers captured some of the market share from the less industrialized production builders (including those that use only a few industrialized parts) (Figure 1). Panelized housing (including domes, precuts and log houses) shows the largest increase in market share over this period, expanding from 37% in 1985 to 47% in 1995, and shows promise of increasing growth [3].

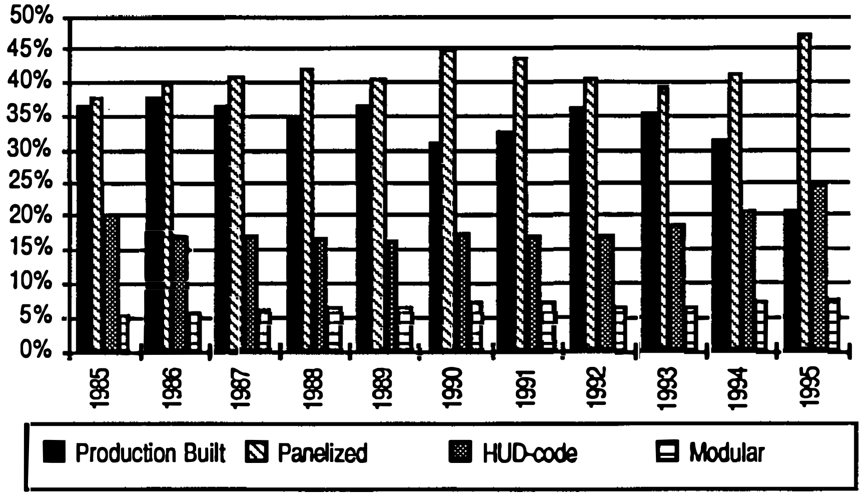

Figure 1: U.S. housing production by market share, 1985–1995 [4]

2. The impact of residential construction on the environment

The cost of housing can be measured in the effects upon the natural environment as well as the economy. Houses impact air, water, and land quality, require raw material extraction, create waste in construction and demolition, and demand energy in operation. The choice of material in construction — wood versus concrete, or engineered wood versus solid sawn lumber — affects the energy used, pollutants emitted, and waste generated during initial fabrication, and represents a potential waste hazard at the end of the building's life.

2.1 Construction material

The construction of houses requires a substantial amount of raw and manufactured materials which affect the natural balance of the environment. In the United States, a typical 194 m^2 (2085 sf) single family house requires 31 m^3 (13,127 board feet) lumber, 577 m^2 (6212 sf) sheathing, 12,685 kg (13.97 tons) of concrete, 216 m^2 (2325 sf) of exterior siding, 225 m^2 (2427 sf) roofing material, 194 m^2 (2085 sf) flooring material, 284 m^2 (3061 sf) insulation, 571 m^2 (6144 sf) interior wall material, 257 L (68 gal) paint/coatings, as well as doors and appliances [5]. Since 90% of single family houses are constructed of wood, housing greatly impacts the quantity and quality of living trees. Single family homes create the largest single market for solid wood products in the United States. "In 1992 an estimated 41.3 million cubic meters of lumber, 9.0 million cubic meters of structural panels, and 3.0 million cubic meters of nonstructural [panels] were consumed in the construction of just over 1 million houses" [6]. Although current annual tree growth is greater than harvest, logging practices of road construction and clearcutting lead to erosion, irreplaceable loss of topsoil, and the pollution of rivers and streams [7]. The demand for sustainably harvested wood in the U.S. has led to the growing number of sustainable forests, currently about 3.5 million acres of forest land [8].

The choice of material used in construction affects the degree of environmental impact. For example, when prefabricated panels are utilized as a treated wood foundation for basements, "the use of wood rather than concrete reduces the amount of embodied energy by about 30%" [9]. Concrete requires 1453–1589 kg (3200–3500 pounds) of raw material for 908 kg (one ton) of finished cement, produces CO_2, NO, and S gases, and requires 2344 MJ/m^3 (1,700,000 BTU/yd) of energy [10]. Wood, on the other hand, is a renewable resource, with low embodied energy, and shows promise of sustainable harvesting. Wood uses the least embodied energy of any building element at 2.5 MJ/kg (639 kilowatt hours per ton). (For comparison, brick uses four times this amount, concrete (5x), plastic (6x), glass (14x), steel (24x), and aluminum (126x) [11].

