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CONSTRUCTION OF NU-FRAME RESEARCH HOUSE

(UTILIZING NEW WOOD-FRAME SYSTEM)

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ABSTRACT

The recently developed Nu-frame system of wood-frame construction includes new types of wall and roof framing and covering components for exterior walls, roof, and interior walls and ceilings. This system was developed to produce a quality house at a lower cost by the judicious use of low-grade wood materials and prefinished components, and by rapid field assembly practices. Laboratory studies had indicated that construction of a full-size research house was justified.

A 28- by 40-foot research house has ken completed. Information and experience gained during construction have indicated that substantial savings can be made by the adoption of such a system of construction. Time and material cost studies have shown a saving in on-site labor for walls and roofs, as well as lower material costs. The use of construction adhesives, a minimum number of mechanical fasteners, and long-lived prefinished components should lead to reduced labor costs. Further, the use of low-grade dimension materials and low-grade boards in combination with other materials is also aimed at lower costs.

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CONSTRUCTION OF NU-FRAME RESEARCH HOUSE

(UTILIZING NEW WOOD-FRAME SYSTEM)

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INTRODUCTION

A new system of light wood-frame construction called "Nu-frame" has been developed and tested at the Forest Products Laboratory. This five-component system includes framing and covering materials for exterior walls, roof, and interior walls and ceiling. The method of framing is similar to conventional construction, as it utilizes standard materials with some differences in the combination of elements and in member spacing and alinement. Framing and covering elements utilize the lower and more inexpensive grades of wood.

In construction of the present-day wood-frame house, it is common practice to use third grade dimension materials for wall studs and plates. Dimension materials in a second grade are normally used for ceiling joists, window and door headers, and rafters, and even a higher grade is used for the members of trussed rafters, depending on species.[2] Very little if any of the fourth grades are used in framing. Furthermore, boards of low-grade wood, which at one time were used extensively for subfloors and for wall and roof sheathing, have all but disappeared in the construction of today's wood-frame house. Instead. sheet materials are used, A problem of the wood industry is to find a greater use for fourth and fifth grade boards.

The Nu-frame system has been designed around the use of fourth grade dimension materials in the construction of the wall and roof-framing elements. Furthermore, in the manufacture of the Nu-frame's interior and exterior covering components, the low-grade board has been used extensively. This has usually been at the expense of some nonwood materials. A saving in the price of the basic wood materials has been accomplished. firthermore, the total cost of a house may be materially reduced through the use of construction adhesives, a minimum number of mechanical fasteners, and prefinished low-maintenance components.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Information on species and grades for different purposes is contained in "Selection and Use of Wood Products for Home and Farm Building," by L. O. Anderson. U.S.D.A. Agr. Inform. Bull. 311. 1967.

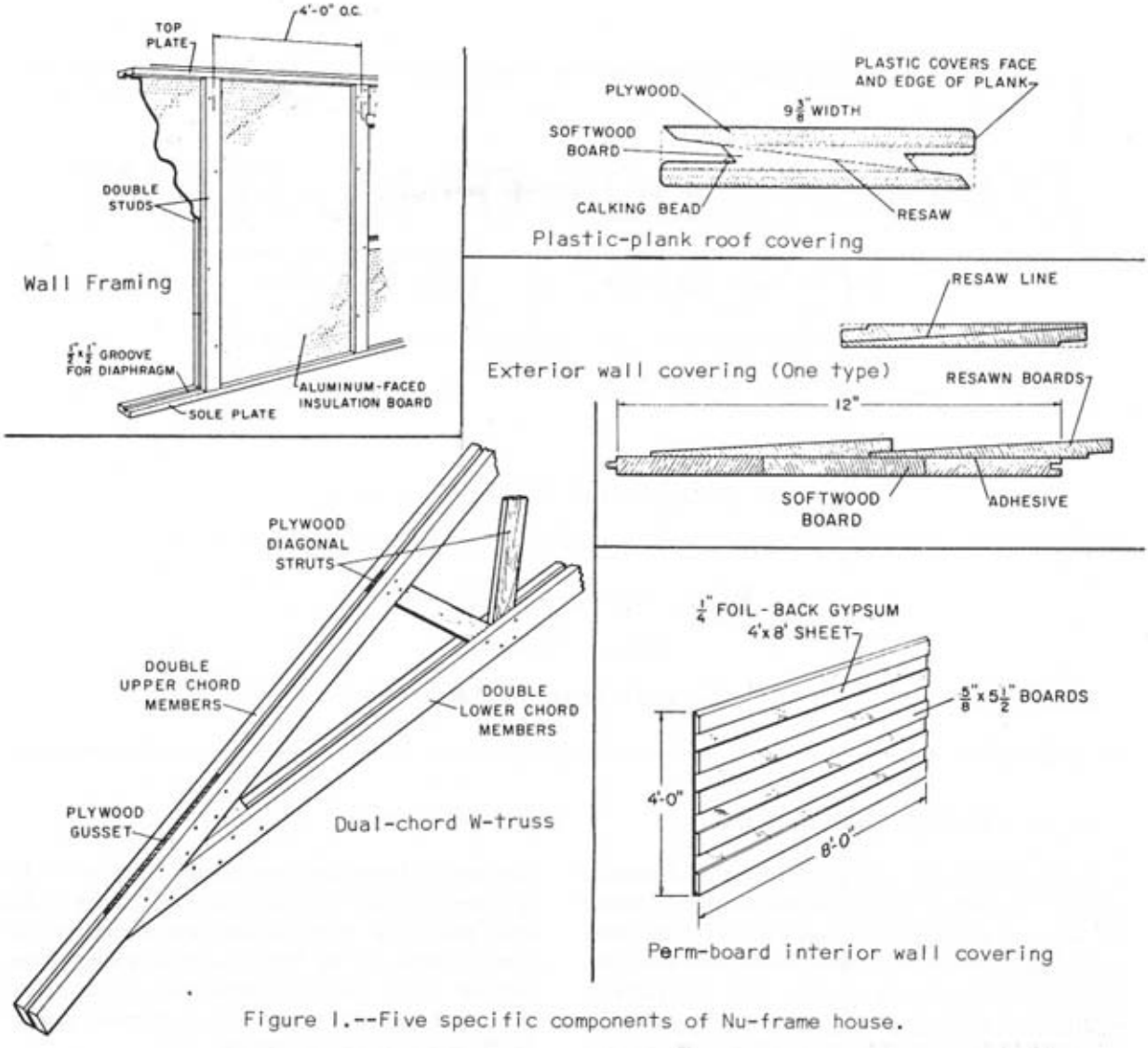


Figure 1.--Five specific components of Nu-frame house.

Five components (fig. 1) make up the Nu-frame system of wood-frame construction. A brief description follows with full details included further in the report and in Appendix I:

1. Nu-frame wall framing.--Consists of low-grade nominal 2- by 4-inch studs doubled and placed flatwise on 48-inch centers, with aluminum-foil-covered 1/2-inch insulation board diaphragms (Insul-2) between them. Top and bottom plates are split or grooved to accept the insulation board.

2. "Dual-chord" W-truss.--Designed for 4-foot spacing, this truss is made of low-grade nominal 2- by 4-inch doubled upper and lower chords. Gussets and web members (diagonals) are made of 5/8-inch plywood and are placed between the doubled chords.

3, Exterior covering.--Three types of siding—"Twinboard A," "Twinboard B," and "Slice-sid"--are designed for 48-inch spacing of studs. They consist of thin, flat or beveled sections of redwood or cedar backed with low-grade boards. Siding is applied by the use of construction adhesive and by blind (unexposed) nailing.

4. Roof covering.--"Plastic-plank," designed for 48-inch spans, is made by gluing a strip of 5/8-inch plywood to each side of a low-grade board, resawing, and shaping in a bevel and locking pattern. Surface is covered with asbestos-backed polyvinyl-fluoride film

5. Interior covering.--"Perm-board" Is an interior drywall finish for walls and ceiling. It consists of 1/4-inch foil-backed sheets of gypsum board reinforced with strips of 5/8-inch-thick

low-grade boards. Boards are glued lengthwise on the inside foil face for horizontal application of the 4- by 8-foot sheets over the 48-inch spaced studs and trusses.

Details of the development and testing of the various components used in the Nu-frame system are included in Appendix I. This information was originally included in U.S. Forest Service Research Paper FPL 47.[3] That report concluded with the recommendation that an experimental house be constructed to further evaluate this system.

Plans for the 28- by 40-foot Nu-frame research house were subsequently developed. This unit was designed primarily to study the techniques of fabrication and construction, to observe and evaluate the performance of the various components, and to provide areas for accelerated and long-time studies. Thus, while the exterior has the general appearance of a conventional house, the interior has fewer partition walls to provide greater convenience in conducting load tests, heat-loss studies, and moisture movement observations.

This publication includes design and construction details of the Nu-frame research house as a continuation of the system's initial conception and evaluation. Testing of new wall panels, which were designed to provide greater rigidity and strength, is one phase. The method of fabricating and testing trusses before installation is another phase. Other factors relating to the construction of the research house are also included. Because none of the components were available commercially, it was necessary to manufacture them in the Laboratory shops. Several manufacturers of building materials cooperated in furnishing some of the basic materials.[4]

DETAILS OF NEW WALL AND ROOF FRAMING AND COVERING

Design and Testing of Wall Panels

The results of the rigidity and strength tests made on the original Nu-frame wall panels indicated that some improvement in these properties would be desirable. These initial results axe shown in table A1, Appendix I. The need for a stronger, more rigid panel was based on the requirements commonly used for acceptable performance; those of the FHA performance standard[5] were for an 8- by 8-foot wall panel. The FHA minimum requirements for a panel tested in a dry condition are:

Maximum load = 5,200 pounds

At load of 1,200 pounds:
Average total deflection = 0.2 inch
Residual deflection = 0.1 inch

At load of 2,400 pounds:
Average total deflection = 0.6 inch
Residual deflection = 0.3 inch

New Wall Panel Designs

Several types of wall panels were developed in an effort to produce an 8- by 8-foot wall panel which would meet or surpass the FHA requirements. Such panels would be used in construction of the Nu-frame research house.

Description of Test Panels.--Five 8- by 8-foot wall panels were constructed using the basic principle of the Nu-frame wall system: the studs placed flatwise on 4-foot centers with 1/2-inch insulation board between. Construction adhesive and nails were used in the assembly. Variations in construction of the five panels were as follows:

Panel No. 1.--Doubled studs were placed flatwise on 48-inch centers with 1/2-inch regular-density insulation board (15-18 pounds per cubic foot) between them. Studs were attached to fiberboard with construction adhesive and twelvepenny

[3] Anderson, L. O. Development of an Improved System of Wood-Frame House Construction. U.S. Forest Service Research Paper FPL 47. 1965. Forest Products Laboratory, Madison, Wis.

[4] Wood Conversion Company, St. Paul, Minn., supplied aluminum-faced fiberboard used in wall construction. Minnesota Mining & Manufacturing Company, St. Paul, Minn., supplied the construction adhesive used in assembly.

[5] Federal Housing Administration. A Standard for Tasting Sheathing Materials for Resistance to Racking. FHA Technical Circular No. 12. Oct. 5, 1949.

nails. Top and bottom plates contained 1/2- by 1/2-inch grooves into which the insulation board fitted.

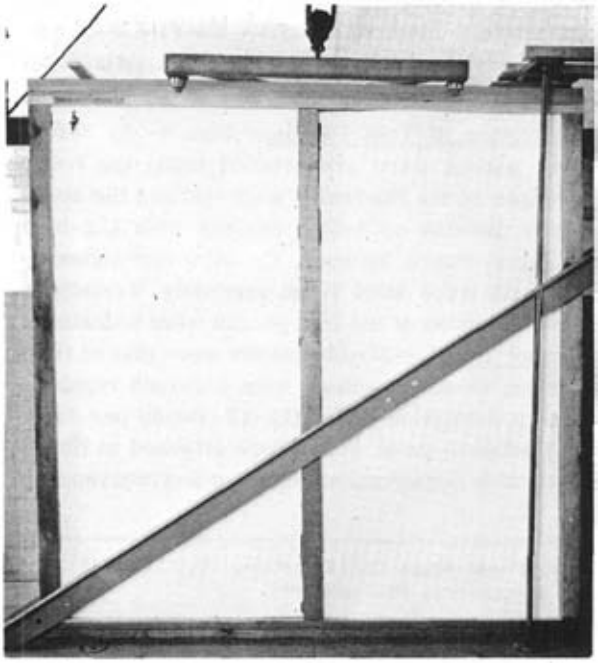
Panel No. 2.--Same as No. 1 except that. insulation board (nail-base, 26-28 pounds per cubic foot) was used between the flatwise studs.

Panel No. 3.--Same as panel No. 2 except that the nail-base insulation board carried through two-piece top and bottom plates. The top and bottom edges of the insulation board and the sides were fastened with construction adhesive and twelvepenny nails.

Panel No. 4.--Doubled studs were placed flatwise on 32-inch centers with nail-base insulation board between them. Top and bottom plates had 1/2- by 1/2-inch grooves into which the insulation board fitted.

Panel No. 5.--Doubled flatwise studs placed on 48-inch centers with nail-base insulation board between. Top and, bottom plates were grooved. (Same as panel No. 2.) In addition, one of the siding components was applied to one side of the wall and fastened with construction adhesive, using one nail for each piece at each stud crossing.

Figure 2.--Test apparatus used to apply racking loads on 8- by 8-foot wall sections. Load was applied at upper left corner. M 131 369



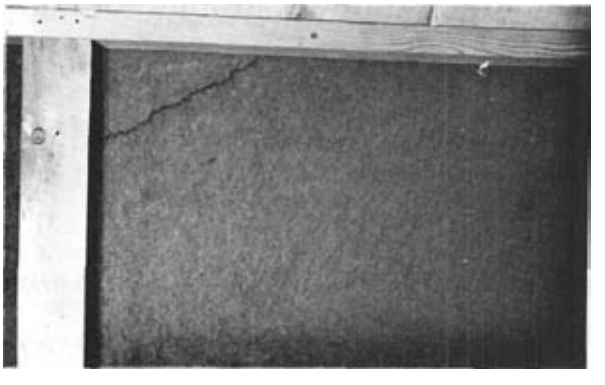
Test Method.--Racking tests were made on the five 8- by 8-footwall panels. Testing procedures, as outlined in ASTM Designation E 72[6] were generally followed. The racking load was applied in a horizontal direction at one upper corner to the test panel, which was anchored at its base, figure 2. Horizontal deflection readings were made at 200-pound increments of load until maximum load was reached.

Results of Tests.--Results of the racking tests are shown in table 1. Panel A lists the minimum FHA requirements.[5] panel B was one of the panels tested during the original development of the Nu-frame system with panels 1 to 5 being slight variations from this design. Panel No, 1 with grooved top and bottom plates was slightly more rigid and stronger than ungrooved panel B. The groove was included primarily to minimize air infiltration in the finished wall.

A second variable included the use of a nail-base insulation board. Panel No. 2 was improved in both stiffness and strength over panel No. 1 with regular insulation board. However, panel No. 2 did not entirely meet the minimum FHA requirements of panel A. (The rigidity requirements were satisfied at 1,200 pounds but not at 2,400 pounds. Maximum load was only about 60 percent of that required.)

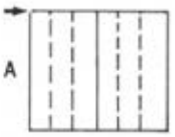
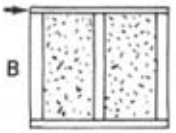
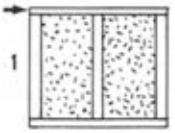
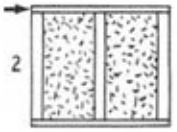
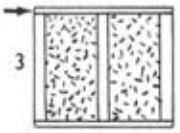
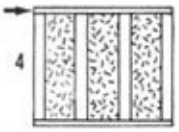
In panel No. 3, the nail-base insulation board carried through split top and bottom plates. The deflections at 1.200 and 2,400 pounds exceeded

Figure 3.--Failure of the nail-base insulation board diaphragm of an 8- by 8-foot wall panel after a maximum racking load of 6,560 pounds. M 131 371



[6] American Society for Testing and Materials. Standard Methods of Conducting Strength Tests of Panels for Building Construction. ASTM E 72-61.

