A DESIGN FOR

PREFABRICATED STEEL HOUSES

A THESIS
Submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

by

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A DESIGN FOR

PREFABRICATED STEEL HOUSES

Date Approved by Chairman
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A DESIGN FOR
PREFABRICATED STEEL HOUSES

I

INTRODUCTION

Low-cost houses are a major problem of the building industry. Designers in this field of housing are faced with the task of providing safe, comfortable, healthful living quarters of long life for men of low incomes. Among the many approaches to this problem has been prefabrication for economy in first cost and use of steel for permanence. It is with this combination of manufacture and material that the house of this thesis has been designed.

Many systems of prefabrication, using light-gauge steel, have been developed. One system prefabricates only the framing members by cold bending and spot welding. The flanges of the channel shaped headers and sill plates are perforated in order that studs and joists may be attached at any point by means of a variety of special light-gauge steel attachments. Any desired material can be field attached directly to the steel.

Another system consists of light-gauge steel framing which is shop fabricated into panels about forty inches wide and covered by non-metallic finishes. Panels are used for the floor, walls, and roof. Field connections are made with steel battens which hermetically seal the joints. Interlocking shop fabricated panels sixteen inches wide
form the nucleus of a system which uses the steel of the panel for the exterior covering. Flat sheets are flanged on the edges into such a shape that the panels overlap and the required structural strength is obtained. Hook bolts are used for the connections. Any interior finish such as rock lath and plaster, or plywood, may be used.

Variations from these systems are numerous. Some use steel as the covering for a conventional frame; others have steel sheets attached to steel panel frames either on the exterior or interior or on both; one in particular is a cellular system which uses sheet steel, bent to form the framing and the exterior and interior covering. Methods of attaching conventional materials and connections of the steel are more numerous than the systems themselves.

The majority of these systems were first introduced during the depression years of the early thirties. Their joint purpose was to use prodigious tonnages of steel which could be produced by the mills and to transform slum sections into garden spots. Experimental houses were built hurriedly. The more practical ones had, or found, sponsors for production. Since that time thousands of houses have been built using the various systems. In the past few years, however, production has slackened considerably because of the return of prosperity to the steel mills and because habits, established over a long period of time in the building industry, cannot be readily scrapped for a new material and system.

Although, from a practical and economical standpoint, the prefabricated steel house has never been fully accepted, there is much
research in the field at the present time. Some manufacturers are actually fabricating and building the houses in profitable quantities. Sociologically, the program of the Federal Housing Authority indicates the present need of a livable and economical low-cost house with the permanence of steel.

This thesis is a design towards the development of a house which combines the comfort of modern engineering and the security of steel construction.
MARKET AND USES

This house is designed to demonstrate the system of construction developed in this thesis and is used, primarily, as the unit of an industrial housing project. It is 24'-0" x 28'-0" and includes a living room, two bedrooms, a bath, and a combination kitchen and dinette. Two closets in each bedroom, one in the entrance hall, and storage space in the heater compartment make it a comfortable home for a family of four.1 Its simple rectangular shape will give a pleasing appearance to a complete project of houses exactly alike.

Panels of steel, shaped to form the structural frame and exterior covering, are used for the walls and roof. Steel will not burn. There is no danger from fire, and there is high resistance to weather. Snow, wind, ice, and blazing suns do not affect the steel construction. This steel framework provides a good conductor to the ground should lightning strike the house. Protective coatings and rust-resistant alloys at critical points prevent deterioration. Panels are anchored to a concrete foundation making the house cyclone-proof and tornado-proof. The metal home is not susceptible to rodents or insects and can easily be cleaned. Practically no repairs will be required because there is nothing in the construction to wear out. About the only maintenance

1 Of the families in the $1,000-$2,000 income group, 25 percent are comprised of two persons, 47 percent of three or four persons, and only 28 percent of five or more persons.
will be the exterior re-painting, interior re-finishing, and equipment repairs. Steel has security and protection never before attained in a low-cost house of this class.

