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TIMBER-FRAMED CONSTRUCTION FOR TROPICAL CLIMATES 1/

by

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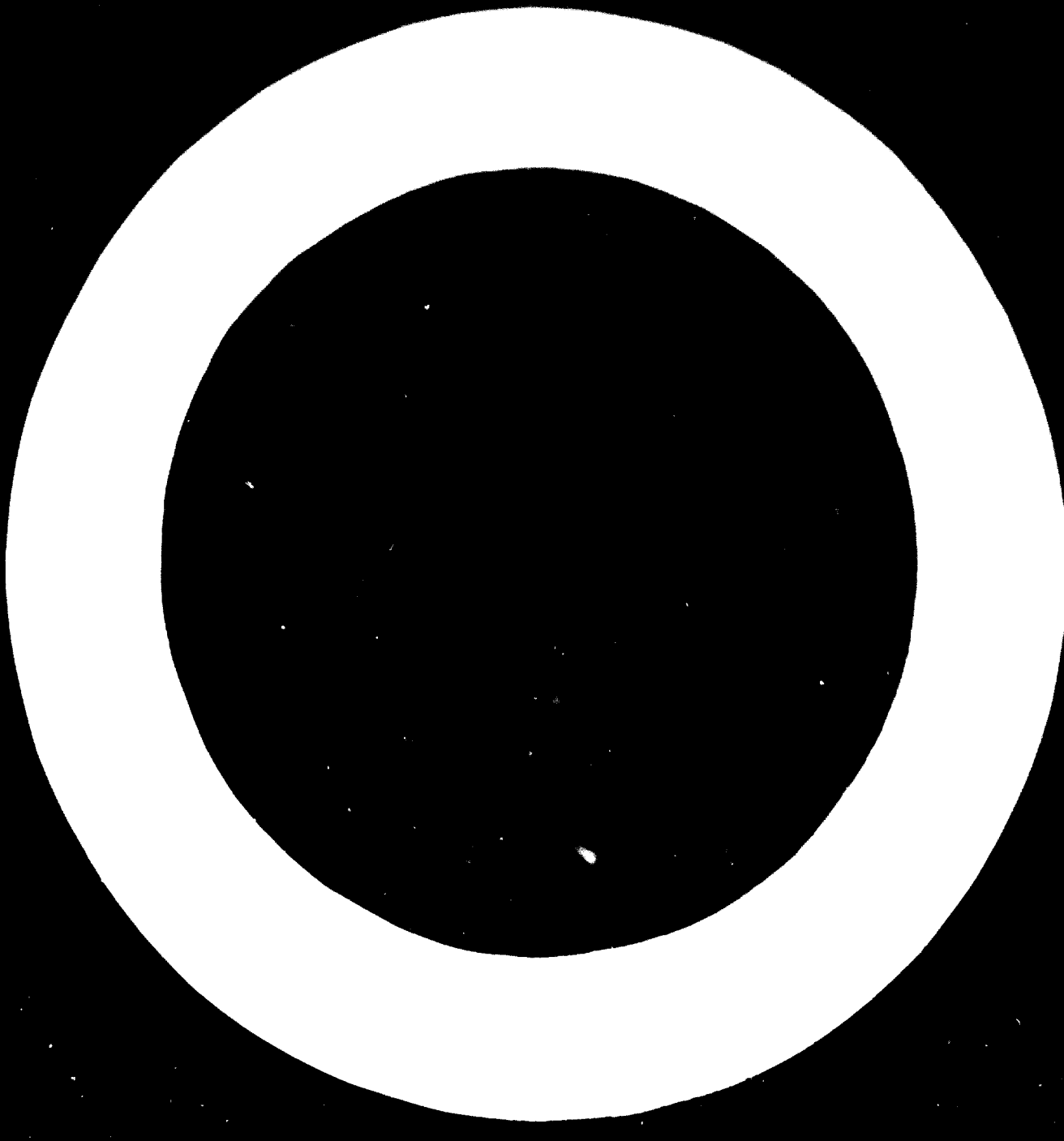

Introduction

Dr. E. George Stern, an internationally-known expert in mechanical fastenings and in wood construction at Virginia Polytechnic Institute, offered an interesting hypothesis recently in a series of lectures in Europe (40) [1]. He postulated that a high living standard is found in those countries whose natural resources, and especially, whose forest products are used with utmost efficiency in production of necessities, including housing. Thus in the U.S.A. the annual consumption of forest products amounts to 67 cubic feet per capita,

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1/ Numbers in parentheses refer to literature listed at the end of this paper.

and in New Zealand, another land with a high living standard, this is 93 cubic feet. On the other hand, in China the annual consumption is less than 1 cubic foot per person. Similarly in Norway and Sweden, with large timber resources and extensive use of wood, the living standard is high, whereas in many South American countries with large timber resources and little utilisation of them, living standards tend to be low. Although this may be rather circumstantial evidence, it is worthy of serious examination in this meeting.

The utilisation of wood and wood products in housing in tropical climates seems to present some interesting paradoxes. Generally tropical countries have a good supply of timber available. For the purposes of this discussion at this conference it is assumed that this is the case, and furthermore, that this timber has not yet been adequately utilised in home construction. There appears to be a number of prejudices against such use of wood in tropical climates, some of which may have some justification. In such climates, insects and other biological organisms such as fungi, and mold are likely to be quite active. Hence deterioration of wood is of natural concern, particularly from insects such as termites, and from decay organisms. In some of these countries, cooking and heating may be provided by open fires in the houses, rather than by furnaces, or electric or gas stoves. Hence, the danger from fire is always present. Compared to brick, stone, concrete, and similar non-wood materials, wood thus seems to have some important limitations, and these have tended to minimize utilization of wood in housing in such areas.

The Need for Better Information on Available Woods

Although there may be a liberal supply of timber available in some developing countries, this may involve a large number of species ranging from low density woods that would be easy to use, but are of limited strength and durability, to very high density woods with great strength, but which are difficult to cut and machine, or to fasten with conventional nails or screws. Such dense woods may shrink excessively and distort in shape and dimensions when dried in use. A basic problem seems to be a lack of adequate technical knowledge of the physical and mechanical properties and of the natural durability of many of these species, so that they can be properly used in construction, based on sound engineering design procedures. In some cases, the species may not even have been properly identified or classified.

None of these problems are new. They have been recognized and faced in all countries where wood has had wide use in construction. We should probably therefore recognize at the start that more research will undoubtedly be needed in developing countries to more adequately identify, classify, and study the available species, particularly to establish their mechanical properties. The patterns for such research are well established for the more common species now widely used in many parts of the world.

Service Conditions to be Met

Another probable need that can be recognized at the start is the need for adequate knowledge of the actual service conditions that wood in various parts of a house will need to meet in specific locations in the developing countries. We need to know just how wet the wood is when in use in the lower parts of a house, near the ground, and we need to know what insects and other biological organisms are likely to be present in, or near, the house. To merely assume that many such organisms are present, and therefore must be protected against, will unnecessarily complicate the selection of suitable wood materials, or selection of preservative treatments that might be required of such woods, where they may not actually be necessary. It must also be recognized that various construction features in building a timber house will influence the severity of potential attack by biological organisms such as in decay, and also affect their resistance to fire. For example, designs which provide good ventilation around the wood members will often reduce the high moisture conditions in such wood, which might otherwise cause decay, if such ventilation was not provided. In the same way, heavier wood construction such as with thick timber beams, will resist fire for extended periods of time in the sense that, although the outer surfaces may char, the interior of the beam will not be damaged if the fire is extinguished promptly. On the other hand, if thinner wood members are used in so-called light-weight frame construction, the same fire might burn through the wood pieces, and cause complete failure.

Competitive Materials

Wood has a long history of excellent performance in homes and similar structures in many countries when it is properly used. Traditional uses of concrete, metals, bricks and other materials in homes in other countries are often based on early use of wood due to ignorance or disinterest as well as due to the more readily available supply of such alternate materials. The relative merits of wood and other materials will, of course, have an important part in selection of the preferred materials and methods of construction. Experience of local crafts men with certain materials will also affect current building practices. In this paper, we want to emphasize how wood can be used effectively in homes in tropical climates, assuming that the economics for its use are favorable.

Basis for Current Discussion

Because most of the published and otherwise available technical information on wood housing is from various countries that can hardly be considered tropical, I will necessarily rely heavily on such experience, and merely suggest how experience in such other countries and climates might be used in tropical climates, particularly in the newer nations where their capabilities for industrial growth in the timber and housing fields are just now developing.

It is further assumed in this paper that we are primarily concerned with single-family housing for lower income families in these tropical countries. Thus economies in design and construction are important, and opportunities for some "self help" by the ultimate

occupants in building the house will be significant. This is an important consideration at present in the United States. The greatest housing needs in the U. S. A. are for the lower income families, both in rural and urban areas. The problem ranges from the need for better homes on [illegible] Indian reservations to better housing in our big city ghettos. At the same time our unemployment problems tend to be worst in just such areas. Hence it would be highly desirable to bring many of these people involved directly into the building program. This [illegible] is not an easy task. House building is not the easiest task to [illegible] and [illegible]. The challenge here is to break down the whole house building process into a number of simple tasks that can be taught to [illegible] unskilled, but presently unemployed workers, provide them with the necessary [illegible] and good supervision, and let them do all of the work themselves. Particularly in big cities this introduces important problems with building codes and restrictions, and interference from labor unions. We will assume that for each of the house building or developing contexts these restrictions are not too critical and that such difficulties can be overcome.

We are encouraged by the rapid growth of our mobile home industry in the U. S. A. which now accounts for some 35 percent of all single family dwellings. These homes are built in relatively simple factories by semi-skilled workers trained to do specific tasks well, much as is done for years in our assembly line production of automobiles. If it can be done here with mobile homes, it should be possible in conventional house building, particularly where a large number of similar homes are to be built at the same time on a single site.

Some Differences in Tropical Housing and Conventional Housing

It can probably be assumed that most tropical homes can be built on lots somewhat separated from their neighbors, so that good air circulation is possible. There are no great needs for bulky walls, extensive thermal insulation, resistance to snow loads, or special heating facilities. What is primarily needed is protection against wind, rain, and insects. Many homes must withstand high winds, heavy rains, and heat. Whereas in colder climates, tight windows [illegible] with double glazing and weather stripping are usually required, many tropical homes do not even use glazing. Occupants may prefer window openings with shutters or louvers, that can be locked securely at night. Main openings are desirable for protection against sun and rain, and covered porches and [illegible] are desirable as important living areas. Typical storm-[illegible] requirements may be fastenings of appurtenant constructions to withstand winds of high velocity force. Roofs must be tight against rain and wind, but must be provided with ventilators of living type. Is needed for heat and ventilation of space under the house, and under the roof is provided to [illegible] the high air temperatures of the latitude that might otherwise foster growth of [illegible] in the

[illegible]

The provision of adequate drainage of surface water is [illegible] available to the [illegible] is necessary to [illegible] the [illegible] mosquitoes that have [illegible] in stagnant water. First, the preferred area has [illegible] to [illegible]

framing have been the lower-density softwoods such as the spruces, pines and firs. These are relatively easy to season, can be nailed and machined satisfactorily in the dry condition, and generally do not swell and shrink excessively when undergoing moisture changes in use. However, when untreated they may not be of sufficient durability for severe service conditions. On the other hand, many of the abundant species likely to be available in developing countries may be of the high density hardwoods, which lack most of the above mentioned properties. Yet they must be used, and studies will be required to learn how to use them successfully in construction, particularly in house framing. Some of these hardwoods will be difficult to season properly, and sophisticated kiln-drying equipment and knowledge may not be available to meet all the needs. It may be necessary to use green, or partially-dried lumber. Although this presents problems, there are ways to minimize them.

The problems of termites, lyctus beetles and other insects must be recognized and understood, as must the problems with decay organisms. But these factors must not be feared or overemphasized. When protection with preservative treatment or other means is needed, it can and should be provided. Moisture tends to cause paint problems on some woods, and these must also be recognized and avoided. The newer, non-film forming stains and natural finishes for wood offer good possibilities here. Some species are more naturally durable against insects and decay than are other species. These species should be identified, and used as much as possible.

Lastly, the actual design of the structure must be developed to meet the structural and aesthetic requirements of the location, and the fabrication procedures adapted to make construction efficient with available tools and labor. For example, green or partially-dried lumber has been used in house framing in some countries, such as New Zealand. Here the framing is done, the roof installed to protect the frame from further wetting, the frame allowed to stand open to the wind for some days or weeks, and other work progresses while the framing lumber dries in place. The wall coverings are put on later. Windows are sometimes installed before walls are covered, and floors are left uncovered as long as possible to permit better air circulation for drying. Subsequent drying in this case may cause some bowing and crooking of some framing members. This may need some further machining in place before the final walls and floor coverings are installed. One advantage of this use of unseasoned timber is the easier nailing of denser species, and it also allows the water-borne, preservative-treated wood to redry on the structure, thus reducing costs of drying before delivery to the site. Each technique has its advantages and disadvantages, and these need to be carefully weighed before making final decisions on procedures to use.

Useful Background Information Available

Although there is not a great deal of published information on low-cost housing of timber in traditional scientific and technical periodicals, there are a number of useful background papers and bulletins from various sources that would assist designers and builders of timber housing for tropical climates. Most of these documents cover construction in general, not specifically tropical situations.

A "European Systems Handbook" (37) published in London reviews a large number of types of prefabricated constructions. Many of these involve concrete and other materials than wood, but the general construction details and the types of approach are also applicable to wood. Some systems are based on wood. They include both panelized systems to be assembled on the site, and full three-dimensional modules, to be assembled in groups on the site. European systems for prefabricated building construction are supposedly more advanced than in other countries. Scandinavian countries particularly have emphasized wood in such systems.