Table 1.--Results of racking tests on improved Nu-frame wall panels

Panel type and number (8 by 8 ft.)	Panel description	Deflection 1,200 pounds	Deflection 2,400 pounds	Load at 1/2-inch deflection	Maximum load
		In.	In.	Lb.	Lb.
A 	FHA Minimum Requirements (Tech. Circ. No. 12)	0.20	0.60	---	5,200
B 	Original Nu-frame panel Regular insulation board No plate grooves (Appendix I)	.33	---	1,530	1,845
1 	Nu-frame panel Regular insulation board Grooved plates	.25	---	1,625	1,860
2 	Nu-frame panel Nail-base insulation board Grooved plates	.18	.84	2,166	3,240
3 	Nu-frame panel Nail-base insulation board Split plates	.10	.21	5,150	6,560
4 	Nu-frame panel Nail-base insulation board 32-inch stud spacing Grooved plates	.15	.34	2,720	3,320
5	Nu-frame panel Nail-base insulation board Grooved plates as No. 2 above Twinboard A siding	.06	.16	5,500	6,540

the stiffness requirement of FHA panel A. The maximum load of 6,560 pounds was 20 percent higher than the FHA requirement of 5,200 pounds. Failure consisted of shearing of the insulation board at an upper corner (fig, 3).

Panel No. 4, with stud spacing of 32 inches, showed no significant increase in strength over panel No. 2 with 48-inch stud spacing. However, the rigidity at 1,200 and 2,400 pounds was greater.

Panel No. 3 was selected as the type of 8- by 8-foot panel to be used at the comers of each full wall in the Nu-frame research house. Other portions of the wall would consist of grooved plates and regular-density insulation board.

Residual deflections of all wall panels tested after release of 1,200- and 2,400-pound racking

loads were well within the requirements of 0.1 and 0.3 inch, respectively, as outlined in FHA Technical Circular No. 12.[5]

It was desirable to determine what additional rigidity and strength wood he provided by the addition of the siding as applied in panel No. 5. This panel, constructed as panel No. 2 with nail-base insulation board and grooved plates, was covered on one, side with "Twinboard A" siding, one of the exterior covering components. Construction adhesive was used in addition to one nail at each stud for each siding board. As shown in table 1, this panel was more than three times as rigid at loads of 1,200 and 2,400 pounds as panel No. 2 without the siding. Furthermore, the maximum load of 6,540 pounds was more than twice as great. Thus, it is reasonable to assume that the rigidity and strength of panel No. 3 and other wall panels in the research house would be significantly increased after application of the siding.

"Insul-2" Insulation Board

The "Insul-2" material used as a diaphragm between the flatwise studs of the Nu-frame wall can be considered a four-purpose material. This 1/2-inch regular-density and nail-base insulation board, in 4- by 8-foot sheets, was covered with aluminum foil on one face by the manufacturer. The opposite face was covered with a kraft-backed aluminum foil at the Forest Products Laboratory. One face of the Insul-2 material was punched to provide 3/16-inch-diameter holes about 1/4 inch deep. Holes were spaced 2 inches apart. The inside face of the aluminum foil was perforated with numerous small pinholes to allow movement of any water vapor to the exterior of the wall.

The four purposes served by "Insul-2" insulation board are:

1. The use of nail-base insulation board in the end panels and regular-density in other portions of the wall provides adequate rigidity and strength.
2. Insulation provided by the reflective surfaces. plus the material itself and the exterior and interior coverings, results in an overall U value (coefficient of heat transmission) of 0.10 for the completed wall.
3. The tightly sealed perimeter of the Insul-2 at the studs and upper and lower plates minimizes air infiltration.
4. The wall should also have sound insulating value because (a) the numerous holes present in the outer face of the Insul-2 act as sound traps, (b) the nature of assembly of the framing and covering materials isolates each of the parts with a thin layer of slightly plastic adhesive, and (c) the use of insulation board and two airspaces provides resistance to sound transfer.

Design and Testing of Roof Trusses

Rigidity and strength tests made of the "Dual-chord" W-trusses during development of the Nu-frame system indicated they were more than adequate for their intended use. Deflection-span ratios averaged 1/1200 or more, and failing loads were about two to three times the design load. This truss differs from a normal truss in that the plywood gussets are used between doubled upper and lower chords rather than on each side of the joint as is standard practice for single-member gusset trusses. Doubling of upper and lower chords permitted a lower grade dimension material than is normally used for single-member trusses. Thus, fourth grade dimension material was used rather than the higher grades commonly selected for single upper and lower chord W-trusses.

Construction

Assembly of the original dual-chord trusses described in Appendix I was accomplished with a resorcinol glue and twelvepenny annular-grooved nails. However, the use of power-driven screws instead of the nails had been suggested. Consequently, screws were used to provide glue pressure when trusses were constructed for the research house, This system eliminated the need for auxiliary clamping sometimes required for a twisted memberwhen nail assembly had been used.

Fourth grade (utility) Douglas-fir was selected for the doubled 2- by 4-inch upper and lower chords. Gussets, which were located between the doubled upper and lower frame members, consisted of 5/8-inch Douglas-fir plywood with exterior glue. The web members (diagonals) were also of 5/8-inch plywood in widths of 5, 6, or 7 inches. The trusses were constructed with a 4 in 12 roof slope.

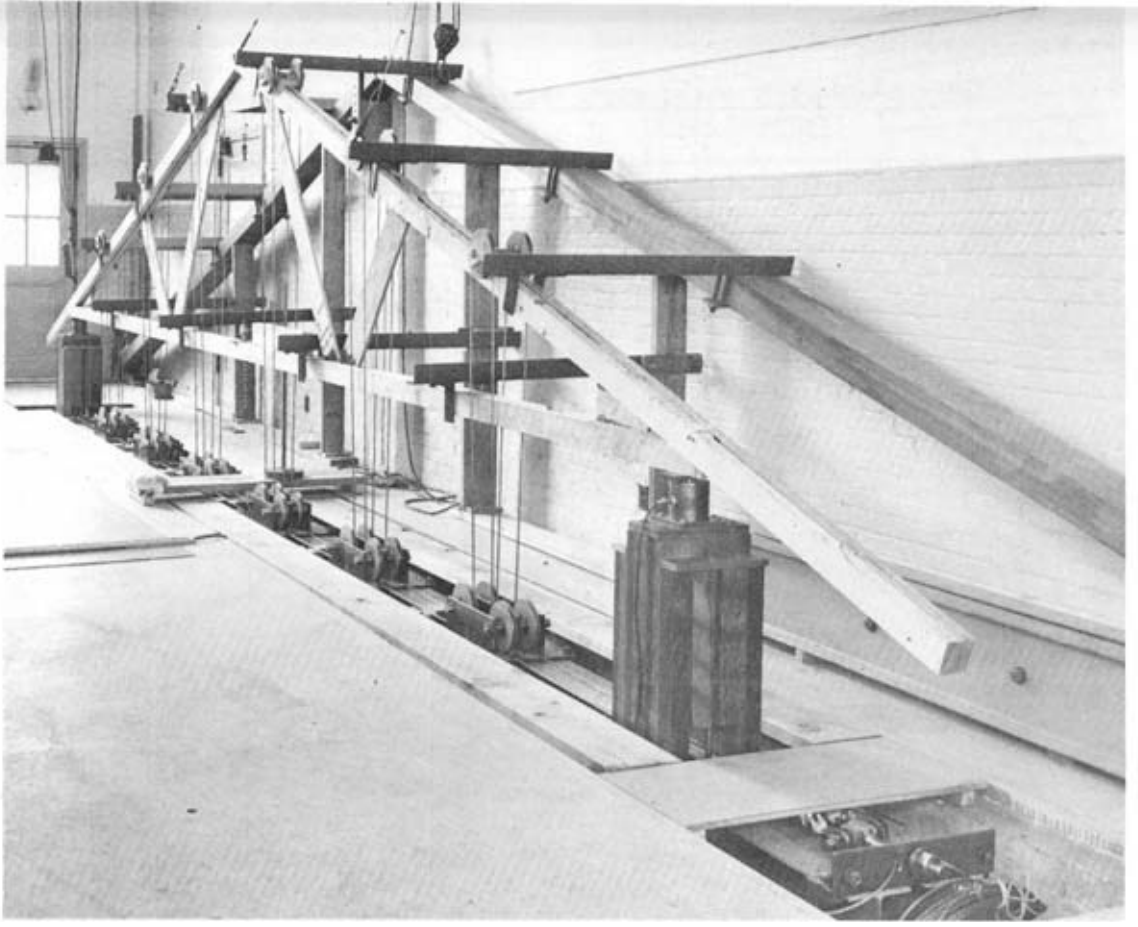


Figure 4.--Nu-frame "Dual-chord" truss ready for testing. Loads are applied through a cable and pulley system.

M 132 065

The new assembly method consisted of the following steps:

1. First set of upper and lower chords were placed on truss jig table.
2. Glue was spread on plywood gussets and plywood web members and positioned on upper and lower chords.
3. Predrilled second set of upper and lower chords were positioned. Holes were located in pairs at 8- to 10-inch centers.
4. Holes were drilled through plywood at predrilled hole locations of the upper and lower chords. No. 12 wood screws, 3-1/2 inches long, were driven in with electric drill and screw chuck.

Trusses were easily and quickly assembled with a two-man crew. Fifty wood screws were used in each Dual-chord truss. This compares with about 350 nails commonly used for two standard nail-glued plywood gusset trusses (designed for 2-foot spacing) which are required to equal the 4-foot spacing of one "Dual-chord" truss. Trusses required no reversing, as is necessary when gussets are used on both sides. They were removed from the jig immediately after screws were driven in place.

Tests and Results

After trusses were constructed, they were evaluated in accordance with the procedures outlined in ASTM Designation E 73.[1] The test setup is shown in figure 4. Tests were carried to design load, 3,860 pounds (37 pounds per square foot), for the nine trusses to be used in the research house. Three additional trusses were tested to failure. Deflection measurements were made at the center of the span during the tests. Table 2 lists the results of these stiffness and strength tests.

The deflection-span ratio averaged 1/1250 for the 12 trusses tested. The average maximum load

[1] American Society for Testing and Materials, Standard Methods of Testing Heavy Truss Assemblies. ASTM E73-52.

Table 2.--Rigidity and strength tests of "Dual-chord" trusses for research house

Truss No.	Width of compression web members[1]	Deflection at design load (3,860 lb.) (stiffness)[2]	Deflection-span ratio[3] at design load	Maximum load	Deflection at maximum load	Times design load at failure (strength)	Location in house, starting at west end as No. 1
	In.	In.		Lb.	In.		
DC-1	5	0.26	1/1250	9,235	0.70	2.4	(4)
DC-2	5	.25	1/1300	---	---	---	1
DC-3	7	.24	1/1350	10,955	.80	2.8	(4)
DC-4	5	.24	1/1350	---	---	---	8
DC-5	5	.25	1/1300	---	---	---	9
DC-6	5	.28	1/1200	---	---	---	6
DC-7	7	.26	1/1250	---	---	---	7
DC-8	7	.26	1/1250	---	---	---	4
DC-9	7	.26	1/1250	8,825	.80	2.3	(4)
DC-10	7	.25	1/1300	---	---	---	5
DC-11	7	.26	1/1250	---	---	---	3
DC-12	7	.30	1/1100	---	---	---	2
Average	---	.26	1/1250	9,670	.77	2.5	---

[1] Tension web members (longest diagonals) are all 5/8- by 6-inch plywood.

[2] Design load of 37 lb. per sq. ft. or 3,860 lb. per truss was used.

[3] Clear span equals 27 ft., 4 in.

[4] Not used in house; tested to failure.

of the three trusses tested to failure was 9,670 pounds, or 2-1/2 times the design load of 3,860 pounds (table 2). Failure in one of the trusses occurred in the upper chord, as shown in figure 5. Failure in the other two trusses occurred in a compression (short) web member.

Description of Siding Components

Three types of stained siding were used on the research house. Each was designed to span the 4 feet between the doubled studs of the Nu-frame wall. Because studs are placed flatwise in the wall, a width of about 3-1/2 inches was provided for fastening the siding. This was especially advantageous when butt joints were made over the studs, as a fastening area of about 1-3/4 inches was available at each side of the joint. Narrow 1/4-inch plywood splines were used at butt joints. Siding was made in 8-, 12-, and 16-foot lengths. All siding was edge- and end-treated with a water-repellent preservative before application.

"Slice-sid" Siding

The "Slice-sid" siding was made of 5/16-inch-thick sections of sliced redwod veneer glued to

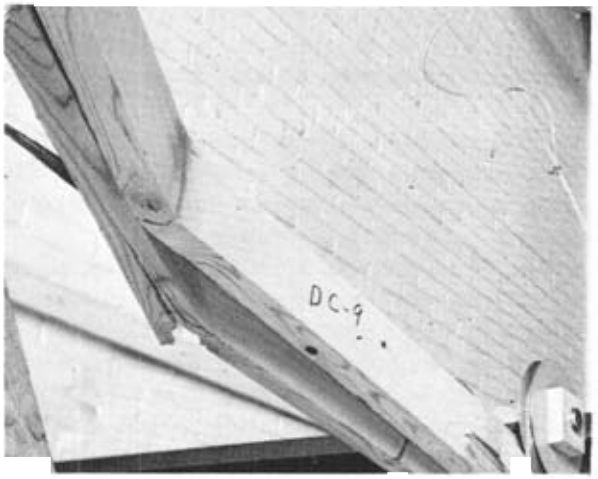
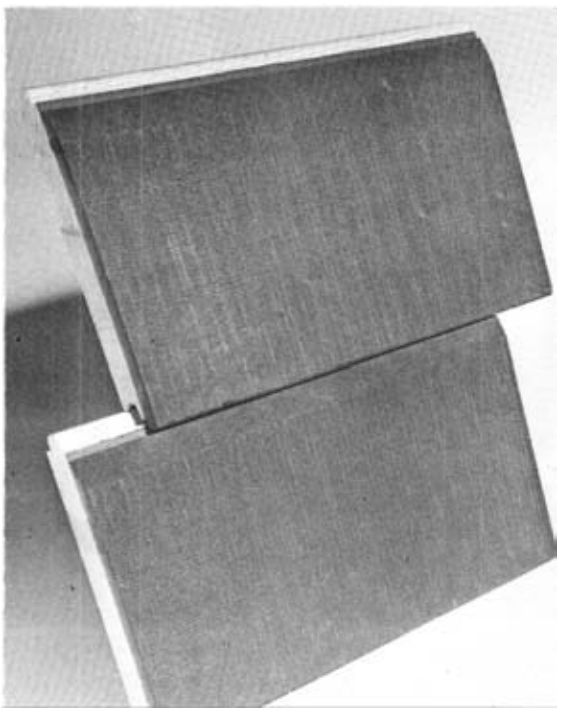


Figure 5.--Failure of upper chords of one Nu-frame truss. Initial failure occurred at knots at a load of about 2-1/2 times the design load. M 132 066

nominal 1-inch low-grade pine boards (fig. 6). Sliced western redcedar or similar species would also be satisfactory for siding. Pine backing boards were No. 4 and No. 5 grade. Face width of the "Slice-sid" siding was 6-1/2 inches. Combination tongued- and-grooved and shiplapped edges were used to provide resistance to wind and moisture penetration through the horizontal joints. All siding and roof covering components were designed to be applied with construction adhesive and a minimum number of nails. Blind nailing eliminated exposed nails.

Figure 6.--A view of "Slice-sid" siding combining a low-grade backing with 5/16-inch-thick slices of redwood. M 132 960



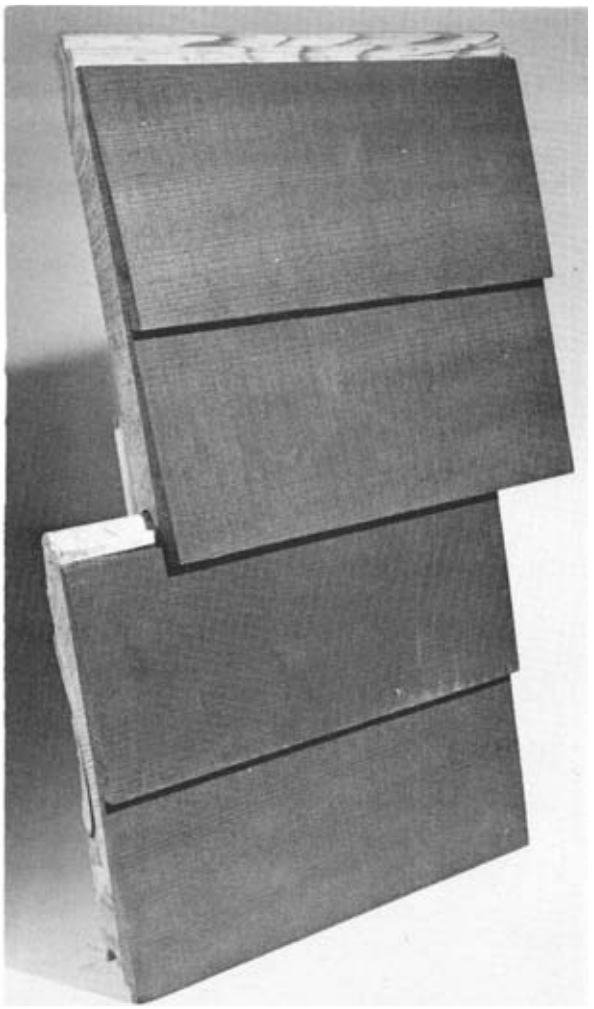


Figure 7.--"TwinboardA" siding combining two thin beveled sections of redwood with a backing of nominal 1-inch low-grade pine board. M 132 957

"Twinboard A" Siding

This type of siding also used a backing of nominal 1-inch-thick low-grade pine boards. As shown in figure 7. pairs of resawn beveled sections of redwood were glued to the backing boards. Top edge was provided with a tongue and bottom with a groove and shiplap edge. Application was in the same manner as the "Slice-sid" siding, with construction adhesive and a nail through the tongued portion at each stud. Face width was 9-1/2 inches.

