has concrete walls 30 inches high above grade line and could be used without benches as a vegetable house or with them for the production of crops requiring such equipment. Such details as the height of the walls and the size and arrangement of the ventilators can be varied to suit conditions. The erection of houses of this type should be intrusted to men accustomed to such work, as these large structures are subject to specially severe strains from wind, snow, and ice, and unless they are well built trouble may occur. Greenhouses of the general type shown in these figures are built as wide as 85 feet and as long as desired.

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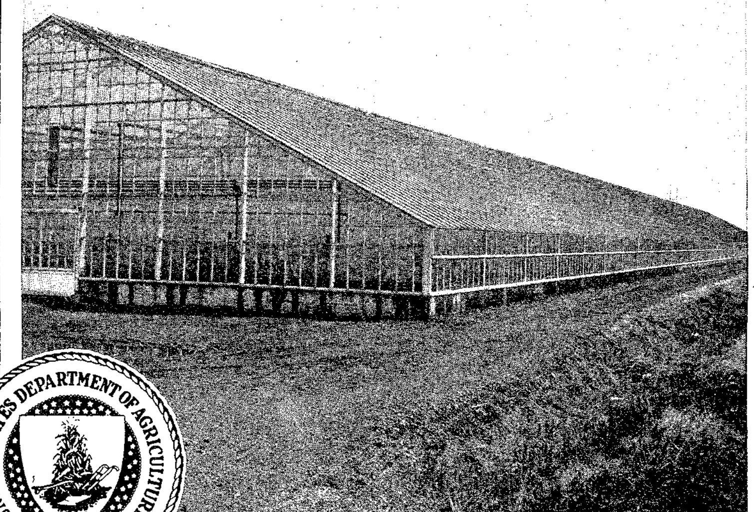
FARMERS' BULLETIN No. 1318

GREENHOUSE CONSTRUCTION AND HEATING



GLASS farming, or the growing of flowers and vegetables in greenhouses, has become an important industry in the United States.

High-quality greenhouse products are finding an increasing demand, and the industry offers special inducements to those having a knowledge of and a liking for the work.

Vegetables produced in forcing houses near the markets reach the consumer in a fresh condition, without the delays incident to long shipment.

Products of exceptionally high quality can be grown under glass, as conditions are more nearly under control than in the open.

In selecting a location for a greenhouse particular attention must be paid to the labor and fuel supply; also to the accessibility to markets.

This bulletin discusses the construction and heating of greenhouses, giving such information as will be useful to those who contemplate engaging in the business.

Washington, D.C.

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GREENHOUSE CONSTRUCTION AND HEATING

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CONTENTS

IMPORTANCE OF THE GREENHOUSE INDUSTRY

THE production of greenhouse crops in the United States is a large industry and has attained importance because of the demand for vegetable and floral products that can be produced in the modern greenhouse. Furthermore, under favorable conditions the cost of growing greenhouse crops permits the products being sold on the northern markets in competition with those shipped long distances from warmer portions of the country. The fact that greenhouse products are acknowledged to be superior in quality to those grown out of doors contributes materially to the development of the industry.

Success in growing vegetables or flowers under glass, in addition to the skill of the grower, will depend upon the suitability and adequacy of his equipment and the use which is made of it. The fact that the quantity of coal used to maintain each acre of space enclosed in greenhouses at the required temperatures varies from 250 to 500 tons a season indicates the need for the practice of every possible economy. Any feature of the construction of the greenhouse plant, its operation, or its upkeep which affects the quantity of fuel consumed immediately reflects itself as an item of cost in the production of greenhouse crops. Fuel losses in greenhouse heating are sustained because of poorly constructed houses, a faulty heating system, or the lack of repair of the house or the heating unit. As the principles of construction and heating come to be better understood it is altogether likely that greenhouse crops will be more economically produced, thus putting the operator on even a more favorable basis than at long distances and take a high freight rate.

The production of such vegetables as lettuce, cauliflower, beets, and radishes can be carried on in simple, inexpensive houses. The starting of the plants of cabbage, tomato, eggplant, pepper, and celery can be carried on with even simpler equipment. It is likewise possible to grow many floral or decorative crops in greenhouses requiring only a moderate outlay for their construction and equipment. In many cases the same houses may be used for both flowers and vegetables, but this practice is not usually followed except in small establishments.

Forcing houses are usually a profitable investment when operated in connection with a market-gardening or truck-crop enterprise. Many persons have found a greenhouse to be an excellent means for the utilization of a portion of their time. There are few enterprises so well suited to the needs of middle-aged or older persons who want some form of work as an entire or partial source of livelihood. Not all locations are adapted to greenhouse work, and the advisability of the undertaking for the individual must be determined after a careful study of the conditions. Most of the large greenhouse enterprises had their beginning in a small way, and it is always well for the beginner to locate his enterprise so that he will have room for expansion. Where there is but little chance that the enterprise will develop into a large business there may be an excellent opportunity for profitable plant growing to supply persons in the immediate vicinity.

LOCATIONS SUITED TO GREENHOUSES

In locating commercial greenhouse ranges several factors should be considered, the most important of which are (1) fuel supply, (2) labor, (3) marketing facilities, (4) soil, and (5) water. It requires from 250 to 500 tons of coal to maintain an acre of glass at the proper temperature for the season. The lower figure refers to ranges growing cool crops, such as lettuce, where the temperature is maintained at 40° to 55° F.; the higher figure, to ranges growing crops demanding temperatures up to 75°. Greenhouse plants so located that they can obtain cheap fuel have a distinct advantage over those less fortunately situated. A large plant should be so located either on a railroad or a canal that fuel can be placed in the boiler room without expensive handling. Many have been located at a distance from large markets because the fuel required could be secured more cheaply. Marked economies may result from such a location, as the weight of the fuel required to produce a greenhouse crop is many times the weight of the crop itself, and it may be cheaper to ship the crop than to ship the fuel.

An abundance of specially trained labor is essential to success in the greenhouse industry. Highly intensive working of the soil, such as is necessary to success in this business, requires that every square foot in the houses be utilized to the fullest extent, and this requires considerable labor. The average annual value of the greenhouse crop of the United States is about $20,000 per acre, and it is evident that each acre of glass will readily furnish profitable employment tions where the industry is already developed, this need not be a deciding factor in the location of a greenhouse, as help can soon be trained to perform the work in a satisfactory manner.

Nearness to market is desirable in many ways, but this need not be a deciding factor. It may be a better plan to build the greenhouse range where cheap land, fuel at low cost, and plenty of labor can be had, provided good shipping facilities are available. It is essential that the crop be placed on the market in the shortest practicable time, and the location of the plant where the product can be moved by truck, by fast express, or by other means, that will put it on the market a few hours after it is harvested undoubtedly has a distinct advantage. Although it is desirable that the greenhouse enterprise be located on good soil, this is not an essential, as good soil can soon be developed. When it is possible to make a selection of the type of soil on which the plant is to be located, a loam is to be preferred for most purposes. In houses without benches the natural soil is usually employed, while in houses fitted with benches and in other houses where the soil is changed from time to time it is possible to modify it to suit the crops to be grown.

Greenhouse crops require large quantities of water, and an ample, never-failing supply should be assured. For small enterprises it is usually more economical to use water from the city mains if it can be obtained. Larger plants requiring great quantities of water may find it more economical to maintain their own pumping plant and storage facilities.