The U.S. Department of Housing and Urban Development has been assembling a number of useful documents on housing. One is their "Manual on Wood Construction for Prefabricated Houses" (17) which is essentially a revision of an earlier book of the same title prepared by the staff of the U.S. Forest Products Laboratory for the Housing and Home Finance Agency in 1947.

"Wood-Frame House Construction" (22) summarizes building designs and construction features for wood-frame homes in the United States, with particular emphasis on on-site building by conventional methods. It includes information on foundations, and mechanical systems, and on some components such as roof trusses. Recently a new "Low-Cost Wood Homes for Rural America-Construction Manual" was released (30), which covers in a somewhat simpler form, similar construction details on low-cost wood homes, to assist small builders in such construction.

The U.S. Department of Housing and Urban Development has also recently released their "Proposed Minimum Standards for Permanent Low-Cost Housing and for the Improvement of Existing Substandard Areas" (14). This document includes standards of construction and performance of such homes.

The subject of low-cost and self-help housing is not a new one. In 1957 the U.S. Housing and Home Finance Agency first published a series of plans and specifications for simple, small homes to be built in the West Indies, Latin America, Southern Europe and the Far East. These were essentially just conceptual designs, rather than complete working drawings. They used mainly concrete and other masonry in walls, but some featured wood floors, wood walls, and wood roof framing. Some wood siding was used. One interesting post foundation system for Surinam specified cement pipe filled with concrete for the piers. This was similar to later wood pier systems for foundations. This report was revised in 1967 (16).

A useful "Manual on Self-Help Housing" (10) published by the United Nations in 1964 covers a wide range of subjects on low-cost housing, of particular interest to developing countries, including the planning, organizing, and supervising of unskilled individuals to work on house construction of various types. The amount of material specifically on wood housing is quite limited, but the general background should be of great value in such self-help housing programs.

General features and problems in planning homes is covered in "Urban Planning in Developing Countries" (17). This covers primarily the preparation and implementation of land-use plans, with specific attention to a case study in Ciudad Guayana, a city being built in Venezuela.

The Building Research Institute of the U.S.A. has assembled a series of interesting and valuable papers under the title "Preassembled Building Components" (5). This document includes several papers on Attitudes on Preassembled Components, Principles of Preassembled Component Construction, Structural Component Case Studies, and Mechanical Component Case Studies. Both wood and metal construction systems are covered.

The American Council to Improve Our Neighborhoods (ACTION) published a useful text on "Design and the Production of Houses" (40), which covers a variety of subjects in a general way, including advances in house designs, industrialized housing, housing industry research, current patterns of fabrication, and building and land use controls.

Although heavy timber construction is not used widely at present in low-cost housing or in single-family housing, the subject of roof trusses, laminated beams, and post and beam constructions are covered in Oberg's "Heavy Timber Construction" (44), and is a useful general reference. It includes a limited amount of information on conventional wood-frame construction, and on pole and log construction.

The subject of heavy timber construction is covered in a more detailed manner, as required by designers, in the "Timber Construction Manual" (11). This will be of great value to engineers designing with heavy timbers and glue-laminated beams. Basic information on physical and mechanical properties of American Wood species is summarized in the Wood Handbook (3). More detailed design data on wood in construction is given in a number of publications. One of importance is "Wood Structural Design Data", Vol. 1 (4). This contains span tables for American species for use as joists, rafters, and for other structural applications in house construction. Many of these aforementioned documents indicate the type of information that will be needed on lesser-known species in other parts of the world, in order to use them most effectively in design of structures. Many other countries have similar compilations available on species of most interest to their own applications.

Since durability of many species of wood can be improved by proper treatment with suitable preservatives, a reference on this subject is useful. The simple booklet is "Prolonging Life of Wood in Houses" [14], which covers this complex subject in essentially layman's terms. Many other good references are available on treated wood, one of the earliest and still good ones being the text by Hunt and Garratt [15].

The subject of temperatures and humidities in homes in warm climates, and the effects on occupants have been considered by a number of investigators [4, 8, 1, 6, 9]. These references will be of great interest to house designers and builders in terms of climatic factors considered to include effects of building locations with respect to sun, vegetation, topography of land, and environmental factors with window and door placements, ventilation techniques, thermal insulations, and the activities of the occupants.

Since each of the subjects just mentioned are complex and only of background significance to the current subject, they will not be reviewed in any detail, and the reader is referred to them for further information.

Some Preliminary General Comments

Considerable correspondence with wood experts around the world recently has amplified some of the author's own impressions of the problem of wider use of wood products in housing in developing nations. We tend to take for granted many things that will cause great problems in providing better housing in less advanced countries.

First, many citizens of developing countries may have entirely different attitudes on their homes, and on home ownership. They may not comprehend the subleties of land ownership, transfer of titles, and the various responsibilities associated with land and home ownership. Their incomes are almost surely very limited, particularly cash incomes that can be applied to conventional ownership. Their attitudes towards the relative importance of a good home as compared to owning radios, livestock, clothing, vehicles, and other commodities are certainly different than ours. Their skills at craftsmanship required in home construction are limited, and their abilities to learn such crafts by traditional instructional methods are limited by lack of adequate reading ability, and familiarity with common technical terms. They may lack motivation to master these skills at the rate that others may expect them to do so.

We tend to accept the easy availability of rather precisely-sized and graded lumber, plywood, and other common building materials, which fit readily into modular construction, such as our 4 x 8 foot modules, and 16 inch joist and stud spacings. We expect a 2 x 4 to be of uniform size, straight and flat, with square corners and smooth faces and edges. Such material is not usually available in developing countries, just beginning to utilize their timber resources. Sawn lumber may be very irregular in size and shape, due to improper adjustments of machinery, improper maintenance, poor skills, and inadequate supervision and management. Skills in cutting and nailing lumber on the house site are likely to be deficient.

Since most other countries are using the metric system, all dimensions used in the U.S.A. are different and not necessarily compatible with designs in other countries. This will require modifications in all drawings and designs.

One problem that must be avoided or minimized is the needless regulation of building construction by various governmental bodies involved in a political subdivision. Overlapping requirements of different types can cause great, and needless confusion. Good minimum building requirements and standards are necessary to assure satisfactory performance of the buildings. But these regulations should be carefully developed, not merely adopted from similar requirements in other countries with different conditions. Each regulation should have a sound technical basis that is understood and accepted. Officials who supervise such regulatory activities should be selected for competence and understanding.

None of these problems and limitations are unsurmountable. They should not be considered as obstacles to wider use of wood in home construction, but they must be recognized and systematically resolved.

Experiences with Wood House Construction in Selected Countries

In order to cover the assigned subject most effectively, certain examples of wood house constructions in a number of countries were selected as illustrations. The list is by no means complete. Because of the author's personal experience in such housing in the United States, this country will arbitrarily be considered first. This review will be limited to small, single-family homes. The American wood framing

system for homes will be considered at somewhat greater length than other systems later. This is not because of its superiority in any way, but because the author is most familiar with it, and it will serve as a basis for comparison with other methods mentioned in less detail.

It is recognized that developments in wood house construction in some important countries, such as Japan, Scandinavia, and much of Europe, have been omitted. This is partially because specific information was not obtained, because methods often are similar to those in other countries covered, and because interesting wood prefabrication systems used in Europe will be covered in a separate paper.

In the U.S.A. we tend to build homes for one or two lifetimes, rather than for centuries. We feel that this is practical and economical. This is not to say that we build only temporarily or shoddily. Loans on our homes are insured for up to 40 years by our Federal Housing Administration, and are expected to last much longer than that. We build with a definite purpose in mind. The present generation knows and assumes that our children and grandchildren are probably not interested in living in homes by today's standards. Homes are likely to be modified, additions built on older homes, and after a couple of generations, the home may be moved or demolished to provide land for a new type of housing with different conveniences. Light wood-frame construction is thus ideal for our purposes.

Conventional Wood Frame Houses in the U.S.A.

Log cabins, and other heavy timber type homes were built years ago in the United States. However, the typical wood home construction in the past 100 years has been based on the platform and balloon framing systems, usually on some sort of masonry foundation. Platform framing, now used almost universally, is shown in Fig. 1, and involves building a wood floor platform fastened directly on the foundation, and then erecting the wall frame on top of this platform. Balloon framing, illustrated in Fig. 2, has the vertical wall framing (studs) fastened directly to the wood sill, anchored to the foundation. Floor joists rest on the sill also, and are fastened to the studs. For two story homes, the studs are continuous in balloon framing from sill to roof rafters, whereas in such a home with platform framing, the studs are one story in height and a second platform is erected over the walls, and another wall framing unit placed over the second platform. One advantage of true balloon framing is that shrinkage of the walls in the vertical direction is less than in platform framing, as there are no wide horizontal wood plates at each floor level to shrink radially or tangentially. This is of some importance in plaster or stucco exterior walls, where cracking might result from such vertical shrinkage. It is of minor importance in homes with wood siding. Balloon framing is seldom seen now in the U.S.A.

It should be noted that these wood framing systems in the U.S.A. work well here primarily because we have standard-size framing lumber widely available, manufactured according to closely-controlled,

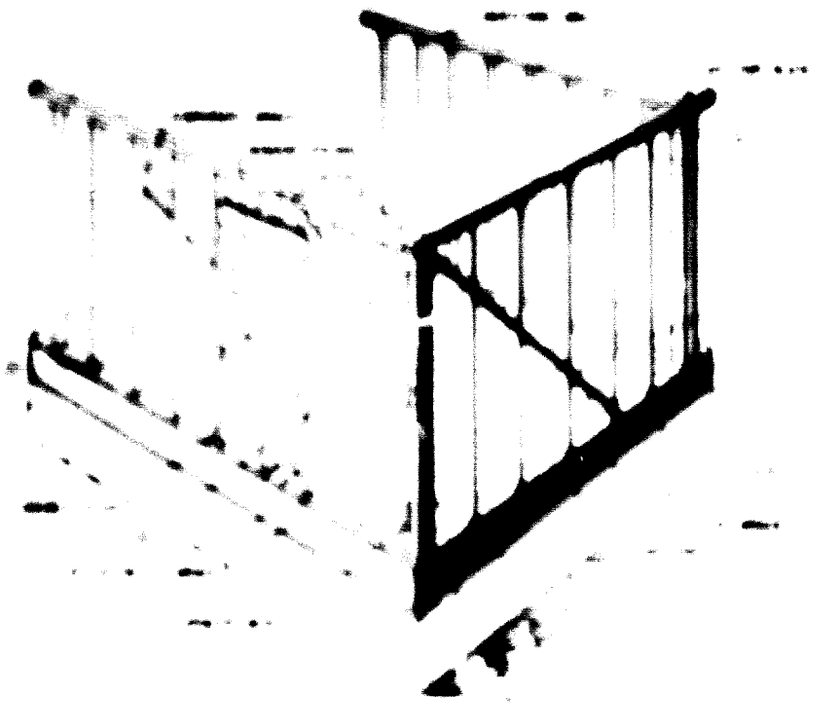

Figure 1.--Platform framing for a wood house in the U.S.A.

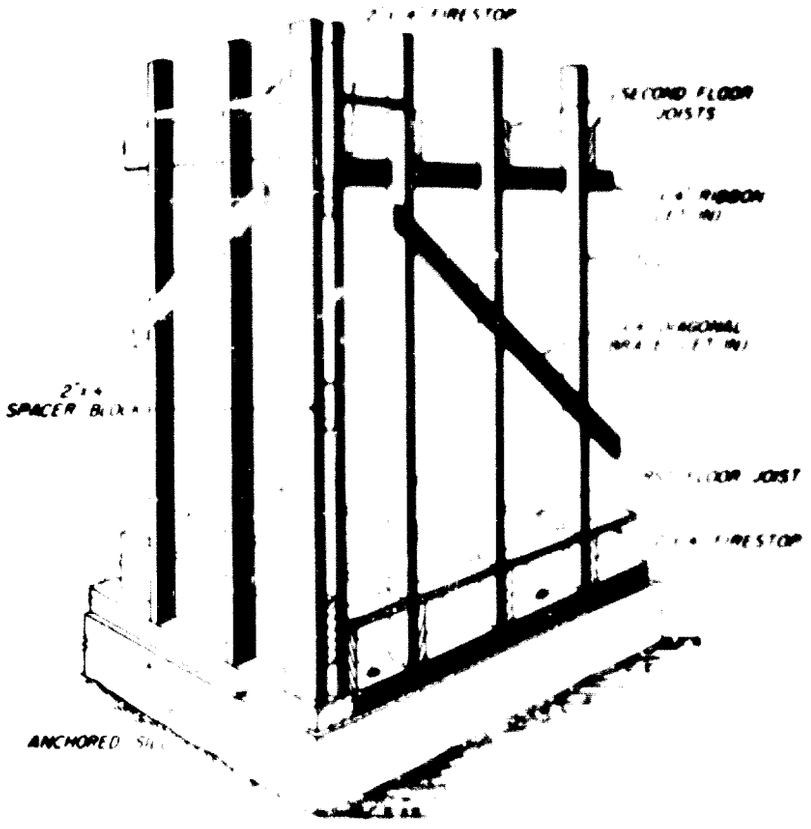

Figure 2.--Balloon framing in a wood house in the U.S.A.

nationally-accepted standards. Dimension lumber for this purpose is nominally 2 inches thick, actually 1-5/8 inch, and in multiples of nominal 2 inch widths, and in multiples of 2 foot lengths. A new American lumber Standard now under consideration also provides for a 1-1/2 inch thickness, when properly dried. Such framing lumber is normally planed smooth on all four faces. Thus the different pieces of softwood dimension lumber used for the various members in the frame can be fitted together with a minimum of cutting and fitting, and easily nailed. Typical species for framing are Douglas fir, southern pine, Western hemlock, Western larch, and other softwood species of sufficient strength and stiffness. There is a growing trend towards machine graded dimension lumber to provide standard minimum fiber stress values for structural uses, as in joists and rafters.