"Twinboard B" Siding

"Twinboard B" siding was made in the same manner as "Twinboard A" siding except that a single resawed bevel section was used on the exterior face (fig. 8). Face width was 8-1/2 inches. Ends are grooved for spline jointing.

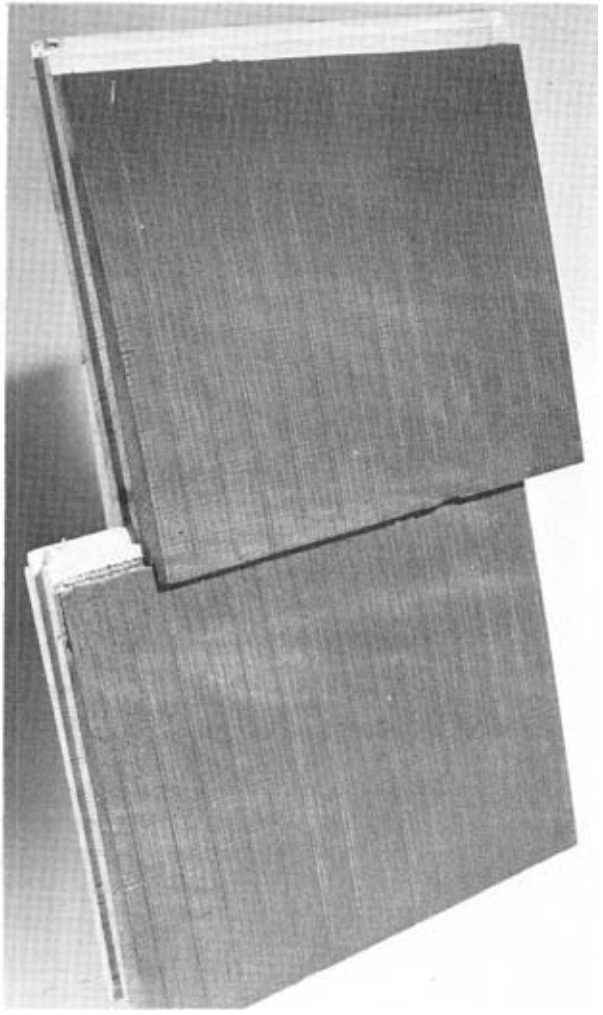


Figure 8.--A view of "Twinboard B" siding combining a single thin beveled section of redwood with low-grade boards, The combined matched and shiplapped horizontal joint can be noted. M 132 958

"Plastic-Plank" Roofing

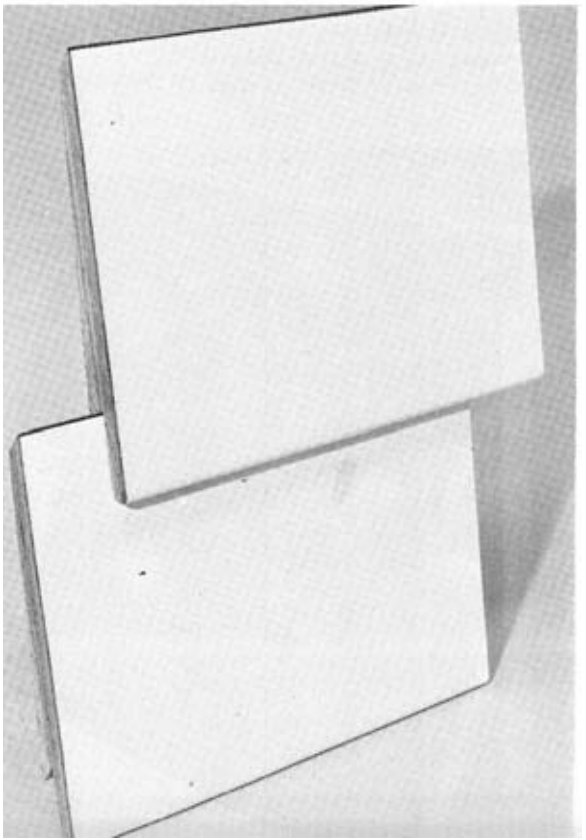
Description

The Nu-frame roofing component, "Plastic-plank" consists of plywood and low-grade 1-inch pine boards, with a plastic covering. Used on the roof as well as on one small section of wall on the research house, it was designed to span the 4 feet between the double-chord trusses or the doubled studs. It was intended to serve both as sheathing and roofing material and last, with little maintenance, almost for the life of the house, discounting mechanical damage.

The "Plastic-plank" was made by gluing 9-1/2-inch-wide sections of 5/8-inch plywood to each aide of a nominal 1-inch pine board. These planks probably could be manufactured in continuous lengths by finger jointing. Plywood was A-C exterior grade and laminating was done with a resorcinol adhesive. After gluing, the sections were resawed to a beveled pattern, shaped with a nosing overlap and a 45° locking edge. A white polyvinyl-fluoride film with an asbestos mat backing was glued to the A face of the plywood as well as over the nosing. This covering is a commercial material. Completed sections of this component are shown in figure 9. Exposure width is 7-5/8 inches.

A small section of roof was constructed in 1964 and exposed ever since to the weather to evaluate the performance of the "Plastic-plank." This 6-

Figure 9.--"Plastic-plank" roofing which serves both as roof sheathing and roof covering The asbestos backing of the polyvinyl-fluoride film provides good fire resistance. M 132 959



by 8-foot roof panel, described in Appendix I, has given excellent service at 6 in 12 and 4 in 12 slopes.

Fire Resistance

To determine the fire resistance of the plastic-covered roof plank (Plastic-plank), a 24- by 24-inch panel was subjected to ASTM Burning Brand Test Procedure under E 108.[8] The polyvinyl-fluoride film backed by a thin mat of asbestos was glued to a 3/4-inch plywood panel with a mastic adhesive recommended for cold application by the manufacturer of the material. Ten 2- by 2- by 1-inch pine blocks were ignited and placed under wires against the surface of the test panel. A fan was directed on the flaming blocks until all were consumed. Figure 10 shows the panel after the test was completed. The polyvinyl-fluoride film had been consumed in small areas with some slight charring of the asbestos. The plywood beneath was unharmed. These areas could be easily repaired by the application of polyvinyl-fluoride tope.

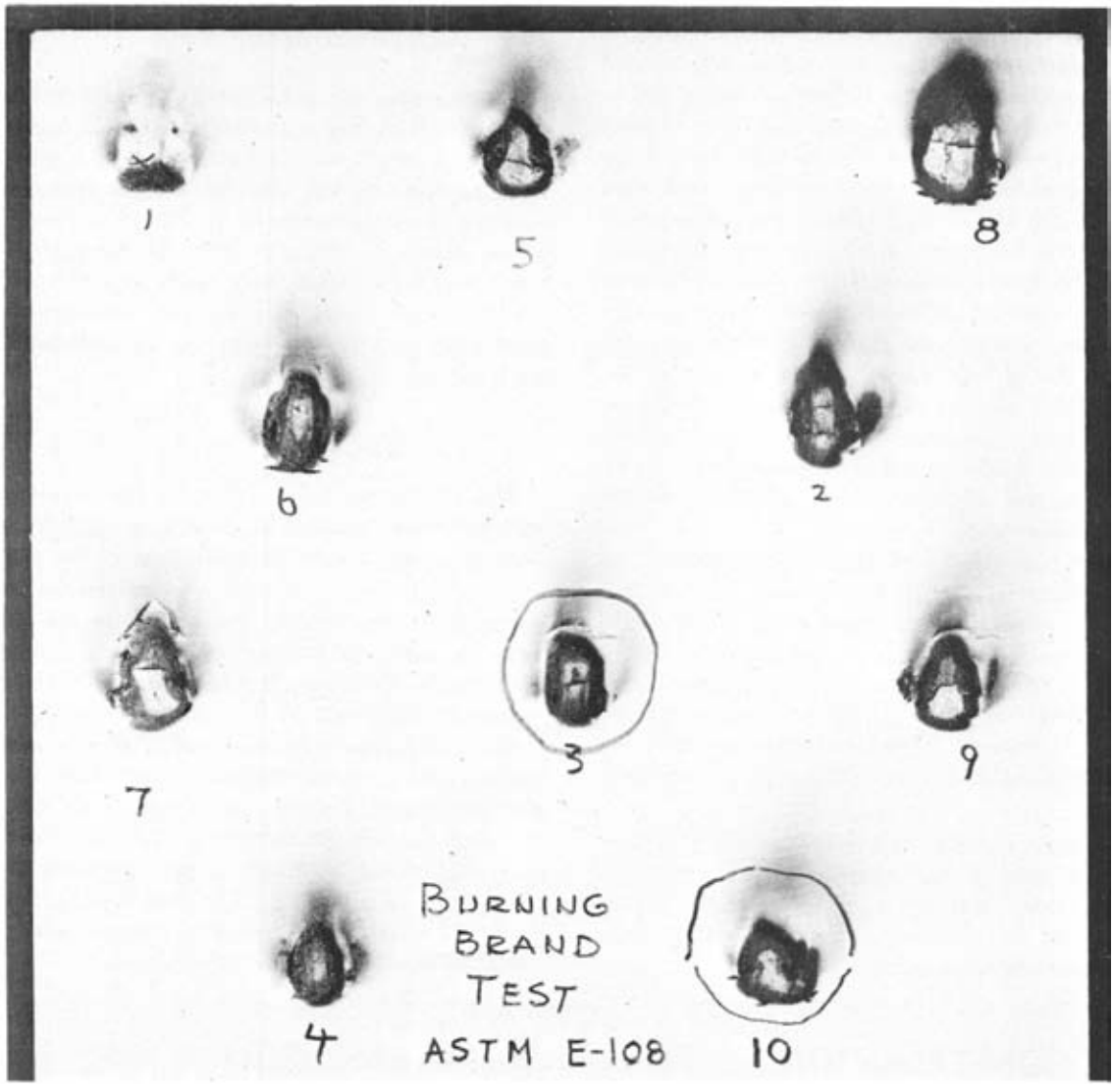


Figure 10.--View of polyvinyl-fluoride-covered plywood panel after being exposed to ASTM Burning Brand Test. The asbestos-backed film provided the resistance to burn-through.

M 132 867

[8]American Society for Testing and Materials. Standard Methods of Fire Tests of Roof Coverings. ASTM E 108-58.

"Perm-Board" Interior Covering

The "Perm-board" interior covering consisted of 4- by 8-foot sheets of 1/4-inch foil-backed gypsum board, reinforced with longitudinal strips of wood. Five 5/8- by 6-inch low-grade boards were spaced evenly across the width and glued to the foil face of the gypsum board. Edges were matched (tongued and grooved) to provide lateral stability between the 4-foot spaced studs. (See Appendix I for further details and tests conducted on this component.)

CONSTRUCTION ADHESIVE

The Nu-frame system was designed around the use of construction adhesives in framing of walls and in application of the various covering materials to the wall, ceiling, and roof. This method of fabrication was aimed at reducing on-site labor costs. Less than 20 percent as many nails were used as are ordinarily required for conventional wood-frame construction. It has been estimated that more than 30,000 nails and staples are used to frame exterior and interior walls, apply sheathing, siding, insulation, make trusses, and apply roof sheathing, roofing, and interior covering in a conventional 28- by 40-foot house. A Nu-frame house of the same size andarrangement requires only about 5,800 nails and screws and about 4-1/2 gallons of construction adhesive for the same processes.

One of the adhesives used in the assembly of the research house had a neoprene base; another type an elastomer base. These types of adhesives can normally be used at temperatures of 35° F. or above, but surfaces must be relatively clean. Both adhesives were effective on dry surfaces but the elastomer appeared to be also effective on damp wood if only the surface was reasonably dry.

Both types of adhesives have gap-filling capacities and provide high shear strength without a wood-to-wood contact. This allows for slight unevenness in the siding or the backing stud. Both types are waterproof.

Neoprene Base

The neoprene-base adhesive was relatively fast setting, and an "open period" of up to 15 minutes was considered satisfactory. While a light dry film formed over the adhesive almost as soon as it was applied, pressure of the following member would cause a "squeeze out" and formation of fresh surfaces. Some very slight elasticity was present after final set of the adhesive had occurred, This type was used in the assembly of the Nu-frame walls.

Elastomer Base

The elastomer-base adhesive had a recommended "open period" of about 1 to 1-1/2 hours. This type was used for application of the siding and roofing components as well as the interior covering (Perm-board). Because some nails are used in the construction of the wall framing, which also includes the aluminum foil-covered "Insul-2" material, it is felt that the slower setting elastomer adhesive would also be satisfactory and perhaps desirable. The nails would provide enough stability for erecting the wall in "tilt-up" fashion. Furthermore, this adhesive has very high shear strength as well as some elasticity after final setting. This should bedesirable when the wood parts change in dimension due to seasonal changes in moisture content.

CONSTRUCTION OF THE NU-FRAME RESEARCH HOUSE

The Nu-frame research house was designed with a rectangular plan and simple gable roof, figure 11. Outside dimensions are 28 by 40 feet (1,120 sq. ft.). The large end panels will be used to conduct accelerated aging tests on various combinations of materials used in a wall.

Later studies of roof design will include small hip and valley sections which will be exposed to determine the best method of roof plank installation at these intersections.

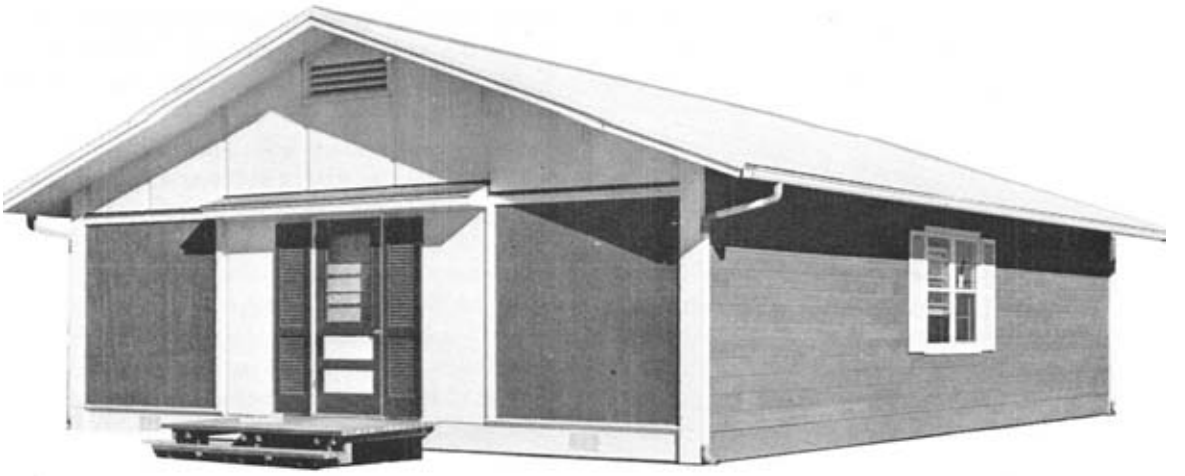


Figure 11.--The completed 28- by 40-foot Nu-Frame Research House.

Foundation

The foundation consists of a 9-inch poured concrete wall and footings on the south side and the east and west ends, and a treated wood foundation on the north side. A partial concrete retaining wall is located 4 feet inside the wood foundation to provide undisturbed soil for the wood posts.

Two types of wood foundation walls were used. One type consisted of two 8-foot treated wood sections constructed of doubled 2- by 12-inch headers with 2- by 4- and 2- by 6-inch posts located 4 feet apart. Material was pressure-treated to a retention of 10 pounds of creosote per cubic foot. Sections were assembled with galvanized spikes.

