RECENT PROGRESS ON HOUSING RESEARCH
AT THE FOREST PRODUCTS LABORATORY

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By
L. J. Markwardt, Senior Engineer

There is an apparent unanimity of opinion that a serious housing shortage exists in the United States, particularly of dwellings in the lower price range, but opinion differs as to the magnitude of the building program required to meet this shortage. President Roosevelt's appraisal of the situation is that 600,000 to 800,000 dwellings should be built annually for at least 5 years. At $4,000 per unit, such a program would involve an expenditure of 16 billion dollars for this period. On the other hand, one widely quoted estimate goes even farther and calls for 14 million new dwellings in the next 10 years, but this estimate, apparently, looks to a radical change in housing conditions, and has been questioned as to practicability even if theoretically desirable.

The trend in dwelling construction for the past 18 years can be visualized from the compilation by the U. S. Department of Commerce shown in Table 1.

Table 1.—Trend in dwelling construction

<table>
<thead>
<tr>
<th>Year built</th>
<th>Dwellings built</th>
<th>Year built</th>
<th>Dwellings built</th>
<th>Year built</th>
<th>Dwellings built</th>
</tr>
</thead>
<tbody>
<tr>
<td>1920</td>
<td>337</td>
<td>1926</td>
<td>830</td>
<td>1932</td>
<td>97</td>
</tr>
<tr>
<td>1921</td>
<td>457</td>
<td>1927</td>
<td>771</td>
<td>1933</td>
<td>60</td>
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<tr>
<td>1922</td>
<td>777</td>
<td>1928</td>
<td>710</td>
<td>1934</td>
<td>60</td>
</tr>
<tr>
<td>1923</td>
<td>861</td>
<td>1929</td>
<td>517</td>
<td>1935</td>
<td>133</td>
</tr>
<tr>
<td>1924</td>
<td>878</td>
<td>1930</td>
<td>320</td>
<td>1936</td>
<td>275</td>
</tr>
<tr>
<td>1925</td>
<td>919</td>
<td>1931</td>
<td>204</td>
<td>1937</td>
<td>300</td>
</tr>
</tbody>
</table>

1—Presented before the Engineering Society of Wisconsin, at Madison, Wis., March 18, 1938.

2—Acknowledgment is made to the various members of the technical staff of the Forest Products Laboratory, the results of whose work is reported herein.
It is obvious from these considerations that the building industry must quicken its pace to cope adequately with present housing needs. Much consideration is being given from coast to coast to the development of new types of construction and materials as one means of giving impetus to the industry, while a house-conscious public awaits any and all developments with both hope and interest. This tremendous popular interest in home building is indicated by over 5,000 inquiries received at the Forest Products Laboratory following a single radio broadcast describing the system of prefabricated construction which has been developed.

I want to present the results of the research work of the Forest Products Laboratory relating to house construction. In doing so, I think I would be remiss if I failed to outline briefly the scope and objectives of the Laboratory so that you may see how the housing research work fits into the forestry picture. As you know, the Forest Products Laboratory is a branch of the U. S. Forest Service, operated at Madison in cooperation with the University of Wisconsin.

If we conceive of our national forest philosophy as resting on three essential supports, we could consider these supports to be the three P's: Production, Protection, and Products. It is with the efficient utilization of products that the Laboratory is concerned. Hence, its work does not consist in planting trees or in fighting forest fires, but its business is with the useful products the trees produce. Its program is directed toward improved efficiency in utilization along five major lines:

1. Reducing the 50 percent waste in the complete utilization of the forest crop.
2. Reducing the costs of wood products to the consumer through improved methods of processing and manufacture.
3. Increasing consumer satisfaction in the service of wood in every form of use.
4. Developing new products and uses for wood which create new social values in a renewable resource.
5. Obtaining, through research, information on the influence of growth conditions on wood and other forest products as a guide to the growing of our future timber crop.

Wood to the pioneer American was a superabundant material, available predominantly in large sizes and clear grades. The timber was mined, without thought of its possible future as a crop. It was used extravagantly, with no close figuring as to size. Thus, economy was neither practiced nor deemed necessary.

