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ANALYSIS OF WOOD-BASE MATERIALS USED IN SMALL SINGLE FAMILY DWELLINGS PRODUCED BY THREE MANUFACTURED HOUSING SYSTEMS

by

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INTRODUCTION

During the last four years there has been a rapid, almost revolutionary, development in the manufactured housing industry. In 1971 the number of manufactured housing units produced in the U.S. was about equal to that of mobile homes. However, when we take a closer look at the technological changes that have taken place in this industry one must certainly talk about evolution rather than revolution. It is only during the last few years that we have seen examples of innovative building technology applied to wood framed structures. Unfortunately, the innovative approaches have too frequently proved themselves uneconomical, and thus we still have a manufactured housing industry whose product is constructed much like any conventionally built house. At any rate, there exists today a distinguishable group of manufactured housing systems with at least somewhat unique material requirements and characteristics.

We should define the basic systems discussed in this report. The "Manufactured Housing Industry" as discussed in this report excludes mobile homes, as well as so called "pre-cut" buildings. The mobile home industry operates under its own code structure, and is not generally subject to the same code requirements as are permanent manufactured homes. Thus material requirements and applications are often greatly different. The pre-cut system is subject to essentially no design or material selection constraints, which differ from on-site construction and incorporates very little prefabrication. Our discussion concentrates on those industrialized housing systems which produce a code approved structure where the in-plant labor component is relatively large. In such systems the house package leaving the factory contains preassembled components, in varying degrees of completeness.

During 1971 we interviewed some 30 industrialized building firms in the U.S. plus a number of governmental and industrial institutions. We analyzed one detached single family dwelling produced by these firms which had an average living area of approximately 1,000 sq. ft. For the purpose of our study these structures are comparable in room configuration and type.

We are presently comparing these structures produced in the U.S. with similar units being manufactured in Scandinavia. A six minute film of a manufactured housing operation in Finland will be shown to illustrate differences and similarities between the industry and in the U.S. and Scandinavia.

The three primary housing systems analyzed were as follows:

1. Sectional System: The sectional system incorporates two three-dimensional modules, each one usually being one-half of the width and the full length of the house. Only one field connection is required to connect the two volumetric modules. The system is by far the most popular modular system in the United States for single family dwellings. It is derived from the mobile home industry and in principle is similar to a mobile home "double-wide".
2. The Free-Design Modular System: This system incorporates two or more volumetric modules with no design constraints other than those imposed by transport and erection.
3. The Panelized System: The Panelized System utilizes factory assembled flat panels for walls, floors and roof. In some cases a three-dimensional wet core accompanies the two-dimensional panels.

The degree of prefabrication as well as exact conformance to the system description varies somewhat between manufacturers. The panelized system is particularly variable. In some cases the panels are completely finished on exterior and/or interior surfaces while in other cases the wall panels consist of only studs and sheathing.

The basic objective of our analysis was three fold. First, to identify the major housing systems, and investigate the technical requirements and selection criteria for wood-based material used in such systems. Second, to analyze the design criteria of these housing systems, clarify possible system dictated constraints, and study the significance of such constraints on the use of materials. And, third to develop indices indicative of material consumption for the major systems.

It is evident that there are some unique differences between the systems. A variety of constraints arise from these differences which affect both the type and amount of wood-base materials used. Let us consider some of these constraints in more detail.

THE SECTIONAL SYSTEM

By definition the Sectional System incorporates two rectangular modules. The width of the modules is limited by transportation regulations to a maximum of 12'-14', and thus the additional floor space must be obtained by adding length to the structure. This design constraint is rather severe, causing unduly high ratios of exterior wall to unit living area in large homes. This also affects negatively the heating and cooling costs. The width limitation of approximately 28 feet means that this system is best suited to relatively small homes, i.e., less than perhaps 1200 square feet. Floor systems usually are designed for the 12 to 14 foot span although in some cases the joists parallel the long axis. The transport vehicle of the section is a steel frame sometimes with negative camber. Many manufacturers find that the section must be stiffened at critical points to withstand the transport induced racking stresses which most frequently show up as cracks in interior wall finish. There is extensive use of glue-nailed plywood sheathing and also interior finish applied so as to provide the needed rigidity to the structure. In the U.S., softwood plywood is used almost exclusively to provide the racking strength. Here the system directly affects material selection favoring the use of board materials on both interior and exterior. Gypsum board and interior decorative hardwood plywood glue-nailed to studs is also sometimes used to increase section rigidity. The location of the vapor barrier can be a problem in this regard.