The second type consisted of three 8-foot-long treated box-beam sections made up of 3/4- by 24-inch by 8-foot treated plywood webs nailed to 2- by 6-inch upper and lower flange members, figure 12. Treated posts consisting of 2-by 6-inch members were located at 4-foot centers.

Twelve-inch-diameter holes were drilled on 4-foot centers along the north building line to a depth of 4 feet below finish grade. After the treated foundation sections were plumbed and leveled, concrete was poured under and around the posts for about a 25- to 30-inch height above the bottoms. This type of foundation could be constructed even during very cold weather by adding fill over the concrete after pouring.

The center beam in the basement, which supports the floor framing, consisted of an 8-inch wide-flange, steel beam (17 pounds per square foot) for the west 26-1/2 feet of the building. The beam was supported by 4-inch round steel columns. The remaining 12 feet of center beam consisted of a 7- by 14-inch plywood box beam

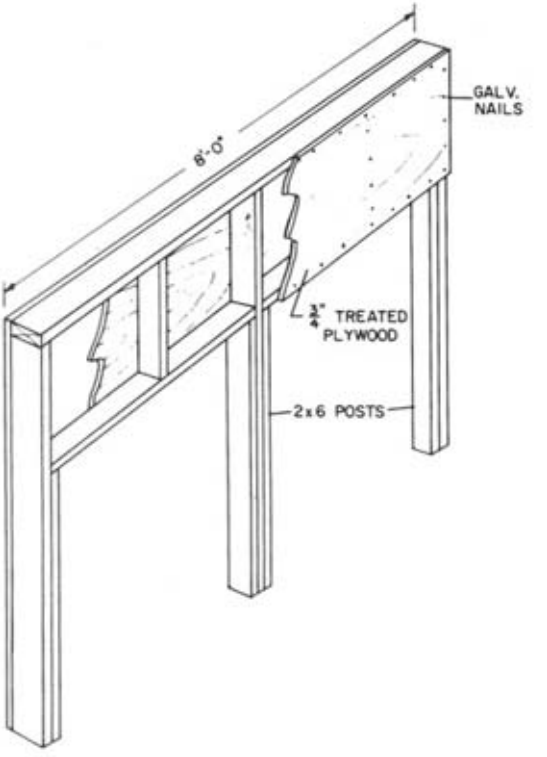


Figure 12.--Treated box-beam foundation.

supported on one end by the foundation and on the other by a stirrup bolted to the steel beam. Webs on each side of the wood flanges consisted of 3/4-inch exterior plywood. Nail-glue assembly was used.

Floor Systems

A number of variables were included in the floor framing for the Nu-frame research house. These designs are not a part of the Nu-frame system but rather a study of stiffness and strength of the floors and factors related to personal preference of floor stiffness. The selection of members takes into account the size, span, spacing, species, and grades of the joists. Joist tables listed in FHA Minimum Property Standards[9] were generally used in selecting the members, Stressed-skin panels and T-section panels were also included.

To accommodate the eight floor-system variables selected for study, the 28- by 40-footfloor area was divided into 8-foot-wide sections across the width of the house. As shown in figure 13, two floor sections, A and H, were 8 by 28 feet in size, while the remainder were 8 by 14 feet. Table 3 lists the variables of size, spacing, and other factors involved.

The floor system was designed and the supports at the foundation walls and center beam so arranged that the top of all the plywood subfloors were the same elevation. Joists over the concrete foundation on the south side were supported by a plate anchored to the concrete wall. Joists at the treated wood foundation along the north wall were supported by nominal 2-inch-thick ledger boards spiked to the wood foundation. Joists at the center plywood box beam were also supported by ledgers. Joists over the steel center beam rested on the beam or on a plate, which varied in thickness depending on the depth of the joists.

The sizes of the joists were based on a 40-pound live load and on maximum or near maximum spans normally recommended for grades and species in FHA and other standard span tables. For example, in panel A, 2- by 10-inch Coast Region Douglas-fir in most grades can be used for spans up to 14 feet with 24-inch spacing. In

Table 3.--Floor system variables in Nu-frame research house

Section[1]	Type of framing	Joists or frame members					Subfloor or covers	
		Size	Spacing	Clear span	Species	Grade	Top	Bottom
		In.	In.	Ft.-in.			In.	In.
A	Joists	2 by 10	24	13 - 0	Coast Douglas-fir	1700f	3/4 plywood	.....
B	.....do.....	2 by 8	16	13 - 0	Southern pine	1750f	3/4 plywood	.....
C	.....do.....	2 by 8	16	13 - 0	Coast Douglas-fir	1700f	3/4 plywood	.....
D	"T" panel	2 by 4	10	7 - 10	.....do.....	Construction 1450f	1/2 plywood	.....
E	.....do.....	2 by 6	24	7 - 10	.....do.....	Construction 1450f	3/4 plywood	.....
F	Joists	2 by 10	16	13 - 0	Western white pine	No. 1 Dimension	3/4 plywood	.....
G	Stressed-skin panels	2 by 6	24	13 - 0	Coast Douglas-fir	1700f	3/4 plywood	5/8 plywood
H	Joists	2 by 10	16	13 - 0	.....do.....	Utility	3/4 plywood	.....

[1]See figure 13 for locations.

[9]Federal Housing Administration. Minimum Properly Standards for One and Two living Units. FHA No. 300. Jan. 1965.

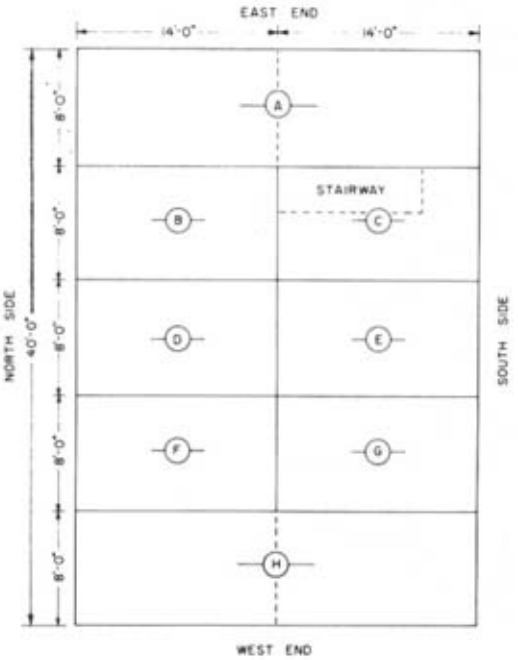


Figure 13.--Plan of Nu-frame experimental house floor system (section details in table 3).

panels B and C, 2 by 8 joists in grades above 1200f for species such as southern pine and Douglas-fir may be used for spans up to 13 feet 0 inch with 16-inch spacing.

Wall Construction

The "tilt-up" system of wall construction was employed in the erection of the walls for the Nu-frame research house. This method is often used in construction of conventional frame walls and consists of laying out and nailing together the top and bottom plates, studs, and window and door headers on the subfloor and tilting up the full-length wall. Sheathing is sometimes applied and window units and siding may be incorporated before the wall is raised.

As previously described. the top and bottom plates of the Nu-frame wall contained a 1/2- by 1/2-inch groove, tapered slightly to accept the aluminum foil-faced Insul-2 diaphragm. However, two 4-foot panels at each end had a slightly different plate configuration to provide additional rigidity (table 1, panel NO. 3). These plates were in two pieces to allow the nail-base insulation board to extend through the plates rather than in the groove, figure 14. Top and bottom plates were

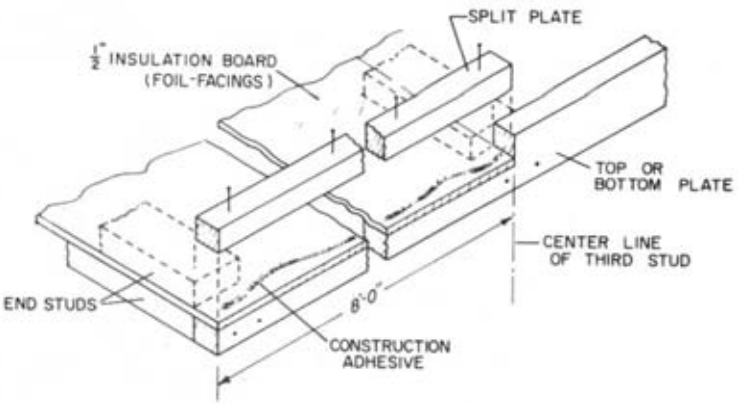


Figure 14.--Top and bottom split plate (end 8-foot section of wall).

12 and 16 feet long, respectively, with the end 8 feet providing the two-piece sections. These lengths and the upper member of the doubled top plate provided good horizontal ties between panels.

Assembly of the wall consisted first of nailing the top and bottom plates to the first set of 2- by 4-inch studs placed flatwise on 4-foot centers. Corrugated fasteners were used to fasten the flange members (headers) to the prenotched studs at window openings. A 2-by 6-inch stud was used at inside corners and at interior wall intersections to provide nailing surfaces for the interior wall covering material, The following sequences were used to complete assembly of the wall.

A. A ribbon of construction adhesive was applied over each stud in a serpentine pattern so as to contact the edges of each adjacent sheet of Insul-2 (fig. 15). Adhesive was also used at the top and bottom split plates of the end panels and at window openings.
B. The insulation board was then sprung into the grooves of the plates, the edges being centered on intermediate studs. A second ribbon of adhesive was applied over the joints at the stud locations and at the headers (flange members) over doors and windows (fig. 15),
C. The top set of studs and the 2- by 4-inch headers over windows were positioned and nailed to the studs and other members beneath (figs. 15 and 16). Five twelvepenny deformed-shank nails were used along the height of each set of doubled studs (21- to 22-inch spacing). Finally, sixteenpenny nails were used to fasten top and bottom plates to the upper set of studs.

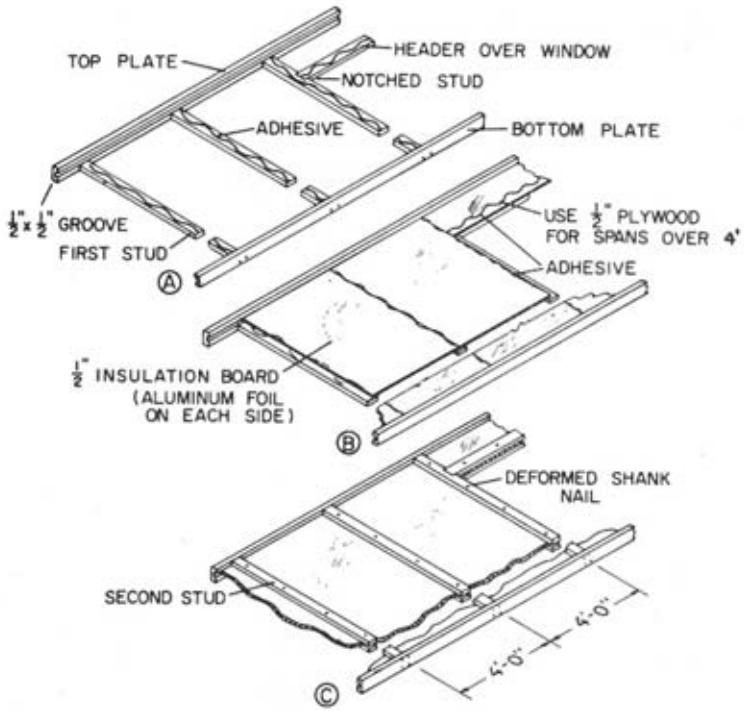


Figure 15.--Fabrication sequence of Nu-frame wall.

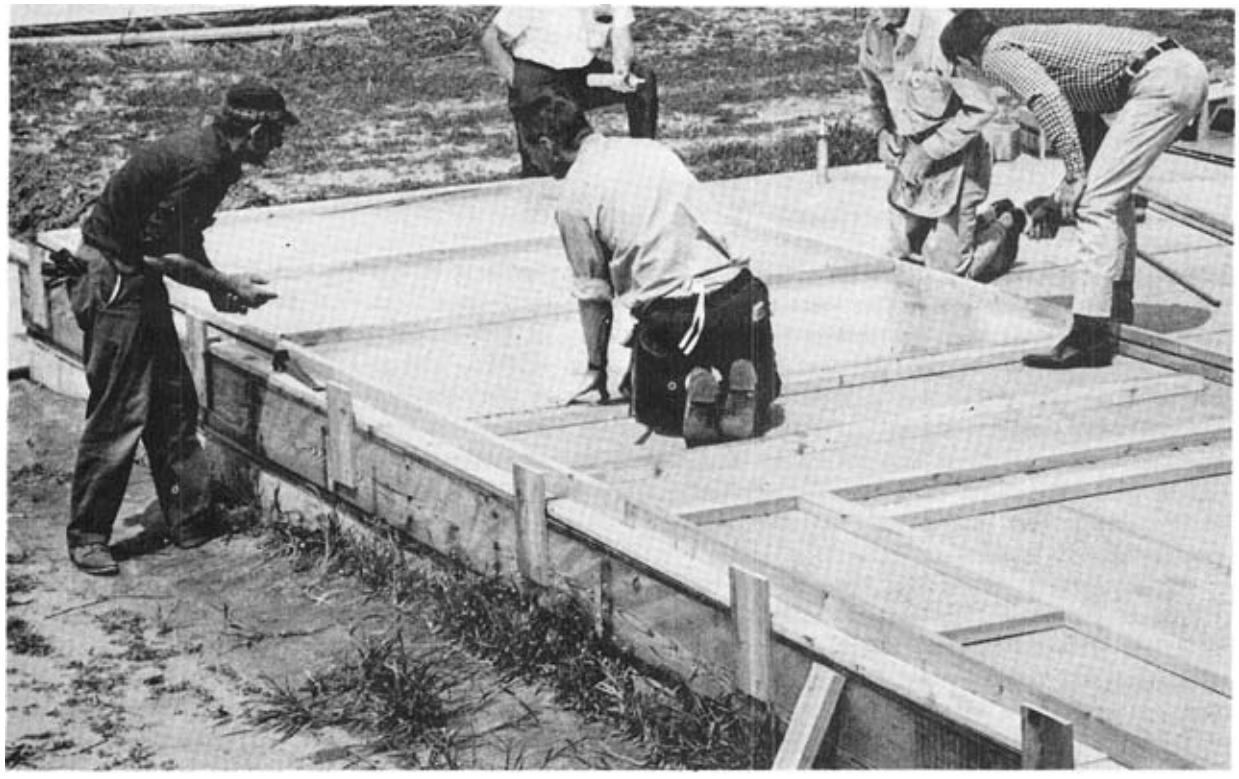


Figure 16.--Assembly of Nu-frame wall on subfloor. After completion, wall is raised, alined, and fastened to the floor framing. M 133 186

After assembly was complete, the 40-foot-long wall was raised, plumbed, braced, and the sole-plate fastened to the floor system Metal strap tiedowns were used at each stud to provide additional anchorage to the floor framing.

A 12-foot section of the Nu-frame wall, flanked by the 7- by 7-foot test panel openings, was used on the east end of the house. This provided a shear wall to resist wind loads on the adjacent north and south side walls. Similarly, a 12-foot center wall section with conventional framing and plywood sheathing was used on the west end of the house.

Installing Trusses

Data on the rigidity of each Nu-frame "Dual-chord" truss, as well as its respective location in the house, are included in table 2. Nine trusses were used, the gable ends being supported by the framed walls below.

Sheet metal brackets were devised to provide a positive means of fastening the trusses to the wall plates, figure 17. These brackets were nailed to the bottom and sides of the truss (fig. 18) before the trusses were raised into place. This method of fastening provided resistance to both thrust and uplift stresses,

While the trusses weighed about 200 pounds, or half again the weight of a conventional plywood gusset truss designed for 2-foot spacing, it is likely that they could be handled and raised in a normal manner with a three-man crew. However, mechanical lifting equipment was used for this

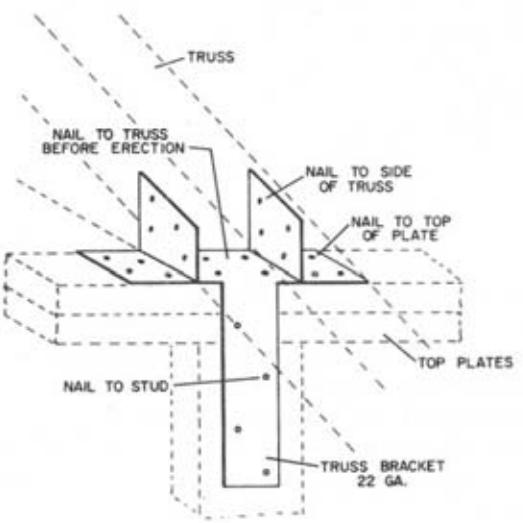


Figure 17.--Metal truss bracket.

