PREFABRICATED HOUSE SYSTEM DEVELOPED

BY THE FOREST PRODUCTS LABORATORY

Original report dated December 1937

Information Reviewed and Reaffirmed
October 1958

No. 1165
In the early thirties the U. S. Forest Products Laboratory undertook re-
search studies to develop design data applicable to stressed-cover panels,
to determine the strength of such panels, and to design and build sample pre-
fabricated houses with such panels for experimental and demonstration
purposes. Prefabrication of wood houses was not new, it had been practiced
to some extent for many years; nor was the stressed-cover principle, except
to house construction.

The first Laboratory prefabricated house was built in 1935; the second, a
one-story, and the third, a two-story, in 1937 (fig. 1). From the outset,
the Laboratory made it clear that the demonstration houses represented a
system under development and not a commercial proposition. Nevertheless,
following the initial demonstration of the first prefabricated house in March
1935, which attracted thousands of visitors, many inquiries were received as
to whether it was on the market, what it cost, and how it was made. This
wide interest, both of the public and members of the building trade, in the
adaptation of the stressed-cover principle to house construction brought about
a development of the prefabricated-house industry under which there were in
1949 about 100 companies producing prefabricated houses in varying quantity
and design. It has been estimated that in that year 30,000 houses, each
worth an average of $4,000 f.o.b. factory, or totaling $120,000,000 in value,
were produced by the 75 percent of the Nation's prefabricating plants found.
utilizing the basic design principles of the stressed-cover type of prefabri-
cated wood house developed by the Laboratory.

1 Original report dated December 15, 1937.
2 Maintained at Madison, Wis., in cooperation with the University of
Wisconsin.
The interest in prefabricated houses and the growth of the industry were stimulated because of the increased costs of labor and material for construction of houses of the conventional type and of the desire of elements of the industry to meet the demands of people for homes at prices within their ability to pay for them. Prefabrication of homes in a factory, on an assembly-line basis, seemed to give promise of reducing costs to such an extent that the demand could be met. The possibilities of such savings, together with details of wood construction and other matters pertaining to the prefabricated-house industry, are discussed in other publications.\(^3,4\) This report is necessarily limited to discussion of the Laboratory stressed-cover type of construction.

It may be said here, however, that the main idea in house prefabrication has been to put the intricate, difficult part of the work inside the factory and thus to reduce the time and expense of assembly on the building site to a minimum and to provide masses of the population with acceptable housing at a price within their reach. Some of the advantages of prefabricated construction that lead to this end are greater speed in construction and more economical use of lumber and other materials. For example, accurately fitting parts can be produced more quickly in a machine-equipped, mass-production factory (figs. 2-4) than on the building site, and stressed-cover panel construction can give greater strength and rigidity with less material than used in conventional construction.

### Stressed-Cover Principle

The basic feature of the Forest Products Laboratory stressed-cover type of prefabricated-house construction consists of two facings, one glued to one side and the other glued to the other side of an inner structural framework to form what is virtually a box girder. The facings may be of plywood or other suitable material. A variation of this construction is the "sandwich" panel, in which a continuous core, rather than stringers, is used. The stressed-cover principle is based upon the engineering conception that all material in a structure should contribute directly to its strength. In conventional

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construction, a structural frame carries the exterior and interior wall coverings, floors, and ceilings largely as dead weight. The stressed-cover principle thus gives opportunity to design more closely and with greater economy of material. Under this principle, prefabrication is something more than the mere transfer of the fabrication operation from the building site to a factory. It begins with design based on recognized engineering principles and includes such factors as quality control, precision manufacture, interchangeability of parts, and the efficient use of new materials and methods.5

The difference between the Laboratory's panel system and the conventional type of construction is marked. To choose an example at random, in the conventional type of floor construction the subfloor and finish floor are nailed to relatively deep joists. The subfloor is nailed diagonally in order to stiffen the building, but it is of little benefit to the strength of the floor framework. In contrast to the foregoing, each panel in the Laboratory's system has a complete and continuous rigid joint between the plywood and the framework formed by the glue between the plywood and joists. This causes the entire panel to act as a unit like a box girder and, as a result, the floor panels will deflect only about one-quarter as much under a given load as the joists acting alone.