The estimated first cost of $2600, including land, is well within the budget of the industrial worker should he desire to own his home. Average annual income for an industrial worker is $1272, based on 1938 statistics. Applying the nominal rule-of-thumb for families in this income bracket, 20 percent of the income or $21.20 monthly may be spent economically for housing expenses including mortgage amortization and interest, maintenance cost, taxes, and insurance, exclusive of heat, light, and refrigeration. Taxes are assumed to be $50 yearly and maintenance cost to average $20 yearly. This leaves $15.37 monthly payment, the present value of which as an annuity represents the amount that can be paid as first cost of the house. In round figures this amounts to $2325.00, and $2625.00 for payments at 5 percent interest.

\[ \text{Total for 5 years, or } $20.00 \text{ per year } \text{or } $100.00 \]

\[ \text{In the formula } 1 - (1 + i)^{-n} \]

\[ i = \text{rate of interest per period} \]
\[ n = \text{number of interest periods} \]

Making quarterly payments \( i = \frac{1}{4} \), \( n = 80 \), or 100

For 20 years \( 3 \times 15.37 \times \frac{1-(1.25)^{-80}}{1.25} = 46.11 \times 50.3867 = $2323.53 \)

For 25 years \( 3 \times 15.37 \times \frac{1-(2.25)^{-100}}{1.25} = 46.11 \times 56.9013 = $2323.72 \)
over a period of 20 years and 25 years respectively. If the usual 10 percent cash payment is made the balance could be paid in 20 years. On a rental basis the investment would be figured for a period of 25 years, a safe period of time for a house of this material. These figures show that the selling price of the house is reasonably close to the purchasing power of the market.

This system of construction is limited neither to this particular house nor to group housing projects. The several types of panels are standard—prefabricated in large quantities to preserve the economy of manufacture. Yet they are adaptable to practically unlimited floor plans and exterior shapes since the holes of one type panel will match the holes of any other type panel. This gives economy of prefabrication and advantages of steel construction in a house of size and arrangement to meet individual requirements. The house shown in these plans would be excellent for a resort cottage. If no heat were needed, a stairway in the heater room would give access to the roof which could be used as a sun deck or as a space for games. The flat steel surface would be ideal for painting in gay tints so familiar to the beach. Single or double houses could be used as officers' quarters at military camps and naval bases. Multiple houses could be erected quickly for use as barracks. Among other buildings that could use this system of construction are barns, garages, warehouses, service stations, offices, and commercial buildings.

Buildings using this system may be dismantled easily, moved, and re-erected at another site. Since the sections are bolted together
they may be readily taken down and set up again with little or no loss. To make the house practically 100 percent portable steel, panels similar to those used for the roof could be used for the floor which would need only a few concrete piers or short steel piles for support. This feature would be especially valuable for construction camps to be used only a few years on any one location—such as camps for projects of the Tennessee Valley Authority or the city built for the construction of Boulder Dam on the Colorado River.
III

BASIC CRITERIA

From an engineering point of view, structural framing and covering are the two most important parts of a house. The basic criteria of a practical system of construction using steel panels to form these two important parts are listed below.

1. Non-Shrinkage
2. Structural Strength and Stiffness
3. Connectivity and Jointage
4. Insulation
5. Durability
6. Surface Finish
7. Economy

There is, following, a general discussion of these basic criteria as applied to the system of construction developed in this thesis. Specific details of design and dimensions of the house are shown on the drawings.

Non-Shrinkage:

Since the steel panels used to form the framing and exterior covering are securely bolted together, they expand and contract as a unit, thus avoiding cracked interior and exterior finishes caused by permanent shrinkage of the framing. For the extreme condition of temperature change from 0°F. to 100°F., the figured expansion of a complete wall of seven panels is less than 1/4" (0.2251). There can be no misfit
of doors and windows which are made into a panel that cannot change shape.

Structural Strength and Stiffness:

Ample structural strength and stiffness are provided in the panels. Flat-rolled steel sheets are used with the edges flanged to form channel sections which become I beams when the panels are bolted together. Intermediate stiffeners welded to the flat portion of the panel also form channel sections and act as studs in wall panels and beams in roof panels. A minimum thickness of 16 gauge steel is used to prevent the panels from denting easily if struck accidentally and from sounding like tin if tapped. Heavier gauges are used wherever necessary or desirable for structural strength or exposure to the elements.