The small greenhouse enterprise is often started as an adjunct to some other business, such as a store, and for this reason it is desirable to locate the structure so that the work can be performed easily. Many locations are totally unsuited to even small greenhouses. With the exception of a few crops grown in the dark, sunshine is essential to the growth of greenhouse crops. If the only available location is such that the greenhouse will be shaded for a considerable portion of the time, or if the location is such that excessive amounts of smoke, dust, acid fumes, etc., are present in the air, it may be inadvisable to enter the business. When it is possible to choose a location, a well-drained piece of land should be selected, preferably with a southern slope and where the house will be protected from winds by forests, hills, or artificial windbreaks. In many cases these small greenhouses are cared for by some member of the family, and it is often desirable to heat such a structure with the hot water or steam heater serving the residence. When this plan is to be followed, the greenhouse should be located at a higher level than the heater, to assure circulation.

LAY-OUT OF THE PLANT

The economical operation of a greenhouse plant depends largely upon the plan and arrangement of the units, such as the boiler room, the packing house, and the forcing houses. It is desirable that the packing room should be accessible to all of the houses by direct, all-indoor routes. The arrangement of the houses and of the remainder of the plant will be determined by the type of house to be erected and by the character of the site. Figure 1 illustrates noted that this arrangement offers an excellent opportunity for the economical handling of the product. Figure 2 shows a range of ridge-and-furrow houses with the boiler room and workroom so arranged that it is possible to receive coal and manure and handle, pack, and ship the product with a minimum of labor.

Figure 3 shows a greenhouse built without any consideration being given to economical operation. The boiler room is far removed from the packing house and is at a higher level than most of the greenhouses. The plant is upside down as far as the heating plant

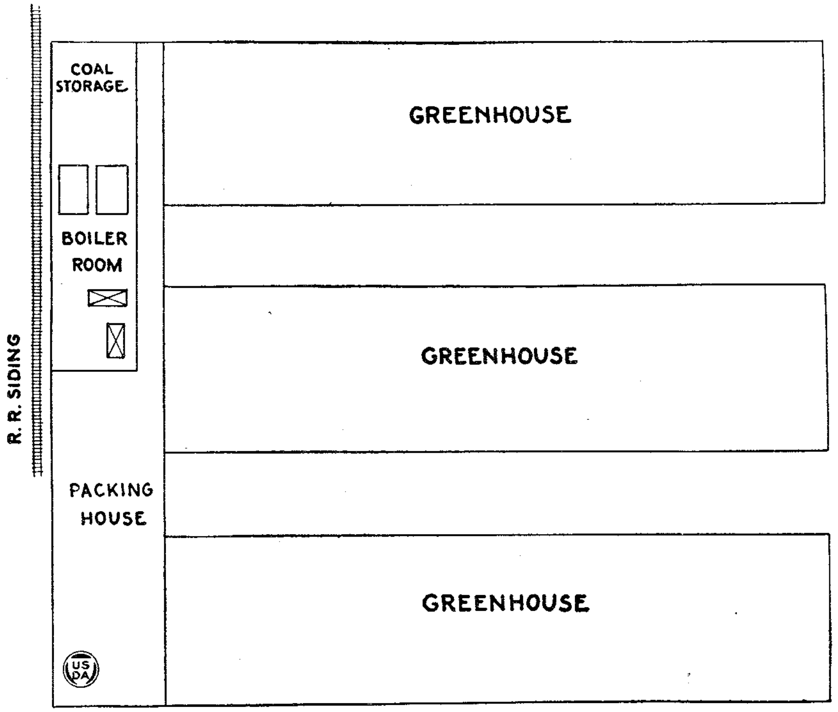

FIGURE 1.—Detached greenhouses with head house across one end; such a plan is often employed in building ranges of greenhouses. This arrangement facilitates the economical handling of the work.

is concerned, for it is necessary to pump all the condensation back to the boilers. No railroad siding is provided, and it is necessary to haul all the fuel to the boiler room and to haul all the product to the railway station. Such a plant costs far more to operate than does a well-planned one.

When it is desired to build a commercial range of greenhouses the plan for the whole range should be made at the start, so that the first house will be a unit that will fit in with the later houses in a harmoniously operating plant. It should be remembered that most greenhouse ranges have small beginnings and that the location of the first house should have careful consideration.

Several well-defined types of greenhouses are in use. The simplest is the lean-to house, which has a shed roof built against some existing structure.

The detached house, as its name signifies, is an independent structure, and may be of any size. For convenience in operating the plant, such houses are usually built in rows and connected by a head house built across the ends of the houses, as shown in figure 1.

Another type, known as the "contiguous" house, consists of several independent units built side by side in such a way that adjoining units have the same inside walls.

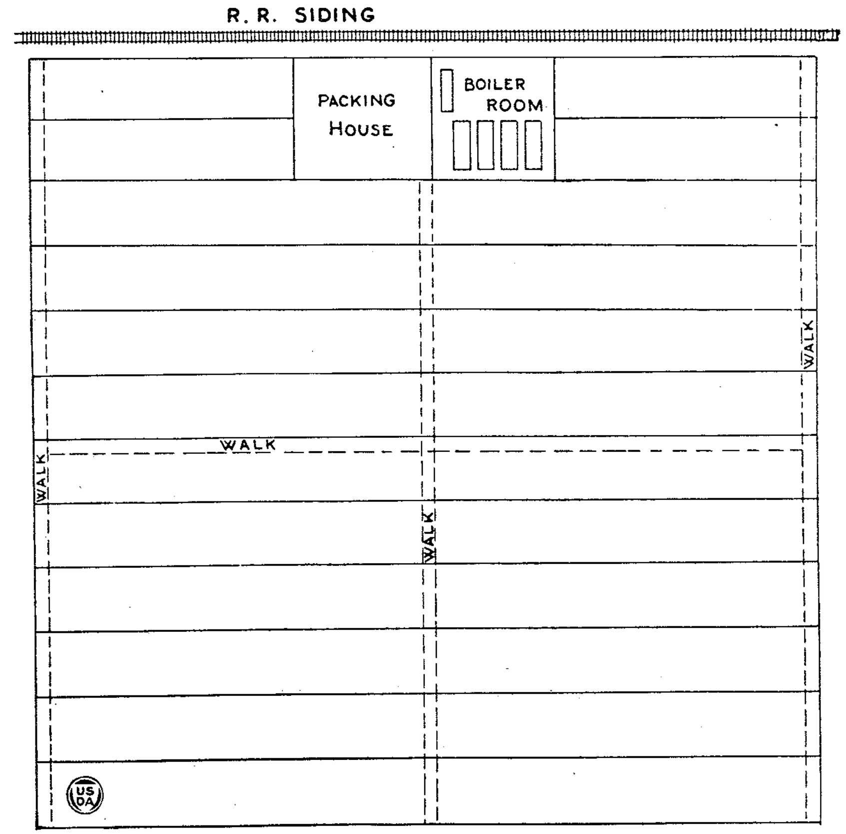

FIGURE 2.—A range of ridge-and-furrow houses well arranged to reduce labor to a minimum.

Another extensively used type is known as the "ridge-and-furrow house", the arrangement of the units in this type being similar to those in the contiguous house, but the inside walls are omitted and the gutters are carried on posts, so that all the units together form one large house (figs. 4 and 5).