On the basis of Laboratory research along these lines, United States patents were granted on Feb. 28, 1939, to John A. Newlin and G. W. Trayer, who were then with the Forest Products Laboratory, for construction methods involving certain features of the stressed-cover principle. These patents were dedicated to the public and have been available for unrestricted use. Although no prefabricator is now producing houses exactly corresponding to those designed and constructed at the Forest Products Laboratory, many of the principles incorporated in those houses are extensively used, with wide variation in detail. The development of plywood construction systems by the U. S. Forest Products Laboratory, and others, has been credited with having had, in fact, a large influence upon prefabrication as a whole.3

### Experimental House Design

The house described herein, erected in 1937, was the second experimental prefabricated house developed by the Forest Products Laboratory -- the first having been erected in 1935. It was built as a one-story building, constructed largely of plywood and containing a living room, kitchen, two bedrooms, a

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bathroom, a utility room, and adequate closet space. Incorporated in it were the Laboratory’s latest results in housing research, based in part upon experiments with the earlier prefabricated house. Construction of the house included, among other things, the use of plywood made up with a phenol-resin adhesive and the provision of moisture barriers within wall, floor, and roof panels. Other features of construction were plywood floors with 1/8-inch hardwood veneer as the wearing surface and the use of mineral-wool insulation material to provide necessary heat and sound insulation. Details of the construction of the house are shown in figure 5. Steps in its erection are shown in figure 6.

Wall Panels

Figure 5 shows a typical wall section, 4 by 8 feet in area. The exterior panels are 3 inches thick, and the covering materials consist of 3/8-inch three-ply plywood on the outside and 1/4-inch three-ply plywood on the inside. The framework consists of vertical members made of 1-inch material 2-3/8 inches wide, spaced approximately 12 inches apart with two end headers, to which the plywood faces are glued. The partition panels are also 4 by 8 feet. Both faces of the partition panels are, however, of 1/4-inch plywood, and the vertical members are 2-1/2 inches wide, with the over-all thickness being 3 inches.

Experiments indicate that these panels, when tested as a beam, require a load of more than 200 pounds per square foot to cause failure. A 60-mile-an-hour wind has a pressure of about 12 pounds per square foot, which is approximately one-seventeenth of the load required to break the panel.

The plywood projects beyond the framework of the panel to form a continuous right-angle groove 2-3/8 inches wide and 1-1/4 inches deep entirely around the panel. A portion of the sill fits up into this groove. A 2-1/2- by 2-3/8-inch solid vertical member is fitted into the grooves on the sides of adjacent wall panels. This vertical member serves as a connecting piece between panels, and also carries part of the roof and floor loads. At the roof a strip glued to the roof panel fits down into the groove at the top of the panel, as shown in the details of figure 5. After assembly, the wall, floor, and roof panels are securely fastened by screws or nails to those parts that fit into the groove, so as to tie wall, foundation, and roof together.

The edges of the face of the panel forming the interior house wall are beveled to form a V-joint when the panels are assembled. The panels forming the exterior surface are beveled on the outside and inside edges, the outside bevel to form a V-joint similar to that for the interior wall surface, but slightly opened, and the inside bevel to form a pocket for mastic that is placed between the panels directly after erection. This pocket permits a sufficient amount of
mastic to be placed between the panels for it to retain its plasticity and thereby provide a tight and permanent seal against the entrance of moisture and the infiltration of air at the exterior panel joints.

**Floor Panels**

The floor panels are 4 feet wide and 12 feet long. The upper face is 5/8-inch plywood of five plies, and the lower face is 3/8-inch plywood of three plies. These faces are glued to a structural framework consisting of three nominal 2- by 6-inch members spaced approximately 24 inches apart, with end headers. All parts of the panels act as a unit, and therefore the panels can be substituted for the usual 2- by 10-inch joists spaced 16 inches apart, as ordinarily used in house construction.

The lateral edges of the floor panels are grooved to permit a spline connection for the distribution of weight to adjacent panels. When panels of this type are tested as a beam over a 13-1/2 foot span, a load of more than 300 pounds per square foot is required to cause failure. Accordingly, the panels far exceed in strength any loads normally put upon them.

Except in the kitchen and the utility room, the upper 5/8-inch plywood is faced with birch 1/8 inch thick to form the wearing and finished floor surface. This construction eliminates the necessity of putting a finished floor over a subfloor, as in ordinary construction.

**Roof Panels**

The roof panels are similar in size and construction to the floor panels. The flat roof was covered with a five-ply built-up felt roofing of the usual commercial type.

**Type of Plywood**

All exterior surfaces of the house are of phenol-resin-bonded plywood. The use of plywood in the past for outside permanent construction had not always proved satisfactory because the glues available were not sufficiently resistant to weathering. With the introduction of the phenol-, melamine-, and resorcinol-resin types of glues, this situation was changed. At the time the house was built, plywood glued with the phenol-resin glues was being used more and more for outside use with every indication that it would withstand the weather indefinitely without the plies separating, providing ordinary care such as painting the edges and surfaces were used. Phenol-resin-bonded
plywood was also being used for interior surfaces because of its somewhat greater fire resistance.