There are a great many details of conventional frame construction with wood, too involved for this brief review. The readers are referred to a number of available documents for greater detail (22, 30, 28). A good review on selection of various wood products for house construction in the U.S.A. has been published by Anderson (28). A typical wood floor framing system used in the U.S.A. is shown in Fig. 3. This shows a wood floor over a masonry foundation. Large plywood sheets, usually 4 x 8 foot, are often used as sheathing over the joists now, in place of the diagonal lumber sheathing shown.

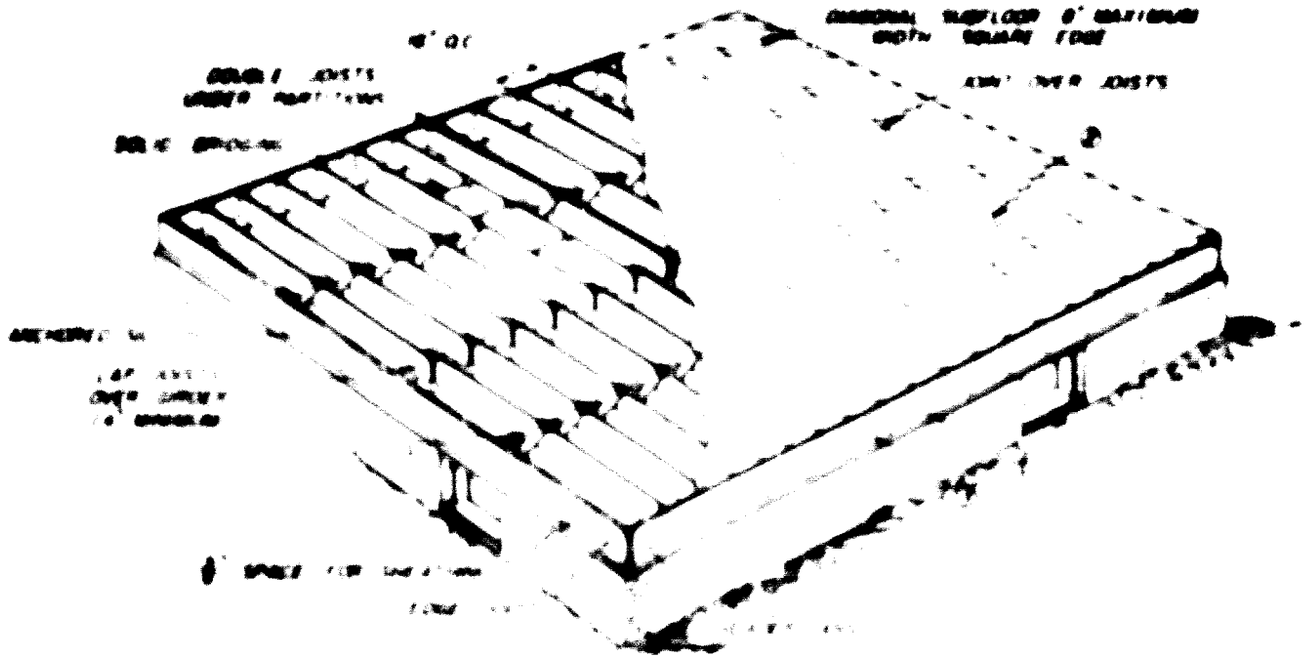

Figure 3.--Typical wood floor over a masonry foundation, as used in the U.S.A.

Many homes are built on concrete slabs, particularly on flat sites in the warmer parts of the country. A typical construction system here is shown in Fig.4 . In tropical climates the floor insulation could be omitted, but the vapor barrier, typically now of polyethylene film, is a good provision to reduce permeating of moisture from the soil through the slab. The finish floor shown, may be either wood or various plastic or asphalt tile materials, bonded to the concrete with mastic type adhesives, typically of an asphalt base.

In the colder parts of the U.S.A. basements are commonly used under the first floor, but these are probably of little importance to the tropical locations under consideration here, and will not be discussed. Details of such construction are available (22).

An overall sketch of a two story wood home, with platform framing, is shown in Fig.5 . This contains many features not of direct importance in tropical construction, but shows the general construction features of wood framing for walls, floors, ceilings, and roofs. The design for the roof framing and end walls in a one story house is shown in Fig.6 . Prefabricated roof trusses of various designs are also widely used for roof framing in place of the framing shown here. Trusses are normally nailed directly to the upper plates of the exterior walls.

The surface over the roof rafters or trusses is commonly provided by nailing either sheets of plywood, or lumber sheathing across these framing members. This serves to brace and stiffen the roof system, and as a base for nailing or stapling shingles of wood or asphalt compositions. The system of nailing narrow lumber strips across

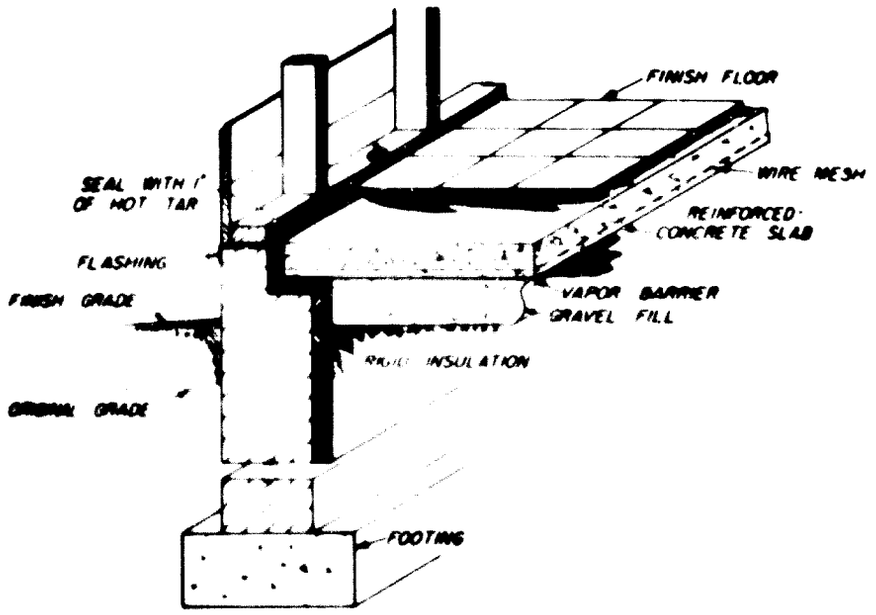

Figure 4.--Typical construction of a wood-frame home on a concrete slab in the U.S.A.

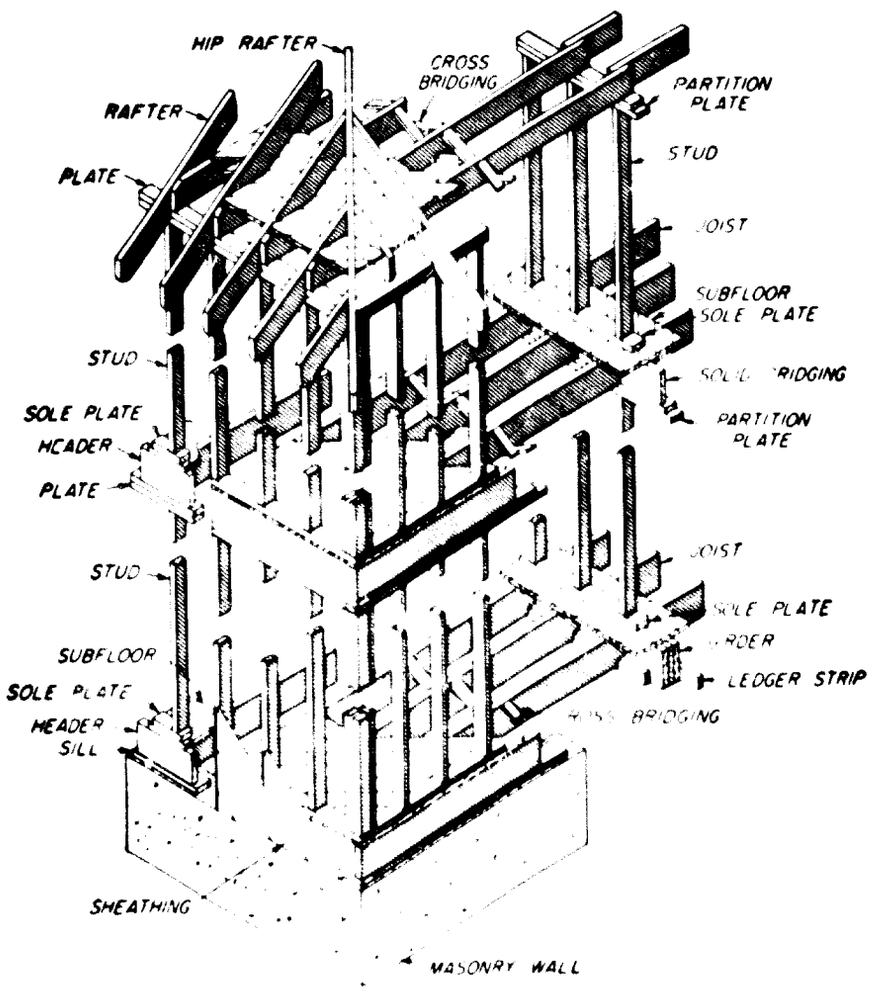

Figure 5.--Platform framing used in a two-story house, showing roof structure attached.

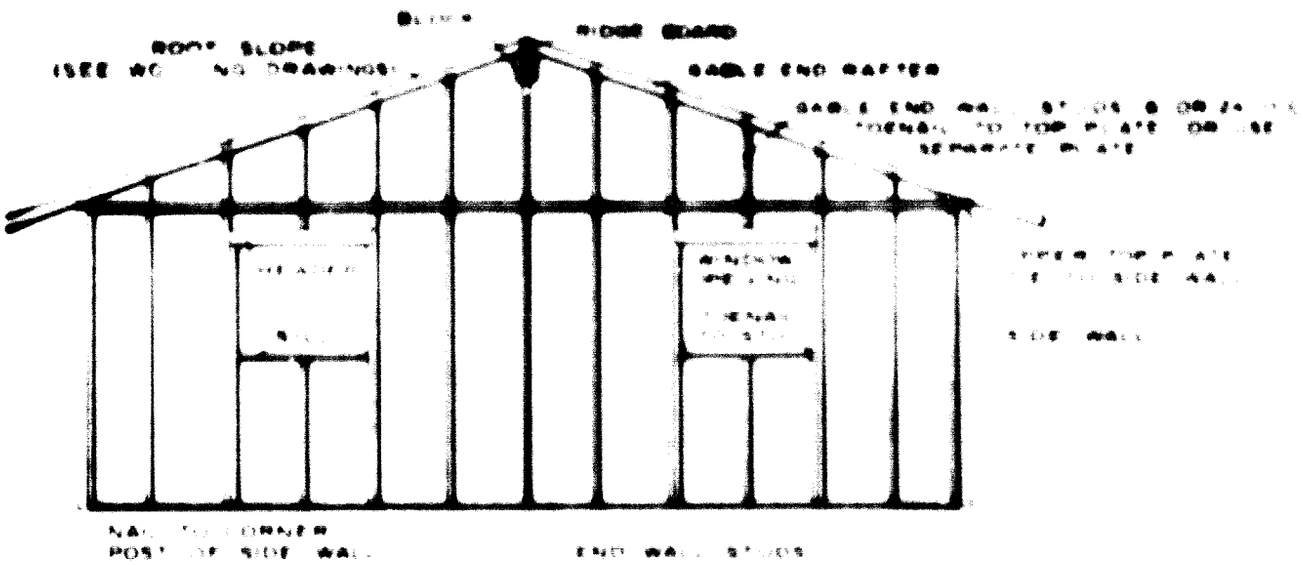

Figure 6.--Typical end-wall framing, with gable-roof, as used in the U.S.A.

rafters, with spacing between them, which is common in many other countries, is used in the U.S.A. mainly where heavy clay tile or thick wood shakes are to be used. Because of the cost, these roofing materials are used only in expensive homes of certain architectural types. These tend to be used mainly in warmer climates, as in Florida, or California.

The outer surfaces of the wall framing are normally covered with large plywood sheets, or fiberboard insulating sheets as sheathing nailed to the wood studs. This serves to stiffen walls in racking and under wind loading, reduces air passage through the wall, and may provide some insulation. The exterior surfaces of such walls may then be covered with various types of thin wood siding, usually of redwood or Western red cedar, medium-density hardboard, and now certain types of aluminum or plastic siding, usually made to look like wood siding. There is a distinct trend now towards wider use of prepainted siding of wood, metal or plastic. Another recent trend is towards use of natural wood surfaces and finishes on exterior walls. These include rough surfaces on plywood and lumber to simulate rough-sawn surfaces. They are finished with non-film forming stains, containing a water-repellent and a preservative, such as the "FPL Natural Finish" (9). Such stains protect the wood, allow the pleasing appearance of the wood to show, and are low in cost and easy to apply by brushing or spraying. Painting of wood on exterior siding has always caused problems in durability, particularly on woods with distinct

earlywood-latewood prominence, and when inferior paints and poor workmanship is involved. Good durable pigmented paint systems are available and are still widely used.