Using fewer trees and producing less wood waste represents less impact on the environment. Engineered lumber consumes fewer trees to fulfill the same structural function as solid sawn lumber. Lumber and timber consume half as much energy (7.38 MJ/kg) as veneer and plywood (14.62 MJ/kg) [12], yet the manufacture of engineered wood is highly efficient, using wood scraps and sawdust, so it saves trees. One manufacturer uses engineered lumber made from fast-growing trees like aspen or yellow poplar; the technology allows for use of "logs that are not large, strong or straight enough to be of structural value in conventional wood products," [13]. Three-quarters of each tree is used, reducing waste from using solid sawn lumber. Another example is the use of Oriented Strand Board (OSB) sheathing instead of plywood; OSB uses 59% less embodied energy as plywood, because it makes better use of wood fibers [14].

2.2 Waste and air pollution

Building houses creates scrap material and other waste products that require time, energy, and means of disposal, whether by recycling or landfill dumping. A typical 186 m^2 (2000 sf) home generates the following construction waste: Metals: 68 kg (150 lbs), Drywall: 908 kg (2000 lbs), Solid Sawn wood: 726 kg (1600 lbs), Vinyl: 68 kg (150 lbs), Engineered wood: 635 kg (1400 lbs), Masonry: 454 kg (1000 lbs), Cardboard: 272 kg (600 lbs), Containers (paints, caulks, etc): 23 kg (50 lbs), and 476 kg (1050 lbs) miscellaneous waste. This combined total of 3632 kg (four tons) of construction waste averages about $511 paid per house for disposal [15]. Wood products can account for 40–50% of residential construction waste stream.

Besides raw materials and waste, another influence residential construction has on the environment is in the transportation of materials to the site. An estimated 20–25% of the total energy for construction is attributable to transportation, which contributes to global warming via carbon dioxide emissions. One fifth to one quarter of total CO_2 emissions are generated from the manufacturing of buildings [16].

2.3 Energy use in operation

The composition and quality of construction of a house's exterior walls, roof and floors — the building envelope — substantially affects the energy consumption and cost over its lifetime. A Norwegian study found that the "energy use in buildings during the service life (50 years) accounts for more than 95% of the total energy consumption throughout the life of these houses," [17]. Residential buildings account for about one fifth of the U.S. primary energy consumption, with 46% of this energy used primarily for heating and cooling [18]. Since energy use primarily requires burning fossil fuels, a more energy efficient house is kinder to the environment in the long run. Heating and cooling residences in the U.S. accounts for 21% of the total U.S. CO_2 emissions from fossil fuels, producing 268 million metric tons of CO_2 per year as well as other gases detrimental to air quality and the atmosphere [19].

3. Less environmental impact with more industrialized panels

The growing usage of panels in housing construction implies a varied impact on the environment through material and energy use depending on the type of panel. The panelized housing industry spans the spectrum of levels of industrialization, defined as the degree of completion of a panel as it arrives on the job site. Less industrialized panels need a moderate amount of finish work on the site, and more industrialized panels require less work on site (Figure 2). *Framed panels,* either open framed or closed framed, are prefabricated components replicating traditional stick framing, displaying low to moderate levels of industrialization. These panels consist of dimensional wood studs attached to wood sheathing such as Oriented Strand Board (OSB) or plywood. Framed panels carry structural loads through a stud frame as well as the sheathing. Predominantly used are the less industrialized *open wood-framed panels,* which are sheathed on the exterior only and completed on site with vapor barriers, interior finishes, and electrical and mechanical systems. More industrialized are the *closed wood-framed panels,* which are shipped to the site sheathed on both the exterior and interior, and are sometimes pre-wired and plumbed. The most industrialized panels, the *Stressed Skin Insulating Core panels,* have a core of expanded polystyrene rigid foam insulation sandwiched by two sheathing layers which carry structural loads. These panels represent a new building component that cannot be fabricated on site, but requires a factory setting for production.