Wood, in our modern industrial economy, is an exceedingly complex and versatile material, yet eminently adaptable for construction,
fabrication, and chemical conversion. Like other materials, it is dependent on research to adapt it to the needs of modern civilization. Borrowing an example from another field, it is of interest to note that in modifying the properties through treatment with synthetic resins, research has again brought wood into favor for airplane propeller blades.

In a recent survey of residences in a large number of cities, over 75 percent of the homes were found to be of frame construction. Again, in a survey of farm buildings in the Midwest, 59 percent of the buildings of all kinds were of wood. Over 60 percent of our annual lumber consumption goes into building and construction uses. But the Laboratory is interested in the building problem not only because of the large amounts of material used, but also because of the social impact of possible developments in this field.

Of the seven technical divisions of the Laboratory, all are contributing, in varying degree, to the housing research program. Quite naturally, many of the results and principles are of broad general application to all types of houses and construction, as, for instance, the work on moisture barriers and on paints. On the other hand, a number of the studies are aimed directly at the development of a system of prefabricated panel construction, with particular emphasis on plywood as a material. Under consideration also is the possible use of lumber in an efficient panel system of construction.

Let us review briefly the results of some of these various studies.

**Strength and Rigidity of Frame Walls**

Small frame structures never have been subjected to a thorough-going engineering analysis. The structural details of such buildings are for the most part governed by precedent, tradition, and judgment without much regard for the particular requirements of a particular structure. It is true that, in principle, the superiority of certain details over others has been known and appreciated by architects, good workmen, and building contractors. Convincing experimental evidence, however, is lacking not only where the superiority of certain details is known, but also where there is an uncertainty as to what is right construction.

A series of tests was made to determine the relative resistance of different types of frame wall construction to longitudinal thrust, to obtain a better understanding and appreciation of the principles involved in wall construction, which tend to make frame dwellings and other small frame buildings substantial structures free from excessive maintenance costs.

The tests were made on wall sections 9 by 14 feet in size, representing the side of an average room. The load was applied to effect
a racking of the panel, simulating the stress resulting from wind loads on a wall at right angles thereto. Tests were made on wall sections both with and without openings. A brief resume of some of the test results on panels without openings is presented in the accompanying chart. (Fig. 1.)

A brief field study of the use of lumber in house construction was recently completed by two of the Laboratory staff members, one an engineer and the other a wood technologist. The object was to study current practice in wooden house construction, to determine the extent to which present knowledge is being applied, to analyze the prevalence of faults, and to appraise the quality and condition of lumber being used. Over 600 houses under construction were inspected in the central, midwestern, southern, and eastern states.

Most encouraging was the fact that so-called "jerry" construction or deliberate skimping of construction throughout the house as a whole to a point of falsification, was conspicuous by its absence, although 82 percent of these homes were built for sale. In most cases sound construction for the house as a whole, judged by local practice, was in evidence and it appears that the home owner is getting honest value for his money. Major credit for this salutary condition should, no doubt, go to the F.H.A., under whose sound principles and alert supervision much of current residence construction is being built.

Of the homes inspected, 60 percent were in the $4,000 to $7,000 class, with 20 percent above and 20 percent below this price range. Statistics as to the proportion of houses of each type and the number of rooms are as follows:

<table>
<thead>
<tr>
<th>Type of House</th>
<th>Percent</th>
<th>No. of Rooms</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>One story</td>
<td>37</td>
<td>4 or less</td>
<td>28</td>
</tr>
<tr>
<td>One and one-half stories</td>
<td>34</td>
<td>5 rooms</td>
<td>27</td>
</tr>
<tr>
<td>Two stories</td>
<td>29</td>
<td>6 rooms</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over 6</td>
<td>11</td>
</tr>
</tbody>
</table>

It is evident that most of these homes do not come within the range of what may be called "low-cost" construction, and do not meet the crying need for homes of those within the lower income brackets — the 82 percent of the urban population shown by Department of Commerce statistics to have incomes in 1933 under $2,000 per year. The failure to find any appreciable amount of "low-cost" houses under construction was due to the absence of such construction, rather than to concentration on other types, for special efforts were made to locate and include them in the survey.