Figure 18.--Metal truss bracket being placed on truss prior to installation. Bracket is nailed to the bottom chords before truss is placed on the walls.

installation and perhaps might be more practical generally. Spaced 4 feet apart, the trusses were fastened to the wall by nailing the metal bracket to both the top plate and the outside of the studs, End trusses were braced to the end walls by 2- by 4-inch diagonals.

Application of "Plastic-Plank" Roofing

"Plastic-plank," designed to span the 4 feet between the trusses, was applied with construction adhesive and one eightpenny galvanized ring-shank nail per board at each truss. Approximately 45 nails were required for each 100 square feet of roof. The roof plank was installed after cornice and gable-end facia boards had been applied,

To provide a water-resistant horizontal joint between each roof plank, a thin ribbon of sealant calk was applied to the inside "V" edge of the plank nosing [fig. 19). While this was done just before the planking was installed, it could be easily applied at the factory similar to the principle of the seal tab asphalt shingle. Exposed wood edges of the plank had been previously treated with a water-repellent preservative.

Butt joints of the planking were made over the center of one of the upper chords of the truss. Construction sealant adhesive was applied at each side of the joint and at all intermediate trusses. Eased bottom ends of the plank formed an inverted

Figure 19.--Applying sealant to the horizontal seam of the roofing plank. This would normally be applied at the factory, similar to that on a seal-tab type of asphalt shingle.

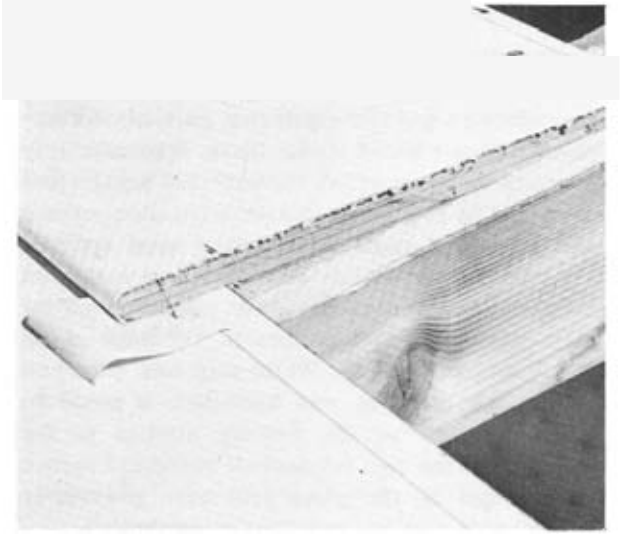


Figure 20.--Roof planking being applied to the upper chords of the trusses. Polyvinyl-fluoride tape and sealant mastic are used to finish the butt joints.

"V" which was filled with construction adhesive, One piece of polyvinyl fluoride tape was used under and around the nosing at the joint and another over the full joint and over the nosing, figure 20. Nails were driven about 3/4 inch from the top edge of the plank into an upper chord of the truss. The overlap of the next plank thus provided about 1-1/4-inch coverage below the nail location. No special precautions were used in walking on the plank during installation except that carpenters wore rubber-soled shoes. They were easily supported, and little deflection was noted between trusses,

The ends of the roof planking were trimmed flush with the gable end facia boards. A 3/4- by 3-inch barge molding was then applied to cover the ends of the roof plank. This junction was sealed with a continuous bead of white acrylic terpolymer sealant to match the color of the roof,

The ridge was finished by applying polyvinyl fluoride tape over the intersection of the last roof planks. This was followed by a formed aluminum ridge cap, which was fastened with construction adhesive and a minimum number of nails. Tape was then applied over the edges of the metal ridge. This system of roofing was selected in part because of the successful performance of the 6- by 8-foot exposure panel erected in 1964 and described in Appendix I.

Window Frames and Exterior Trim

Standard double-hung window units were specified for the Nu-frame house, and only minor modifications were necessary. A 1/4-inch strip of plywood was used as a backer behind the brick mold casing at the blindstop location. This required only the removal of the loose stops on the inside edge of the jambs and sill to provide for the 7/8-inch-thick "Perm-board" interior finish. To insure a tight seal around the windows, strips of laminated paper were used behind the outside casing and at the sill, which is normal procedure in conventional woad-frame construction. However, these flashing strips were fastened to the back of the casing with contact adhesive,

Exterior trim, including the cornice, rake, and associated moldings, generally utilized standard materials with no changes necessary for use in the Nu-frame system Because two 7- by 7-foot test panel openings were included in each end of

the building, some changes were made in the casing widths around these frames. The louvered gable-end outlet ventilators were made with a somewhat greater area than normally required to provide for size variables in ventilating studies. Inlet vents, located in the soffit area of the cornice, consisted of a 2- by 10-inch screened opening between each truss-chord extension. This provided a total net inlet area of about 1/900 of the ceiling area, which is the area normally recommended for gable roofs with both inlet and outlet ventilators.

Installing Siding

The three types of stained siding were installed in the same general manner as the roof planking. Ribbons of elastomer adhesive were applied to the face of the studs (fig. 21), and the siding fastened with galvanized finishing nails. Each type of siding had tongued-and-grooved edges with an additional shiplap edge, as shown in figures 6, 7, and 8. Nails were driven into the upper tongued edge and set slightly. The next siding piece covered the nails so that none were exposed. Joints were made over the center of the studs, figure 22, and ends were grooved to receive the 1/4-inch plywood splines.

The 6-1/2-inch-wide "Slice-aid" siding was used over the Nu-frame wall on the south side of the research house. The two types of "Twin-board" siding were used on the north side.

Figure 21.--A ribbon of construction adhesive being applied to the face of each stud before siding is installed. Flashing paper behind frame consists of a laminated waterproof material.

M 133 254 #2

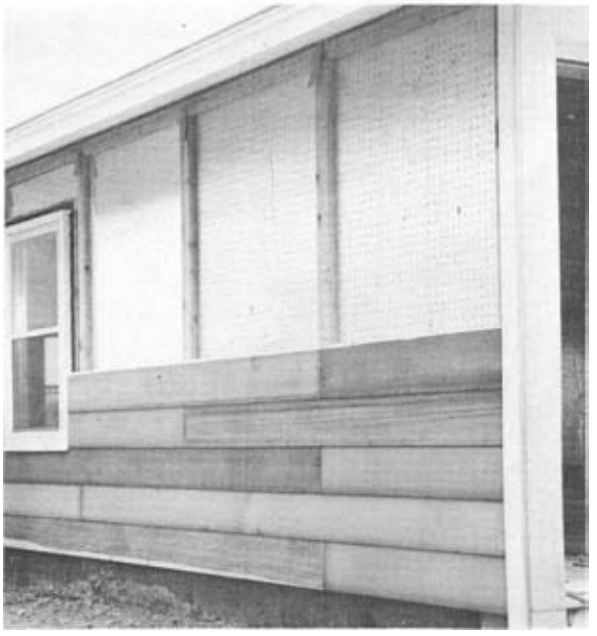


Figure 22.--"Twinboard" siding being applied to the exterior wall. Joints are made over the stud, and siding is blind-nailed to each stud with a galvanized finish nail. M 133 254

To determine any changes which might occur in the insulating value of the wall over a period of years, several sets of thermocouples were installed (fig. 23) in the north and south walls, These were located in the third 4-foot panel from the east end (10 feet) and 18 inches above the floor and 18 inches below the ceiling line, The thermocouples were installed to record outside air and outside surface temperatures, as well as temperatures of the various interior wall surfaces. In addition, moisture probes were placed in the siding and in the backing boards of the "Perm-board" covering to observe changes in moisture content.

In order to determine the adaptability of the "Plastic-plank" roof covering as a siding material, a small section of the east wall was covered with this material. This 8- by 12-foot center section of the Nu-frame wall contained a window and was flanked by two test panel openings, figure 24. Elastomer adhesive was used in addition to one nail at each stud crossing in applying the plastic-faced covering material to the wall.

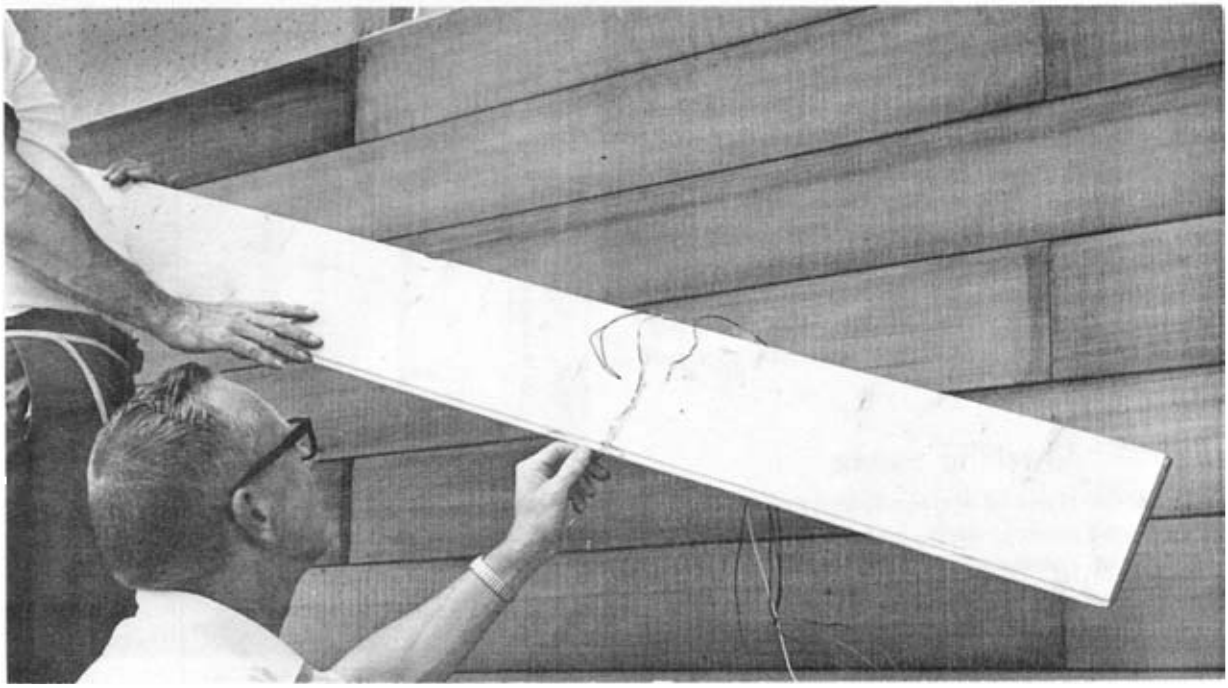
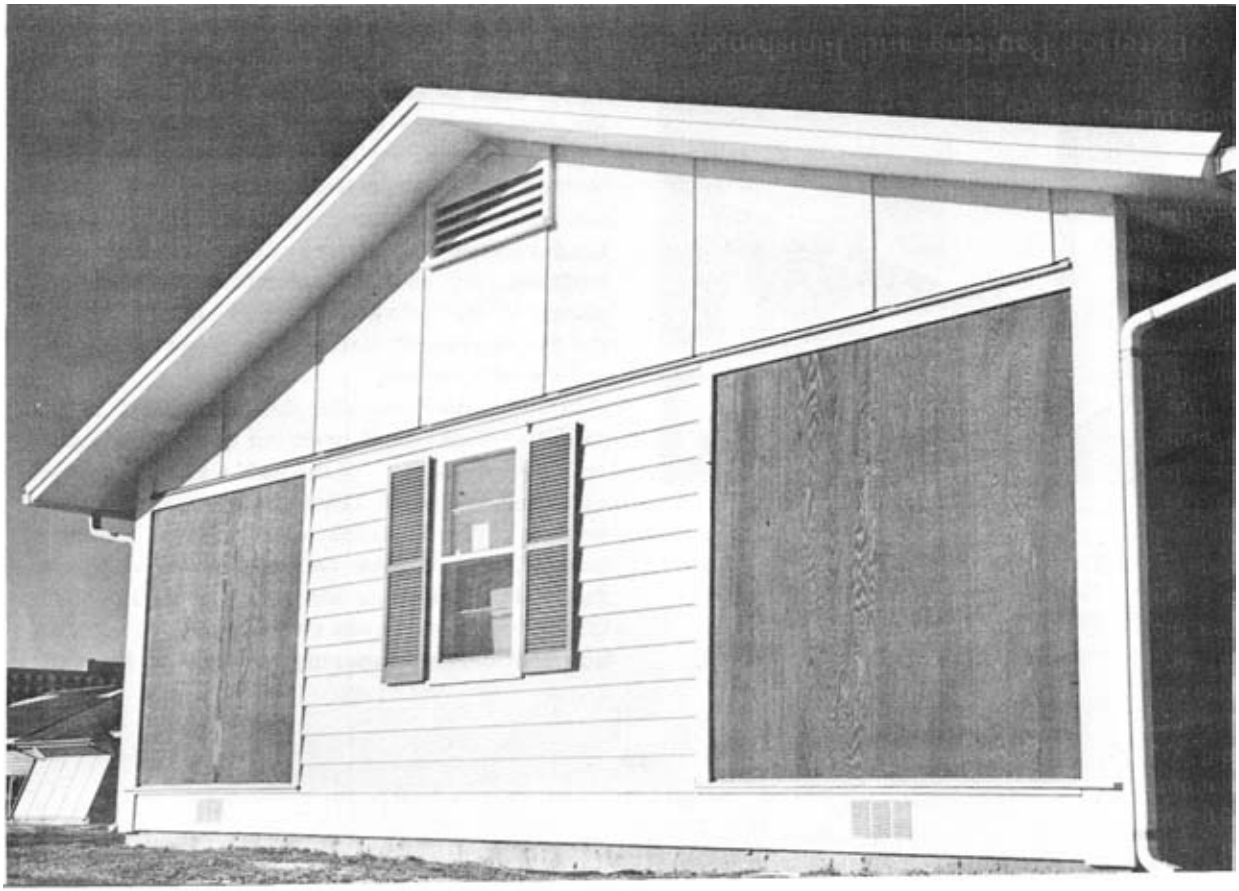


Figure 23.--Thermcouples and moisture probes being installed on a siding board. Moisture and temperature readings will be made to determine changes in moisture content and for heat-loss measurements. M 133 254 #6

Figure 24.--Polyvinyl fluoride-covered roof planking installed on a Nu-frame wall section. Large openings will be used to conduct accelerated tests on typical wall constructions. M 133 285 #2



The east and west ends of the research house were sided in a reverse "board and batten" pattern. An exposed width of 4 inches was used for the inverted batten with a 44-inch-wideboard. Paper-overlaid plywood was used for both boards and battens.

Exterior Painting and Finishing

All rough-sawn siding on the south and north sides of the Nu-frame research house was stained a light olive green. This FPL-developed pigmented stain covered well with one coat.

Exterior trim, including facia, soffits, window sash and casing, and the east and west ends of the plywood board and battens were painted white. Two coats of white latex paint were used over a white-lead base coat. Shutters on the north and south stained siding walls were painted white, and shutters on the east and west walls were painted a light olive green, as a contrast to the white siding (fig. 11).

Application of Interior "Perm-Board"

The "perm-board" interior covering component was designed to span between the studs of the wall and the bottom chords of the trusses, each of which was spaced 4 feet on centers. This covering is described in Appendix I. It consists of 4- by 8-foot sheets of fail-backed 1/4-inch gypsum board reinforced with low-grade boards. Nominal 4- or 6-inch-wide boards 5/8 inch thick and 8 feet long were spaced evenly across the 4-foot width and fastened with a modified polyvinyl-acetate glue to the foil side. The edge of the outside board of one panel was tongued and the edge of the first board in the next panel was grooved to provide a matched horizontal joint. This joint provided a positive tie between the upper and lower sheets after they were applied to the framing members. Moisture content of the boards when glued to the gypsum hoard averaged about 10 percent.

The 4- by 8-foot "Perm-board" sheets were applied lengthwise across the lower chords of the trusses with the end joints staggered. Ribbons of elastomer adhesive applied to the backer boards supplemented the nailing (fig. 25). Two sevenpenny nails were used for each board at each truss ox about 30 nails for each 4- by 8-foot sheet, less than one per square foot, This is about one-half the number normally used in dry-

Figure 25.--Construction adhesive being applied to the backing boards of the 4- by 8-foot sheets of "Perm-board." Small ribbons of adhesive are placed at contact areas with the lower chords of the truss or at contact points with the studs. M 133 462 #7

Figure 26.--Placing insulating batts in ceiling. First row of "Perm-board" component has been fastened in place to the bottom chords of the trusses.