No actual test of the strength of one of these panels has been made, but a wall panel of another system similar in dimensions and structural shape did not deflect when subjected to an 8000 pound load by its manufacturer. The maximum load imposed upon a wall panel of this house under a beam roof loading of 50 pounds per square foot is only 1200 pounds. If the reaction of a floor load were added, the stress would come well within the safety limits. Sections of the roof panels act as beams and are made deeper than those of the wall.

4 From a photograph and caption in a bulletin, Pre-Fab in Pictures, Harnischfeger Corp. n.d.
The stress figures of an intermediate stiffener section are shown on sheet 7 of the drawings. The figures show 13,300 \#/sq. in. as the load stress for a maximum span of 12'-0" under a 50\#/sq. ft. load. Most specifications allow 20,000\#/sq. in. stress for hot rolled beams with laterally fixed compression flanges. The thickness of material in this beam section was increased to give a low stress and an added margin of safety since the use of cold-formed steel in framing is not yet well established on sound engineering principles. The table (Fig. 1) on the following page gives a tentative basis by which sheet steel design may be computed. If the panels were used to carry a floor load, the panel proper should be increased to 16 gauge instead of 18 gauge steel, and the stiffeners to 14 gauge instead of 16 gauge steel. The structural framing sections used in both the roof and wall panels check closely — on the safe side — with those used in many of the systems which have been manufactured and tested.

Connectivity and Jointage:

The panels are bolted together in the field as shown by the drawings. All connections are easily accessible before the application of the interior coverings of insulation board. Sufficient bolts, placed in two rows, make tight, rigid joints. The joints are fully sealed against infiltration of moisture and insulated against heat and cold by a felt strip gasket painted on both sides with mastic. Connections to the foundation are made through anchor bolts. The bottom of the panels are given a heavy coat of asphalt paint and are set on a thick strip of asbestos felt which acts as a gasket when the anchor bolt nuts are tightened. The interior covering of insulation board is connected to
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<th>Continuous</th>
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<td>T</td>
<td>T</td>
<td>W</td>
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DEGREE OF FIXITY
- One Boundary Free
- One Boundary Stiffened
- Both Boundaries Fixed or Continuous

| RATIO W/T | 10 | 30 | 100 |

Note: Solid areas in diagram above are merely conventional representations of effective widths.

Tentative Ratios of Maximum Flat Width (W) to Thickness (T) of Element to be Assumed as Effective in Computing the Geometric Properties of Individual Sheet Steel Sections.

*Fig. 1*

*Reproduced from "Address on Light-Gage Flat Rolled Steel in Housing" by F.T. Llewellyn, Annual Convention of the American Institute of Steel Construction, White Sulphur Springs, W. Va. October, 1937*
the panels by nailing to furring strips, bolted to the flanges of the panels. The exterior covering needs no attaching because it is an integral part of the steel panel.

With the bearing value of bolts on light-gauge steel the governing factor, the joints between the ends of the roof panels and the tops of the exterior wall panels are the critical connections for strength. Figures on sheet 7 show allowable bearing values for each bolt to be twice that required for the figured load.

Insulation:

Insulating building board, manufactured by several companies, breaks conductivity and insulates walls and ceiling against heat and cold. The insulation board is applied on the inside of the house to form the interior finish. For additional insulation, paper-backed mineral wool may be glued to the inside of the exterior panels. Insulating blocks under the roofing material make a dead air space between the roof and the ceiling board. This double insulation of the roof is protection against heat loss in winter and hot sun rays in summer.

The wall board, which has very efficient sound deadening qualities, also serves as insulation against passage of sounds between rooms. No experiments have been made with this system of construction regarding reverberation, such as that caused by the opening and closing of doors. This reverberation, however, should not be of disturbing intensity since interior doors are made of wood and felt strips between the exterior joints break the conductivity of the steel thus preventing transmission of sounds throughout the house.
Durability:

The durability of steel is determined, primarily, by its resistance to corrosion. Before leaving the shop the panels are given a rust inhibiting treatment which consists chiefly of spraying with a good metal primer having a lead or zinc base. Additional paint, applied to all exterior surfaces after erection, forms an efficient protective coating against weather.