THE FREE DESIGN MODULAR SYSTEM

The users of free design modulars state that their systems have considerably fewer design constraints than the sectional system. However, it must be immediately admitted that transportation continues to be a limiting factor. Compared to sectionals, the free modules tend to be more nearly square rather than rectangular. The firms interviewed utilized modules such as 12 x 12' 12' x 16' and 12' x 32' (max.). While large module size minimizes field connections it adds to transport and erection problems. The design is severely influenced by the construction methods used, transportation mode and transportation distance as well as erection method.

One of the firms interviewed utilized an advanced stressed-skin structure with two component structural adhesive. This system used plywood extensively in all components and cites as its major advantages the simplified material selection and inventory requirements, the relatively low total factory labor component due to the use of sheet materials, and the high degree of prefabrication possible due to small amount of transport and erection damage. Structural elastomeric adhesives are commonly used on most sheet to frame connections.

As in the sectional system the free modular system offers only limited floor plan flexibility to customers. Plans are most frequently prepared by the manufacturers, and only minor changes can be made by the customers. Changes in opening sizes, positions

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of bearing walls, etc. would necessitate structural alterations and are thus not practical. Some of the most innovative building systems being proposed are of this type. These include structural sandwich or honeycomb structures, steel frame structures and concrete units. However, the actual commercial application of such new materials to single family dwelling is limited. The firms we studied utilized wood frames and skins. The free design modular system seems better suited to multifamily dwellings than to small single family units.

THE PANELIZED SYSTEM

Panelization has relatively few system dictated constraints. Regardless of the layout of the structure one can almost always successfully panelize it. However, some changes in the position of windows, doors, and walls may be necessary from the manufacturing point of view to construct a more balanced element, and enable more efficient use of standardized raw material sizes.

The panelized system is used throughout the world in numerous variations from small-sized 60 x 240 cm elements up to 1200 x 245 cm completely finished elements. The tendency is certainly toward more and more finished components, which are handled by crane in the factory and at the construction site. The flexibility of the system is demonstrated by the fact that, for example, in Finland hundreds of custom designed houses are panelized, prefabricated and shipped to Sweden and Germany. The project sizes vary from 100-400 houses. Alterations in customers plans that need to be made to enable more efficient factory manufacturing are generally made without much difficulty with acceptance by the buyer.

In certain cases, handling of the heavy elements both in the factory and during erection necessitates special consideration. Needed stiffness, however, is obtained by proper fastening technique and appropriate use of board materials, not necessarily plywood. In Scandinavia nailed or glue-nailed gypsum board and 3mm hardboard provide adequate stiffness for large size wall elements, and no additional limitations are placed on the choice of the remaining materials by the system.

Some panel manufacturers have developed a wet three-dimensional core to accompany the units. This method concentrates all heating, plumbing and principal electrical work in one module which is manufactured by a specific crew. The rest of the elements are thus simplified, and more efficient production as well as erection results. The wet core can be standardized to the principal house types offered by the company and thus even greater economies are achieved.

MATERIAL REQUIREMENTS

In order to compare the amount of wood-base materials used per square foot of house we developed a "material efficiency index". This index is based upon typical use of material in a conventionally built single family dwelling of 1100 sq. ft. This structure was assigned an index value of 1.000. The index is simply an indication of the amount of lumber and plywood used.

The purpose of the material efficiency index is to indicate possible differences in the use pattern of external wall framing, internal wall framing, floor framing, roof framing and structural panel materials used for sheathing, siding and underlayment. The computed index numbers are directly related to the total quantity of wood materials used. A smaller number indicates relative saving in material usage.

The total material efficiency indices for the systems we analyzed were as follows:

Conventional site built house (basis)	1.000	1.000
The Sectional System	0.950	
The Free Design Modular System	0.792	
The Panelized System	0.919	

The differences in the indices are relatively small although there is clear evidence that all manufactured housing systems tend to utilize materials more efficiently than conventionally built units. Code restrictions may limit attempts at engineering optimization of materials and hence the differences are not great. It should be pointed out that one of the companies included in the free design modular data above operated under an Operation Breakthrough Contract and was able to optimize material to a greater extent than if designing for existing building codes.