Interior wall surfaces are provided by nailing gypsum wall board, hardboard or plywood to studs, and then painting or staining. Ceilings are finished with gypsum board, or some types of fiberboards. Whereas lath and plaster were formerly used widely as interior wall and ceiling surfaces in homes, this use is decreasing significantly in most areas because of higher costs, and the delays in construction caused by the time required for the two or more separate coats of plaster to dry. Water in drying such plaster has always caused some problems with the wood already in the structure through increases in moisture content, followed by subsequent redrying in service.

Wood floor systems in the U.S.A. have often surprised overseas observers, who question the need for the double layer of floor over the joists. We normally use the plywood or lumber sheathing over the joists, installed before the outer wall framing is installed in the platform system, as previously mentioned. In addition to stiffening the framing against horizontal racking, sheathing serves as a useful work platform. Usually the last interior work is installing the second layer of finish floor, which may be hardwood strip flooring, thin wood parquet flooring, or various types of resilient tiles of linoleum, plastic or rubber, bonded with adhesives. Usually a house has hardwood flooring in some rooms, and the rest of the house has resilient tile or wall-to-wall carpeting. To provide uniform floor heights here,

a second layer of sheathing is normally nailed over the subfloor sheathing. This is known as "underlayment", and may be plywood, hardboard or particle board. The surface of such sheet underlayment is usually of higher quality than conventional subfloor sheets, so that surface defects in the underlayment are not noticeable through the thin resilient tile.

Other systems are available for wood-frame floors, such as the "2-for-1" thick plywood which is nailed directly to the joists, usually over greater spans than the usual 16 inches-on-center spacing. Such flooring is normally installed before walls are erected. Ends and edges of such single-layer flooring panels are usually tongue and grooved to provide restraint from vertical movement at the joints. Resilient tile or other finish materials are applied directly to this. These thicker single-layer floor systems seem to have had only limited acceptance at present.

Pole-Frames in the United States

The idea of using preservative-treated poles and posts as foundations for buildings is old, and has been used in various ways for some years, particularly in farm buildings and some industrial buildings such as warehouses and machine sheds. Use of untreated poles to support houses has been used overseas for many years in a rather crude way. Recently there has been a considerable interest in using such pole-frame systems in low-cost homes. Such systems have great potential for sloping sites, where a minimum amount of soil

disturbance is desirable in order to prevent erosion, and earth shifting after conventional grading and construction. An example of such a pole-frame home is shown in Fig. 7 . A number of useful references are available (32, 45, 21). Examples of actual low-cost pole-frame homes in South Carolina are described by McAlister (43). One detailed design for such a home, developed in Athens, Georgia [2/] is illustrated in Fig. 8 . A variation on the pole-frame system is the wood-pier system, in which tops of treated poles come to the first floor level, and support a wood-frame floor system, over which an essentially conventional frame house is built, as in the platform framing system, previously described. An example is the low-cost rural home, also designed at the Athens laboratory [2/], and illustrated in Fig. 9.

2/ This design was developed by H. F. Zornig, Housing Research Unit, Forestry Sciences Laboratory, Southeastern Forest Experiment Station, Athens, Georgia as part of an extensive research and development program on better wood housing for low-income rural families. Results of this work have not yet been published, but detailed plans and specifications of this pole-frame house and other designs are available from Athens.

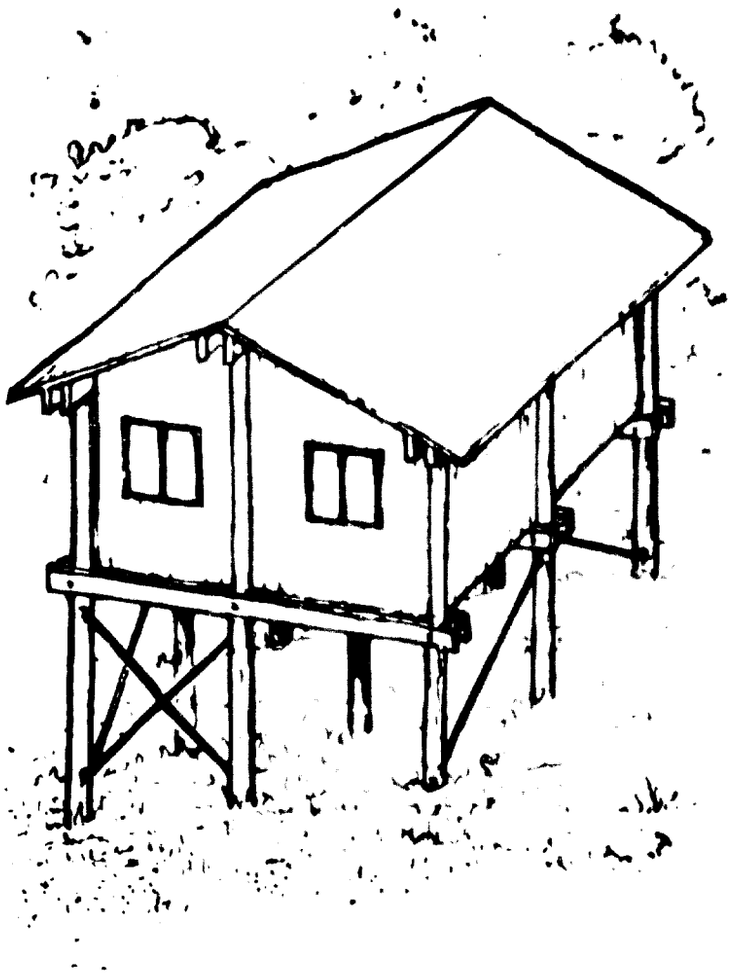

Figure 7.--A schematic design for a wood pole-frame house for a hillside location.

Figure 8.--Low-cost home of wood for rural families in the U.S.A., featuring wood pole-frame construction. (SE-3)

Figure 9.--Low-cost home of wood for rural families in the U.S.A., featuring a wood-pier foundation system. (SE-2)

In the pole-frame system, the roof structure is supported on the poles, usually by attaching a horizontal beam along the exterior lines of poles. Roof trusses are commonly used in this system. Since the roof load is supported on the poles, exterior and interior walls are non-load bearing and can be of lighter construction, such as with thin sandwich panels, which can be prefabricated as in the Athens design [3/]. It has generally been found most practical to place these walls inside the lines of poles, rather than to fit wall panels into the poles, or place poles inside the walls. The rough, natural appearance of the poles is considered attractive, and a number of high-priced, individually-designed private homes have been built with this pole-frame system, particularly on hilly sites in California, where they have been very favorably received.

There are some unusual design and construction details involved in pole-framing that have been studied and developed, including methods of fastening horizontal beams to poles, pole bracing, and pole embedment techniques. These are discussed in some of the previously mentioned references (32, 45, 21, 43). Use of such pole and pier systems is just beginning to be widely utilized in homes in the U.S.A. As with any other unconventional construction system, numerous problems must be overcome. These include acceptance by building codes, lending agencies, the builder, and home owner. Conventional builders generally resist any new system that they don't readily understand, and which requires some additional study and changes in their normal building practices.

Stern has recently developed another interesting design for a wood home, based on the pole system. This is an integral foundation-framing post construction system, combined with a floating wood-floor and trussed-rafter system (50). The floating wood floor is similar to that used in the SR-1 plan developed in our laboratory at Athens [3/]. Stern's system is illustrated in Fig. 10.

Since many rural builders have had experience in placing poles for barns and other utility buildings on farms, they are more likely to adapt the system than are conventional large-scale city home builders. Even with such rural builders, they must master the other changes in normal techniques for installing walls, floors and roofs on the pole structure, although these need not be complicated. Obviously since the poles and piers are embeded in the soil, they must have adequate resistance to decay and insect attack. This can be provided by proper treatment with preservatives and with soil poisoning. For such wood preservation, water-borne chemical treatments are preferred because they don't contain oil residues that soil clothing, cause odors, and interfere with painting or other finishing. Examples include chromated copper arsenate, and ammoniacal copper chromate systems. These can be expected to give many years of satisfactory service when properly applied, by conventional vacuum-pressure treating processes.

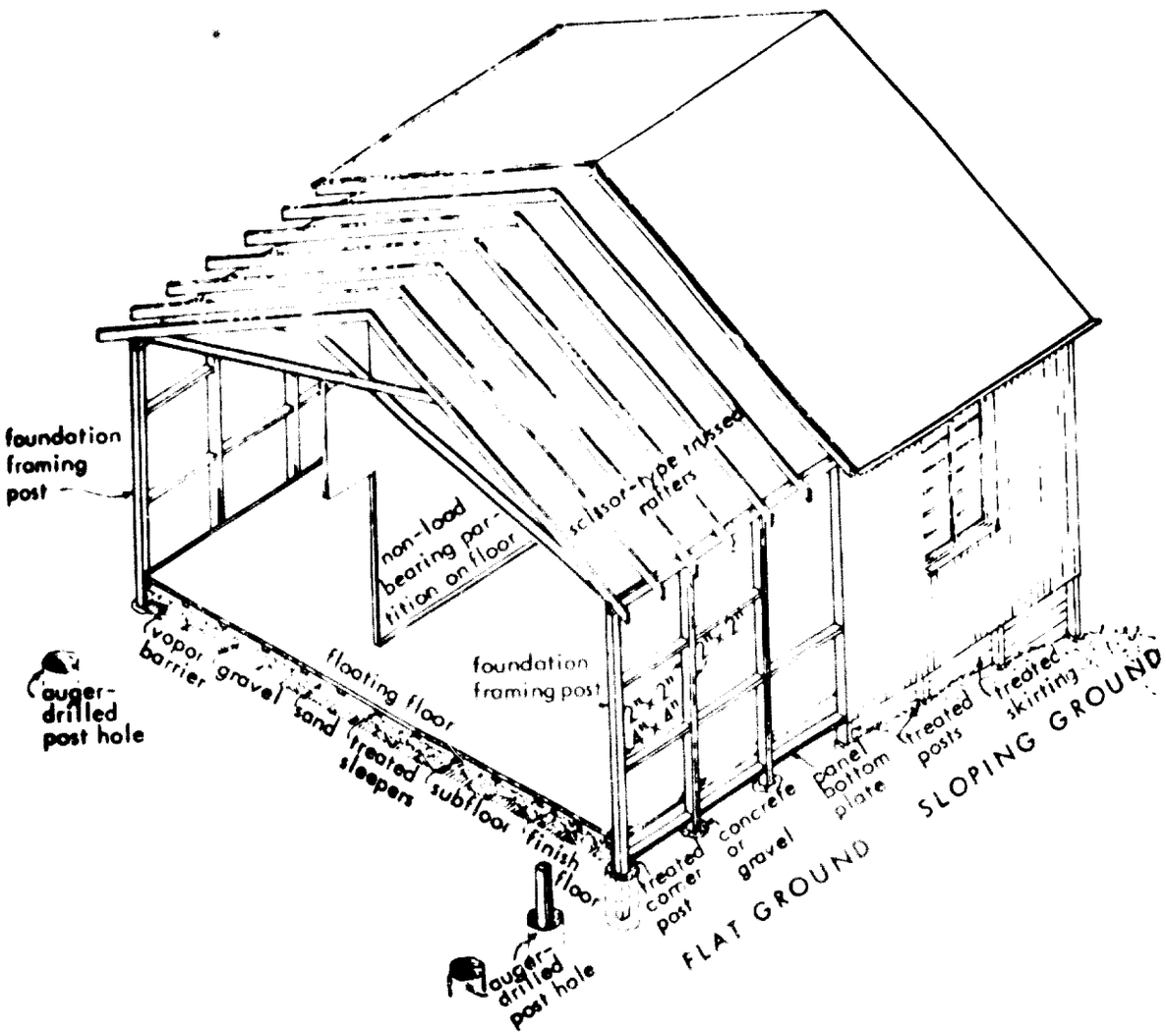

Figure 10.--Proposed integral wood foundation framing post house construction system, combined with floating wood floor and trussed rafter system.