The principal faults observed were primarily due to lack of knowledge or carelessness. Lack of knowledge was particularly evident in failure to follow known principles of good construction, such as
providing adequate ventilation and drainage to keep the wood dry and thus insure the structure against the inroads of decay.

One of the serious faults observed was the use of green or but partially dried lumber, not universally, but notably in certain cities where cut-throat competition is rampant. Moisture meter readings showed that about three-fifths of the pieces of lumber examined were above the maximum that is considered desirable for good construction in a large portion of the country, about 14 percent moisture content. Excluding two large cities where conditions were particularly bad, the proportion of green lumber was much less. Unwillingly of the dealer or contractor to pay the additional cost of drying, and disposition of some mills to dispose of lumber direct from the saw, is no doubt responsible for this condition. At the same time reputable mills stand ready to furnish grade-marked, trade-marked, dry lumber, at any time.

It was discouraging to find in some cities that considerable substandard thin lumber was used in boards $\frac{3}{32}$ inch and in dimension $\frac{1}{16}$ inch under the standard thickness. In the development of American Lumber Standards much consideration and study was given to the necessary thickness of a "so-called" 1-inch board, and 25/32 inch was adopted as standard thickness. The Forest Products Laboratory believes that for substantial construction, and for the present accepted methods of building, lumber of standard thickness should be used and that the utility value more than offsets any extra cost that may be involved over substandard lumber.

Considerable nonuniformity of the quality of lumber within the grade was observed. In some localities the grades were "sweetened," that is, they contained material of higher quality than would normally be expected in the grade. An occasional lot showed some below-grade pieces. In general, the grading was good as was the selection of the grade best adapted to the use. Some grade-marked lumber and trade-marked lumber were encountered, but considering the protection that grade-marking usually affords against substandard sizes, inadequate seasoning, and off-grade pieces, there should be considerably more demand for grade-marked stock.

It would perhaps be too much to expect entire freedom from all construction faults. Many examples of bad construction details were observed. These faults comprise such practices as cutting load-carrying girders in two to install plumbing fixtures; failure to recognize the necessity of equalizing shrinking and swelling, by inadvisedly combining details of both balloon and platform construction in the same unit; failing to follow the manufacturer's recommendation for nail spacing in applying fiberboard sheathing; and failure to protect against the hazard of decay either by providing drainage and ventilation for exposed parts, or by using durable species or treated material.
Protection of Wood by Paint

Wood is subject to two kinds of deterioration — weathering and decay. Decay, as you know, is caused by minute organisms called fungi. Long service from wood exposed to decay hazards can be obtained by using heartwood of durable species, or by using wood treated with a wood preservative. Paint, in this sense, is not a wood preservative.

Weathering is the checking and deterioration of the wood surface resulting from exposure to outdoor weather conditions. It is the role of paint to protect wood from weathering, to maintain a smooth surface, and to give the fine appearance desired. The weathering of wood does not necessarily mean rapid deterioration — the siding on some buildings of the Amana colony in Iowa, built in 1858 and never painted, is still intact and serviceable. Weathering is objectionable as a rule only where the appearance of weathered wood is undesirable from the point of view of decoration. Painting is, of course, of little protective value after weathering has once well started.

The Laboratory's study of the painting of wood is aimed simply at making reliable and economical paint maintenance more easily and certainly attainable and at avoiding costly blunders in paint maintenance. The importance of painting can be visualized from the fact that the annual paint bill of the nation for material alone is about 400 to 500 million dollars, of which perhaps one-third represents exterior house paint. Add to this the labor charges, amounting to at least twice the cost of the paint, and we find that the home owners' bill for exterior painting work totals 400 to 500 million dollars annually. Obviously, any improvement in the serviceableness of paints presages the possibility of enormous savings in the home owners' budget.