Table 1 presents a summary of the amount of lumber, plywood and particleboard used in the houses analyzed. The figures are expressed in terms of board feet of lumber or square feet of plywood per square foot of gross floor area. Plywood figures are based upon 3/8 inch thick and particleboard upon 3/4 inch thick material. It is apparent that the manufactured homes require less lumber but more plywood than conventionally built structures.

In Table 2 the use of plywood and lumber in the three industrialized systems is compared to the consumption in the conventionally built house. The relative number of man hours per unit is also shown. It must be pointed out that these figures were obtained from only a few manufacturers representing each building system. Therefore, any comparison between systems is heavily biased by the efficiency of the firm studied as well as the effects of the system. We had hoped to gather information from enough firms to overcome this problem but as yet have not been able to do so. Our data on the free design modular system may be particularly non-representative since one manufacturer we studied in this class was using a very nonconventional all-plywood floor system.

TABLE 1

Average Living Areas and Wood Material Use
In Those Single Family Dwellings Studied

SYSTEM	Average Living Area (sq. ft.)	Consumption of Framing Lumber (bf/sq. ft.)	Consumption of Softwood Plywood (sq. ft./sq. ft.)[1]	Consumption of Particleboard (sq. ft./sq. ft.)[1]
CONVENTIONAL	1100	6.510	2.890	0.270
SECTIONAL	1069	4.475	4.570	0.028
MODULAR	1071	1.900	14.110	0
PANELIZED	1116	4.150	4.890	0

[1] Sq. ft. of material per square foot of floor area.

TABLE 2

Average Comparative Data on Material and Labor Requirements of Conventional and Manufactured Housing Systems

SYSTEM	Relative Lumber Consumption	Relative Plywood Consumption	Relative Total Amt. of Direct Labor Time
CONVENTIONAL BASIS	1.000	1.000	1.000
SECTIONAL	0.688	1.580	0.610
MODULAR	0.291	4.890	0.435
PANELIZED	0.636	1.695	0.440

SELECTION CRITERIA FOR WOOD-BASE MATERIALS

Each firm interviewed was asked a series of questions regarding how and why they selected and specified the types and grades of lumber, plywood, particleboard and other wood products which they used. They were also asked for comments or problems they had experienced with these materials. We hoped to find if there were any strength, appearance, durability, straightness, or sizing requirements desired or specified by manufactured housing firms which differed from the needs of conventional builders.

The present state of technology being used by manufactured housing producers which we studied was essentially the same as for conventional builders. Floors were designed as in most conventional homes based upon strength and deflection of joists acting independently. Although glue-nailed subflooring was used this fact

was not utilized in engineering the joist sizes or spacings. Single panel floor construction of 2 x 8 joists and 5/8 plywood is commonly used but 2 x 10's and 3/4 inch plywood is also used by some firms over the 12 foot to 13 foot spans.

Structurally, the place where the manufactured house and the conventional home differ the most is in the wall sheathing materials and application. Insulation board or plywood nailed to studs is, of course, conventional wall construction but manufactured homes will invariably use plywood sheathing nail-glued to studs. The half-truss rafters are generally of 2 x 4 members. Single panel wall construction (combination sheathing-siding) was not used widely by the firms studied. The reason seems to be the popularity of some of the hardboard type prefinished sidings which must be applied over sheathing. The only place where 2 x 3's were generally used rather than 2 x 4's was in the middle common walls of the sectionals.

Most firms purchase their dimension lumber in grades and sizes to exceed the code minimums. They tend to purchase a higher grade than required for strength because of reduced warp. Three major concerns when purchasing lumber seem to be warp, proper sizing and proper drying. Manufactured housing firms are more critical of these factors than many conventional builders. A number of firms expressed some dissatisfaction with warp and size variability of framing lumber but only one manufacturer we visited was contemplating a shift to a steel floor framing system.

Particleboard was not being used by the firms we visited except as a counter top material. Unlike its wide use as decking in mobile homes, particleboard as subflooring - underlayment does not yet appear to have wide acceptance by industrialized housing firms.

In summary, we concluded that at this time the material specifications and technical requirements of wood-base materials used in manufactured housing do not differ from those in conventional housing. This situation however will change if the industry begins to shift to more non-conventional structural methods.