Post-and Beam-Construction

Although this system of timber construction has been used for centuries in larger buildings, and is now used extensively in schools, churches and other public and industrial buildings in the U.S.A., its use in residential construction has been limited. Recent introduction of economical glue-laminated straight beams has tended to increase interest. Construction details are fairly well known and documented (44, 2). This is a system of great potential interest in developing countries, where standard-sized framing lumber is not yet available. Heavy solid timbers, even hand-hewn, could be used to provide the frame, and then used with various types of wall and roof systems, essentially modifications of conventional platform framing. Another roof system is the use of thick lumber decking, preferably tongue-and-grooved, nailed across the roof beams. This is standard timber construction for modern beam-roof systems (44). An example of such post-and-beam construction is shown in Fig. 11. This type of construction is commonly used on flat sites, such as where the floor or foundation is a concrete slab. However, it can also be used on sloping sites. It should be noted that the pole-frame system, previously described, is essentially a post-and-beam system. There have been a number of examples where round poles, as well as sawn timbers, were used as posts above a concrete slab, to support beams and the roof decking mentioned earlier. Although treated timbers or poles may not be required as posts, since they are not embeded into the ground, the lower ends of the posts must be properly protected when in contact with the slab to avoid moisture buildup and resultant decay. This can be done by placing

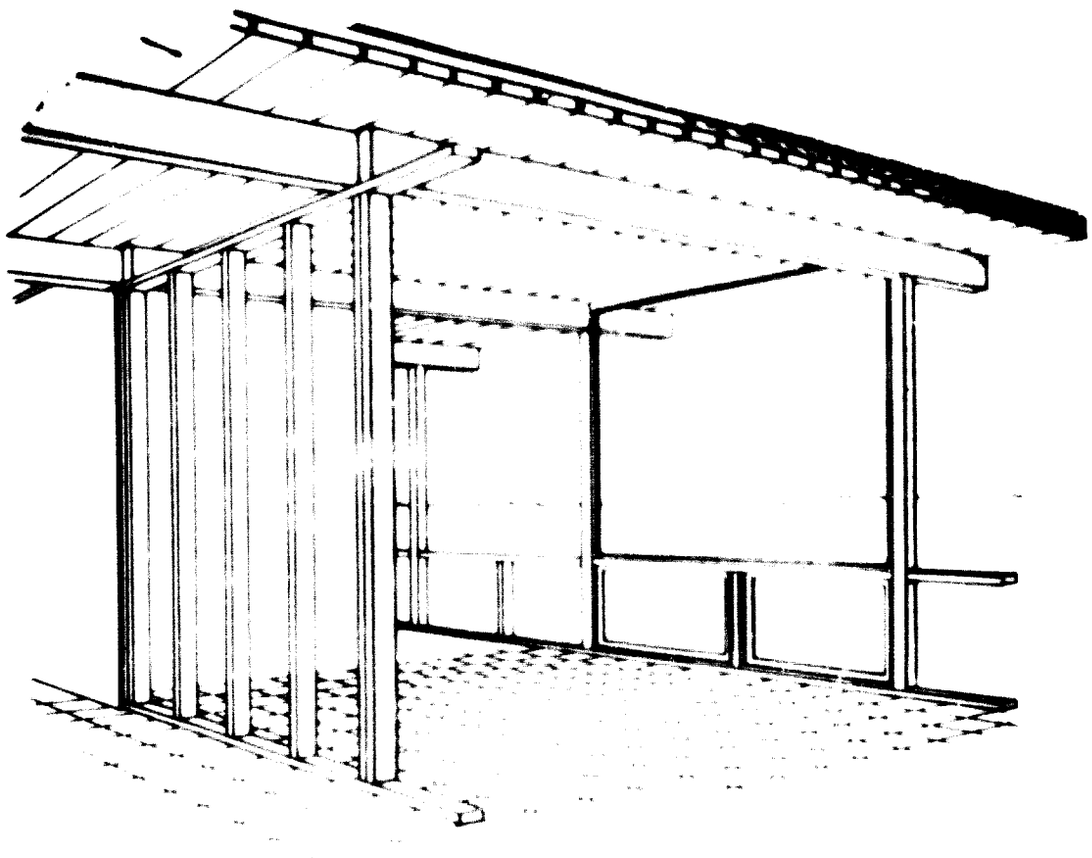

Figure 11.--Wood post-and-beam construction, with timber decking system.

the lower end of the post on a low concrete pillar or block, and by providing for good air circulation. Some dip treatment of the post end in water-repellent preservative solution, or an actual preservative would be good protection.

Use of Wood Components

Although prefabricated component parts of buildings may be considered primarily as prefabricating building construction, to be covered by a separate paper, some mention of these components should be made here since they fit nicely into conventional building constructions, and are of particular interest in self-help programs for better housing. The commonest component is probably the roof-truss mentioned earlier. There are a great many designs for these trusses. They have been of particular interest in the U.S.A. for low-pitch roofs, and for homes where interiors are to be left open, without load-bearing interior walls. Earlier designs used lumber framing of 2 x 4 or 2 x 6 members with joints fastened with plywood gussets, either nailed, or glued and nailed to the lumber. Gluing, of course, provides additional stiffness to the joints as compared to nailing. Nails are used with glues primarily to provide gluing pressure until the glue sets, since the nails can not act in such joints until the glue fails in service. Such failure can be prevented by proper use of durable glues, such as the resorcinol, and phenol-resorcinol resin glues. More recently various types of metal fasteners, incorporating protruding points to embed into the wood have been used widely.

These are the so-called "gang nail fasteners". A principal advantage is their rapid installation either by pounding the points into the wood with hammers, or in various hydraulic presses and roller presses. Because the metal gusset is thinner than a plywood gusset of the same load-carrying capacity, the metal-gusset trusses stack together more compactly for ease in transportation. Trusses should be designed for specific applications, particularly for the distances to be spanned, and the roof loading required. They may be placed farther apart in the roof system, than for conventional lumber rafters, and thicker plywood or lumber roof sheathing used to provide the necessary stiffness. One problem, not always recognized with such trusses, is the distortions that occur in them after coming to moisture equilibrium in service unless the lumber is carefully selected and seasoned before manufacture of the trusses. Such distortion will give an uneven contour to the roof itself, and cause problems with installation of ceiling materials on the lower surfaces of the bottom chords.

Wood windows and doors are now commonly prefabricated and assembled, ready to install in the rough openings in the framing. Such preassembled units contain all the necessary weatherstripping, sash balances, hardware, hinges and other metal units. Trim is usually applied after installation in the rough opening. Units may be prefinished if desired. A big advantage of such shop-assembled units, fabricated with suitable stable jigs, is the precision of fitting together the various parts, use of power tools for final machining, such as installation of door locks and catches, and the

opportunity to use semiskilled help to do this particular task well, when properly trained and supervised. These advantages also apply to any prefabricated component. Exterior wood doors and windows should be treated with a short dip treatment in a suitable water-repellent preservative solution, which penetrates into end grain, and into all joints. This effectively reduces absorption of water, and reduces the dimensional changes in the wood, and decay hazards. Conventional paints and finishes can be applied over such treatments in the usual way.

Various designs of floor, wall and roof panels can be fabricated in small shops, and then taken to the site and installed. Much development work has been done in this area. Panels must be designed carefully to provide the necessary strength and stiffness, thermal insulation if required, for ease and precision of manufacture particularly with semi-skilled labor and with available tools, and particularly so that the various panels can be efficiently joined together in the final structure on the site. Obviously if precisely-dimensioned component panels are to be fitted into the building frame, such as of the pole-frame, or post-and-beam types, the frame itself must be precisely built on the site. Corners must be square and dimensional tolerances carefully controlled, or else special designs used to fit the panels into the structure. Suitable assembly jigs for such prefabrication must be designed for efficient, precise operations.

Another factor that must be considered in the design of the entire structure, containing prefabricated panels, is provision for electrical, plumbing, heating and ventilating facilities. Because the panels are usually fabricated with both skin surfaces completely covered, it is not possible to work inside these panels on the site to string wire, or run pipes and ducts. Cutting into such panels should be avoided since this raises costs, and tends to destroy structural and aesthetic properties of the panels. Electrical raceways may be provided by leaving off portions of the faces of the panels, and later covering them with suitable trim, or by using external raceways installed along the floor in wall panels, much as with modern modular baseboard heating units. In designing any house for use of prefabricated panels, it is very important to do a lot of good planning on paper before starting fabrication. Solving problems of installation of services after erection on the site is costly, time wasting, and results in unsatisfactory appearance and performance.

Cabinets, closets, and other wood built-in units can be readily and effectively premanufactured in essentially final form, including prefinishing, and then trucked to the site and installed. Here again, advance planning, before starting to manufacture, pays great dividends. In the same way, stairs, porches, decks and verandah floor, railing, and roof sections can be designed for prefabrication before installation on the site.

The general subject of prefabrication is covered in a number of references (17). The American Plywood Association, Tacoma, Washington, and its affiliate, Plywood Fabricators Service in Tacoma, have done an excellent job of collecting, designing, and publishing good information for the practical builder, as well as architects and engineers, on various types of plywood components such as roof trusses, box beams, floor and wall sections, and for complete home designs [3/].

Sandwich Panels in House Construction

Sandwich panels have been defined as "a layered construction comprising a combination of relatively high-strength facing materials intimately bonded to, and acting integrally, with a low density core material" (3). The cores may include paper honeycomb, foamed plastics such as cellulose acetate, polyurethane, or polystyrene, or even foamed glass. Facing materials, also referred to as "skins", include plywood, hardboard, metal, plastic or other sheet materials. They are bonded to cores with suitable durable adhesives. An early use of sandwich construction was in aircraft, for leading and trailing edges of wings, horizontal and vertical stabilizer surfaces, and

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[3/] The American Plywood Association recently published three useful documents: Plywood Building Systems for Low-Income and Moderate-Income Housing, Plywood Construction Guide for Residential Construction, and Plywood Construction Systems for Commercial and Industrial Buildings. These all feature new and unique applications for American softwood plywood panels, and are available from the Association offices at 1119 A Street, Tacoma, Washington 98401, U.S.A.

radomes. An example was in the British Mosquito bomber of World War II, where the panels consisted of two skins of thin hardwood plywood and a core of end-grain balsa. Such sandwich constructions of wood have had limited use in house construction in the U.S.A. and overseas. One application has been in flush doors, where an inexpensive paper honeycomb core is typically used with thin hardwood plywood skins along with a lumber frame. The U.S. Forest Products Laboratory pioneered in construction uses of such sandwich panels. In 1947 they built an experimental structure with a variety of panel designs at Madison, Wisconsin. This unit has been exhaustively evaluated over a 15-year period (24), and studies are continuing. This is cited primarily here for information, since this type of construction may be of only limited interest for housing in developing countries at this time. It might be noted here also that this laboratory also built a series of stressed-skin type prefabricated homes in Madison in the mid-1930's and has been evaluating them since. These buildings involved wall and floor panels of plywood skins, glued to lightweight lumber-framing members. Results after 25 years of service have been summarized and indicate that this type of construction is practical and permanent. Again, this type of prefabricated wood construction would probably be of only limited interest in developing countries, and will be covered in a separate paper.

Other House Designs in the U.S.A.

Hurricane resistance.--The Southern and Southeastern Coasts of the United States are periodically subject to severe hurricane damage.

These storms which usually begin in the Caribbean Sea and then often travel inland some distances, and with various severities, have caused great damage to all types of buildings. Damage noted is due to both water wave damage along the coast, and to high winds. The most severe hurricane damage in recent years was from Hurricane Camille in August 1969, which centered its damage on the Gulf Coast of Mississippi and Louisiana. Smith and Anderson have made extensive surveys of structural damage to homes and other structures in past hurricanes in the South (27), and have proposed a number of factors to provide better performance in wood structures in such strong wind conditions. These include good nailing and fastening practices, and the use of special supplemental reinforcing with special anchoring, metal strapping, as well as selection of the proper material for each use in framing, sheathing, and coverings of wood homes. Of special importance here is proper seasoning of wood before construction so that it is near the equilibrium moisture content of service. This will greatly reduce the loosening of nails and other fastenings due to subsequent shrinkage in drying, and resultant losses of nail withdrawal strength. Numerous examples of excellent resistance to damage by properly-built wood houses were noted in this study. The principles outlined for hurricanes are also applicable for tornadoes and various tropical storms, and should be carefully noted by designers and builders of wood structures in tropical areas subject to such high wind hazards.

The subject of performance of wood buildings in a severe earthquake in Anchorage, Alaska in 1964 has also been studied (23). This study indicated that properly-designed wood structures could effectively reduce damage to homes and other buildings subjected to severe seismic vibrations, and that such good wood construction was likely to be more effective than typical masonry construction.

Low-Income rural housing.--Because of the great need for better housing of rural families with low-incomes in various parts of the U.S.A., the Forest Service of the U.S. Department of Agriculture, has been conducting studies to meet these needs using wood as effectively as possible, based on the results of current research knowledge in wood and wood products. The Forest Products Laboratory in Madison, Wisconsin has designed a series of five rather conventional homes with floor areas of 540 to 768 square feet. They have also prepared a very useful construction guide to use with these and similar wood homes (30). The Housing Research Unit of the Forestry Sciences Laboratory, Athens, Georgia, has designed a series of six wood homes with from 800 to 1125 square feet. The pole-frame, and wood-pier homes were mentioned previously. Each of the six Athens designs contain a number of experimental features, which are being studied by building actual prototype buildings in North Carolina, by a commercial home builder, under the Federal Housing Administration's Experimental Housing Program. Three homes have been completed, sold, and are occupied by actual families. Others are under construction.

Details of this work are soon to be published (31). Plans and specifications for all these low-cost homes developed by the Forest Service are available from the individual laboratories where they were developed. All were developed to meet a goal of $7 per square foot of floor area, without land, and external water and sewerage facilities such as wells and septic tanks. Present experience in building these prototypes indicate that these cost figures are realistic.

Use of hardwood in house framing.--Most of the previous discussion has involved use of softwood lumber, such as pine and fir, for the framing of homes. From time to time interest has been centered on the use of surplus lower-grade hardwoods, such as oak, for framing lumber, as well as for exterior siding. One study by Conway (35) and associates in Kentucky involved several small house designs to use native hardwood from local sawmills, in place of softwood lumber from other sources. A few homes were constructed, which included some modular wall panels, and roof trusses of hardwood. Numerous technical problems were encountered and some solved adequately. This experience is useful particularly because of the many situations encountered with the rather isolated mountain families with very low incomes, for whom the homes were intended. Many of these didn't understand land ownership, long-term financing, building contracts, and some would not accept the designs after the houses were finished, and were reluctant to occupy them. Technical problems encountered included establishing minimum standards for the lumber from the

local sawmill, establishing proper moisture content requirements for lumber to reduce future dimensional instability problems, and finding suitable nails and fastenings to be compatible with the dried, dense hardwoods. All are problems likely to be encountered with building wood homes in developing countries, particularly those where hardwoods are most available and should be used. This program was also conducted as a self-help program, coupled with a vocational education program for trainees with little or no previous building or craftsman experience.