The lean-to house is simple, inexpensive, and fairly satisfactory for some purposes and some locations. The contiguous type has built side by side, so that there is side ventilation on one side of each house, a thing impossible except in the two outside houses when several are built side by side. Both the ridge-and-furrow and the detached types of houses have much to recommend them, and most of the houses of new construction are of these types. As pointed out

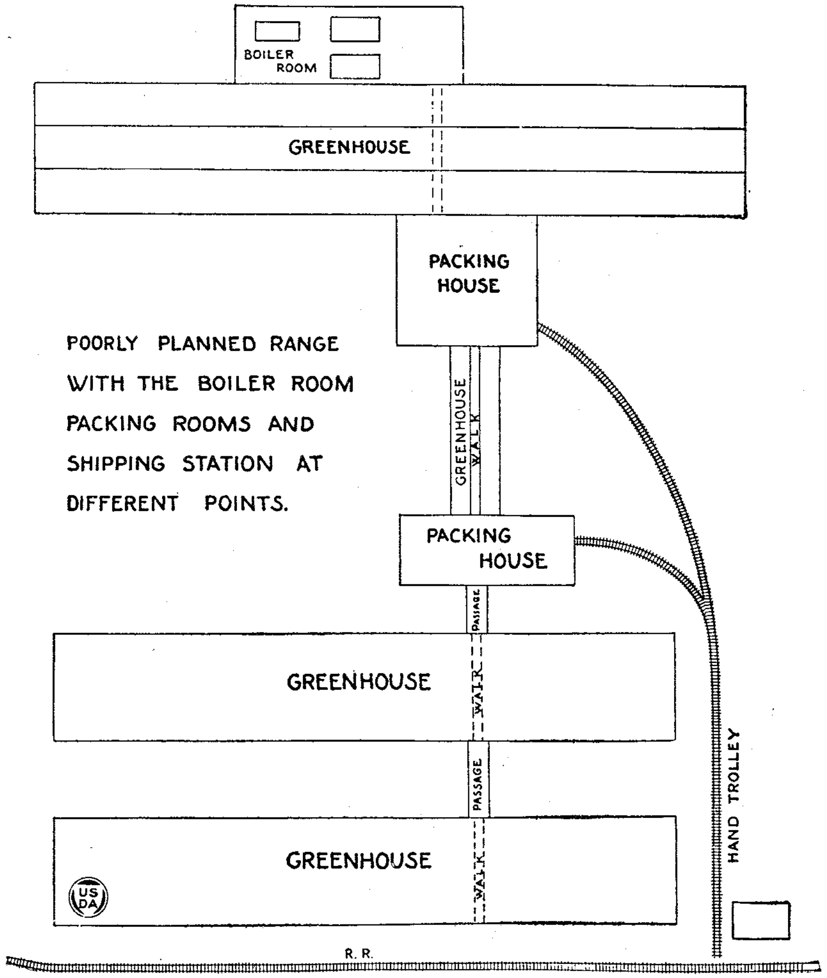

FIGURE 3.—A poorly arranged greenhouse plant.

in an earlier paragraph, the lean-to house always has a roof sloping one way.

The other types may have roofs with the ridge in the middle of the structure, such a house being an "even-span house"; or with the ridge three fourths or any other fractional distance from one wall or the other, making an uneven-span roof. Greenhouses with uneven span roofs are particularly desirable for sidehill locations. Any of these four types of greenhouses may have curved eaves or other simple and as inexpensive as is consistent with the purpose for which it is to be used. When, for instance, it is the purpose to produce

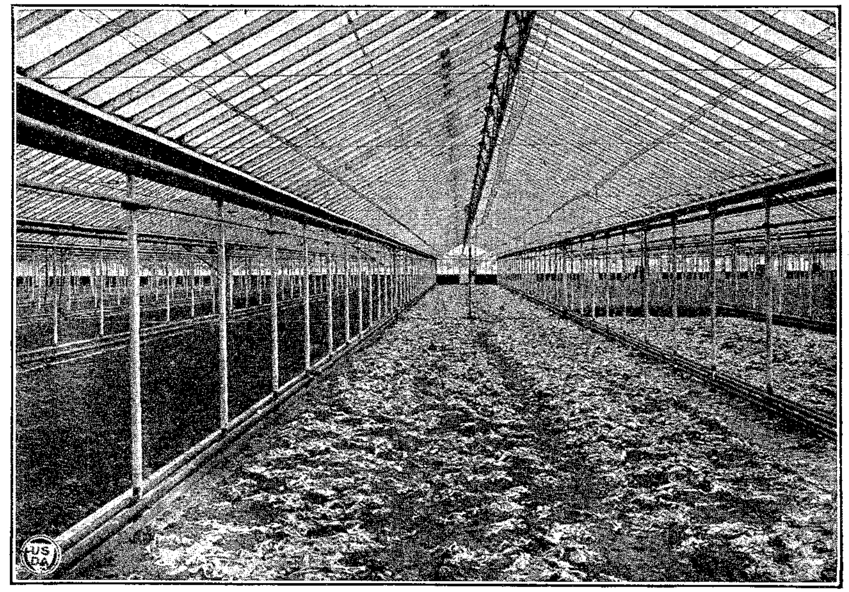

FIGURE 4.—Interior of ridge-and-furrow greenhouses.

vegetable plants, and in some cases some of the more common ornamental bedding plants, such as geraniums and scarlet sage, the houses may be of the simplest construction. If, however, it is the purpose to

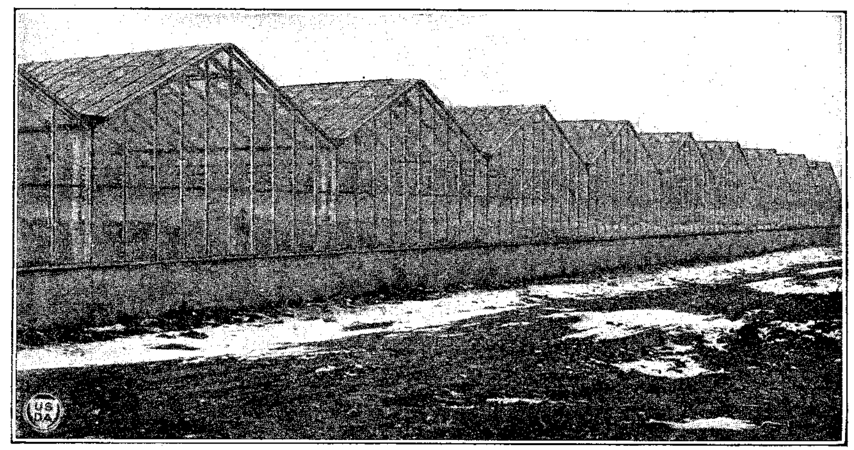

FIGURE 5.—Exterior of a range of ridge-and-furrow greenhouses.

grow winter vegetables and flowers for sale, the houses must be more elaborate and, of course, more expensive.

The necessity for a careful study of the conditions, so as to determine the particular line of work that is most likely to succeed, can simple equipment and the production of easily grown crops be too strongly urged. Many beginners in the greenhouse business fail because they attempt the production of such difficult crops as violets, roses, orchids, or muskmelons, when they probably would have succeeded with bedding plants, vegetable plants, or even greenhouse lettuce or carnations.