M 133 462 # 2

wall construction when ceiling joists are spaced 16 inches on center. Six-inch ceiling insulation batts wre placed over the "Perm-board" as it was installed (fig. 26).

The "Perm-board" was applied to the walls after the ceiling had been covered. The 4- by 8-foot sheets were applied horizontally (wood backer strips across the studs) with the end joints staggered, figure 27. The tongued-and-grooved edges between the upper and lower sheets provided resistance to horizontal loads between the studs at this intersection. The method of application was the same as used for the ceiling covering, adhesive and nails at each backer board at each stud.

The conventional method of treating dry-wall joints was used on the walls and ceiling covered with the "Perm-board." Joint cement combined with joint tape was used over all joints and at interior corners. A textured base coat of paint was applied to all wall and ceiling surfaces before the finish coat was applied.

Figure 27.--Nailing a 4- by 8-foot "Perm-board" sheet to wall studs. Vertical joints are staggered. All joints are taped and filled in normal dry-wall fashion. M 133 645 #6

CONCLUSIONS AND RECOMMENDATIONS

Construction of the Nu-Frame Research House has indicated that no major problems were encountered with this system. The evaluations previously described and those made during the development of the Nu-frame system (Appendix I) have demonstrated its rigidity and strength. It is felt that the various construction sequences were relatively simple and were accepted and adapted to by the workmen.

This system is based primarily on the use of the low grades of wood and on reduced labor costs. As shown by the time and material cost studies (Appendix II), it not only reduces on-site labor needs. but results in lower material costs as well.

Its public acceptance should not be a problem because appearance wise it is similar to its conventional brother. Codes and local building regulations founded on performance requirements should not be a problem From the standpoint of strength and rigidity of the structural components, it meets and exceeds FHA Minimum Property Standards.

Following is a partial list of studies which should be conducted to obtain further information on this system of construction:

1. Moisture movement and heat-loss studies of various combinations of wall materials.
2. Attic ventilation studies.
3. Sound-transfer studies made of the Nu-frame interior and exterior walls.
4. Development of alternate reinforcing system of "Perm--board" interior wall covering component.
5. Further laboratory evaluations relating to column loading and racking resistance capacities of the Nu-frame wall.
6. Development of details for hip and valley construction with the "Plastic-plank" roofing.
7. Continued development of prefinished siding combinations utilizing low-grade boards (Appendix III).
8. Further investigations of the use of construction adhesives in the fabrication of interior coverings, trusses, and other components as these adhesives are improved.

In addition, marketing and manufacturing studies should be made of the "Plastic-plank" roofing, the interior covering, and the exterior

siding components, as well as the Nu-frame structural systems. Because this new method of wood-frame construction is aimed at conserving the better grades of wood and the maximum use of low-grade dimension materials and boards, laboratory and field studies should have high priority.

As indicated by the time and material studies, there are specific evidences that the cost of a wood-frame house can be substantially reduced when this system is used. A possible 10 to 15 percent or more saving in the cost of a house and the conservation of the better grades of wood can help to insure a continued supply of this natural resource for future generations.

APPENDIX I

DEVELOPMENT OF THE NU-FRAME HOUSE CONSTRUCTION SYSTEM

FOREWORD

Development of the Nu-frame system of wood-frame construction was originally covered in U.S. Forest Service Research Paper FPL 47, "Development. of an Improved System of Wood-Frame House Construction." published by the U.S. Forest Products Laboratory in October 1965. Pertinent data from FPL 47 are included in this appendix

DESCRIPTION OF COMPONENTS

The Nu-frame system began with the development of a siding-sheathing material which consisted of thin beveled sections of a desirable wood species laminated to low-grade nominal 1-inch softwood boards. This prefinished siding was capable of spanning 4 feet because of its thickness and, consequently, development of the wall framing and the roof system was also based on 4-foot spacing of members. Interior covering material and roof planking were developed to span 4 feet. Thus, the five components would be suitable for wood-frame houses constructed over any type of floor system such as concrete slabs, crawl spaces, or full basements.

Wall. Framing

All wall framing members of the new frame system, including studs, plates, and window and door headers, are based on dry thicknesses of 1-1/2 to 1-9/16 inches and widths of 3-1/2 to 3-5/8 inches. Exact dimensions are not critical but a constant thickness is desirable.

Wall framing consisted of doubled studs spaced 4 feet apart. They were placed flatwise and nailed to the top and bottom plates so that faces were flush with the edge of the plates. A space of 1/2 to 9/16 inch between the inner and outer studs allowed far diagonal bracing, plywood web members over openings, ox the 1/2-inch aluminum-faced insulation board material (fig. A1). The second top plate was a nominal 2- by 4-inch member. Plate splices were made at the studs.

Headers over long-span windows consisted of a 1/2-inch-thick plywood web and nominal 2- by 4-inch flange members placed in prenotched studs (fig. A2). When openings were 4 feet or less, 1/2-inch insulation board was normally used.

Diagonal corner bracing with 9/16- by 6-inch or wider boards was used in one system of framing (fig. A1, lower right). The boards were inserted between studs and fastened by nailing through the studs and the brace with twelvepenny nails. However, a second method of providing rigidity to the wall (use of aluminum-faced insulation board, known as "Insul-2") seemed to have more promise as it also incorporated acoustical and thermal insulation, figure A1. "Insul-2" is basically 1/2-inch insulation board in 4- by 8-foot sheets. Each face is covered with an aluminum foil which provides reflective insulation with a total stud space resistance of about 5.3 (equivalent to about 1-1/2 inches of flexible

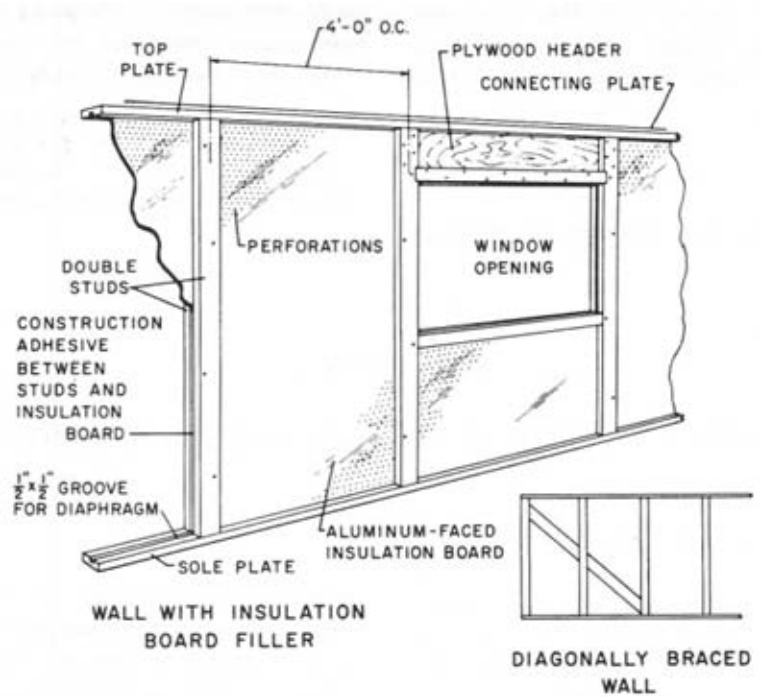


Figure A1.--Detail of Nu-frame wall framing system. M 129 529

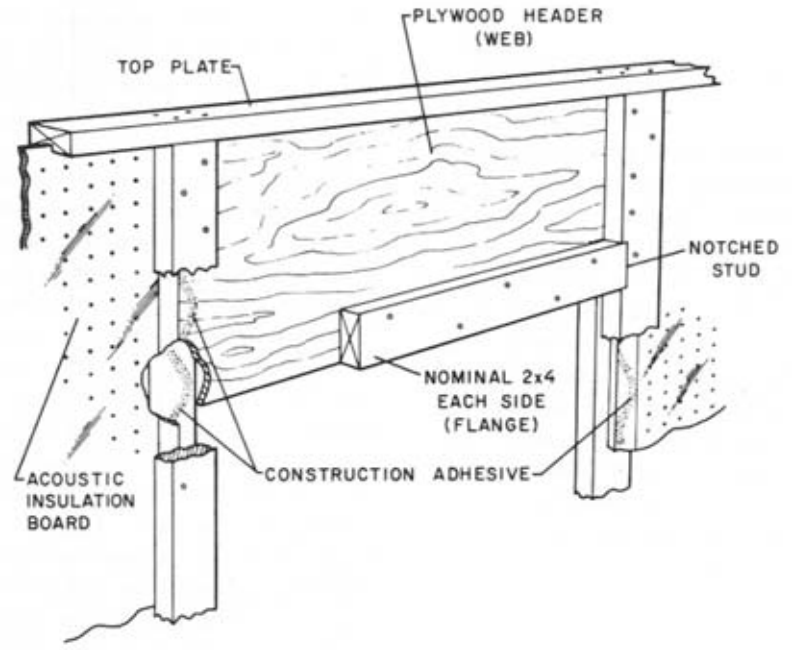


Figure A2.--Detail of door and window header. M 129 528

insulation). The outside of the sheet material has punched holes to provide small sound traps as well as to allow movement of any water vapor, figure A3. The foil on the inner face is perforated to allow escape of water vapor.

Assembly of the new wall framing was accomplished with nails and a construction adhesive applied with a calking gun. The inner studs were first placed flat on the subfloor and nailed to top and bottom plates. Plywood headers (webs) were than fastened in place over doors and windows. The 1/2-inch insulation board sheets (Insul-2) were placed vertically over a ribbon of adhesive. The top or outer studs were then fastened to the plates and to the studs beneath, after adhesive had been applied to the insulation board.

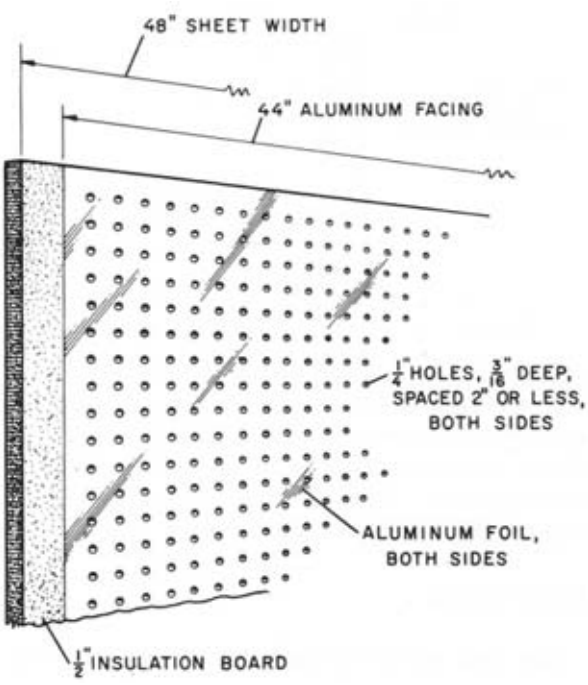


Figure A3.--Detail of acoustic insulating board (Insul-2). M 129 523

Roof Framing

Roof framing consisted of special wood trusses spaced 4 feet on center. They were constructed with doubled upper and lower chords of low-grade nominal 2- by 4-inch material. Plywood gussets 5/8 inch thick were used between the doubled members. The web members in the W-truss (diagonals) were also made from 5/8-inch-thick plywood.

Conventional gusset-type trusses are normally designed for 2-foot spacing, with the gussets located on each side of the single upper and lower chords. Thus, although the gussets for the "Dual-chord" W-truss of the Nu-frame system are larger and thicker, only four are required for each truss. Two conventional single-member W-trusses for the 4-foot span would require 32 gussets.

Two types of trusses were designed and tested, the conventional "W" or Fink truss with a 4:12 slope using 2- by 4-inch chord members, and the "king-post" truss with a 2:12 slope using 2-by 6-inch chord members, figure A4.

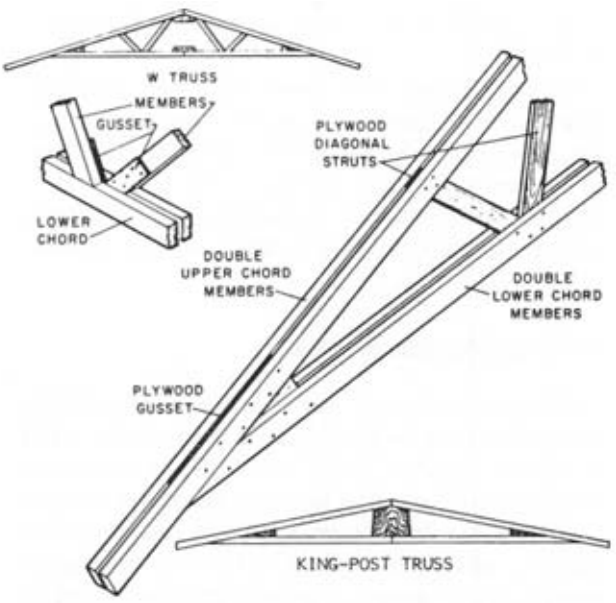


Figure A4.--Construction details of W-truss, especially "Dual-chord" (center), and of king-post. truss (bottom). M 129 527

The W-trusses were constructed in two manners. In one, the web or diagonal members were nominal 2 by 4 inches in size; they were fastened to upper and lower chord members with plywood gussets, which were nail-glued to the diagonal and between the double-chord members. Other connections were made by means of nail-glued plywood gussets between truss members. The other type of W-truss (Dual-chord) was constructed with the plywood gussets and web members located between the doubled chords. figure A4, center.

The king-post trusses were made with the gussets located at the heel and at the center, which also served as the king-post. Assembly of the king-post truss with the low pitch was more difficult than the W-truss when a "twist" occurred with the long 2- by 6-inch members. Clamps were thus required when such trusses were nail-glued.

In assembly of the "Dual-chord" trusses, precut truss members were positioned in a prepared jig. The 5/8-inch-thickplywood gussets, the plywood web members, and contact areas of the frame members were then spread with glue and upper and lower frame members were fastened in place. Twelvepenny annular grooved nails were used and were quite effective, if members were straight, in providing pressure until glue had set. However, the following system using screws would probably be more positive and require less time:

(a) Top frame members could be predrilled at gusset and diagonal locations before assembly.
(b) After glue spreading, 3- or 3-1/2-inch-long wood screws could be turned in place with a clutched power-driven screwdriver. This method would probably eliminate the need for clamps.

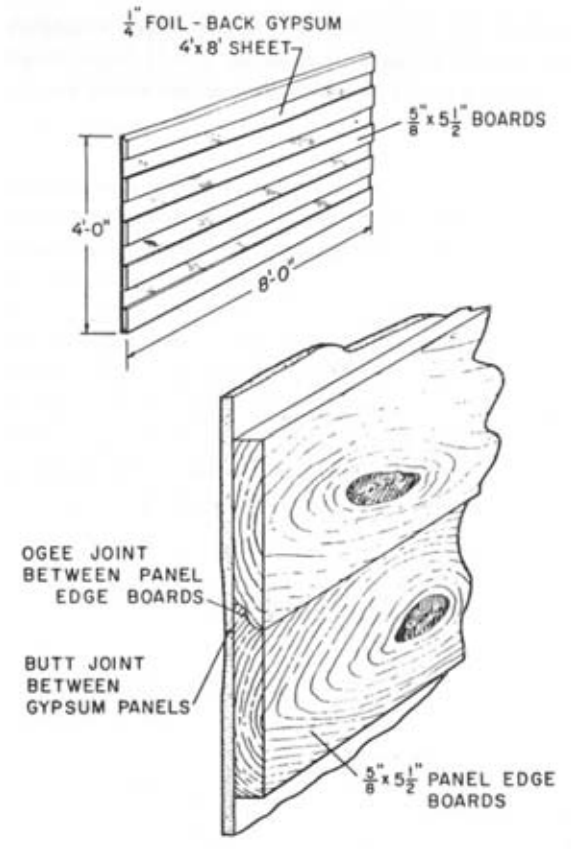


Figure A5.--Interior drywall covering for walls and ceilings (Perm-board).
M 129 525

Interior Covering Material

Because both wall and roof framing members were spaced 4 feet on center, the material used to finish interior walls and ceiling had to be designed for this spacing. This was accomplished by combining low-grade softwood boards with a gypsum sheet product to form "Perm-board" panels. Foil-backed 1/4-inch gypsum board in 4- by 8-foot sheets was used as a base material and 5/8- by 5-1/2-inch or narrower boards were spaced about 6 inches apart and glued lengthwise to the foil side of the sheet, figure A5. Edge of the outside board of each panel was molded or matched to provide a lock joint with the next panel. and horizontal stability. This was desirable because the 4- by 8-foot sheets were applied lengthwise across two 4-foot spaces with staggered vertical joints. Application to frame members was accomplished with a ribbon of construction adhesive and nails at each framing member, figure A5. Joints were finished in the conventional gypsum drywall manner, with tape and joint cement.