Utilization of lower-grade wood in housing.--The U.S. Forest Products Laboratory recently completed an important design study to see what could be done to utilize lower-grade softwoods and smaller pieces in construction. The design for a small, one-story home involves a special wall-panel construction with two flatwise 2 x 4's, spaced 4 feet on centers as studs, with aluminum-faced fiberboard sheathing between the two 2 x 4's, and the whole assembly bonded with a mastic construction adhesive. Exterior siding is of resawn bevel siding glued to a panel of edge-glued low-grade softwood lumber in panel form, and attached to the exterior of studs with the same mastic and a minimum of nailing. Composite roofing boards have a layer of plywood facing glued to a low-grade lumber core piece. The outer plywood surface is covered with a durable plastic film. The roof boards are attached to the prefabricated roof trusses with a mastic adhesive and a few nails. The design details and materials fabrication are described (26), and building of the actual full-size

prototype is also described (29). This experiment is useful as an indication of problems and potentials in fabricating new building products from lower-grade materials through gluing various individual components, and the use of these new products in a final structure. The big problem encountered to date has been the lack of interest by industry in making these new products so that builders can use them in the new design.

Hawaiian house construction.--The state of Hawaii is the most tropical state in the U.S.A. Since traditional insulation is not needed there, a simplified wood house design has been used for many years. This is essentially a wood post-and-beam frame, with 4 x 4 posts, spaced 8 foot apart to support roof beams. Slightly pitched roof rafters are supported on a center beam on posts, and on the side beams over posts. Conventional roof trusses are also used. A unique feature of these homes is a single thickness of 1-inch tongue-and-grooved siding, placed vertically on a wood sill on the floor, and butting into the roof beams at the top. This wall is stiffened by a single horizontal lumber piece about at midheight of the wall on the outside. Interior walls are similarly of a single thickness of lumber. Redwood is traditionally used for all lumber here because of its durability under their tropical climate. They have developed special designs for milling their lumber sills, siding and other pieces to fit this type of construction. It is reported that in some designs for these single-wall homes in Hawaii, no actual permanent wall studs are used. The roof is temporarily supported on removable studs or posts. When the single thickness tongue-and-grooved wall is installed, and

stiffened by the horizontal 2 x 4 at midheight, the temporary studs or posts are removed. The roof load is thus supported only on the single-thickness exterior wall, and the similar interior walls. No corner posts are even used here.

In Hawaii they typically also use a single layer of hardwood strip flooring over the joists, without subfloor, as contrasted with the usual practice on Mainland U.S.A. This technique of omitting subfloor, is also used widely in other parts of the world. Floor joists are normally 16 inches on center, and laid across 4 x 6 floor beams, supported on concrete pillars a few inches above ground level on level sites. Concrete slabs are also used as foundation-floor systems.

There is a trend now in Hawaii to use our double-wall construction with the conventional studs and two layers of interior and exterior panel surfaces. This is presumably to provide space for thermal insulation where air conditioning is used. Contractors report that the cost for the double walls is about the same as for the former single walls. The amount of material is naturally much greater in the double-wall system, and there is considerably more labor to install it. The high cost of the single-wall system is attributed to the cost of the clear grade of redwood used, and the better carpentry required to fit the pieces together properly. This suggests that the conventional double wall system is easier to build with run-of-the-mill workmen, since it doesn't require precision to do an acceptable job. This would seem to be debatable.

One large company has introduced a new design for one-story homes in Hawaii, with 2 x 4 studs, 4 foot on centers and using a single 1/2-inch softwood plywood panel fastened to the studs as another type of single wall house. This has not yet been accepted by the Honolulu building inspectors.

Wood Housing in Australia and New Zealand

In these two advanced countries, wood-frame home construction has been used for many years. As many as 85 percent of Australian houses are wood framed, and 75 percent are in New Zealand. In Australia 75 percent of homes are sided with wood, and 65 percent in New Zealand. In Australia a large amount of their dense hardwoods, mainly belonging to the Eucalypt family, are used for framing. This offers problems because such dense woods are hard to nail when dry. When used green or partially dried, they may warp and bow during seasoning in the frame. The usual technique used is to frame the house with the green material and then let it partially dry in place before completing the home by closing in walls, floors and roofs, as mentioned previously. Optimum fastening of the dense hardwoods is best accomplished with slender hardened-steel nails.

In New Zealand the most widely used framing lumber now is their Radiata pine, a softwood species imported from California many years ago, and now systematically raised in plantations over much of the country. This species is typically protected with a boron-diffusion preservative treatment in the lumber plant to reduce damage by insects in use. Treated lumber may only be partially seasoned when delivered for use, and thus is handled much like untreated green lumber.

Lumber sizes and grading systems used in both countries are quite similar to those in the U.S.A. Both countries are now beginning to use machine grading of structural lumber, as in the U.S.A. Both countries are using finger-jointed lumber, as in the U.S.A. to better utilize short lengths of otherwise good lumber.

House framing is generally similar to the platform framing in the U.S.A. Little sheathing of floors, walls or roofs is observed. Typical floor construction is to either leave the floor joists uncovered until the house is nearly completed, or the final layer of hardwood strip flooring is first oiled on the back side, placed loosely spaced over the joints and upside down and unfastened, to serve as a temporary working platform. They tend to use 3-1/4 to 4-1/2-inch wide strip flooring, rather than the 2-1/4-inch strips in the U.S.A. When the house is nearly completed, the strips are reversed and then face nailed directly into the joists. In the U.S.A. face nailing is avoided, and strip flooring is customarily "blind nailed" through the edge at the tongue side. This is primarily a matter of standards of visual acceptance. Both hardwood and softwood strip flooring is used, with hardwood being quite universal in Australia because of its ready accessibility and supply. For some long-forgotten reasons, American carpenters don't seem to want to work on a wood-joist floor without a firmly-nailed subfloor of plywood or lumber before putting up the walls and roof. This does not seem to bother overseas carpenters, as in Australia and New Zealand.

In these two countries, roof sheathing as we know it in the U.S.A. is not used. They typically have used clay tile roofs, and now are going more to cheaper corrugated metal sheets, and also corrugated asbestos-cement sheets. Typical roof construction thus involves nailing 1 x 2-inch lumber strips across rafters like thin purlins, with several inches of space between them. The tile or sheet roofing is then fastened to these strips with wires or nails. Similarly, wall sheathing on exterior walls is generally omitted. After the wall framing has dried in place, one layer of either bevel wood siding, or "drop siding" is nailed directly to the framing as the single exterior covering. Plywood exteriors are little used at present, but would seem to be a good economical single-layer siding. Often the siding boards are painted on both faces and both edges, and allowed to dry before nailing on the frame. Such painting is typically done on the job site, but could readily be done in a factory-prefinishing operation, when developed. Wood windows and doors are typically used. It is considered good practice to use dry framing lumber as lintels and studs at window and door openings in the frame, so as to minimize distortions here from drying in place, which would make installation of prehung windows and doors difficult.

Roof trusses are quite commonly used in homes. These are prefabricated in shops, as in the U.S.A. In Australia hardboard is often used as gussets and splices in such trusses, in place of plywood. Interior walls are normally faced with gypsum board, although some hardboard is used. Plywood panelling does not yet seem to be popular for interiors, as it is in the U.S.A. This will probably

change. Little softwood plywood is used in either country in house construction, although New Zealand is very much interested in developing a softwood plywood industry based on their readily-available radiata pine resources. Both countries have used wood imaginatively in both homes and in larger buildings, such as schools. Laminated timber is used quite extensively in larger wood buildings in New Zealand, but not in homes. The production and use of laminated timbers in Australia has been much slower, possibly because their supply of suitable softwood timbers for this use is limited. Both countries are much concerned with insect damage to wood in use, particularly Lyctus (Powder Post Beetle), and Anobium. The European House Borer (Hylotropes) is also of concern. Decay is also a potential hazard, associated with high moisture conditions. Preservative treatment of wood for housing and other uses is common practice, and is controlled by governmental agencies, much more closely than in the U.S.A. Water-borne treatments are much more widely used than oil-borne treatments.

Little specific information is available on housing in Papua and New Guinea, two somewhat tropical protectorates of Australia. One responsible Australian government official with some background in this area has reported informally that efforts to provide good low-cost housing of wood for New Guinea natives has been rather unsuccessful to date. Problems encountered are probably typical of many other underdeveloped areas, and include difficulty in obtaining suitable quality of timber economically, need for adequate preservative treatment and drying of timbers for tropical exposures,

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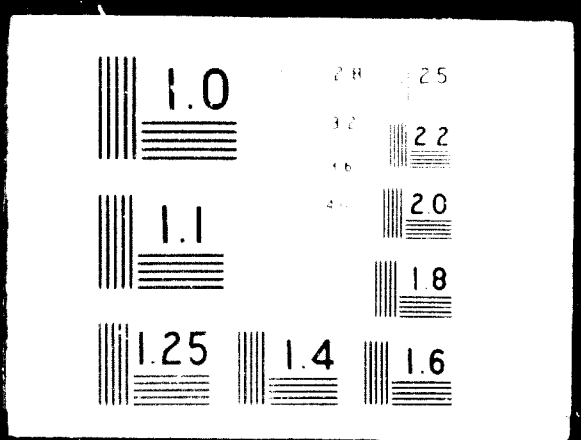

unfamiliarity with common woodworking and building techniques on the part of native labor, difficulties in training and supervising such labor, and the non-uniformity of sawing and sizing the timbers to properly fit pieces together efficiently, due to poor machine condition, and inadequate supervision and management. Typical rectangular native housing is quite similar to constructions used earlier in other countries. Vertical round posts or poles are spaced at intervals, with horizontal floor and roof members, also round timbers, fitted together at joints by cutting out flat surfaces, and joining them with vines or similar fastenings. This is similar to our pole-frame systems. A crude type of king-post truss system is often used for the roof structure, fabricated of round or sawn timbers. Small round timber purlins are fastened across, and thatch and other natural materials used as roof coverings. Bamboo-type materials may be used to enclose walls. Floors are often of dirt. Sometimes rough-sawn timbers are used as floors. Galvanized iron is used, when available for roofing in place of thatch, and sawn lumber may be used for door and window closures. Open gable-end roofs are preferred because this allows escape of smoke from cooking fires inside, without use of chimneys.

These buildings are crude. Efforts to replace this type of construction with more sophisticated wood framing systems, as described previously, have been delayed by the various factors mentioned earlier. Efforts to overcome each of these obstacles must be made in order to advance the use of such "newer" methods of home construction.

Housing in the Phillipine Republic

The traditional system of building timber houses in the Phillipines is the post-and-beam type, in which loads are transmitted through roof trusses or rafters and floor joists, then to roof girts and floor girders, and finally to wood posts resting on concrete piers. In rural areas, pole-type constructions have also been widely used, usually with the single floor raised several feet above ground so that open windows receive cooling breezes. Space under this floor is used for play, work, and storage. Walls are non-load bearing, and wall studs in newer construction serve mainly as nailing strips for wall boards. Conventional building is all done on the site. Platform framing, as previously described has only recently been introduced in a few houses.

Roof trusses of rather conventional designs are built entirely of wood or a combination of wood compression webs and steel tension members, fastened together with nails, bolts, and split-rings. These have been used in light-, and heavy-framed constructions for many years. Nailed trusses are used primarily in residences. The latest architectural trend for homes has been with a peak-and-cambered beam, or inclined-rafter roof system. Metal truss connectors have been recently introduced, and are used in prefabricated timber roof trusses of the "W" type for low-cost housing projects.

One-story homes usually have concrete floors on grade. Two-story homes have wood floors on the second floor, with single layers of tongue-and-grooved wood flooring toe-nailed to floor joists, supported over single or double wood girders.

Although most one-story homes have walls of concrete block from concrete slab to ceiling, some wood siding is used. Wood siding, often with a "V" cut, or "stone-cut" pattern, is used on second floor exterior walls. These patterns are narrow strips with a type of tongue-and-grooved edge joint. Such siding was formerly placed horizontally, but a new trend is to install this vertically for aesthetic purposes.

Plywood and fiberboard are the most common sheet materials for interior wall panels and ceilings. Prefabricated modular panels for room partitions, closets and ceilings are becoming more prominent now.

Wood windows and doors are widely used, and these are now being prefabricated as in the U.S.A. Wood jalousie windows are widely used in low-cost homes. Aluminum-framed glass jalousies have displaced the sliding and awning-type windows to a large extent.

The Phillipine Republic is facing an acute housing shortage, as in other countries, and a number of government-assisted programs have been developed to meet the problem. Two major problems recognized are the need for a stress-grading system for structural lumber and timber, and the need for more knowledge of the efficient utilization of wood in house construction. This is the same situation as in other countries.

Most housing project developers are now using preservative-treated lumber to reduce insect and fungi damage in their climate, but many individual homes are still built without such treated lumber. Treated lumber is reported to cost 50 percent more than untreated lumber. Most of the framing lumber used in the Phillipines is of native species, some of them hardwoods.

In general, modern wood housing in the Phillipines is quite similar in design and fabrication methods to conventional wood framing described for the U.S.A., with certain adaptations for their warm, tropical climate.

Housing in South Africa

Timber-framed construction is not a traditional form of construction in South Africa. Recent interest in wood construction has developed as a result of an increase in demand for domestic housing, with an interest in looking at other new building materials, and systems, particularly with industrialized building methods. As in other countries, the greatest demand for more housing is among the low-income groups. Solid brick construction has been most widely used for house walls in the past, and it is relatively cheap. Hence, wood will be used only if it can be made competitive with such brick construction. Various studies and developments have been undertaken to make wood effective in such home construction.

As in other countries, it was soon recognized that more research is needed to provide better answers to various technical questions concerned with the utilization of their local species, and the use of such timber under local climatic conditions. Educational and promotional activities are also needed to assist architects and builders unfamiliar with wood construction techniques and designs. One other problem recognized is that the greatest need for new home construction, where wood might be considered, was for the low-income families in densely populated communities, which traditionally used open fires for

cooking and heating, and hence introduced serious potential fire hazards. Efforts to introduce particle board, fiberglass, asbestos board, and aluminum for exterior siding on homes have all had their problems, with varying degrees of success. Problems in providing adequate paint performance on exterior wood surfaces, and potential maintenance problems with such painted wood, under local climatic conditions have apparently delayed wide acceptance of wood in housing. The desirability of protecting non-durable locally-grown timber and wood-base board products, such as particle board, for exterior use is recognized and needs further study. These problems currently tend to favor the continued use of brick veneer exteriors, as is noted also in certain areas of the U.S.A.