One of the important phases of paint research has been the study of the mechanism of paint holding in wood, and the correlation of paint holding ability with the characteristics and structure of the different species. Paint test fences were established in 11 different regions of the country to study paint performance under different climatic conditions. This work has led to the classification of the various species into five groups (including hardwoods), in accordance with their painting characteristics, ranging from the easy painting woods like cypress, redwood, and the cedars that render the best paint service, to the hardwoods with large pores that are unsuitable for conventional house painting because a filler is required to fill the pores properly.

The effect of numerous features of wood on paint performance has been worked out, such as better adhesion of paint to the radial than to the tangential face, the better paint performance of a piece when the bark side rather than the pith side is exposed, and the advantage of material with narrow rather than wide growth rings.

The painting of wood has been and is still associated with many premature failures. Too often it has happened that the paint interests
blame the wood, and the wood interests the paint in a vain effort to shift the responsibility. The Laboratory has been analyzing paint failures so that in many cases they can now be classified as to cause, and the appropriate remedy applied. Some of the most conspicuous causes are as follows:

1. Excessive moisture in the wood, due to moisture accumulation in the walls. Moisture barriers are an effective agency in reducing paint failures.

2. Incompatibility of paints, caused by difference in nature and amounts of pigments, as for instance when white or tinted paints are applied over full-color paints like brown, green, or red.

3. Mistakes in thinning paints and in the amount of paint applied.

4. Mistakes in length of time allowed to elapse between paint jobs.

5. Spreading a paint job over six months or more, before the finish coat is applied.

The effectiveness of aluminum primer has been demonstrated for the heavier woods that hold paint less well.

The paint study has further brought out the necessity for the homeowner to plan in advance some program of paint maintenance. If he anticipates a long period of neglect after the time for repainting has arrived, he should use a soft type of paint; for programs with 4 or 5 years between paintings any good type of paint may be used, but repainting should be done with the same type. For maintenance programs with more than 4 or 5 years between repainting, the colored paints of great durability are particularly suitable. Buildings painted with hard paints must, however, be repainted before serious disintegration appears.

The great variety of paints now available, with the increase of ready mixed paints, has greatly complicated the painting problem and increased the possibility of paint failure through incompatibility. One possible solution lies in the classification of ready mixed paints by the manufacturer as to group, type and division, so that the paints in any one class can be handled by one prescribed method, and that a paint may be readily selected to fit any predetermined maintenance program. Such a system has already been proposed by the Laboratory. The proposed system still leaves the manufacturer much latitude in formulating any one type of paint and leaves him responsible for the quality of his product, but makes it possible to give the public specific advice about the characteristics of commercial paints and the correct ways of applying and maintaining them.
Moisture Condensation in Walls

The tendency to maintain higher humidities in homes either accidentally or intentionally brings in its wake increasing troubles from moisture condensation in walls and attics with several attendant ills. The ill effects of moisture accumulation in walls manifest themselves by establishing conditions favorable to decay, by promoting rust, by reducing the effectiveness of insulation, by damage to plaster and interior finish, and by causing exterior paint failures. That this condition is not a theoretical one is indicated by the hundreds of cases that already have come to the attention of the Laboratory. It should be pointed out, however, that the problem of moisture accumulation is largely confined to the colder climates of the northern and northeastern states. Particular attention should be given to humidity control and to methods of avoiding condensation in relation to air conditioning equipment.

The Laboratory has been studying methods of preventing moisture condensation in walls. For those wishing to obtain the benefits associated with higher humidities, and for the numerous instances beyond such control, two obvious remedies may be considered, namely, ventilating the wall, and establishing moisture barriers to prevent the entrance of moisture. Ventilation of the walls, of course, means not only heat loss but does not assure control, and for that reason particular attention has been given mainly to the possibility of the second method, namely, the use of moisture barriers.

Studies relating to moisture barriers have been of two kinds. First, an analysis of the temperature and moisture gradient within walls of different construction and secondly, the evaluation of the various mediums that may be inserted as moisture barriers.