It was important that a moisture content of about 9 to 10 percent for the boards be reached before they were glued to the gypsum board. This minimized the tendency of the boards to cup as they reached moisture equilibrium.

Roof Covering

The roof sheathing and roofing were combined into a laminated plank, "Plastic-plank," designed to span the 4 feet between each roof truss. The Plastic-plank was manufactured by laminating a nominal 1-inch board between two pieces of 5/8-inch plywood, resawing to a bevel shape, and machining to form a locking pattern, figure A6. Two planks were formed from one board. The exposed face and edge surfaces of the plank were covered with an asbestos-backed polyvinyl fluoride film providing a prefinished, long-lived surface. Lengths of the planks were 8, 12, or 16 feet to correspond with the 4-foot spacing of the trusses.

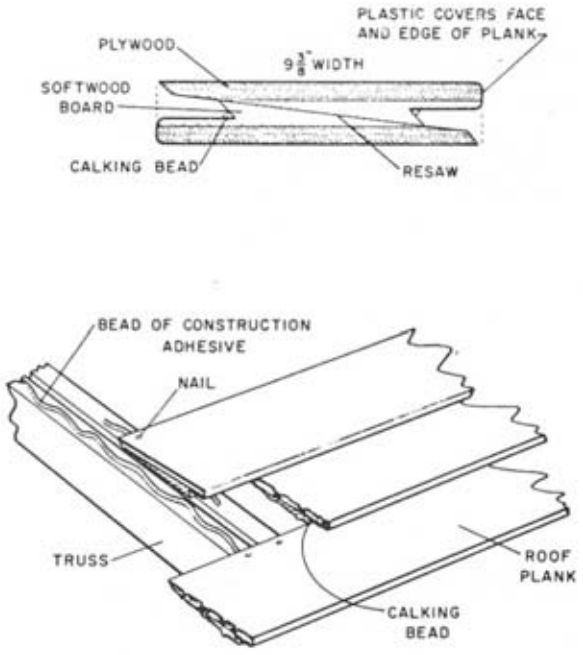


Figure A6.--Details of prefinished roof plank (Plastic-plank). M 129 524

The roof planking was fastened to the upper chords with construction adhesive and one ring shank nail for each board at each truss, figure A6. The lap of the succeeding plank covered the nails below. A positive horizontal seal was provided with a bead of sealing compound between the locking joints, Butt joints were made over the truss and finished with a polyvinyl fluoride tape.

Siding-Sheathing Covering

The combination siding-sheathing material, "Twinboard," which was the original material developed for the Nu-frame system of construction, was made of vertical-grain redwood in combination with low-grade softwood boards. The Plastic-plank roofing previously described can also be used as a combination siding material,

Redwood boards were resawn to form thin sections of bevel siding, and two such pieces were glued to a backing of low-grade pine boards to make up the Twinboard units, figure A7.

The finished siding-sheathing material provided a locking double-lapped horizontal joint with interlocking end joints. All joints were made over the studs. Lengths were 8, 12, and 16 feet to conform to the 4-foot stud spacing. The plank was made so it produced a 12-inch face width when installed. Siding was applied with construction adhesive and

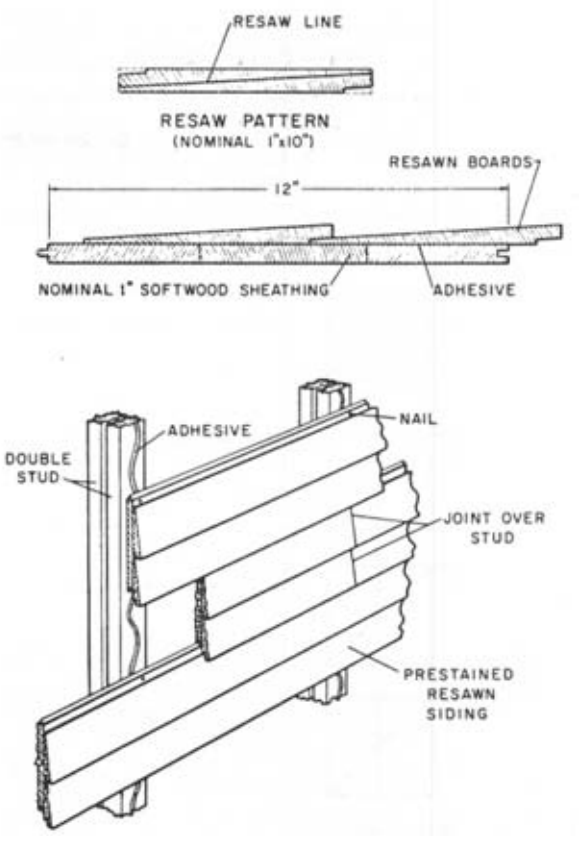


Figure A7.--Details of first type of siding-sheathing component (Twinboard). M 129 526

blind nailing. The resawn outer surface of the siding was stained.

In combinations such as the Twinboard, it is important that the moisture content of the two materials be about equal at the time of gluing. An average moisture content of about 10 to 12 percent should be satisfactory for most parts of the country except the dry Southwest.

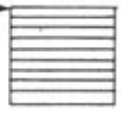
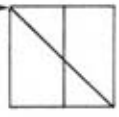
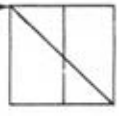
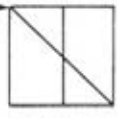
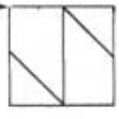
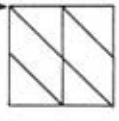
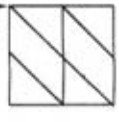
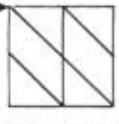
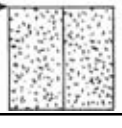
RESULTS OF EVALUATIONS

Strength and rigidity tests were made on wall panels and roof trusses as well as on several other of the components used in the newly developed framing system An exposure test is also being conducted on a roof panel made up of the laminated Plastic-plank

Wall Framing

Racking tests made on the original 8- by 8-foot wall panels complied with ASTM E-72 previously

Table A1.--Results of racking tests of Nu-frame wall panels

Design	Diagonal braces		Load at 0.5-inch deflection	Relative rigidity	Maximum load	Relative strength
	No.	Size				
		In.	Lb.		Lb.	
A  [1]	None	Control panel	690	1.0	1,310	1.0
B 	1	1 x 6	850	1.2	875	.7
C 	1	1 x 8	860	1.2	880	.7
D 	1	1 x 10	1,060	1.5	1,127	.9
E 	2	1 x 10	375	.6	1,100	.8
F 	3	1 x 6	990	1.4	1,150	.9
G 	3	1 x 8	1,240	1.8	1,665	1.3
H 	3	1 x 10	1,450	2.1	2,013	1.5
I  [2]	None	Insulation board between studs	1,530	2.2	1,845	1.4

[1] Control panel--2 x 4 Studs 16 inches on center, 1 x 8 horizontal sheathing, two eightpenny nails per stud crossing.

[2] Insul-2 1/2-inch insulation board.

described. The results of these tests on the various combinations of materials are shown in table A1. As noted, no panels met minimum FHA stiffness and strength requirements. Modifications were later made to remedy this, and those results are shown in table 1.

Roof Trusses

Results of the tests made of the original W-trusses are shown in table A2. Bending tests were also made on several low-slope king-post trusses. Deflection-span ratios averaged 1/1100 and maximum loads averaged 2.2 times design load.

Exposure of Roof Panel

To determine the ability of the Plastic-plank roof board system to resist water entry, a 6- by 8-foot roof section was mounted on a simulated truss framework designed for variable roof slopes. figure A8. Exposure since April 1964 has been at a 6/12 slope and toward the southwest for maximum exposure to rains.[1] Assembly of the roof planking conformed to the details previously outlined except that one 8-foot-long horizontal joint was protected by brush coating the edges of the boards with a water-repellent preservative rather than using a calking seal. The back side of the roof panel was examined after each significant rainfall. After a 1-year exposure, each horizontal joint treated with the calking bead was free of visible moisture. The joint treated with water-repellent preservative once showed a very slight trace of moisture but only after a heavy rainfall when wind velocities were more than 40 miles per hour.

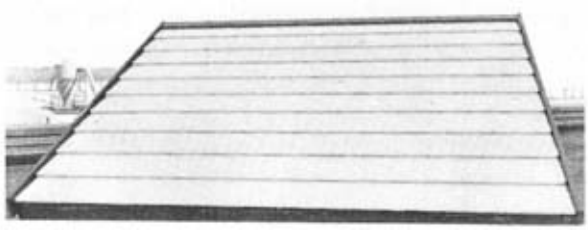


Figure A8.--The roof planking overlaid with plastic film shows no deterioration after 1 year of exposure. M 128 107

Strength Tests of Perm-board

Concentrated load and impact drop tests were made on (a) a 4 by 8 sheet of the Nu-frame Perm-

Table A2.--Results of bending tests of W-trusses[1]

Truss No.	Size of diagonals (web member)		Lower chord splice gusset	Stiffness at design load[2]	Maximum load	
	Compression	Tension			Pounds	Times design load
	In.	In.				
W-2/4-1	2 x 4	2 x 4	Small	1/1600	6,320	2.1
W-2/4-2	2 x 4	2 x 4	Medium	1/1460	7,400	2.5
W-P-1	5/8 x 5-1/2	5/8 x 4-1/2	Small	1/1500	6,270	2.1
W-P-2	5/8 x 5-1/2	5/8 x 4-1/2	Medium	1/1500	5,500	1.8
W-B-1	5/8 x 5-1/2	5/8 x 5-1/2	Small	1/1200	7,670	2.5
W-B-2	5/8 x 5-1/2	5/8 x 5-1/2	Medium	1/1850	8,820	2.9

[1] Trusses constructed for 26-foot span, 4/12 slope, with double, 2- by 4-inch upper and lower chords.

[2] Deflection-span ratio at design load of 3,100 pounds.

[1] Roof slope changed to 4/12 slope after 2 year's exposure.

board with support members spaced 4 feet apart and (b) on a 4 by 8 sheet of 3/8-inch gypsum board nailed to 2- by 4-inch studs spaced 16 inches apart.

Concentrated load test.--The concentrated load lest consisted of a load applied to a 1-inch-diameter round steel rod located midpoint between supports. The load at a deflection-span ratio of 1/240 was 40 pounds for the gypsum board and 110 pounds for the Perm-board panel. Maximum load at failure was 125 pounds for the 3/8-inch gypsum board and 388 pounds for the Perm-board panel.

Drop test.--The drop test was conducted by dropping a 60-pound bag onto the center of 4- by 8-foot panels supported at each end. The 3/8-inch gypsum panel failed at a 6-inch drop. The Perm-board panel failed at a 12-inch drop after sustaining the first 6-inch drop.

PROTOTYPE STRUCTURE

A small scale model building incorporating the principles of the Nu-frame construction system is shown in figure A9. Simplicity of construction is the most evident feature. The number of pieces to handle during assembly and the need to cut and fit 2-inch dimension material has been considerably reduced. The exterior roof and wall components axe composed of interlocking units that require only one nail for each 3- to 4-square-foot area; the fastening load is shared by construction adhesive. Relatively lory-cost materials arc used throughout with no compromise in structural quality.

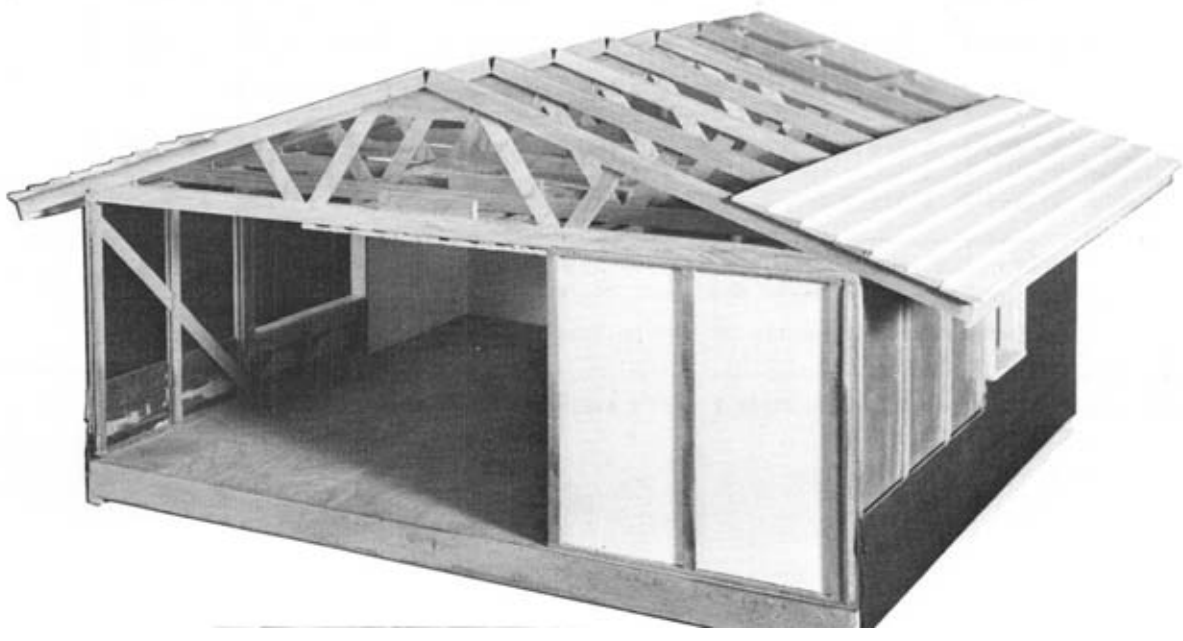
CONCLUSIONS AND RECOMMENDATIONS

The Nu-frame construction system with factory assembled, prefinished components lends itself well to rapid assembly and requires a minimum of on-site labor. It is also adapted to preassembled systems with fully or partly completed wall sections delivered to the building site. The system combines economical wood products in panel-type units which are fastened to wall and roof framing with both construction adhesive and nails. Strength and exposure studies have shown that the components of the system compare favorably with conventional construction,

Based on the laboratory evaluation of the Nu-frame construction system, it appears that a full-scale research building is justified. Detailed recommendations for such a unit have been prepared. A 28- by 40-foot building is proposed which will incorporate not only the various components of the Nu-frame system but also moisture, temperature, ventilation, and acoustical studies.

Figure A9.--View of Nu-frame model showing trusses, wall, framing, and covering materials.

M 129 403



APPENDIX II

TIME AND MATERIALS COST STUDIES OF NU-FRAME SYSTEMS

INTRODUCTION

Time studies were made of various construction sequences during erection of the Nu-Frame Research House. These studies covered fabrication of the trusses: framing and erection of the exterior walls; erection of the roof trusses; and application of the roof planking, and siding, and the interior covering. The time data were compared with time studies made during construction of two conventional wood-frame houses by the Division of Building Research, National Council. of Canada.

Cost comparisons were made of materials required for a typical 28- by 40-foot wood-frame house and an equivalent house utilizing the Nu-frame system Only those construction phases which differed were studied and did not include exterior and interior trim, millwork, flooring, and similar items.

TIME COMPARISONS

To compare information from the Nu-frame system of construction and that obtained from the Canadian study of conventional construction, time data were recorded in man-minukes per square foot. This eliminated hourly rate differences and assumed that the proficiency of the American and Canadian workmen was about equal.

It was difficult to include accurate total elapsed time for the various phases during construction, partly because of the delays due to a photographic record being made of the Nu-frame system. However, for each of the five phases of the Nu-frame system, six to eight time-application recordings were made. The averages of these recordings were used in determining the man-minute-per-square-foot values. It was noted that as the workmen became more familiar with each of the phases, their efficiency improved.

The data for conventional wood-frame houses were obtained from a study conducted by the Division of Building Research, National Research Council of Canada.[1] The objective of this study was to determine how much the cost of a wood-frame house could be reduced if it was built to the minimum residential standards normally defined for Canada. The control house was built to the standards normally used at the housing development studied. The minimum standard house was identical except for the slight changes in structural and decorative details. Time data of the Nu-frame house were compared with the control house of the Canadian study, based on a time-per-square-foot basis.

Exterior Walls and Roof

Time comparisons of the Nu-frame system with the conventional wood-frame house included the exterior walls and the roof-ceiling construction. The wall included all labor required for a completely finished wall, except for the millwork, exterior painting, the taping of dry-wall joints. and finish painting. The roof-ceiling construction included framing, sheathing, application of the roofing, and installation of the drywall ceiling covering. All time data were seduced to man-minutes required to construct or install 1 square foot of wall or roof area.