SIZES AND PROPORTIONS OF GREENHOUSES

It is usually better for those without greenhouse experience to start with a small unit, to which additions can be made. At the same time the house should be large enough to justify the full time and attention of the operator. A surprisingly large number of plants can be produced in a well-planned greenhouse of small size. In planning the house, it should be remembered that the proportions of the structure markedly affect the ease with which the work can be handled and the economical use of the space enclosed.

Most of the small houses used by beginners in the business are devoted to crops that make greenhouse benches desirable, and the house should be of such width that the space can be economically divided between walks and benches. They should be so proportioned that there is just room in the walks for the operator, and in the case of a house over 50 feet long, for a small truck or wheelbarrow for the placing and removal of the soil, manure, and the plants themselves. When the house is of such length that the use of a truck or wheelbarrow is unnecessary, a walk 2 feet wide will be ample. The benches should be of such width that an adult can just reach across them. A lean-to house 6 feet 8 inches wide, outside dimensions, and with one walk 2 feet wide allows just room enough for one bed 4 feet wide, this being about as wide a bed as the average person can reach across. (See fig. 15.) The house shown in this figure is of a type very frequently built by beginners.

Lean-to houses can be built of any desired width and with two or more walks, but this type of house is not at all common (fig. 6). A house 10 feet wide allows room for a 2-foot walk in the middle and two 3½-foot benches.

The same considerations of width hold for detached houses (fig. 16). Figure 16 shows an even-span house 10 feet wide. Where benches are to be used the next economical width of a house is 20 feet, which allows for 2 walks, 2 side benches, and 1 middle bench about 7 feet wide, the middle of which can be reached from either aisle (fig. 17). The above considerations as to width do not apply to houses not fitted with benches, where the crops are to be grown on the ground or in slightly raised ground beds, as is usually the case with vegetable houses. These structures can be any desired width, as in such houses it is usually possible to cultivate the crops with hoes or other long-handled tools, or from boards resting on the curbs or on low trestles set on the walks along the sides of the beds. At the present time the tendency is toward very large houses, those 60 to 80 feet wide and 500 to 600 feet long being not uncommon. The house may be of any required size, depending upon the use to be made of it and the character of the site.

It is always desirable to secure greenhouse materials from concerns making a specialty of their manufacture, as practically all parts of a greenhouse are of special character and have been evolved through many years of experience in building such structures. The earlier houses were of extremely heavy construction, and while strong they were open to the objection that a large portion of the light was kept out by the size of the framework. The structure has been gradually lightened through the use of better materials, until the frame of the modern house presents very little obstruction to the entrance of light.

FOUNDATIONS

The foundation of the greenhouse must not only carry the weight of the structure but must tie it to the ground and support it against

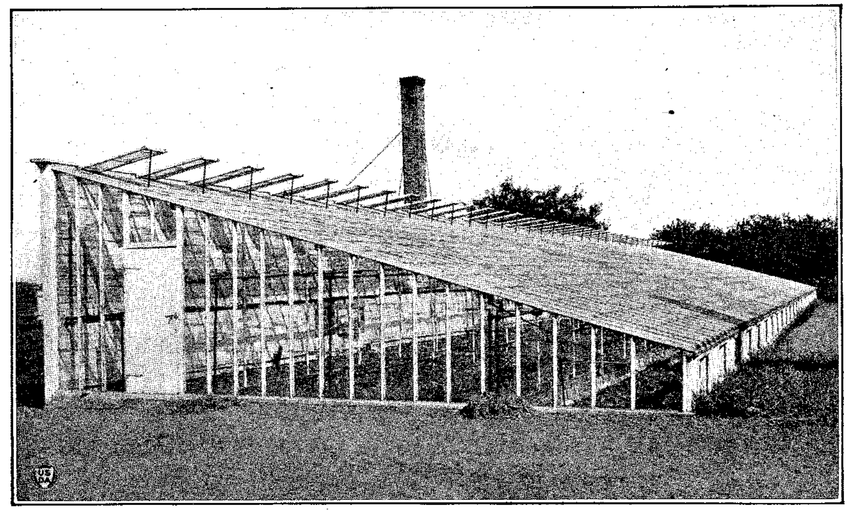

FIGURE 6.—Lean-to house with two or more walks, which may be of any desired width. Instead of the house shown here being built against an existing wall, it was constructed with one wooden wall.

the force of the wind and the weight of snow and ice. Many of the difficulties experienced by greenhouse owners have been due to the fact that their houses were built without sufficient foundations. The character of the foundation necessary is determined by the kind of house to be built and by the subsoil. With simple houses supported on wooden posts it may be sufficient to have concrete or masonry footings under these posts, while with semi-iron or steel-frame houses it may be necessary to have continuous footings under the walls; the footings should extend below the frost line and should be of sufficient size to support the structure during the heaviest snowstorms and the highest winds. Without sufficient foundation for the house, settling is almost sure to occur, causing the glass to loosen or be broken, the doors to sag, the gutters to get out of line, and the structure to weaken generally.

The frame of the greenhouse may be of wood or of a combination of wood and steel. The all-wood structure, as the name suggests, has wooden posts, sheathing, gutters, sash bars, etc. The portion of the wall from the top of the foundation to where the ventilators begin is usually sheathed, covered with paper, and then sided. The house is fitted with wooden plates and gutters, the latter resting on top of the side posts, and frequently the braces, ties, and purlins used on the inside of the structure are made of steel pipe when the width of the house requires such support. Many ridge-and-furrow houses are of this type of construction.

The semi-iron house is a combination of wood and steel members, with bar, channel, or pipe posts embedded in the concrete side walls and an angle-iron eave plate or an iron gutter attached to the posts and sash bars by special fittings. These houses have inside pipe posts with pipe or angle-iron purlins and purlin braces. Such a house is described later (fig. 17). In this house the pipe posts are embedded in the concrete side walls, the method used being to set the posts in position first and pour the concrete around them. This house is 20 feet wide and has two rows of inside posts, but for narrower houses one row of posts is sufficient. For houses of moderate width this type of construction is admirable.

The steel-frame house differs from the semi-iron house in that the roof is supported by built-up structural members carried by side posts set in the side walls. For houses of this type up to 40 feet wide no inside posts are ordinarily used, while houses as wide as 80 feet can be built with but two rows of inside posts, these being made usually of steel pipe, rarely of wood. The steel-frame house is generally used for large-sized units. However, the person just starting in the greenhouse business with the idea of growing the simpler crops will usually find a less expensive type satisfactory for his purposes.

Whether the all-wood, the semi-iron, or the steel-frame type of house be selected, the superstructure while sufficiently strong to withstand the hardest storm must be made of parts so small that little shade will be cast. This requirement has led to the general use of iron and steel instead of wood. For certain parts of the greenhouse wood is looked upon as an ideal material, while for other parts iron or steel is best. The uses to which each material is best adapted will be discussed in the following pages.