The outside surfaces of the house will require re-painting every five to ten years. The outside of the panels, of course, are easily accessible, but the inside cannot be re-painted after the initial coating without removing the interior covering which is an expensive and useless operation. Corrosion on the inside of the panels, watertight from the outside, would be caused by condensation of warm, moist air, from the inside of the house, collecting on the cold steel surfaces. This condition is effectively prevented by placing the insulation board between the steel and the interior of the house to permit only a very slight, if any, infiltration of warm air or moisture. The rust inhibiting treatment will easily withstand the slight possible condensation for a long period of time. The felt and mastic seal the joints against moisture from any source.

Light gage steel framing with adequate protective coatings have shown no evidence of corrosion after periods of 30 years and over. One example is a house built in 1907 for employees of the Tuxedo Park Association. The wall and partition studs, floor and roof joists, were composed of sheet steel sections supporting stucco and plaster.
"It is reported that portions of the floors, roof, and walls were opened up in 1932 for the purpose of making alterations, and that the steel sections, after 25 years service, were found to be in as good condition as when they were installed."\(^5\)

Numerous other examples of sheet steel framing, used in various localities, have shown an equal or even more satisfactory result. It is reasonable to assume, therefore, that with adequate protection from the excess of moisture, an improved system of rust inhibiting treatment would prove even more successful for the protection of interior steel work.

For added assurance of permanence, copper bearing steel is used where the probability of corrosion is greatest — at the base plates and crown plates of the exterior panels. No basis for a close estimate of the life of a house using this type of construction is available; but with proper maintenance, 50 years would seem conservative.

Surface Finish:

The exterior appearance of the house, which has simple lines of modern architecture, is best judged from the perspective rendering (Fig. 2). Well defined architectural trends, such as the flat roof and the disposition of windows near the corners of rooms, are features readily and economically adaptable to this prefabricated house. The exterior paint, in addition to protecting from corrosion, forms a

\(^5\)From an article "Steel in Residence Construction", by F. T. Llewellyn and F. M. Speeler, The Architectural Record, June, 1933.
pleasing and durable surface available in a wide variety of colors and finishes.

Economy:

Although this house of steel has low maintenance cost, long life, and is superior in many ways to one of conventional materials, the first cost for the completed house must be sufficiently low to be attractive in the low-cost housing field. Since steel is a more expensive material than certain low-cost non-metallic materials, its additional cost to the house must be offset by fabrication in the factory where suitable equipment and economies of mass production may be obtained. This prefabrication leaves a minimum of work to be done at the building site.

Of the more important details of economy in shop fabrication, the panels, shaped to form the exterior covering and structural framing combined, are cold-formed and punched simultaneously; the design requires a minimum number of dies and die changes for the pressing operations. Inexpensive, precision-built jigs make the fitting and welding of panels an efficient and fast procedure. Costly fabrication of special attachments is eliminated by the use of standard low-priced bolts for connections.

Panels are erected and the interior finish of insulation board is attached at the building site in a fraction of the time required for conventional houses. Pre-framed doors and windows, holes in the panels for passage of wiring and piping, and a heating system of little more than the heater itself are typical of the features which reduce the cost of collateral materials and equipment. The drawings and descriptions show numerous other details for reduction of the first-cost of the completed house.
IV

CONSTRUCTION

Construction of this house is divided into two parts: Shop Fabrication and Field Erection. The several kinds of panels used for forming the framing and exterior covering are manufactured at the factory in large quantities and held in stock as standard parts until required for shipment. These panels, with accessory materials and equipment, are assembled at the building site. (The following descriptions and drawings constitute a design based on a study of other systems and on the student's own experience in the steel and building industries. The actual building of an experimental house or the fabrication of a test panel are beyond the scope of this thesis.)

Shop Fabrication:

The basic unit of the system is the 4'-0" wide panel. Walls using panels of this width are easily computed, have a small number of joints, and are small enough to be formed from sheets coming within the limit of mill rolling widths and to be handled easily. They are large enough for complete door and window assemblies in single panels. 4'-0" is a standard width for insulating board.

The panels are fabricated from ordinary open-hearth hot-rolled steel sheets by punching, cold-bending, and fusion welding. Copper bearing steel is used for the cap and sill plates of exterior panels and canopy panels since these parts are most subject to corrosive action.