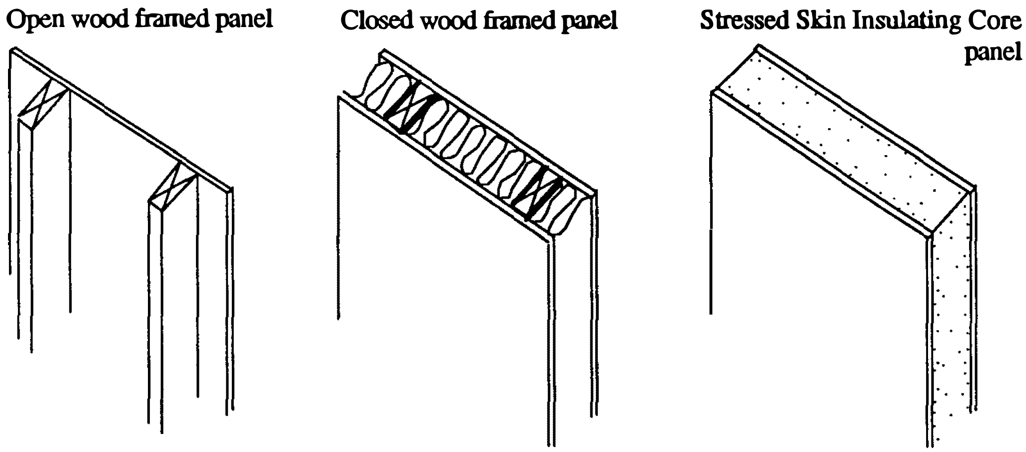

Figure 2: Types of industrialized panels

3.1 Fewer trees consumed with stressed skin paneled housing

Evidence shows that housing built with Stressed Skin Insulating Core (SSIC) panels consumes fewer trees compared to housing constructed with less industrialized methods. In an experiment conducted at the University of Oregon, the construction of a SSIC Panel Demonstration house was compared to that of a reference house of the same design and energy performance, but built with conventional on site wood frame construction. The SSIC panel house used 5% less total wood, and 50% less framing lumber [20]. In another study, a stressed skin panel house and stick framed house, identical in plan, were constructed in a side by side comparison at the 1996 National Association of Home Builders (NAHB) convention. The more industrialized stressed skin panel house consumed the same amount of sheathing material, but 26% less framing lumber (35.6 m^3 or 15,100 board-feet) compared to the traditionally constructed stick frame house (48.1 m^3 or 20,400 board-feet) [21].

Using less framing lumber reduces the total number of trees required for the SSIC house and lessens the impact on the environment. Only 63% of a tree can be manufactured into solid lumber. However, more than 95% of a tree can be utilized when producing engineered wood and other composite wood products such as plywood and OSB [22].

3.3 Reduced waste with panel construction

Housing built with panels can reduce the amount of wood waste entering landfills, since panels use primarily OSB and are factory produced, centralizing waste. Composite sheathing plants such as those that produce OSB divert about 8.2×10^9 kg (9 million tons) of residual wood from North America's landfills every year [23]. Highly industrialized processes such as panel production benefit from the centralized function and economies of scale of a factory, especially when directing waste. "Materials which are assembled into finished components under factory-controlled conditions usually make more efficient use of resources, and disposal of waste from a factory is more easily controlled" [24]. When waste is centralized and consolidated, it is more likely to be recycled properly instead of buried in a landfill. In NAHB's side by side test, the Stressed Skin panel house produced 76% less waste on site (3 m^3 or 4 yards) than the less industrialized wood-framed house (13 m^3 or 17 yards) [25].