POSTS

The posts supporting the greenhouse side walls and roof may be of wood, wrought-iron or steel pipe, or of structural steel in the form of bars, channels, or I beams. The conditions in a greenhouse are particularly favorable for decay or corrosion, and whatever material is used must be well protected from decay or rusting. Wood should be of a decay-resisting timber, such as redwood, cedar, or cypress, and it is usually advisable to soak the portion that goes in the ground in creosote or some other wood preservative, and embed it in concrete. Figure 7, *C*, shows the usual method of constructing greenhouse walls with wooden posts. When iron-pipe posts are wooden posts are employed only when wooden gutters are used, and the gutter is secured to the top of the posts. When steel posts or pipe posts are used, either with wood or semi-iron houses, the gutter or angle-iron eave is secured to the posts by means of special post top fittings (fig. 8, *A*). When the steel-frame house is employed, the roof trusses are riveted to the posts, and special post top fittings are used.

Inside posts may be of wrought iron, of steel pipe, or structural steel, or of wood. The tendency is toward the use of steel pipe or structural steel, as this class of material is light, strong, and of small size as compared with wooden members suitable for the same uses (fig. 8, *B*). In wider houses the same material is used, as is brought out in figure 8, *C*. In all cases where pipe is used for inside posts and braces it is necessary to use special fittings to fasten the members together, as shown in figure 8.

BRACES, TIES, AND PURLINS

The sash bars carrying the glass must be supported at close intervals by the frame of the greenhouse. The distance between these supports varies with the type of house and the size of the sash bar, but unless these supports are spaced not over 8 feet apart trouble is likely to be experienced through sagging and possible breakage, especially under heavy loads of ice and snow. The purlins employed to give this support in wooden or semi-iron houses are of angle iron, I-beam steel, or pipe. They are either carried on top of posts or by braces to the posts (fig. 8, *B* and *C*). In steel-frame houses the purlins are carried either on posts or by the trusses supporting the roof.

The greenhouse must bear heavy strains due to winds, snow, and ice and must be well braced so that it will be perfectly rigid. The side walls of wood and semi-iron houses are usually tied together at the eaves with rods fitted with turnbuckles. There is a tendency for the houses to spread, owing to the weight of the roof, and these ties counteract this tendency. The tie rods are usually spaced about 10 feet apart. The roof is also braced against twisting by tie rods running in diagonal directions from the purlin braces to the eaves. These braces are usually installed only on every third or fourth set of purlin braces. Even in steel-frame houses this bracing is desirable.

GUTTERS AND EAVE PLATES

The wooden gutter is expensive and unless kept well painted is short-lived and likely to leak through the joints. Cast-iron and steel gutters are used and give satisfactory results, but must be kept well painted, or they, too, will deteriorate. In houses such as ridge-and-furrow houses and contiguous houses inside gutters must be used, and these should be of as simple construction as possible. Figure 7, *B*, shows a type of gutter that is simple and efficient.

Many detached houses are now being built fitted with angle-iron eave plates, such as are illustrated in figure 8, *A*. The house shown on the title-page of this bulletin is built in this manner. Such construction is long-lived and strong and does not allow snow and ice

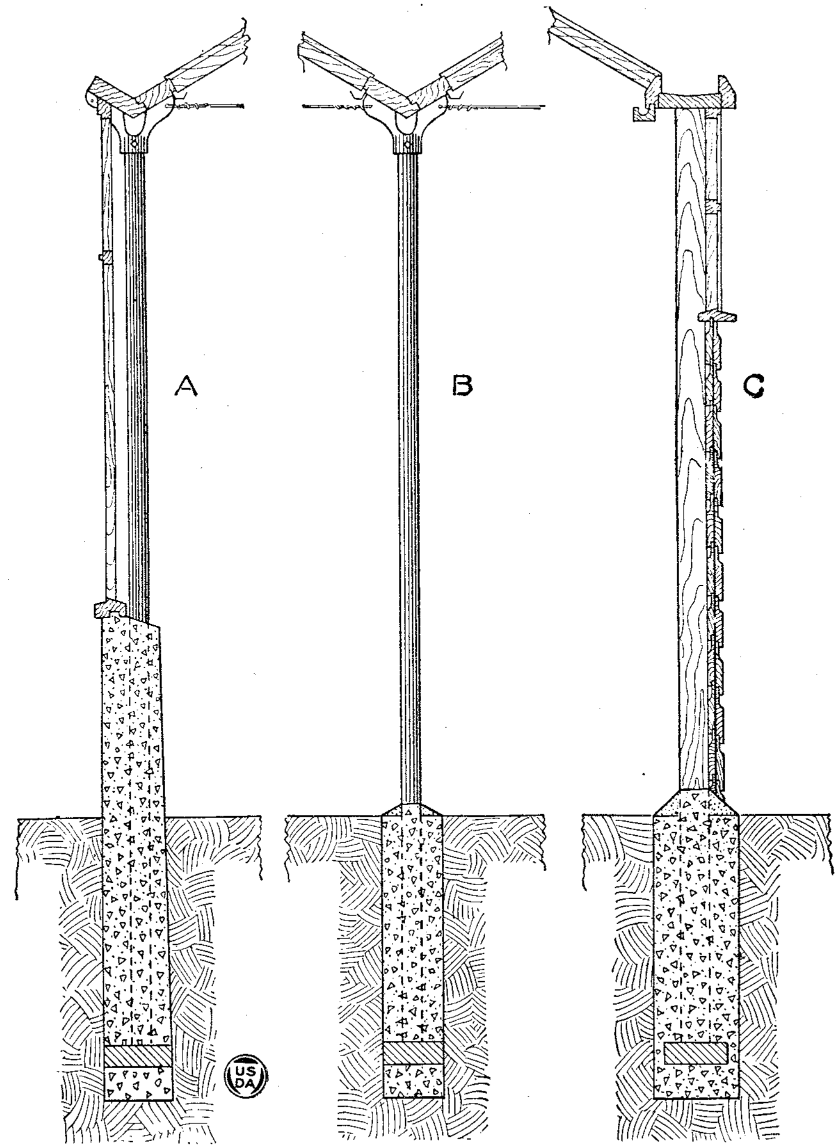

FIGURE 7.—Detailed plans of walls, posts, and gutters for a ridge-and-furrow house: *A*, Outside wall with iron post embedded in concrete; post top fitting and wooden gutter construction; *B*, inside gutter with iron-pipe post; *C*, outside wall, wooden post, gutter, and sheathing.

water running off the roof and convey it to the sewer. Provision for such drainage can be made by constructing a gutter alongside the greenhouse, into which the water can fall from the roof.