Conventional wall construction normally includes: (a) framing, (b) sheathing, (c) siding, (d) insulation, and (e) interior covering. In the Nu-frame system, however, the wall construction phases are reduced to three: (a) framing, (b) siding, and (c) interior covering. Wall sheathing material is part of the siding component, and the insulation (reflective) is part of the framing process.

It was found during the Canadian time studies that a certain percentage of the workman's day could be classed as idle time when actual production stopped. This included rests, time for

[1] Hansen, A. T. A cost study of two wood-frame bungalows. Division of Building Research, Canadian National Research Council Technical Paper NCR 9590. June 1957.

Table B1.--On-site labor for construction of conventional wood-frame house and Nu-frame house components

Unit	Man-minutes per square foot: Conventional[1]	Man-minutes per square foot: Nu-frame[2]	Time saving
			Pct.
Exterior wall - Framing	0.60	0.45	
Sheathing	.38		
Siding	2.90	1.77	
Insulation	.62		
Dry wall	.42	.59	
Total.....	4.92	2.81	43
Roof-ceiling - Framing	[3] .57	[4] .40	
Sheathing	.31		
Shingles	.51	.56	
Dry wall (ceiling)	.42	.59	
Total.....	1.81	1.55	14

[1] Based on Canadian study.

[2] 23 percent increase for idle time included.

[3] Conventional ceiling joist and rafter construction

[4] Includes manufacture of trusses (0.34 man-min. per sq. ft. for manufacturing and 0.06 for erection).

instructions, and similar slow-downs. These non-productive periods were highest in such operations as construction of the basement and lowest in the painting operation. The average, however, was found to be about 23 percent of the total time. Thus, in summarizing the data from the time studies conducted on the Nu-Frame Research House, a factor of 23 percent has been added to the average recorded times of the various operations.

A summary of the time studies for conventional and Nu-frame construction is shown in table B1. All values have been reduced to man-minutes per square foot.

As noted, the man-minutes per square foot required for the conventional exterior wall were 4.92, compared to 2.81 for the Nu-frame wall, a saving of 43 percent. The difference in time of installing siding for the two systems might be attributed in part to the fact that aluminum siding was used on the conventional Canadian house. A prefinished wood siding component is standard for the Nu-frame system

The construction of the ceiling-roof portion of the two houses also favored the Nu-frame system A saving of 14 percent in time was indicated over the conventional roof construction consisting of ceiling joists and rafters. The Nu-frame house was roofed with the "Dual-chord" truss, a total of nine being required for the 28- by 40-foot unit.

Interior "Acoustic" Walls

The Nu-frame wall system when adapted to interior walls, should provide desirable acoustic properties. Not only is a low-density insulation board used between the doubled studs, but the construction adhesive used for assembly, in effect, isolates each of the materials from each other. This should provide a seasonably good Sound Transmission Class (STC) rating in resisting passage of air-borne sound. Study of these factors will be included in future research programs.

When a conventional interior wall is constructed to provide a satisfactory STC value at

a reasonable cost, 1/2-inch sound board is often used over each side of the framed wall, followed by gypsum board. Thus four layers of sheet materials, plus the wall framing, are needed to provide this type of wall. Based on available data from the wall time studies, it is estimated that construction of such an acoustic would require 2.28 man-minutes per square foot. A Nu-frame interior wall would require 1.63 man-minutes per square foot to construct, or a saving of about 28 percent in labor.

MATERIAL COST COMPARISONS

A 28- by 40-foot three-bedroom house was used in estimating the amount and cost of materials required for conventional wood-frame construction and for Nu-frame construction. Only those phases where construction of the two systems differed were considered. These included complete exterior and interior walls and roof and ceiling construction. The floor system and flooring, millwork, and interior and exterior trim were not included because there is little difference in these phases. Basic costs of the materials were obtained from price lists issued by wholesale-retail lumber dealers. Cost estimates were made of the nonconventional components in the Nu-frame system from the best data available.

In general, the dimension materials used for Nu-frame walls and roof trusses are a lower grade than is commonly used in conventional construction. This is substantiated by the fact that studs in the walls and the upper and lower chords of the trusses are always doubled, which allows the use of a lower grade than if the members were used singly. Fourth grade dimension material has been used for Nu-frame components, and nothing larger than nominal 2- by 4-inch members is required except to provide nailing at corners. Boards used as backing material for the covering components were mainly No. 4 and No. 5 grades, usually in the western pine group. Thus, the cost of the basic wood materials is not only much lower than normal but also materials are of lumber grades that are seldom used in the construction of today's conventional house.

Normally, a wood-frame house uses a third or better grade far studs and plates. Furthermore, conventional wood trusses are usually made with stress-grade dimension material of 1,250 to 1,750 pounds per square inch, depending on the type of member. The cost of these dimension materials may be 20 to 50 percent greater in conventional construction than the fourth grades used in the Nu-frame system.

Wood and Nonwood Materials

In the 28- by 40-foot house being used for an example to compare material costs, both wood and wood products and nonwood products are used. However, the Nu-frame system utilizes more wood (low grade) and less nonwood materials than the conventional house. This has led to a reduction in the total cost of materials required. A comparison of the materials required for the two systems and the approximate costs are shown in table B2. The total amount of 15,000 board or square feet is nearly the same for the two systems, but the type, thickness, and unit costs vary somewhat. However, a material saving of about $300 or 18 percent is realized for the Nu-frame house. While about 2,400 more board feet of wood are used in the Nu-frame system, about the same amount less is required in wood and nonwood products.

This is not the entire picture in material savings, however. It is estimated that the Nu-frame roofing components will have at least double the life of a conventional asphalt shingle roof. This would mean a further saving of about $400 for replacement costs after 18 to 20 years.

Dimension and Boards

A further breakdown of the wood required for the two systems is shown in table B3. Here the differences in the types of wood used are shown. The Nu-frame system uses about 840 fewer board feet of 2-inch dimension material but more than 4,000 board feet of low-grade boards. Furthermore, because the Nu-frame siding component is made of 5/16-inch slices of the better siding species, only one-third the number of board feet of these increasingly scarce woods are required. The backing consists of low-grade boards at a basic cost of only 20 percent of the facing. The saving of all wood items is estimated as about 14 percent.

Dimension Material Required

The distribution of the 2-inch dimension material required for several items in conventional and in Nu-frame construction of the sample house

Table B2.--Comparison of materials required[1] for a conventional and a Nu-frame house

Item	Conventional		Nu-frame	
	Amount	Approximate cost	Amount	Approximate cost
	Bd. or sq. ft.	Dollars	Bd. or sq. ft.	Dollars
Wood (Dimension and boards)	4,585	890	6,960	770
Wood products (Plywood and insulation board)	5,220	436	3,900	343
Nonwood products (Gypsum board; insulation)	5,240	280	4,140	197
Total	15,045	1,606	15,000	[2]1,310

[1]Exterior and interior walls and ceiling-roof construction for a typical 28- by 40-foot house.

[2]A saving of 18 percent in cost of materials.

Table B3.--Amount and cost of wood materials required[1] for conventional and Nu-frame systems

Item	Conventional		Nu-frame	
	Amount	Approximate cost	Amount	Approximate cost
	Bd. ft.	Dollars	Bd. ft.	Dollars
Dimension (2 by 4's and larger)	3,085	440	2,240	260
Siding	1,500	450	500	150
Boards (low grade)			4,220	360
Total	4,585	890	6,960	[2]770

[1]Exterior and interior walls and ceiling-roof construction for a typical 28- by 40-foot house.

[2]A saving of about 14 percent in cost of materials.

is shown in table B4. For the interior and exterior walls and the trusses, not only is less material required for the Nu-frame system, but also the basic costs are lower. An estimated 27 percent saving in the amount of dimension material and 41 percent in the cost is realized in these phases of construction.

Pieces Required

The number of pieces which must be handled on the job usually has a direct bearing on the on-site labor cost. Fewer pieces mean less cutting, fitting, and fastening, The Nu-frame system has a definite advantage in this respect;

Table B4.--Dimension material required[1] for conventional and Nu-frame systems

Item	Conventional		Nu-frame	
	Amount	Approximate cost	Amount	Approximate cost
	Bd. ft.	Dollars	Bd. ft.	Dollars
Outside walls	975	117	860	93
Inside walls	980	120	520	52
Trusses	970	184	700	96
Gable end and rake	160	19	160	19
Total.....	3,085	440	[2]2,240	[3]260

[1]Dimension, 2- by 4-inch size and larger, required for exterior and interior walls and ceiling-roof construction for a typical 28- by 40-foot house.

[2]27 percent saving in amount of material.

[3]41 percent saving in cost of material.

Table B5.--Pieces required[1] for several phases of conventional construction and Nu-frame system

Construction phase	Pieces required		Savings in Nu-frame	
	Conventional	Nu-frame	Conventional	Nu-frame
	Number	Number	Number	Pct.
Outside walls (136 linear feet)	672	502	170	25
Inside walls (130 linear feet, acoustic)	290	197	93	32
Trusses (assembled off site)[2]	19	9	10	52
Trusses (total pieces) (assembled on site)	456	144	312	68

[1] Pieces required for the various construction phases in construction of a typical 28- by 40-foot house.

[2]Assuming assembled trusses are received at the job site, these is a total saving of 28 percent in the number of pieces. (981 pieces vs. 708 pieces)

Considering complete exterior walls, interior walls, and the trusses, a saving of 28 percent in the number of pieces handled can be realized with the Nu-frame system These details are shown in table B5. A further advantage is, of course, apparent if the roofing with asphalt shingles is compared to the Nu-frame roof planking. Furthermore, a saving of 68 percent in the number of pieces is accomplished during assembly of conventional gusset trusses and the Nu-frame dual-chord truss, whether at the factory or at the building site.

Fastenings

The number of fastenings used on the job or off the job site for prefabricated components has a direct bearing on labor costs. It is estimated that it costs an average of 3 cents to drive one nail in construction of a house.[2] Thus, any reduction in the number of nails required should reduce overall construction costs.

The Nu-frame system has been based on the use of construction adhesives and a minimum number of nails. This saving in the number of nails must be balanced by the time required to apply ribbons of adhesives. However, from time observations made during construction of the Nu-Frame Research House, a very substantial saving in labor can be realized by this new system of fastening parts. Framing members are spaced 48 inches apart rather than 16 inches, and most of the components serve several purposes, eliminating the need for great numbers of nails.

Table B6 lists the approximate number of nails required in the construction of walls and roof and in the application of insulation and covering materials for the 28- by 40-foot house. Trim, millwork, and flooring are not included, as there is not a substantial difference, in these phases.

As noted in the table, over 30,000 nails are used in conventional construction, compared to about 5,800 for construction of the same Nu-frame components. This amounts to a saving of more than 80 percent in the number of fasteners required. About 4-1/2 gallons of construction adhesive are required in addition to the 5,800 nails.

CONCLUSIONS

Based on the time studies and the material cost estimates, it appears that the Nu-frame system has great potential for reducing the cost of a wood-frame house. This reduction can likely approach 15 percent or more of the total price of the house, Furthermore. the utilization of low-grade wood means a continuous supply of the

Table B6.--Fasteners required for convention, I and Nu-frame construction in a typical 28- by 40-foot house

Unit	Conventional		Nu-frame		
	Estimated number of fasteners	Type of fastener	Estimated number of fasteners	Type of fastener	Estimated tubes of construction adhesive[1]
Outside walls	10,300	Nails and staples	1,800	Nails	16
Interior walls	5,300	Nails	2,200	Nails	16
Trusses (plywood gusset)	3,300	Nails	500	Screws	16
Roof--sheathing	2,400	Nails			
shingles[2]	7,400	Roofing Nails	600	Nails	8
Ceiling covering	1,700	Nails	700	Nails	4
Total.....	30,400	.....	5,800	.....	44

[1]A tube of construction adhesive is 1/10 gallon.

[2]Based on 6 nails for each 12- by 36-inch strip.

[2]From paper "Low-Cost Housing Design Standards," by Prof. D. J. Stith, University of Wisconsin. Presented at Economy Housing Seminar, University of Nebraska. Nov. 13-15, 1967.

grades which now have little use in the home construction. The great need and use of wood and wood products by all construction industries in the future demand that some method such as the Nu-frame system be developed and used.

It is recommended that further time and cost studies be made of the Nu-frame construction system to provide more specific information on the manufacturing and installation costs of the various Nu-frame components.

APPENDIX III

DESIGN OF COVERING COMPONENTS

Three combinations of prefinished siding-sheathing materials were used on the Mu-Frame Research House, as described in the main report. In addition, the roof covering (Plastic-plank) combined sheathing and shingles in a laminated section. All types were satisfactory from the standpoint of stiffness and strength in spanning the 4-foot spacing of studs and trusses. The appearance of each siding component is very similar to standard lap siding or dressed and matched paneling. The rough-sawn surfaces provided an excellent base for the pigmented stain used as finish. The deep-nosed edge of the "Plastic-plank" roofing gives the appearance of a Bermuda-type roof. While a white polyvinyl fluoride film was used an the asbestos-backed facing. several pastel shades are available.

The shape and size of the roof plank made from the laminated sections seemed to be very satisfactory. The wedging effect of the 45° inverted "V" groove over the tip of the course below appeared to be effective in providing good contact with the truss members below. Beyond minor changes that might be made in size or thickness,

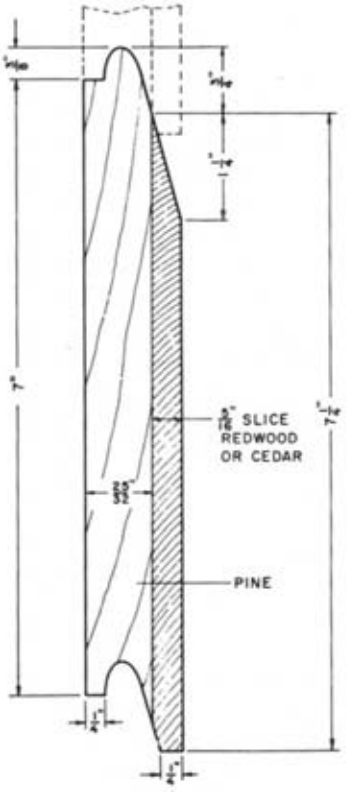


Figure C1.--Slice-sid--new form.

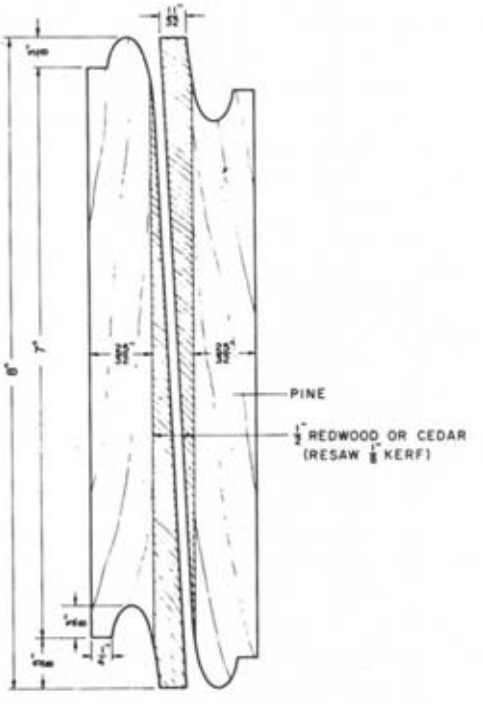


Figure C2.--"Twinboard"--new form.

it is felt that the "Plastic-plank" as shown in figure 9 of the main report would be satisfactory for spans up to 4 feet. A thin plastic, plywood, or similar spline for butt joints might improve the overall roofing system It is also felt that the plywood should be 5/8 inch thick for a roof covering of this type, as was used for the planking on the Research House. Because plywood is the principal material used in the planking, stability is assured and cupping or warping is minimized. Treatment of raw wood edges with a water-repellent preservative on surfaces not covered by the film is desirable. The use of a soft mastic sealant bead along the inverted "V" edges is likely necessary to prevent rain entry during high winds.

While the matched and shiplapped edges of the wood siding components (figs. 6, 7, and 8 of the main report) worked out reasonably well, it is felt that a modified edge shape would be more effective. The details of the new form "Slice-sid" and "Twinboard" sidings shown in figures C1 and C2 combine the matched and shiplapped edges in a simple fashion. The tapered butt edge of this form provides a wedging effect and a tight joint. A simple spline butt joint and edges treated with a water-repellent preservative should result in a very satisfactory single all-purpose covering material for spans up to 4 feet.