Most local authorities' building regulations in South Africa at present exclude the possibility of using timber houses. Steps are underway to overcome these limitations, particularly for homes built by local authorities, utility companies, and other bodies defined in South African Housing Act to use funds from the Department of Community Development. Some local and provincial authorities are changing their regulations to allow some local discretion in allowing timber houses to be built. A South African Code of Practice on Timber Buildings is being prepared. Local building authorities have in the past exercised control over the appearance of buildings, and these have been heavily oriented towards the traditional brick buildings. This will require education of architects and designers in using wood to best advantage, particularly for exterior appearance,

and the development of adequate treatments and finishes for such wood exteriors to insure that the buildings will remain attractive and serviceable without excessive need for painting and other maintenance. In spite of these many obstacles to the introduction of wood housing in South Africa, intelligent research, development and education on proper design and use of wood in housing is underway, particularly by the Timber Research Unit of the South African Council for Scientific and Industrial Research in Pretoria. This includes work on brick veneer faces on timber-framed home constructions. This organization has also recently developed a low-cost timber house, suitable for simple prefabrication by inexperienced workers, and intended for low-income non-white families. This design provides a one-story house, with two bedrooms, living room and kitchen, and about 420 square feet, with another slightly larger version which includes a bath, with a total area of 475 square feet. The homes are designed with a well-consolidated earth filling, over which a thin concrete slab is placed. Prefabricated wall panels have preservative-treated lumber framing, hardboard or asbestos-cement interior skins, and horizontal wood siding on the exterior face. The FPL natural finish (9) is proposed for the exterior finish, although it may be painted. Exterior walls are insulated within the stud spaces. Flat ceiling-roof panels are also prefabricated, with corrugated galvanized steel sheets on the top, and softboard on the interior ceiling side. Fifty of the smaller size homes were built at Selosesha, Thaba Nchu, and accurate cost figures obtained. Average cost of each house in this

program was R121.00. This development program is well documented (51) and should serve as a useful guide for similar studies to develop and evaluate low-cost timber housing in other countries. Some other useful reviews on the problems in acceptance of timber housing in South Africa are also available (33, 20).

Wood Housing in India

As in other countries, India has done a good job of studying their native species, and developing engineering data and structural designs based on these species. Much of this work is done at their Forest Research Institute at Dehra Dun. One feature of their research has been the utilization of 87 secondary species, instead of relying on only four to six of their most popular structural species. Techniques for use of small-dimensioned short pieces of these secondary species, which previously had been used mainly for fuel or used not at all, were developed and demonstrated in construction of prototype buildings. Examples included design and fabrication of roof trusses of such small material for spans up to 100 foot, as well as hollow-box-type columns, solid web-type timber girders, and nail-jointed timber beams.

The program in wood engineering at Dehra Dun during the past 15 years would serve as a useful guide to programs in developing countries who want to use their timber resources more effectively in building construction. Their work included: development of engineering data on available species, development of timber engineering manuals, design handbooks, scale models of prototype buildings and blueprints for such designs, lectures and demonstrations to architects, engineers,

and particularly at universities training people in the building industry, plus specialized courses in timber engineering for engineering personnel and master carpenters. They have recognized, as have others in many countries, that new research developments won't get used effectively in actual construction of buildings without extensive, well-planned extension-type programs to inform the potential users of just how such specialized new information can be used.

One principal interest at Dehra Dun was development of roof truss systems of various types and sizes to utilize the smaller pieces of their secondary species. Some of these designs are shown in Fig.12. (42). In addition to the obvious conservation of these shorter pieces from logging and milling wastes, and reclaiming timbers of small sizes from thinning operations in forestry, the use of small pieces in such trusses was an advantage in building in remote areas, where material had to be transported to the building site on muleback or similar methods. Nail jointing by semi-skilled workers is commonly used. A wood-dowel system has been used, including a simple machine for making the dowels in the field. It is obvious that such roof trusses can compete with steel trusses. Proper seasoning and preservative treatments, where necessary, are considered in these developments. Short lengths and thin pieces of lumber are fabricated by nail laminating into large beams, as for roof purlins.

From information obtained from Dehra Dun, it appears that Indian homes still generally involve masonry walls, and non-wood floors, but that wood roof systems are quite well developed.

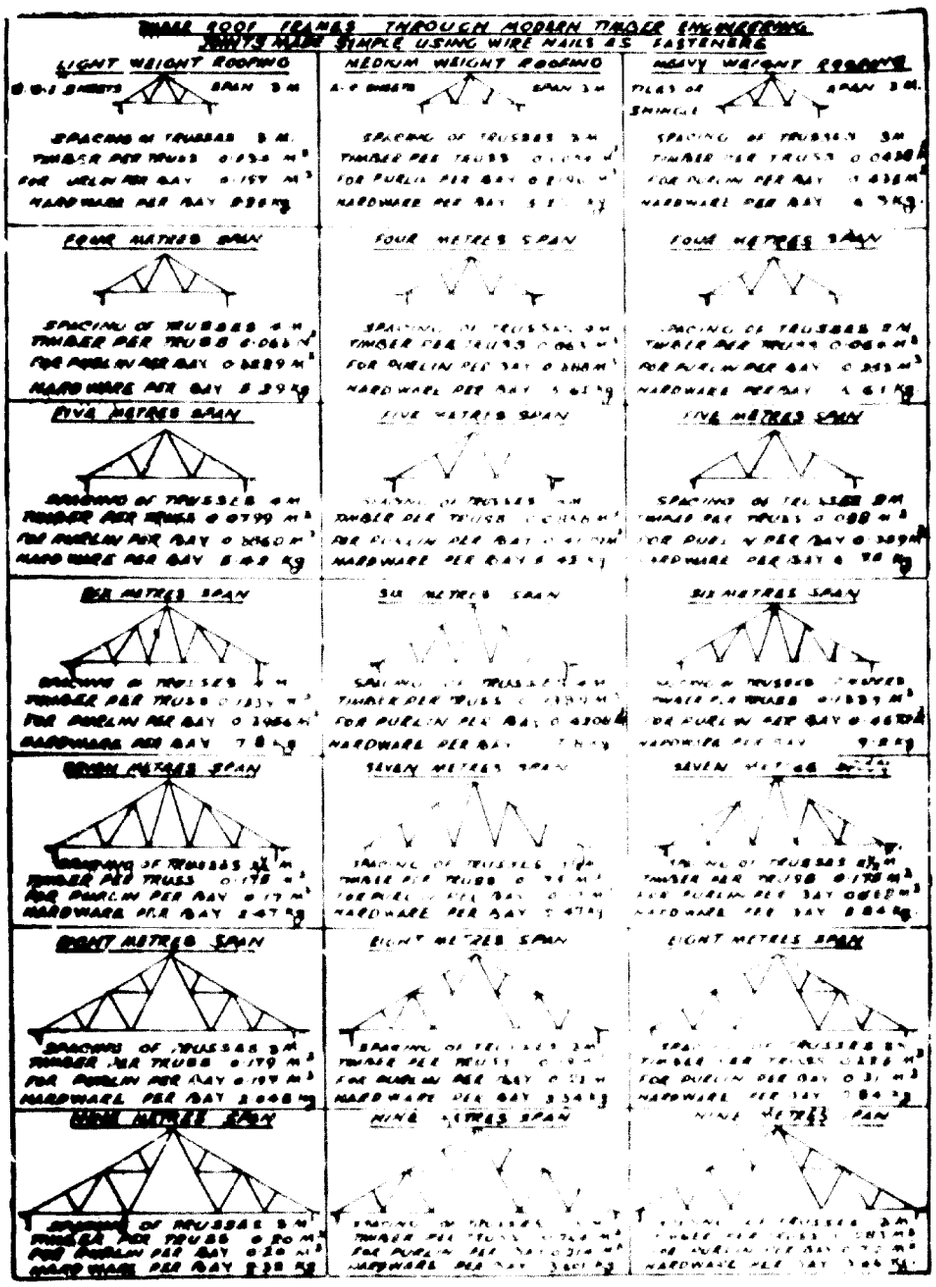

Figure 12.--Roof trusses designs to utilize short lengths of timber, as developed in India.

Wood Housing in Canada

Although Canada is certainly not a tropical country, some of their developments in wood construction are of interest here. As in the U.S.A., platform framing is the standard method of conventional wood house construction, with 2 x 4 studs on spacings up to 24 inches.

With a considerable number of native Indians, Canada has attempted to provide better housing for these natives, who are nearly always in the low-income category, and need low-cost housing. Although "self-help" programs have been attempted here, to involve the Indians themselves in doing some of the construction, this has apparently not been very successful, and quality of such construction has sometimes been rather poor. The present means for providing such low-income housing has generally been to build more-or-less conventional housing, and subsidize much of the cost from government funds.

Canadian wood-frame house construction is described in their manual (15), which is essentially a copy of the earlier American manual (22), and updated for differences in Canadian construction methods. The Forest Products Laboratory of the Canadian Department of Fisheries and Forestry in Ottawa conducts most of the basic research on use of wood in construction in Canada, and has a series of useful reports on nailed plywood gusset roof trusses for residential construction, span tables for wood joists and rafters of Canadian species for housing, and other related subjects which are useful references.

The Canadian Department of Indian Affairs and Northern Development, Indian Housing Section, Indian Affairs Branch in Ottawa has a useful bulletin on "Indian Affairs House Designs"(34), which includes a series of architectural designs for homes for Indians, many of which are of wood construction. Most of these homes are of conventional wood construction, with floor areas from 400 to 1250 square foot. Only schematic floor plans, elevations and perspective drawings are included, without construction details. Working drawings are available upon separate request for specific designs. An example of such a design is shown in Fig.13. This is a small house with about 350 square foot, and provision for additions later.

The Canadian Mortgage and Housing Corporation, a government agency in Ottawa, has compiled a set of about 100 house designs developed by various architects for that agency (19). Many of these are of standard wood construction, with from 800 to 1500 square foot. These are not low-cost homes, but include a wide variety of aesthetic designs.

The Canadian Division of Building Research in Ottawa has conducted some limited studies of housing in Northern Canada for eskimos and other natives. Here the conditions are much different than in the tropics, and provision for good thermal insulation and tight sealing are of paramount importance. Special attention was given to prefabricated members in the design, and an attempt was made to include self-help provisions. Of particular importance was savings in shipping weights of building materials and prefabricated components to remote areas, reduction in on-site labor in order to achieve economies in areas of

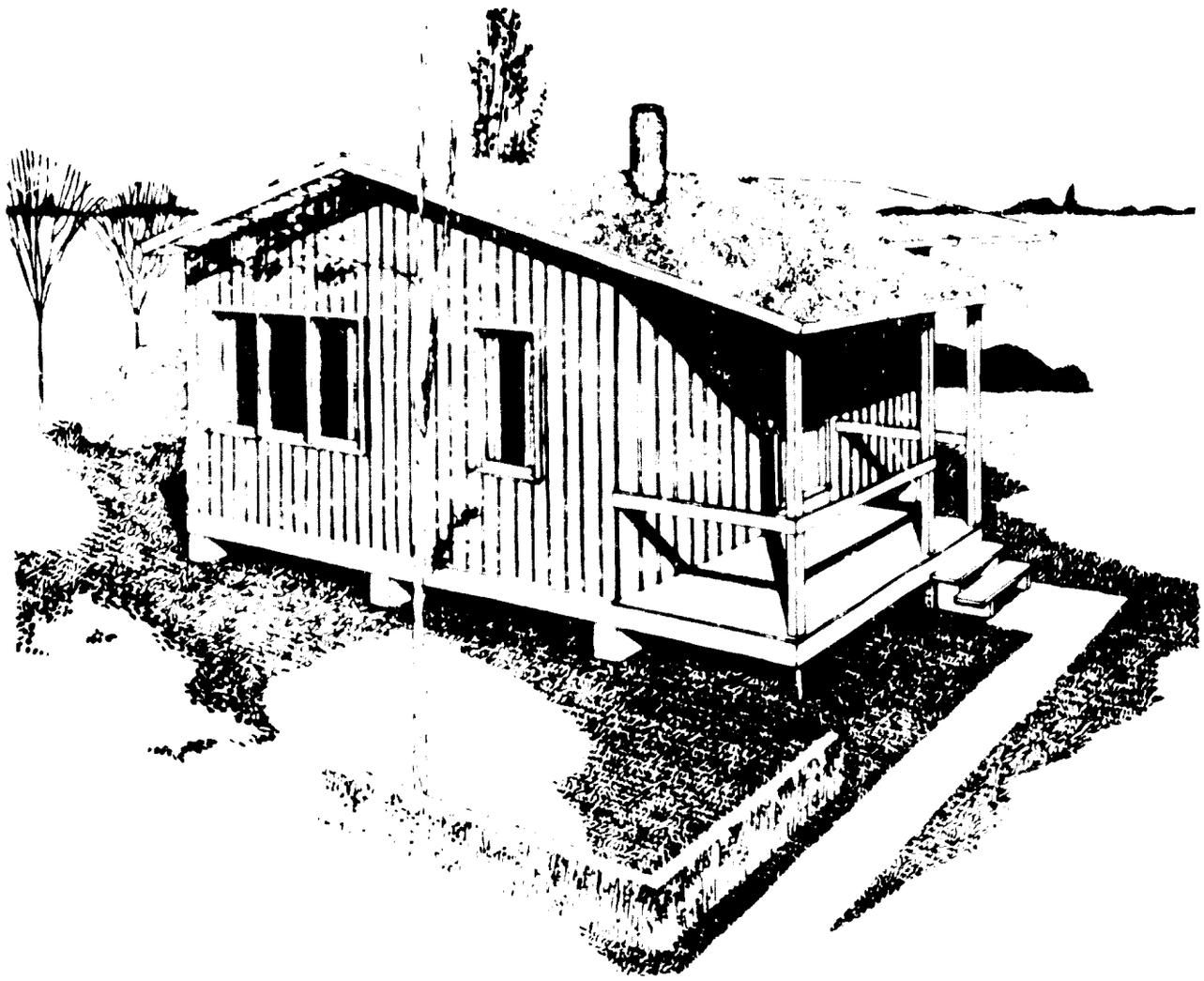

Figure 13.--Simple wood-frame home for Indians in Canada.

high labor costs, and great construction difficulties because of the severe weather. Dickens and Platt (36) reviewed several approaches to providing efficient small homes for northern Canada utilizing stressed-skin and sandwich panel constructions as much as possible. One simple design is shown in Fig.14. Although these particular designs may be of little direct value for tropical climates, the design approaches have potential applicability, particularly the approaches used for prefabrication. A later design for a small eskimo home in Northern Canada was described by Platt (46). This again uses stressed-skin panels, with unfinished cedar plywood glued to wood framing. The joint problems in connecting the various panels in these prefabricated homes received special attention to make them simple and efficient to use in the cold weather, and to protect against wind and moisture entry into the finished structure, and loss of heating efficiency.