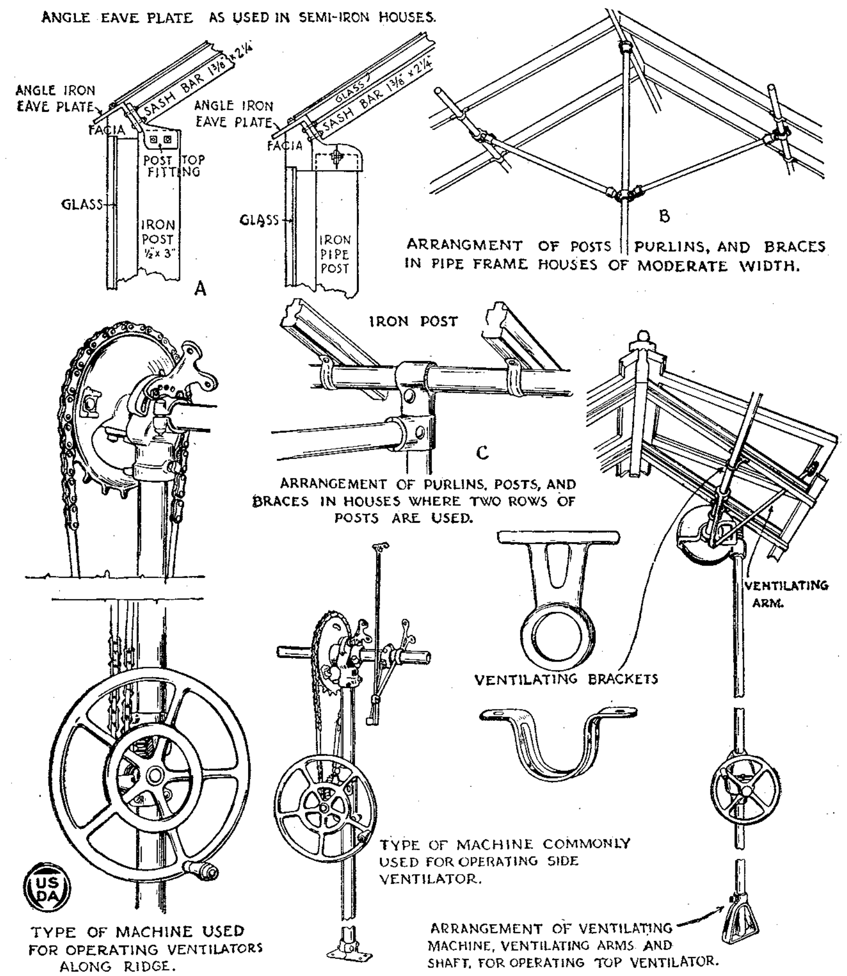

FIGURE 8.—Details of construction of special features for a wooden or a semi-iron greenhouse: *A*, Iron and iron-pipe posts with special top fittings; *B*, arrangement of inside posts and braces where one row of inside posts is used; *C*, when two rows of posts are used they are usually placed under the purlins and tied together, as shown.

RIDGE CONSTRUCTION

In wooden and semi-iron greenhouses the ridge members are usually of wood (fig. 9). The size and type of the ridge parts are determined by the character and size of the house, but typical ridge parts are shown in the illustration. It will be noted that the sash bars are inserted so far below the top of the ridgepole that there is room between the top of the sash bars and the cap for the ventilator ried on top of a steel I beam, this construction being necessary on account of the methods used in constructing the roof frame. The wooden parts are used for convenience in attaching sash bars, cap, and ventilators.

SIDE WALLS AND ENDS OF THE GREENHOUSE

The portion of the side walls of the greenhouse not occupied by masonry foundations and ventilating sash is constructed of sash bars and glass. In cases where high masonry walls are used, the remainder of the side walls is usually taken up with ventilators (fig. 10). In cases where the ventilators occupy but part of the

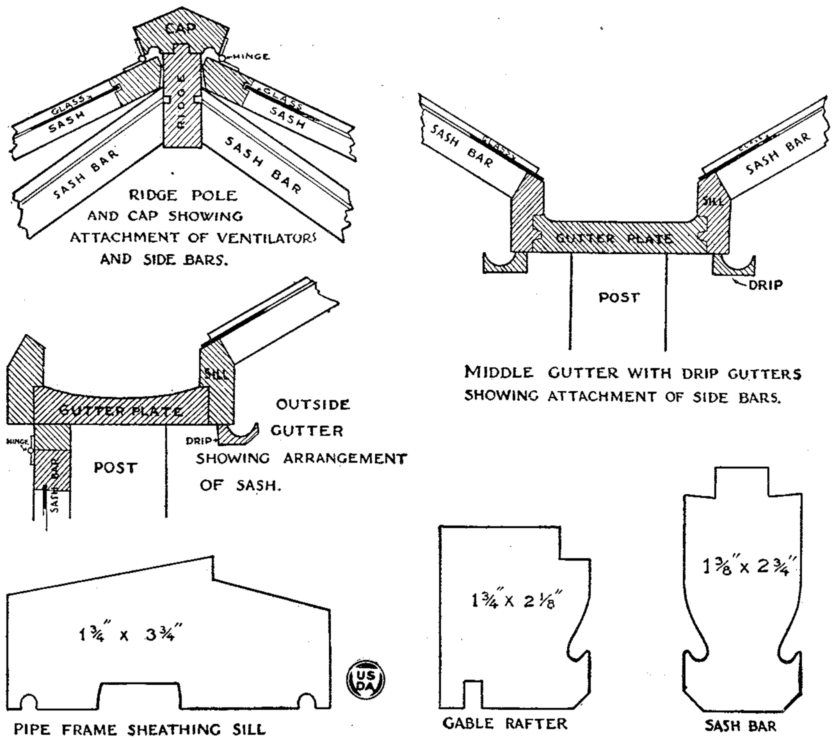

FIGURE 9.—Some greenhouse parts made of wood.

space between the top of the masonry walls and the eaves, it is necessary to use a plate located at the bottom of the ventilators, this serving as an attachment for the sash bars.

Aside from the portion occupied by masonry construction and doors, the ends and gables of the greenhouse are usually of sash-bar and glass construction. Owing to the pressure exerted by the wind on such exposed parts, it is necessary that the gable end be well braced. In small houses the area exposed is so small that the purlin ends are a sufficient brace. In semi-iron houses a set of posts and purlin braces is sometimes placed at each end to give strength to the structure. In steel houses one of the roof trusses is placed at each end and the gables attached to these. The doors are nearly always