The Forest Products Laboratory has been making tests on the vapor resistance of various materials used in wall construction and also on many materials that might be used for moisture barriers. Although these tests are still under way and have not covered all possible materials, enough information is available to permit the selection of a number of materials that are highly resistant to the passage of water vapor. Among these are (1) asphalt impregnated and surface coated sheathing paper, glossy surfaced, weighing 35 to 50 pounds per roll of 500 square feet; (2) laminated sheathing paper made of two or more sheets of kraft paper cemented together with asphalt; (3) double-faced reflective insulation mounted on paper.

Figure 2 shows the relative efficiency of various materials as moisture barriers in walls.

The barrier when located on the warm side of the dewpoint position resists the passage of moisture while it is in the form of vapor and therefore before it has a chance to condense into water. Hence there is no hazard of water forming behind the plaster or other interior wall finish. The barrier also prevents moisture from getting into the wall or attic space during the construction period, particularly during the plastering operation.
The following recommendations are based on the results of the work to date:

For new construction it is recommended that a suitable vapor barrier be installed on the side wall studs and below the ceiling insulation and that some attic ventilation also be provided. This will not only protect the house for normal humidities but should prove ample protection in case winter air conditioning is installed. Further, it offers protection during the construction period, particularly if plastering is done in cold weather.

For existing houses that have been or are to be insulated, and where humidities during cold weather are low, attic ventilation alone should be adequate. Should evidence of moisture appear in mild weather following a cold period, cut off all possible sources of humidity for the balance of the winter and some time later in the following summer, after the moisture has had time to disappear, coat the inside of the exterior walls and the ceiling below the roof insulation with two coats of aluminum paint after which redecorate as desired.

For existing houses that are equipped for winter air conditioning follow the foregoing suggestions and during periods when outside temperatures are below 15° F. carry relative humidities not higher than 30 percent and in subzero weather reduce to 20 percent relative humidity.

The suggestions offered here are based upon tests now under way at the Forest Products Laboratory, combined with observation and experience in occupied homes. As these tests and observations are continued and additional information becomes available more specific recommendations for protection against moisture condensation will be forthcoming.

Thermal Conductivity and Vapor Transfusion

Closely related to the study of moisture condensation in walls is that on thermal conductivity and vapor transfusion. No analysis is made at the Laboratory on the relative thermal efficiency of various insulating materials as such, but tests have been conducted to determine the over-all heat loss through walls of different construction, with and without insulation and the amount of vapor transfusion under different conditions. Measured also was the temperature and moisture gradient at various stations in the wall under varying conditions.

For the measurements of thermal conductivity and vapor transfusion an entirely new technique was worked out. Space does not permit of a detailed description, but essentially the method consists in placing the wall panels to be tested in openings in the partition wall between two controlled rooms, one maintained at room temperature and constant humidity, the other maintained at winter conditions in which temperatures can be kept below zero degrees Fahrenheit when desired. A well-insulated
cabinet, open on one side, is sealed and held tightly against the warm side of the test panel, so that the open side of the cabinet is toward the panel. The cabinet is maintained automatically at exactly the same temperature and humidity as the room in which it is placed. Any cooling of the chamber and any lowering of its humidity are thus due to loss through the test panel. The procedure in evaluating thermal conductivity consists simply in measuring the amount of heat supplied to the chamber. Likewise the permeability of the wall to vapor is determined by measuring the amount of moisture added to maintain the humidity. Thermocouples are provided for measuring temperature at 11 places in and adjacent to the wall, and measurement of the moisture content of the wood at different places is made.

Tests on this project are still under way. Measurements, however, have been made on the moisture transfusion through a number of wall constructions. Included in the study was the determination of the effectiveness of the moisture barriers in the wall panel with stressed plywood covering used in the new prefabricated houses erected by the Laboratory. This prefabricated wall panel was 3 inches in over-all thickness, and was constructed with 1/4- and 3/8-inch resin-bonded plywood for the inner and outer faces, respectively. The 2-3/8-inch wall space was filled with insulation. Measurements for this construction show that the addition of an asphalt impregnated and coated paper as a moisture barrier reduced the vapor transfusion from 0.019 gram (0.000042 pound) to 0.0047 gram (0.00001 pound) per square foot per hour, for a temperature differential of 70° F. and for a relative humidity in the warm room of 40 percent. In other words, the moisture movement was reduced three-fourths by the moisture barrier.