Standard sheets are ordered from the mill and cut to the required size by a shearing or striping machine. The trimmings are used to make
tie bars and small sections. Punching and bending is combined into one operation by a power press which has dies for the several various sections. Channel sections of the interior panels are stamped as complete sections. Edges of wall and roof panels are formed individually thus requiring a machine of reduced size and power as well as a reduced size and number of dies. Simple sections such as tie bars, strut angles, clip angles, and sill plates are made using jigs for accuracy and speed on the usual punch and plate brake machines.

The sections thus formed are clamped in precision-built jigs for welding into panels. Resistance welding is used if the volume of production warrants special equipment required for each individual welding job. Otherwise, welding is by the electric arc method with which metal as thin as 22 gauge has been economically fabricated.

After welding, the panels are wiped with a chemical inhibitor solution which removes all surface impurities and leaves a thin film as the initial treatment to seal the panels against corrosion. They are then sprayed with a rust-inhibiting compound which is a metal primer serving also as a base for field paint.

The furring strips are of wood which has been given a dipping treatment of zinc chloride or equivalent preservative treatment to protect woodwork against termites, rot, and fire. Standard size for the strips is 5/8" x 1-1/4". A piece 5/8" square is nailed to 5/8" x 1-5/8" strip to form an L-shaped section for use at the corners of the rooms. Holes for bolting to the panels are drilled to templet with combination drill and countersink bits. The standard size strip is bolted to all flanges except at room corners where the L-shaped section is used on
one flange and omitted altogether on the other. Unless houses all alike are to be built, the corner furring conditions are provided for on special order thus keeping the number of different stock panels low.

Door and window panels are completely made up, including doors, sash, hardware, trim, and glazing. These panels are specially crated for shipment to prevent damage to trim or breakage of glass. Sheet 5 of the drawings shows typical door and window sections. Switch boxes and convenience outlet boxes are welded to the frames in locations shown on the floor plan. Like the corner furring conditions, this work is performed on special order unless fabrication is for unit houses all alike. Holes for the passage of wiring and piping are punched in the web of all wall panel sections as part of the punching operation. For roof drainage, special panels are made which have the top of the cap plate slightly below roof level for about one-third the width of the panel.

Punching and forming the sections with dies and welding in precision jigs assures accurate fitting of all field connections as well as interchangeability of each type panel. Holes are spaced so that each type panel is connectible to any other type panel. For instance, partitions may be worked off any flange of exterior panels or bolted to any flange of other partition panels. This gives a room size multiple of only 1'-4" which, in special cases like closets, may be reduced. Strips spanning between two flanges take the partition connections. Roof panels will connect to any arrangement of interior panels and to all flanges of exterior panels. In cases where the basic 4'-0" width of the interior panels is changed (see sheet 3 of the drawings), the
increase or decrease is made from the center-line of the standard 4'-0" unit. This maintains the connectivity of partitions in 1'-4" multiples. An increase in thickness is made in the same way.

The above procedure is for manufacturing with moderate but sufficient capital to meet a medium volume of business. Experimental or single houses could be produced at considerably increased cost on the usual machinery of plate or structural shops. On the other hand, extremely large numbers of panels could be produced very economically by having a special machine for each operation of each type panel. The exact procedure of shop fabrication depends upon such factors as size of shop, amount and kind of equipment, financial backing, and the number of panels to be produced.

Field Erection:

A wire-mesh reinforced concrete water-proofed floor slab and panel footing requiring very simple form work is poured in one piece over a well tamped non-capillary-acting fill. The top of the floor slab is brought to a smooth, level, steel-troweled finish to receive the floor covering. Anchor bolts are spaced according to the panel layout. Bolts 8" long are used in the footings and short bolts with a hook or expansion shield are used for the partition panels. The grout shown in the outside wall section on sheet 1 of the drawings is poured before the panels are set and is used to obtain a smooth, true, level, surface after the occurrence of any shrinkage in the concrete. Cold air returns encased in concrete under the floor are poured as part of the foundation.

At the building site, the panels are quickly erected on the foundation. Exterior panels are painted with heavy asphalt paint on the under
side of the sill plates and set on a thick asbestos felt strip. Interior panels rest directly on the concrete floor slab. All panels are bolted together with galvanized bolts. Exterior connections are sealed with a light felt strip painted on both sides with mastic. Sheets 2, 3, and 4 show typical wall, roof, and canopy panel connections. All connections are easily accessible before the insulation board is applied. Specially trained labor is not required; one semi-skilled man is used for the mastic work and four common laborers for bolting and helping— all under the direction of a foreman. It is estimated that this crew would require about two eight-hour days to completely erect the panels as delivered from the shop.