A centralized production scheme reduces transportation. For example, a stick built house requires separate transportation of relatively small amounts of drywall, studs, and sheathing. A panel produced in a factory means larger shipments of these items, capitalizing on the economy of scale. The standard 1200 mm x 2400 mm (4'x8') size of panels originated because "the economical transport of a factory-built house suggested the dimensions of a standard trailer truck as a design criterion — the 2400 mm (eight foot) width being particularly crucial" [26].

3.4 Less energy consumed in operation in stressed skin panel house

The more highly industrialized the panel, the better the energy performance of the panel built house due to quality of insulation installation and thermal performance of insulation type. A study performed at the University of Oregon compared the thermal performance of six housing units constructed with open wood-framed panels, closed wood-framed panels, and SSIC panels. The units constructed of closed panels (Unit 2, Unit 5, and Unit 6) and the SSIC panels (Unit 1) were more airtight and had fewer thermal defects in wall insulation than the units constructed with less industrialized open panels (Unit 3 and Unit 4).

Fan de-pressurization results suggested that the more industrialized panel construction achieved tighter construction resulting in reduced infiltration. The air changes per hour (ACH) measured 0.16 for the SSIC panel unit, 0.27–0.28 for the closed panel units and 0.34–0.39 for the open panel units [27]. Constructed a year later, the Demonstration House (DH) built with SSIC panels floor, walls, and roof showed even tighter construction at a measured 0.09 ACH (Figure 3) [28].

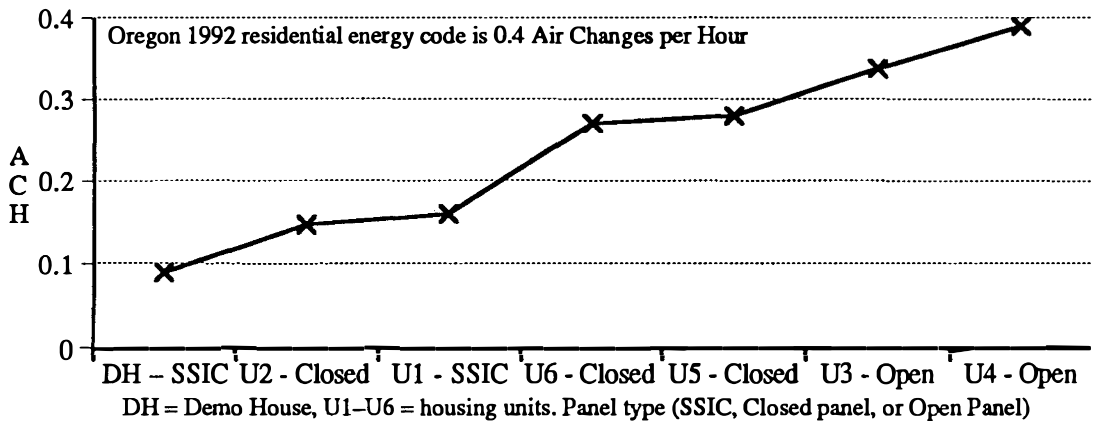

Figure 3: Tighter construction achieved with industrialized panels.

The results from thermographic imaging and coheating tests indicate that a higher level of quality control is achievable in the factory when installing insulation. The infrared imaging detected thermal weak spots caused by missing or poorly installed insulation in the site installed insulation, predominantly the open panel units. The open frame and closed frame panel units showed more heat loss through thermal bridging due to studs than the more industrialized SSIC panel unit, where the thermally broken splines were only detectable at building corners. Coheating tests indicated that the more industrialized closed panel units had lower overall thermal transmittance (UA) than the open panel units [29]. The 1280 sf SSIC Demonstration house had a measured UA value of 133 BTU/h °F compared to 198 BTU/h °F for Unit 3 (800 sf) built with Open panels.

Two identical houses were built in Louisville, Kentucky, one constructed of SSIC panels and the other using conventional site built wood framing. The SSIC panel house outperformed the wood-framed house by 12–19%, mostly due to reduced loss from infiltration and thermal bridging. The air changes per hour (ACH) of the SSIC house were measured at 0.21 compared to 0.4 to 0.7 ACH for a conventional house [30].