Typical results of an analysis of the heat loss through walls is shown in figure 3. It may be noted that the conventional uninsulated frame wall has a thermal coefficient of about 0.25 (B.t.u. per hour, per square foot of surface, per degree Fahrenheit of temperature difference) as against 0.17 for a common type of insulated wall. The lower the thermal coefficient, of course, the greater the efficiency of the insulation.

Another phase of the work on thermal conductivity of walls was the development of a wall for the Forest Products Laboratory system of prefabricated construction. The insulated wall panel being used in the latest prefabricated houses constructed by the Laboratory have a thermal conductivity of about one-half that of the conventional uninsulated frame wall.

Glues

Perhaps no single factor has been responsible for such significant advance in the field of modern wood construction as the development in glues and gluing technique. The past decade has brought us synthetic
resins, the phenols and urea glues, that have greatly enlarged the horizon for fabricated products that must resist continued adverse exposure to moisture changes. Advances with other glues have also been important.

One of the newer wood products obtaining increased markets in building construction is plywood. Before discussing what can be expected of these newer glues, let us look at how they are expected to function in plywood.

Plywood, as you know, consists of a combination of three or more plies of veneer, with the grain of alternate plies at right angles. Wood is inherently weak across the grain. In plywood the material is redistributed so that the strength becomes more nearly equal in the two directions. The problem then is to get some adhesive that will hold the material together effectively under adverse moisture conditions.

The cross banding of the veneer in manufacturing plywood results in a material that can be made in large sizes, and that has relatively little shrinking and swelling with moisture changes. It is tough, puncture resistant, and can be nailed near the edges without splitting. When glued with starch or hide glues, plywood is not water resistant, but commercial test panels made with phenolic resin glues and without protection of any kind have been reported to the Laboratory as showing no failure of the glued joints after being exposed to the weather for periods exceeding 2 years. This increases confidence in the possibilities of plywood for uses involving exterior exposure.

During the war there were available starch glues, hide glue, fish glue, casein glue, and blood glue, the latter two being water resistant. Research on glues has been centered around the study of conditions essential to secure a good glued joint with all glues when used with different woods and the evaluation of the serviceableness or durability of glued joints by means of accelerated tests and exposure cycles.

For the more commonly used woodworking glues exposure tests have been in progress for several years and these tests have provided rather accurate indications of the limitations of common adhesives. On the phenolic resin glues, introduced commercially about 5 years ago, our accelerated exposure tests have been in progress slightly more than 4 years and on the urea resin glues, introduced about some 3 years ago, our tests have been under way for something over 2 years. Of the accelerated tests, the one ordinarily employed is that involving a soaking-drying cycle (2 days soaking in water followed by 12 days drying in 30 percent relative humidity) approaching the conditions that will be encountered when plywood is exposed unprotected to the weather.

It may be noted in table 2 that the starch and animal glues lose all their strength at the first soaking. Obviously they are not the answer to a completely weather-resistant material. The casein glue is much more water resistant, but by the end of 2 years has lost its strength. It is an excellent glue for mild conditions of exposure and has the advantage that it can be applied cold. The blood glue is losing its
effectiveness toward the end of 4 years or 200 cycles of accelerated testing, and the failures of the test samples are in the glue. The phenolic resin glue, on the other hand, is still maintaining a high standard of strength and a high percentage of wood failure. It has excellent possibilities and gives us confidence in the use of resin-bonded plywood for house construction and other outdoor use. The tests on the urea resins have not been under way long enough to give the 4-year comparison.