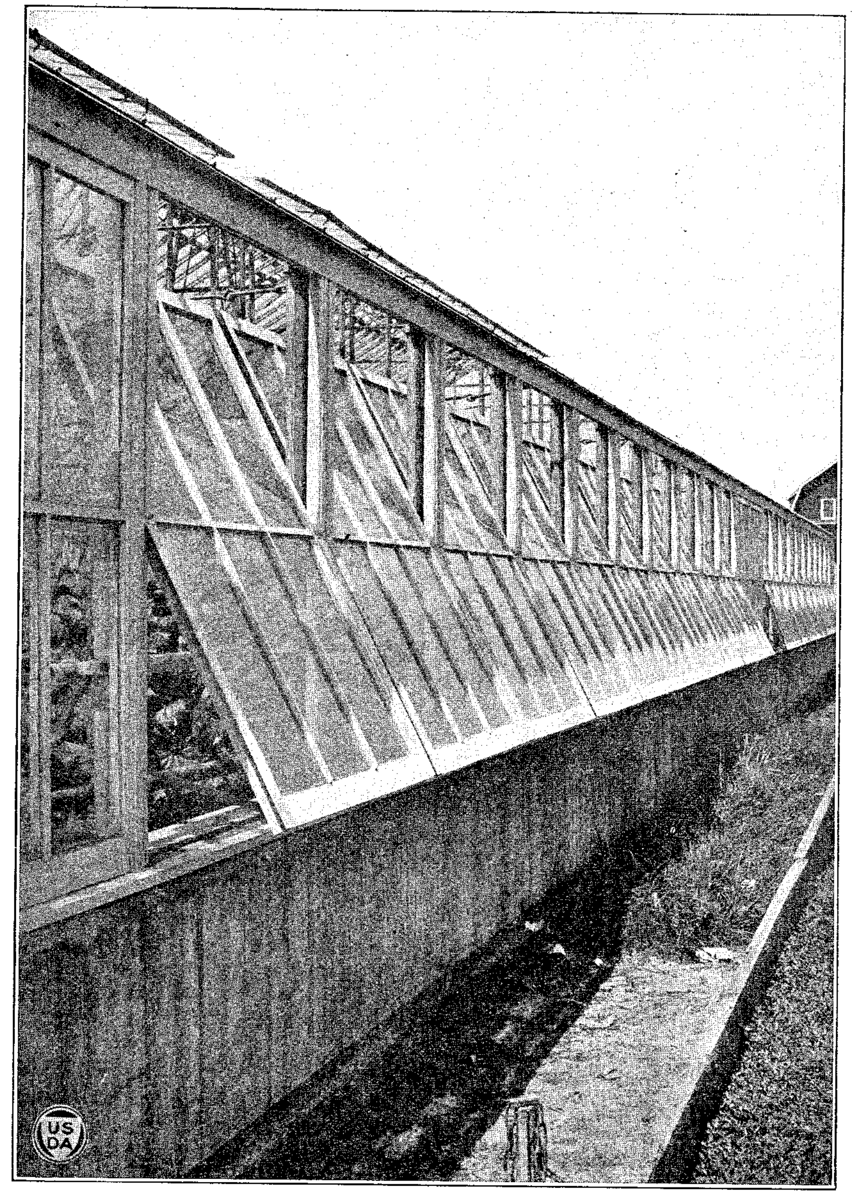

FIGURE 10.—A type of construction where the portion of the wall of the greenhouse between the masonry and the eave plate is taken up with ventilators.

doors should be of such size that easy access can be had to the structure for the placing and removal of soil, manure, and implements required in the work (fig. 11).

SASH BARS

The sash bars in a greenhouse serve the same function as the rafters in a house—that is, they carry the roof itself, in this case the glass. The usual form of wooden sash bar is illustrated in figure 9. Sash bars are made in a variety of sizes and shapes. There are several makes of metal sash bars but wood is most largely used. Heart cypress is the material ordinarily selected for the making of sash bars, and, needless to say, it should be of first grade. Where it is possible the bars should run the full length of the roof without

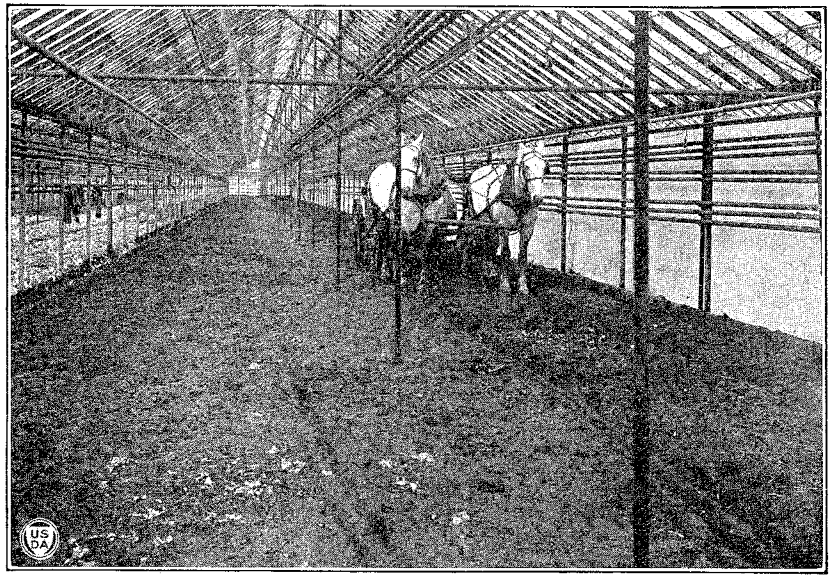

FIGURE 11.—Hauling manure into a greenhouse fitted with end doors large enough to admit a team and dump wagon.

splices, but in wide houses it is necessary that splices be made, and extreme care should be exercised to make these tight and strong. Owing to the small size of the sash bar, metal plates, as a rule, are used to make the splice strong.

Sash bars are spaced to accommodate the width of the glass to be used. Most greenhouse glass is 16 inches wide by 24 inches long. The sash bars have a tongue one half or five eighths of an inch wide, and this comes between the different courses of glass, so the sash bars must be spaced 16½ or 16⅝ inches apart, as the case may be. As a rule, no extra clearance for the glass need be left, but where the sash-bar tongues are full dimension and are heavily coated with paint an additional clearance or space of one thirty-second to one sixteenth of an inch should be allowed, so that the glass will fit close but not bind along its edges. In houses using angle-iron

these being bolted or riveted to the plates. The sash bars are attached to pipe purlins by clips, such as are shown in figure 8, *C*, to angle purlins by bolts or screws, and to the ridgepole by screws or nails.

MISCELLANEOUS STRUCTURAL PARTS

Practically every part of the greenhouse is of special construction, having been developed through a long period of time and especially adapted to some particular part of the structure. In the foregoing paragraphs some of these special fittings and parts have been described. Figures 8 and 9 show these and other parts. It is never advisable to attempt to use any but the parts and fittings adapted to the purpose. These can be procured from firms making a specialty of their manufacture.

VENTILATION

Any greenhouse, however small, must be fitted with suitable means of ventilation. In the lean-to house, such as is shown later (see fig. 15), the ventilators as a rule are placed in the side walls below the gutter and in the roof along the ridge. In detached houses, side ventilation and roof ventilation are usually deemed necessary. The ventilators in any house may be placed at intervals of a few feet or may be a continuous line of sash extending the length of the house. For most types of houses the latter kind is preferable. For roof ventilation the sash is hinged at the ridge, the joint being protected by a cap extending over each side of the ridgepole (fig. 9). The ventilators are operated by a machine so arranged that it is within convenient reach of the operator. Figure 8 shows the arrangement of the ventilators and ventilating machines in a medium-sized house. Ventilating machines capable of operating long lines of sash can be obtained, but it is never wise to overload the machines by attaching them to longer lines of sash than they are designed to handle, or breakage may result. In small houses it is sometimes feasible to avoid the expense of a ventilating machine by simply raising the individual ventilating sash and securing it at the desired height with a notched stick or flat iron bar attached to the ventilator sash, with holes every 2 or 3 inches which allow the bar to be secured at any desired point. Such devices are not very satisfactory and should be employed only as temporary expedients.

Side ventilators are usually hinged at the top where the joint can be protected by a drip cap, or they may be pivoted in the middle. The illustration on the title page shows a house with hinged ventilators, and figure 10 shows one equipped with the pivoted type. The pivoted type is less desirable and it is not generally used. Side ventilators as a rule are operated by machines, but they can be opened and closed by hand. Figure 8 shows some of the more important parts of the ventilating equipment. Planning the greenhouse so that standard-sized sash can be used for ventilators makes it possible to secure these along with the other greenhouse material.

Moisture conditions existing in the greenhouse make it particularly desirable that all parts be kept well painted. At least one coat of paint should be applied before the structure is erected. For wooden parts a white-lead, zinc, and linseed-oil paint or an aluminum paint primer is used, while a red-lead oil paint is satisfactory for the metal parts. After erection, at least two coats of paint should be given, and it is a good practice to apply at least one coat each year thereafter. New sash bars should have at least two coats of paint before the glass is placed. Unless this is done the putty is likely to come loose through having its oil absorbed by the fresh wood.