Moisture Barriers

Coincident with the introduction during recent years of more moisture into homes by means of humidifying apparatus, houses were also being made tighter by the use of storm windows, weather strips, and the more general use of insulation within the walls and roofs. In houses loosely constructed, the moisture-laden air, which flows from the warm inside to the colder outside, is easily carried away, but in houses with good insulation and tighter construction, either of conventional or of prefabricated type, it is not, and when it reaches the cooler areas within the wall it may condense. Over an extended period considerable moisture may accumulate, the insulation may become wet, and its efficiency may be greatly reduced. Even when warm weather arrives the moisture disappears slowly and may make conditions favorable for rust, mold, and decay. Many paint problems, such as the peeling of outside paint, also arise from the accumulation of moisture within the walls. Obviously, it is very important to prevent such conditions; therefore moisture barriers were used in the outside walls of the house.

The moisture barriers used in the house consist of asphalt-impregnated and surface-coated paper weighing 50 pounds per roll of 500 square feet. The barriers are placed within the panel and against the back face of the inner walls, against the back of the upper face of the floor panels, and against the back of the lower face of the roof panels; that is, in all cases the moisture barriers are placed within the panels and against the back of the face nearest the inside of the room.

A moisture barrier is placed in each space between framing members and consists of a single piece of paper so folded as to fit snugly against the plywood face and along the sides of the framing members. Those parts of the sides of framing members that are in contact with the moisture barriers were given a brush coating of asphalt paint just before the barrier was placed, after which the barriers were held to the framing members with wire staples at intervals of not more than 6 inches to keep the paper tightly against the framing members and in contact with the fresh asphalt paint.

Insulation

The space within the wall panels is entirely filled with a mineral-wood insulation giving a coefficient of heat transmission for the wall of approximately 0.12. This is superior to that of conventional construction with one-half inch of blanket insulation.
In addition, the use of large plywood sheets in wall panels is very effective in making the structure windtight. Insulation has also been placed in the partition walls for sound-deadening purposes.

The floor panels are insulated with nominal 2-inch mineral-wool bats, and the roof panels with 4-inch bats.

Fire Resistance

Fire tests of plywood at the Forest Products Laboratory show that the plies of plywood bonded with phenol-, melamine-, or resorcinol-resin glue do not separate while burning as do plies of protein-bonded plywood. Phenolic-bonded plywood will therefore give somewhat greater resistance to fire than plywood glued with protein glues. On this account, resin-bonded plywood was selected for the inside as well as the outside walls. To obtain greater fire resistance, a mineral wool of high density was selected as an insulating material.

Rooms

The floor area (fig. 5) of the house is 24 by 36 feet. The house includes a 12- by 20-foot living room, a kitchen, two bedrooms, a bath, connecting halls, and a utility room. In addition, there is a coat closet and a linen closet off the main hall, two closets in the larger bedroom, and a wardrobe closet in the smaller bedroom. A large garage was placed close to the house, with a space partitioned off at one end for storage. The garage was connected to the house by roof panels.

The walls of the living room are of natural finish birch, while the ceiling was painted a light color. The floors are of birch-faced plywood, as are all the other floors except the kitchen and utility room, which are of Douglas-fir plywood. The walls of the hall are also of birch, finished natural. The walls of the other rooms are of Douglas-fir, painted.

The house was heated with an oil burner. A warm-air forced-circulation system was used, and the heating ducts were confined mostly to the portion of the hall connecting the various rooms. This portion of the hall has a lowered ceiling to accommodate the ducts. A post and plank foundation of creosoted wood was used.

In prefabricated houses there is a decided tendency toward one-story homes. It is, however, both practical and feasible to erect two-story houses (fig. 1) with the Laboratory's prefabricated panel system.
Continued Research Desirable

Despite the great development of the prefabricated-house industry along lines of the stressed-cover principle, the experience of the Laboratory with its second prefabricated house indicates that when it was built in 1937 perfection had not yet been achieved and that there is still need for further research to attain it. In fact, during the 15 years since the house was built, research carried out at the Laboratory dealt with many of the technical problems besetting manufacturers, such as dust patterns, interwall condensation, and the bowing of panels due to changes in moisture content; and the work of the Laboratory with new materials and production techniques had great import for most of the firms in the industry. For instance, since the exterior and interior surfaces of a wall are exposed to different environments, they will tend to attain different moisture contents in the course of time; consequently, if a stressed-cover panel is built true at a time when the exterior and interior sheets of plywood have the same moisture content, the panel may bow later on. The Laboratory has recently been conducting research to discover the optimum initial moisture content for plywood sheets to be used in stressed-cover construction.