Table 2.—Comparison of glues under accelerated tests

3/16-inch, three-ply yellow birch plywood
cycle: 2 days soaking, 12 days drying

<table>
<thead>
<tr>
<th>Kind of glue</th>
<th>Loss in strength of glued joint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soaked and Tested Tested</td>
</tr>
<tr>
<td></td>
<td>tested soon: after after</td>
</tr>
<tr>
<td></td>
<td>after gluing: 2 years 4 years</td>
</tr>
</tbody>
</table>

- Animal: Complete
- Vegetable: Complete
- Casein: Slight Complete
- Blood: None Moderate Marked
- Urea resin: None Slight (No data)
- Phenolic resin: None Slight Slight

Treatment for Dimension Changes

One of the major problems in the use of wood has been due to the fact that it is a hygroscopic material, and changes dimensions with changing moisture content. Sticking doors, sticking bureau drawers, and cracks in floors are evidence of these dimension changes. Woodworkers have long sought remedies to minimize shrinking and swelling.

The Laboratory is carrying on some work on treatments along two lines: impregnation of wood with waxes, and impregnation with synthetic resins. The waxes are effective in reducing the tendency to shrink and swell over short periods, and impart some desirable properties to the wood, but are not the answer to the need for a remedy under long continued exposure to moisture. Tests with resin impregnation, however, give indications of permanent changes in properties, as the resin enters into the finer structure of the wood and is fixed through polymerization under temperature.
As an illustration of the changes in properties made possible through a 20 percent resin impregnation, the shrinking and swelling is permanently reduced by 50 to 75 percent, a very significant improvement. In addition, the moisture transfusion of impregnated plywood is only about 10 percent as great as that of the untreated material, when tested under the method previously described. This means that the treated plywood may be considered as an effective moisture barrier. Some of the mechanical properties are also increased significantly, particularly the across-the-grain properties. Side hardness, for instance, may be increased 40 percent with a moderate treatment, see figure 4.

Exposure tests on treated and untreated panels are now under way. The treated panels may be painted readily and some painted samples are included in the exposure tests. Preliminary results based on 4 months' exposure indicate excellent weather-resisting properties, as evidenced by freedom from checking, raised grain, and other weathering defects.

Tests on wood treated with phenolic-resin-forming materials indicate that the treatment imparts a considerable decay resistance to the wood. In an accelerated laboratory test using a single type of wood-destroying fungus (Trametes serialis), treated blocks remained quite sound, whereas untreated specimens were badly decayed. Further experiments will be necessary to obtain more conclusive results. The treated wood also shows an appreciable increase in resistance to acid.

From the standpoint of cost, results to date indicate that very satisfactory performance, both as a moisture barrier and in resistance to weathering, can be obtained by treating the two outer plies only, rather than the entire plywood.

Fire Studies

The Laboratory is naturally interested in fire studies on wood, and has considerable equipment for this work. The work of the Laboratory in this field is directed toward reducing the fire hazard and toward increasing the resistance of wood and wood products when exposed to fire. The studies in progress relate specifically to developments in design, chemical treatments, and coatings, that may be effective in making wood perform better under fire conditions.

One phase of this work was the development of a fire-resistant wall panel for the Forest Products Laboratory prefabricated house system. Flame penetration tests using the standard curve of increasing temperature were made on a variety of construction, employing a number of different insulating materials. By proper selection of plywood and insulation it was possible to secure a resistance to flame penetration of over 1 hour. These data apply specifically to the wall panels with
stressed plywood covering, 3 inches in over-all thickness, employed in the latest prefabricated house erected by the Laboratory.

Another interesting result of the flame penetration tests was the observed difference in the behavior of plywood made with phenolic resin glues and that made with soybean glues. In the soybean-glued plywood there is a decided tendency for the successive layers of veneer to separate in the fire test and fall off. In the phenolic resin-bonded plywood, on the other hand, the veneer does not separate along the glue line, and a charring of the entire thickness takes place, resulting in improved fire resistance.

Prefabricated Panel Construction

For several years there has been under development at the Laboratory a system of prefabricated panel construction, aimed at exploring some of the possibilities of unit construction. First the feasibility of shop manufacture of the plywood panels to required tolerance was established, as well as the practicability of the system. This was followed by studies directed toward the solution of various technical problems, such as improved fire resistance, incorporation of moisture barriers, the use of synthetic resin-bonded plywood and the like. The results of these developments have been incorporated as far as possible in the new experimental prefabricated plywood houses recently erected at the Laboratory, and elsewhere described.