4 On-grade floor panel system consumes less energy

The foundation and floor of a typical residence affects the environment through materials used in the initial construction phase, through energy performance in operation, and by disposal at the end of its lifespan. A recent experiment using SSIC panels at the University of Oregon combines floor and foundation to reduce cost and the amount of concrete at the onset, maintain energy and structural performance in operation, and provide easy dismantling and recycling upon demolition of the structure [31]. The prototype floor/foundations system uses one sided SSIC panels on a compacted gravel bed, using engineered lumber as the perimeter beam (Figure 4). This floor/foundation system can potentially replace concrete slab floors, which represent 42% of the new single family residences in the U.S. in 1995 [32], with materials having lower embodied energy and cost. The on-grade panel floor costs 18% less than an equivalent slab-on-grade foundation and 40% less than a crawl space foundation. Thermal analysis indicates better energy performance than a slab on grade floor, with a measured F value of 0.1, compared to 0.5 required by code for a concrete slab. The ease of dismantling the structure indicates potential in recycling and reuse at the end of its lifecycle.

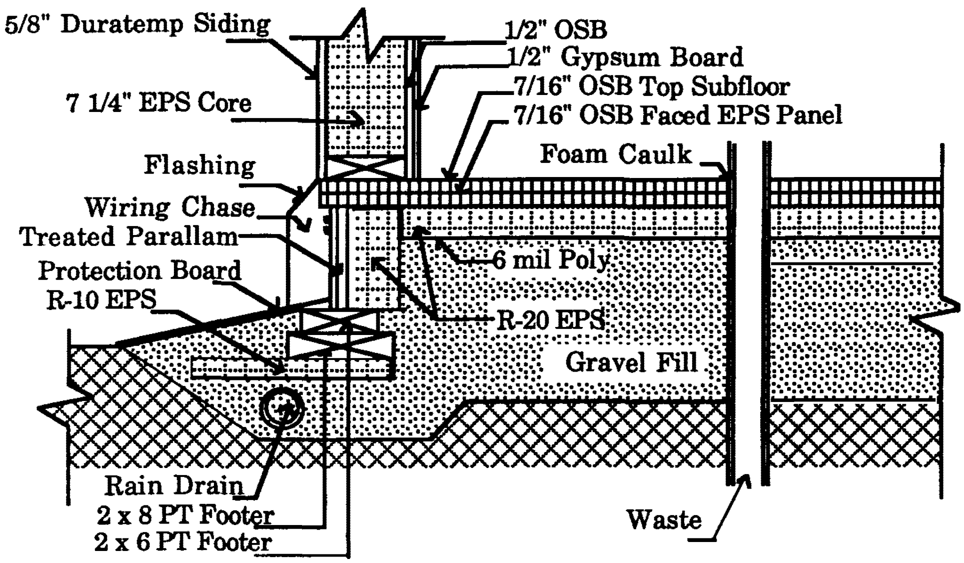

Figure 4: On-grade insulated panel floor system

5. Conclusion

This paper demonstrates the potential of industrialized panel construction in housing in reducing environmental impact by using fewer trees and creating less waste in construction, consuming less energy in operation, and showing greater potential for reuse at the end of a house's service life than conventional stick frame construction.

Many critics contend that industrialization is the antithesis of environmental regard. In residential construction this translates into a movement towards building products that have less processing and use more labor. While this low tech approach has value it is clear that higher levels of industrialization at least in housing can also lead to reduced environmental impact.

Acknowledgement

This paper is drawn in large part from the work of researchers in the Energy Studies in Buildings Laboratory, University of Oregon. These researchers include Dana Bjornson, John Briscoe, Kendra Carson, Erik Dorsett, Jerry Finrow, Sean Fremouw, Paul Larocque, Jeff Kline, Pawan Kumar, Dale Northcutt, Lisa Nixt, Josh Powell, Marshall Schneider, Marc Sloot, and Zhunqin Wang.