Service Findings

Any type of house construction is likely to have some feature that is undesirable. In conventional house construction, for example, cracks are very likely to occur in plastered ceilings and walls. In fact, they are so common as to be generally accepted as unavoidable. With dry-wall construction the hiding of the joints between sheets of wallboard is extremely difficult; another fault is the pushing out or "popping" of nail heads.

Checking of the plywood surface both on the inside and outside has occurred in the Laboratory prefabricated house built in 1937. This does not, however, injure the house structurally and the plywood does not delaminate, but the checking does, of course, affect the appearance of the house. While a means of preventing checks has not been devised, it has been found that the checking of the surfaces, both exterior and interior, can be practically eliminated by using plywood that has been covered with resin-impregnated paper at the time of manufacture. If checking has occurred in unfaced plywood, it can be satisfactorily concealed by application of ordinary wallpaper. Observations indicate that the paper does not break over the checking.

Dirt patterns are another common occurrence in prefabricated houses with large plane surfaces. They appear over the framework of the wall panels and
are apparently caused by unequal insulation properties at and between framing members. It is most noticeable with thin walls; it could probably be largely eliminated by using a thickness of insulation between framing members equal in heat transmission to the framing members so that all parts of the wall would be equal in resistance to passage of heat. Many manufacturers are now using shingles or bevel siding to cover the outside walls, and thus the panel appearance suggestive of prefabrication is eliminated and any dirt patterns that might form on outside wall surfaces are obscured.

Dirt patterns also often occur over nail heads. This can be eliminated by using presses rather than nails to obtain necessary pressure during the setting of the glue.

**Vapor Barriers Efficient**

The vapor barriers in the house have proved very efficient. They have held moisture accumulations in the walls to a minimum even when the relative humidity in the house was kept at 40 percent in cold weather.

In other respects, the house has stood up well compared to conventionally built houses over the same period of time. During this time it has received only maintenance usually expected for any conventionally built wood house. The floors, built of birch plywood over a Douglas-fir core, were, however, neglected until their finish was worn off and dirt worked into them. When they were refinished, they presented an excellent appearance.

The roof, of built-up asphalt composition over the roof panels, has given satisfaction.

Because of the tight construction and the full wall insulation, the house is easily heated and the fuel bills are correspondingly low.

**Success Depends on Other Factors**

Although all problems of the prefabricated-house industry are not solved, the industry, on the basis of experience up to the present, holds an optimistic outlook as to the future. The Forest Products Laboratory in its research work is limited to problems of the utilization of wood, which include those of design and construction in prefabrication of houses. The industry, however, must cope with other problems, even though design and construction of prefabricated wood houses are sound. Among these problems are those of purchasers' financing of prefabricated homes; management; procurement of raw materials; production and plant facilities; marketing; and competition,
not only from conventionally built homes but from mass production of homes on subdivisions and real-estate developments with crews of workmen, on the assembly-line principle, each assigned to a special task in construction, and moving on from house to house, and from houses prefabricated from materials other than wood. These problems are discussed in another publication.
Figure 1.--Prefabricated houses built by the Forest Products Laboratory in 1937 as part of its research in developing the stressed-cover principle with wood and plywood for prefabricated housing. The one-story house in the foreground is the one discussed in detail in this report.
Figure 2.—View of a modern mass-production prefabricated-House factory that marks the development of the industry since Forest Products Laboratory research first applied the stressed-cover principle to housing. The picture shows the horizontal type of a continuously moving chain-conveyor system.
Figure 3.--Continuous-belt conveyor system used to carry panels to and from high-frequency dielectric presses in modern mass-production prefabricated-house factory.
Figure 4. Press utilizing high-frequency dielectric heating for setting blues in wall panels in modern mass-production prefabricated-house factory.
Figure 5.--Details of construction of prefabricated one-story stressed-cover plywood house developed at the Forest Products Laboratory, showing floor plan, wall section, exterior wall panel, and roof panel.
Figure 6.--Steps in erection of prefabricated one-story plywood house at the Forest Products Laboratory. A, floor panels on foundation, ready for fitting with spline connections. B, first roof panel being put in place; strips on panel fit into grooves of wall sections for tying roof and walls together. C, all house panels assembled and garage nearing completion. D, panels all in place and house completed.