Insulating building boards are easily and quickly nailed to the furring strips to form the interior finish and to insulate the walls and ceiling. Average thermal conductivity per inch of thickness is 0.33 Btu per hour per square foot per degree F. The one-half inch thickness used is equal in insulating value to 1-1/2" of wood or 7-1/2" of common brick. For colder climates additional insulation of paper-backed mineral wool is glued to the inside of the steel exterior wall and roof panels before the vapor seal and insulating board is applied. Standard width boards 4'-0" are used, with either square or grooved edges. Wire nails having heads driven flush with the surface are used for square edges. Grooved edges are of the concealed nailing type. Openings or special pieces are neatly cut with an insulating board cutting tool. The inside finish is a glazed washable surface available in a wide variety of colors, color combinations and grooved designs. Bath room walls and those at the kitchen sink are covered to a height of 5'-0" with an 1/8" thickness of
water resisting hardboard, applied with polished head drive screws over natural finish (unglazed) insulation board. In the heater room 22 gauge sheets for positive fire protection of walls and ceiling are bolted to the panels.

Floor covering is 1/8" asphalt tile throughout the house. The tiles are applied with asphalt tile cement directly to the concrete floor slab.

A three-ply coal tar pitch and slag roof is used. In addition to being practically permanent, this type has been found to be most suitable to resist prolonged contact of the roof with water which is the condition with a flat-deck roof. Sheet 3 shows a section through the roof. Drainage is at the rear of the house through two copper downspouts soldered to the drainage panels. Asbestos felts, immune to destructive forces of rot and decay and undamageable should disturbances of the slag permit temporary exposure to the sun, are used as assurance of permanence with minimum upkeep. In addition to providing insulation, one inch thick insulating blocks prevent transmission of any strains to the roof from possible expansion and contraction of the roof deck.

The electrical and plumbing work is similar to that in conventional houses. Holes in the web of the panel sections greatly facilitate the work of running electric wires and laying plumbing pipes. Electrical fixtures are installed in the usual manner with the exception of base plugs and switch boxes, already located and rigidly connected to the panels. Plumbing fixtures are connected to the furring strips or clamped directly to the flange of the panel sections. Plumbing work required for the floor plan shown on sheet 2 is most economical since
all pipes are located in or very near one section of wall.

The heating system is a very simple one requiring practically no duct work. Any one of several types of suitable heaters, preferably gas or oil fired, is located in the steel-lined heater room whose ceiling becomes a plenum chamber. Warm air is transferred to two rooms directly through grills located near the ceiling in the heater room walls and to the other rooms through a simple sheet metal duct system, fastened to the flanges of the roof panel in the hall. To permit concealed passage of ducts, the ceiling in the hall is lowered seven inches by using long bolts with pipe spacers to suspend the furring strips. Return grilles located in the floor at all corners of the house draw the warm air down from the ceiling, circulate it throughout the house, and return it to the heater through return ducts in the foundation.

The panels are examined before erection for any shipping damage to the rust-inhibiting coating and given a patch coat of rust-inhibiting compound if required. After erection all exterior steel surfaces are painted with at least two coats of good quality weather-resisting paint.

The exact kinds and quality of collateral materials are not limited to those outlined above. They may be chosen from among many suitable products to conform to individual requirements. Like shop fabrication, the exact method of erection depends upon such factors as location, collateral materials used, and conditions at the building site.
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FOUNDATION PLAN

OUTSIDE WALL SECTION

SECTION THROUGH DUCT RETURN
Felt & Yankee Strip

4'0 Panel Width
1 1/4
7/16 Gage Steel Panel

1/2 Insulation Board
3 1/2 ft.

TYPICAL EXTERIOR WALL

3 5/8 5 1/2 Stem Dim.

CORNER

DETAIL

NOTES:
Ceiling in hall to be 7' lower to accommodate stair ascents.