References

1. U.S. Bureau of the Census. (1994-1995). Construction Reports, Series C-22, Housing Completions and Series C-20, Housing Starts.
2. Brown, G. Z., D. Bjornson, K. Carson, E. Dorsett, J. Kline, and L. Nixt. (1996). *Industrialized Housing Trends in the U. S.* (10015/R96-4:db). Center for Housing Innovation, Univ. of Oregon.
3. Morgan, Rick. (1995, November). Lower Manufacturing Costs Will Cause Panel Sales to Soar. *Building Systems Magazine* . 14.
4. Brown, loc cit.
5. National Association of Home Builders website. (1996). (http//:www.nahb.com).
6. Ince and McKeever. (1995). *The Role of Markets and Technology in Conservation of Timber Resources.* Forest Products Lab.
7. World Resources Institute. (1993). Environmental Almanac.
8. Robertson, Lance. (1997). *Sustainable products catching on.* The Register Guard, Eugene, Oregon. Dec 8.
9. Friedman, A., and V. Cammalleri. (1994). Reducing Energy, Resources and Construction Waste Through Effective Residential Unit Design. *Building Research and Information, 22:2.* 107.
10. Wilson, Alex. Cement and Concrete: Environmental Considerations. *Environmental Building News, 2:2.*
11. Lyle, John Tillman. (1994). *Regenerative Design for Sustainable Development* . New York: John Wiley and Sons. 119.
12. Friedman, Avi, and Vince Cammalleri. (1995). The Environmental Impact of Building Materials in the North American Building Industry. *Building Research and Information, 23:3.* 165.
13. Trus Joist MacMillan. (1996). Product literature. Boise, Idaho.
14. Friedman and Cammalleri, loc cit.
15. Construction Waste Management New Industry Challenge. (1996, Nov 18). *Nation's Building News.* National Association of Home Builders. 1.
16. Malin, Nadav. (1996, September/October). On Using Local Materials. *Environmental Building News, 5:5.*
17. Fossdal, Sverre, and Knut Ivar Edvardsen. (1995). Energy Consumption and Environmental Impact of Building. *Building Research and Information, 23:4.* 224.
18. U.S. Department of Energy. (1995, October). OBT Buildings Data Summary Sheets. *Office of Building Technologies Core Databook on Industrialized Housing.*
19. U.S. Congress, Office of Technology Assessment. (1991). *Changing by Degrees: Steps to Reduce Greenhouse Gases,* OTA-O-482. Washington DC, U.S. Government Printing Office.
20. Brown, G. Z., P. Kumar, P. Larocque, and Z. Wang. (1995). *Stressed Skin Insulating Core Panel Demonstration House Thermal Testing Report* 9159/R95-2:tb. Center for Housing Innovation, University of Oregon.
21. Wood Truss Council of America. (1996). Framing the American Dream [brochure].
22. Engineered Wood Association. (1995). Essential Ecology. from CRBT web site: [http://www.montana.com/crbt/].
23. Ince and McKeever, loc cit.
24. Friedman and Cammalleri, loc cit.
25. Wood Truss Council, loc cit.
26. Anderson, Stanford. (1995, November). The Acorn House: Lessons from the 'Complete Dwelling.' *Architectural Review,* 68.
27. Brown, G.Z., P. Kumar, and P. Larocque. (1995). *University Housing Thermal Testing Report* 8326/R95-2:TB. Center for Housing Innovation, University of Oregon.
28. Brown, Kumar, Larocque, and Wang, loc cit.
29. Brown, Kumar, and Larocque, loc cit.
30. Rudd, Armin and Subrato Chandra. (1994). *Side-by-Side Evaluation of a Stressed-Skin Insulated Core Panel House and a Conventional Stud-Frame House.* Florida Solar Energy Center.
31. Brown, G.Z. et al. (1997). *On-Grade Panel Floor System,* Center for Housing Innovation, University of Oregon.

32. National Association of Home Builders website. (1997). (http//:www.nahb.com).