Building Regulations for the Tropics

The British Building Research Station, Garston, Watford, has developed a series of model building regulations for developing countries, particularly those in the tropics where hurricanes and earthquakes may be important hazards. The requirements in these proposed model regulations are said to be based on a consensus of opinions from various sources, rather than on specific research results. As expressed in some of the publications on these model codes by the Building Research Station, the purpose of such building control is to protect the health and safety of the occupants of the buildings. Control is exercised by determining,

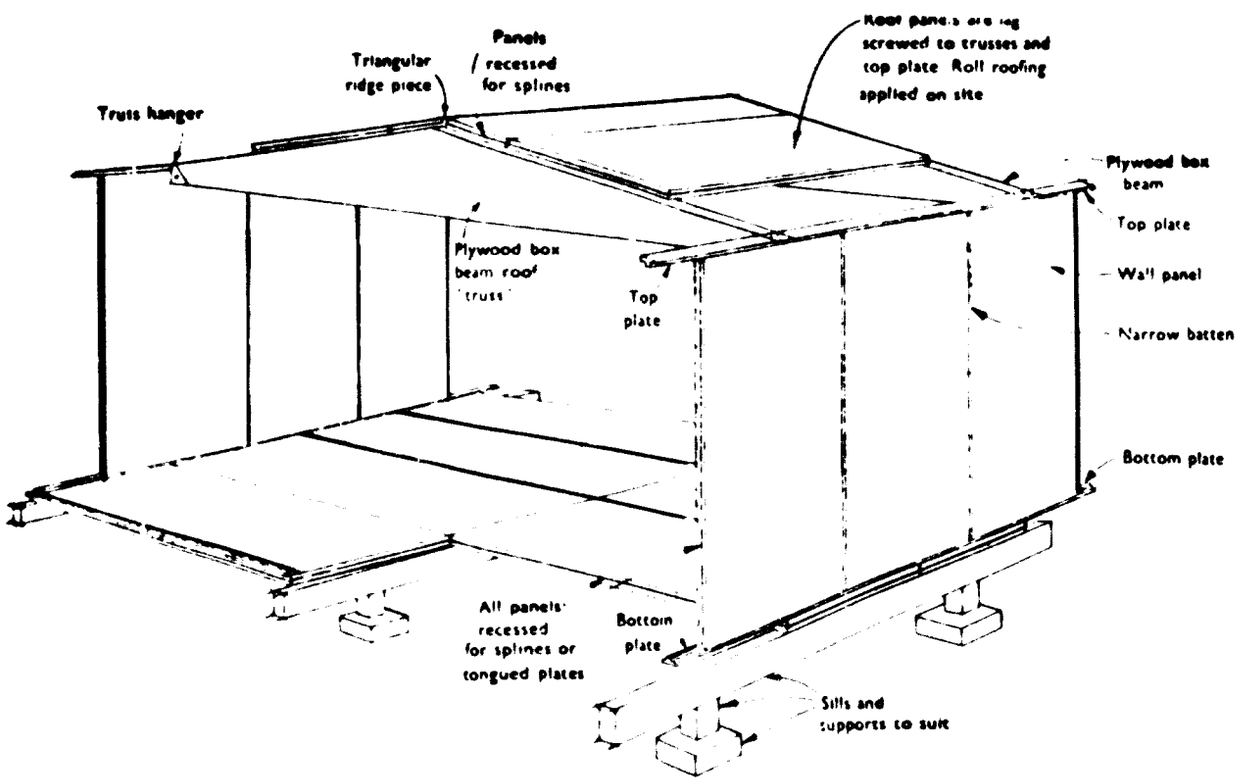

Figure 14.--Proposed home for Eskimos in Northern Canada, featuring stressed-skin wood panels for floor, walls, and roof.

enacting, and then enforcing certain minimum standards below which no person is permitted to build, assuming that anyone adopting lower standards would endanger the health or safety of others. Minimum standards should cover (1) Accommodation factors (room sizes, light, ventilation, etc.); (2), Construction factors (structural safety); (3), Drainage and sanitation; and (4) Fire factors (spread of fire and escape from it). The Station anticipates the need for several versions of such building regulations to meet the needs, experience, and backgroumd of different classes of individuals. One set of rather complex technical requirements is needed by professional designers or architects. A second set of less complex requirements in less-technical terms is needed for small builders, and a third set is needed for control of homes built of temporary materials to prevent uncontrolled building of "shanty towns".

The subject of building codes and regulations is a very complex one, too extensive to discuss in this paper. It is a subject of much mysticism, emotion, and considerable lack of information, or even presence of erroneous information. Selfish interests on the part of certain labor crafts and unions, and promoters of certain building materials tend to influence such regulations. Nevertheless some minimum level of building control is necessary and desirable in developing countries. Development and adoption of such regulations will probably be an evolutionary process. Two specific reports on these model regulations from the Building Research Station in England are "Tropical Building Legislation-Mode' Regulations for Small Buildings"

(6), and "Tropical Building Legislation-Model Regulations for Small Buildings in Earthquake and Hurricane Areas"(14). These are cited here merely to indicate their existence for reference as needed. They include wood constructions, as well as other types of construction. There may be other model building regulations for wood buildings for tropical countries. No effort was made to uncover such additional material for this paper.

Other Information on Housing in Developing Nations

There are a number of interesting short general reports on housing efforts in different countries in warm climates. Much of this concerns efforts towards low-cost housing. Many do not involve much wood construction, but the general backgrounds on economic and social factors in the different countries and approaches to the problems are of interest in this paper.

One study conducted for the Agency for International Development in Panama covered an experiment in providing decent and adequate housing for subsistence farm families with very low incomes. This involved self-help efforts on the part of the families themselves, and included establishing a credit union and a housing cooperative to handle financing and business arrangements. Local people were trained in basic skills, such as making and laying concrete blocks, and some rough carpentry. Each prospective home owner was also required to obtain a specified amount of sand, cane and native hardwoods, which were to be on hand before purchased materials by the cooperative were delivered. The design (Fig. 15) consisted of a concrete slab, partial

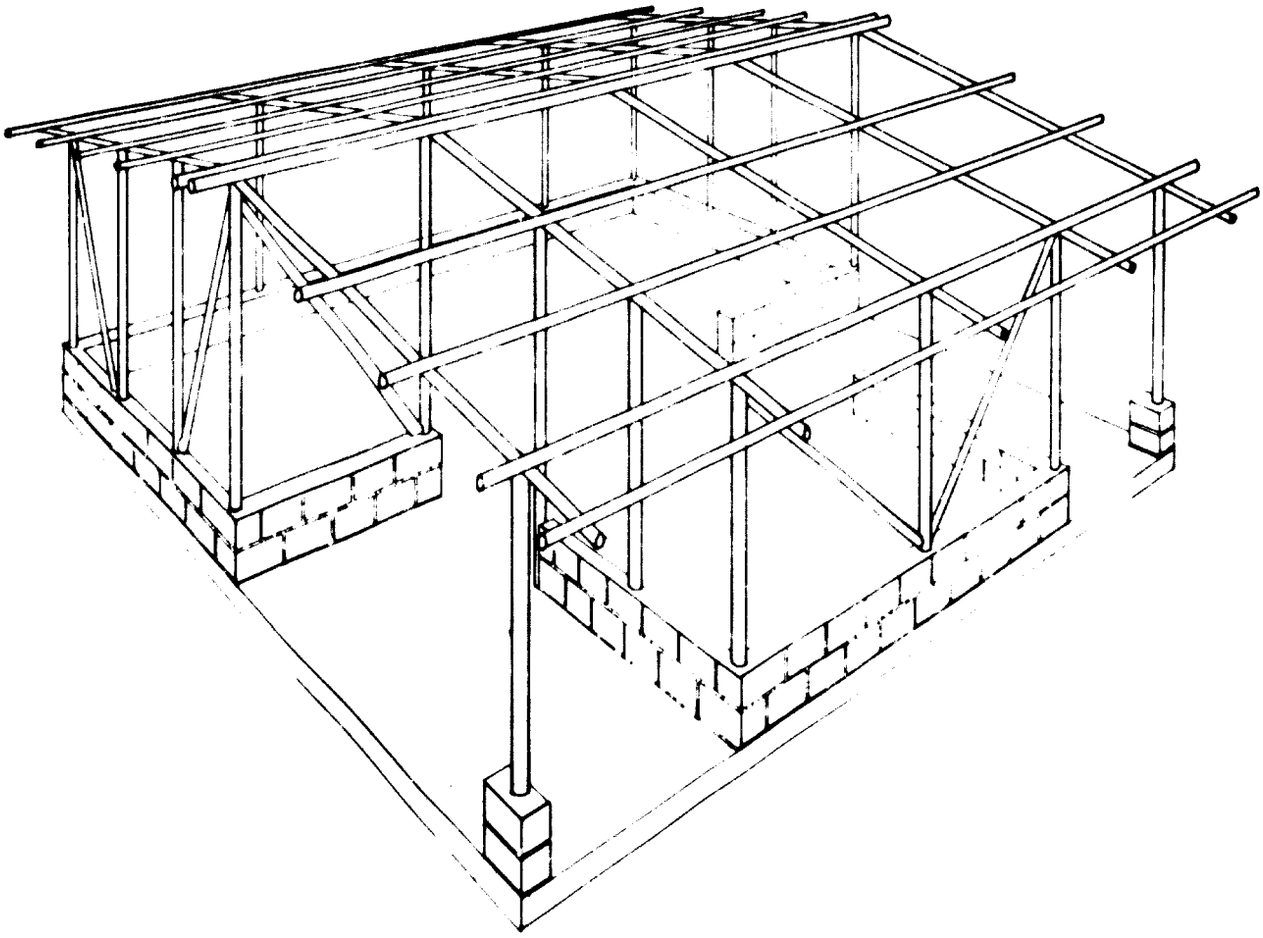

Figure 15.--Round wood pole frame construction, over a low concrete-block wall, used in a self-help housing project in Panama.

lower walls of concrete blocks, and a wood-pole frame for the upper walls and roof. Native cane was then used as siding on walls, and corrugated sheet metal used as roof covering. Buildings were designed as modules so that expansions could be added later. The results of this experiment from planning through execution will be of considerable interest (11).

The Division of International Affairs of the U.S. Department of Housing and Urban Development has an interesting series of short bulletins on housing in Ghana, Ivory Coast, Liberia, Ethiopia, Jordan, and probably other countries of Africa. These are designated as their "Country Report Series". A survey of several of these reports failed to show any significant current extensive uses of wood in homes in these countries, with the exception of some use of roof beams on masonry walls to support sheet metal roofing, some wood window and door frames, and wood shutters and doors. Very little information is given on specific designs of such items of wood. This "Country Series" also includes some Latin-American countries, such as Nicaragua, and Guatemala. Since none of these reports have much specific information on wood construction, they are not listed in the references. This interesting series of reports, as well as another series from the same agency on self-help housing projects, would be useful as backgrounds for officials in developing countries interested in general approaches to housing problems elsewhere. There are usually good reasons cited for not using wood in these countries. Sometimes it is because timber is not readily available, sometimes there are

prejudices against use of wood because of decay, insects, fire or maintenance problems, and probably sometimes because of a general lack of knowledge, and experience in the use of wood in construction in these countries and cultures.

Summary

This paper presents a review of wood construction in the United States, and a few other countries overseas where the author could obtain fairly specific information on different methods of wood-frame construction in homes. The review was limited essentially to single-family homes, rather than multi-story buildings for multiple occupancy. The designs and methods of fabrication are suggested only as a starting point for use in other countries, particularly tropical ones. Each developing country will probably have their own native species which should be considered for home construction. A first important task will be to identify and classify these species, and then determine some of the most important physical and mechanical properties of these species of most interest. Natural durability of these species should also be established. Some preservative treatment may be necessary with non-durable species to make them satisfactory for use in areas where decay and insect attack in service would otherwise result in excessive damage, and need for costly maintenance. These service requirements should be adequately established for each locality. Some minimum standards should be established for building constructions in each area. These should be realistic, but not overly severe and restrictive. These requirements can be modified and extended later, as more experience is obtained.

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