FLOOR PLAN

SHEET NO. 2
FRONT ELEVATION

SECTION THRU WINDOW

TYPICAL DOOR JAMM

(HERE SIMILAR)
General Panel Notes:

Panels to be fabricated in shop ready for Field Erection.

Erection B etc., applied in Field. Standing, Turning Stages to be 24 x 24, bolted to panels in shop - special stages area.

When required cut corners.
VI

COST ESTIMATE

Figures 3 and 4 show an estimated cost break-down of the house shown on the drawings.

It is difficult to estimate cost with any close degree of accuracy on an unconventional house that has yet to be built for the first time. It is more especially difficult if the cost depends upon the number of units manufactured and erected. However, the estimate is made from figures obtained from steel fabricators, manufacturers of the collateral materials, and a study of cost break-downs of other low-cost houses.

Costs on shop fabricated material are for a continuous output of panels by the manufacturing procedure described. Panel costs are figured on a pound-price basis. An average of about $2.80 per hundred pounds is figured for metal bought in standard sheets, pickled for welding and otherwise ready for fabrication. Prices shown for windows, doors, furring strips and miscellaneous includes both material and additional labor. Prices shown for shop fabricated material include all material cost, shop drawing cost (very small on standard units), labor costs, overhead and profit; and are for panels and miscellaneous materials completely fabricated and ready for shipment. Prices shown for field erection include erection only for the steel panels and both material and installation for items of conventional materials.

An amount for supervision of complete erection (proportioned among several houses built simultaneously) is listed separately. All
items of field erection are based on erection of houses in groups; but the number of houses built would not vary erection unit costs as much as shop fabrication unit cost.

Fabricators and manufacturers were reluctant to quote close prices on indefinite work such as this necessarily must be. Therefore the figures are most likely on the safe side for quantity production; but an experimental house would probably cost two or three times as much.
**COST ESTIMATE**

**Shop Fabricated Material:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior Panels (26)</td>
<td>3,250*</td>
<td>$325</td>
<td>$880</td>
</tr>
<tr>
<td>Interior Panels (27)</td>
<td>1,360</td>
<td>175</td>
<td>233</td>
</tr>
<tr>
<td>Trusses (3)</td>
<td>60</td>
<td>75</td>
<td>450</td>
</tr>
<tr>
<td>Roof Panels (14)</td>
<td>2,770</td>
<td>275</td>
<td>750</td>
</tr>
<tr>
<td>Canopy Panels (5)</td>
<td>200</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Heater Room Steel (*22ga)</td>
<td>230</td>
<td>15</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>7,870</strong></td>
</tr>
<tr>
<td>Rust-Inhibitive Treatment</td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>11 Windows (Sash, Glass, Screen, Trim)</td>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>2 Metal Ext. Doors (Trim, Hdle)</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>11 Wood Int. Doors (Trim, Hdle.)</td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Furring Strips (3,200 lin. ft.)</td>
<td></td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Field Bolts, Felt, Mastic, and Misc.</td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$1,200</strong></td>
</tr>
</tbody>
</table>

**Fig. 3**
COST ESTIMATE (Cont.)

Field Erection:

Preparation, Clearing Ground, and Foundation, Complete (13.3 Cu. Yds.) $150.

Erecting Steel
- 34 Labor Hrs. @ 45¢  
- 10 Labor Hrs. @ 75¢  
40

Supervision (Pro-rated)  
40

Insulation Board (Mat. @ $50/1000 sq. ft.)  
80

Additional for Hardboard (94 sq. ft.)  
15

Floor (670 sq. ft. @ $15 per sq. ft. laid)  
100

Roof (104 sq. ft., complete, plus flashing)  
75

Plumbing (Fixtures, Pipe, etc.)  
150

Heating (Heater, Ducts, Grilles, etc.)  
80

Electrical (Fixtures, Wire, etc.)  
75

Painting  
40

Cabinets, Sheet Metal, and Misc.  
65

$ 910

Shop Fab. Mat'l.  
$1,200

Freight  
40

Field Erection  
910

Cubage: 5,500  
Sponsor's Profit, Eng, etc  
150

Construction Costs:  
Total Construction  
$2,300

Land and Improvements  
300

42¢/cu. ft.  
To Sell at  
$2,600

FIG 4
CONCLUSIONS

Steel, through its inherent qualities, is a most desirable basic material with which to build low cost houses. It will not shrink or change shape during the life of a steel house. It is incombustible, rigid, and resists destructive attack of vermin and insects. Protective coatings and rust-resistant alloys readily make it permanent.