While much of the development work on unit construction has centered around the use of plywood as a material, the consideration of lumber has not been overlooked. A number of wall panel units employing lumber as the principal material have been constructed, and further analysis and development is under way. The general availability of lumber and its ease of fabrication even in small shops are salient factors indicating the possible extensive use for prefabricated houses.

There are, it is known, many difficulties which beset the widespread introduction of any type of prefabricated construction. Only time will tell whether these difficulties can be overcome within a reasonable enough time to let prefabrication take its part in meeting the present housing shortage, and in providing increased employment of labor.
### Strength and Rigidity of Frame Walls

**Results of Tests of 9ft. by 14ft. Wall Panels**

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Relative Rigidity</th>
<th>Relative Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Sheathing</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Diagonal Sheathing</td>
<td>4.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Cut-in-Braces</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Let-in-Braces</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Plaster on Wood Lath (No Sheathing)</td>
<td>7.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Plaster on Wood Lath (Horizontal Sheathing)</td>
<td>7.9</td>
<td>5.6</td>
</tr>
<tr>
<td>Plaster on Wood Lath (Diagonal Sheathing)</td>
<td>9.5</td>
<td>7.8</td>
</tr>
<tr>
<td>Plywood Sheathing (1/4 in. well nailed)</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Plywood Sheathing (Glued)</td>
<td>4.8</td>
<td>8.6</td>
</tr>
</tbody>
</table>

![Fig. 1](image)

### Relative Efficiency of Various Materials as Moisture Barriers in Walls

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Moisture Transfusion (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kraft Paper</td>
<td>642</td>
</tr>
<tr>
<td>Plastered Wall; No Paint (Plaster Board)</td>
<td>240</td>
</tr>
<tr>
<td>Plastered Wall; No Paint (Wood Lath)</td>
<td>128</td>
</tr>
<tr>
<td>Slaters Felt (Best Type)</td>
<td>58</td>
</tr>
<tr>
<td>Duplex Paper</td>
<td>16</td>
</tr>
<tr>
<td>Plastered Wall; 2 Coats Al. (WL)</td>
<td>14</td>
</tr>
<tr>
<td>Asphalt Coated Paper, 35 LBS. per 500 SQ.FT. ROLL</td>
<td>12</td>
</tr>
<tr>
<td>Asphalt Coated Paper, 50 LBS. per 500 SQ.FT. ROLL</td>
<td>6</td>
</tr>
<tr>
<td>Metal Coated Paper</td>
<td>1</td>
</tr>
</tbody>
</table>

Moisture transfection is given in grams per 100 sq.in. per 15 days exposure under a relative humidity gradient of 100/50% at 80°F.

![Fig. 2](image)
HEAT LOSS THROUGH WALLS

CONVENTIONAL FRAME WALL

NOT INSULATED 100 .25

INSULATED; 1/2' BLANKET TYPE 68 .17

INSULATED; 3/4' MINERAL WOOL 24 .06

PREFABRICATED PLYWOOD PANEL 48 .12

EFFECT OF SYNTHETIC RESINS ON PHYSICAL PROPERTIES OF WOOD

(WEIGHT INCREASE ABOUT 20%)

SWELLING OF WOOD

UNTREATED 100

TREATED 25

MOISTURE TRANSFUSION THROUGH PLYWOOD

UNTREATED 35

TREATED 9

SIDE HARDNESS OF WOOD (MAPLE)

UNTREATED 100

TREATED 142

CONVENTIONAL FRAME WALL: WOOD LATH AND PLASTER, 4IN. STUDS. WOOD SHEATHING AND WOOD SIDING.

PREFABRICATED PLYWOOD WALL PANEL: 2 1/2 IN. FRAME MEMBERS FACED INSIDE WITH 1/4 IN. AND OUTSIDE WITH 3/4 IN. PLYWOOD.

Fig. 3

Fig. 4