The forming of light sheets into panels, combining both the structural framing and the weather-resisting exterior covering, provides an economical use of this comparatively expensive material. The panels, designed to require a minimum of manufacturing equipment, are economically fabricated by multiple production methods.

All necessary collateral materials and equipment, such as the concrete foundation, insulating building board used for the interior finish, floor and roof coverings, plumbing, electrical work, and heating system, readily combine with the panels into safe, durable houses for modern living.

Of the housing need, placed by well informed economists at 1,200,000 dwelling units annually, more than one-third are needed in the large, stable, practically untapped market comprised of U. S. non-farm families having annual incomes of $1,000 to $2,000. In this group at the present time (1940) there is a deficit, conservatively estimated, of 3,000,000 units—a colossal figure if all these families could find new houses to buy or rent. There is little doubt that the size of the market justifies research towards suitable low-cost houses. The house
used to illustrate the system developed in this thesis is essentially
a four room house designed to accommodate over three-fourths of the fam-
ilies in this income group. It is safe, sanitary, substantially built,
and will have a low maintenance cost throughout its long life. Easy,
long-term government financing brings this house, having an estimated
first cost of $2,600 including $300 for land, within the ability-to-pay
of its potential market.

Naturally, the unit construction cost of 42 cents per cubic foot
is somewhat high because of the small cubic content — 5,500 cubic feet.
For comparison of cost, a four room wood and insulating board prefabric-
ated house of about equal living conveniences costs $2,116, or, also,
42 cents per cubic foot to construct. In a Kentucky low-cost housing
project, four room conventional wood frame houses of minimum construc-
tion sold for $1,970, including $100 for land. Construction unit cost
was 37 cents per cubic foot and contents 6,000 cubic feet. Fireproof
or fire resistant houses of this size are rarely built. However, a
house of 5040 cubic feet content with insulated, solid brick walls costs
$3,500, or 69 cents per cubic foot, to build in Chicago, Illinois. A
frame house with exterior covering of Portland cement plaster costs
$2,800 to build (6,500 usable cubic feet) in Phoenix, Arizona. Unit
cost was 43 cents per cubic foot, and only a flue ($20) was included for
heating. These are a few examples of low-cost houses meeting recognized
construction requirements. Unit construction cost depends upon the size,

6For comparison, cubage is figured as floor area multiplied by
celling height.
amount of finished living space, type of construction and location.
In prefabricated houses the cost variation for location is reduced
since most of the material is fabricated in a central factory and
depends upon shipping cost rather than the large sectional differences
in labor wage scales.

Although the price of steel constructed houses is within the
budget of potential owners in the low-cost housing market and would
show an investment profit for industrial housing projects, the advan-
tages of steel construction must be fully explained and impressed
before psychological resistance to the new material can be overcome.
An educational campaign can explain the advantages. To impress them is
a more difficult problem. Houses will have to be built and tested
over long periods of time to actually show their value.
BIBLIOGRAPHY

Beauty, Comfort, and Quiet, The Celotex Corporation, 1940

Double Duty Fir-Tex, Fir-Tex Insulation Board Company, 1938

Homes of Steel, Steel Buildings, Inc., Middletown, Ohio, n.d.

House of the Modern Age, National Houses, Inc., 1936


Johns-Manville Fiberglass Insulation Board, Johns-Manville Technical Data Section, New York, 1940

Llewellyn, F. T., Light-Gage Flat-Rolled Steel in Housing, an address, American Institute of Steel Construction, Inc., 1937

Low-Cost Steel Houses, National Houses, Inc., New York, 1937


Modern Decorative Interiors, Johns-Manville Corporation, New York, 1937

Modern Homes, General Houses, Inc., Chicago, 1937

Modern Homes and Buildings Fabricated in Steel, Columbian Steel Tank Company, Kansas City, Missouri, n.d.

Pre-Fab in Pictures, Harmschfeger Corporation, Milwaukee, Wisconsin, n.d.

Steel Framing for Small Residences, Subsidiary Companies of United States Steel Corporation, 1933