There is a great difference in the light-transmitting qualities of different grades of glass, and it is especially important that a good grade be used. The best glass is designated "AA", while the next grade is "A", and the third "B." Grade A glass costs much less than the AA grade and is usually satisfactory for greenhouse glazing. The tendency at present is to use large glass, as this means fewer sash bars to cast shadows in the houses. Most of the houses now being built are arranged for glass 16 inches wide by 24 inches long. The glass is lapped one eighth of an inch, this being sufficient to prevent leakage. A greater lap than this would be likely to cause breakage, due to the freezing of moisture between the panes.

Greenhouse glass is bedded in putty or some other glazing compound in order to make the roof watertight and to exclude cold air. The putty or other glazing material may be applied to the sash bars, the glass pressed down into it and then secured in place with special 5/8-inch glazing nails, 2 about 2 inches from the end of the pane, 2 about the middle, and 2 directly below the lower edge of the pane, to keep it from slipping downward. In setting the glass it should be remembered that most glass is slightly curved, or is "right" and "left", according to the term used by glaziers. The glass should all be placed with the curve up, so that the joints will be perfectly tight.

GREENHOUSE HEATING[1]

Fuel is one of the large items of expense in the operation of a greenhouse. Economical heating equipment properly handled is essential to the profitable operation of the plant, and careful attention to the planning and installation of this part of the equipment of the greenhouse is necessary. The finest greenhouse may give unsatisfactory results because of poor heating facilities. There are many forms of heating equipment for greenhouses, and the one best adapted to the needs of a particular case must be determined by such considerations as the size and type of the house, the crops to be grown, the attention that can be given the heating plant, and the kind of fuel available. The requirements of a heating system are (1) it must be capable of maintaining the proper temperature for tion and not require too close attention, (3) it must be adapted to the fuel to be used, and (4) its cost must not be out of proportion to that of the remainder of the plant and to the value of the crops to be produced.

[1] This bulletin was prepared especially to meet the requirements of the farmer or greenhouse man who might want to buy material and construct a small or medium-sized greenhouse in which no particularly difficult engineering problems would occur. Greenhouse heating is more fully covered in U.S. Department of Agriculture Circular 254, Greenhouse Heating. Out of print, but may be consulted in libraries.

OIL AND GAS HEATERS AND STOVES FOR SMALL GREENHOUSES

The Department of Agriculture receives frequent inquiries as to the suitability of oil and gas heaters for small greenhouses. Such devices are adapted only to very small houses, and, owing to the injurious effects of the products of combustion, extreme care must be taken to ventilate properly, or the plants will be injured if not killed. Such heaters should have a pipe for the removal of the products of combustion, and their use is not to be recommended except as a temporary expedient.

Coal and wood stoves are also objectionable, owing to the difficulty in obtaining an even distribution of the heat and to the dust that is always incident to their operation. It would be unwise to build a greenhouse with the intention of depending on such heaters.

FLUE HEATERS

Flue heaters made of brick or masonry located under the benches and running the length of the house are sometimes used, and, while they are superior to stoves and similar devices, only fair results can be expected from their use. Where low first cost is essential and where only crops requiring low temperatures are to be grown, their use may be advisable. They are usually constructed with the furnace at one end of the greenhouse, so that it opens into a separate room, usually the structure used as a workroom. This furnace is usually built of brick, with iron grates and iron doors, which may be obtained from firms making a specialty of this type of equipment. The size of the furnace depends on the size and length of the house, but a furnace 13 inches wide, 16 inches high, and 3 feet long is large enough to heat a house 10 or 12 feet wide and 60 to 80 feet long. For the first few feet the flue is lined with fire brick and has walls 9 inches thick that are arched over the top; the remainder is usually of ordinary building brick, and the walls are 4 inches thick. The last half of long flues may be of terra cotta of suitable size, with the joints closed with fire-clay mortar. The chimney itself may be of brick or terra cotta, and should be sufficiently high to give good draft. It is usually located at the opposite end of the greenhouse from the furnace, but in some cases the flue is carried around the inside of the house the entire distance, and the chimney is located in the workroom or the opposite corner from the furnace. To insure draft the flue should have a slight rise from the furnace to the chimney. These heaters cause more or less dust, and in houses where they are used it is difficult to maintain the proper moisture conditions. As a means of heating greenhouses the flue heaters leave much to be desired.

STEAM AND HOT-WATER HEATING

The gravity hot-water heating system with cast-iron boiler and large cast-iron pipe came into general use in greenhouse work as the

The use of this principle in heating is not at all new, as according to historical records the Romans employed hot-water heating systems with copper boilers and copper pipe to heat hotbeds used for the production of winter luxuries. Its use in this country dates back about a half century, and improvements have been made from time to time until the modern hot-water heating system, when properly installed, is highly economical and efficient. Such a system is particularly desirable for small houses and ranges where it is impossible to give close attention to the heater, for a well-planned hot-water heating system can be depended on to maintain a uniform temperature with a minimum of attention. In ranges containing less than 20,000 square feet of glass hot-water systems are usually looked upon as best, while for larger plants steam is believed to be more economical. In large plants where firemen are in attendance most of the time it is possible to maintain a uniform temperature with steam. Steam requires less radiation than does hot water and is usually less expensive to install. However, within the past few years the use of forced-circulation hot-water systems has brought about results comparing favorably with the most efficient steam systems. On the other hand, the development of so-called low-pressure and vacuum systems has made steam heat more popular than ever. It is altogether probable that both systems will continue to have their advocates and that both will be used to a large extent. It is believed that gravity-circulation hot-water systems will prove to be the most desirable in small greenhouses.

THE GRAVITY HOT-WATER SYSTEM

The gravity system of circulation works on the principle that hot water is lighter than cold water and the water when heated tends to rise to the highest point in the system. The principle is well illustrated by the ordinary house-range boiler, where the water is heated in the coil in the range and passes through the top pipe to the boiler, being replaced at the same time by cooler water through the bottom pipe, this process going on indefinitely. In greenhouse practice the heater is usually located lower than the heating pipes, and as the water heats in the boiler it expands and rises, forcing the cold water ahead of it, and finally makes the circuit of the system and enters the boiler through the return pipes attached near the bottom of the boiler. Figure 12 illustrates the principle upon which this system works. In practice the main or flow pipe is branched so as to provide the proper amount of radiating surface; this illustration is diagrammatic only. In the older installations it was the practice to have the highest point in the system at the end of the house farthest from the boiler, but the modern method is to have it immediately above the boiler, so that the water flows downhill for the entire distance through the house, as brought out in the diagram. The important point to bear in mind in planning a hot-water heating system is to have the pipes uniformly graded and to avoid short turns and bends, so that the water will have an uninterrupted course through the entire system. Another important point to remember is that water expands as it warms, and as the system is filled with water it is essential to provide an expansion tank to take care of this increase in volume.

quired to keep a greenhouse at the desired temperature. This is usually figured as square feet of pipe surface and is referred to as "feet of radiation." The most practical method for ascertaining this is to determine the number of square feet of glass in the greenhouse, and after taking into account the temperature to be maintained, to allow a definite amount of radiation for each 1,000 square feet of glass or its equivalent. By equivalent is meant the side walls of wood or masonry construction, 4 or 5 square feet of each side-wall surface being figured as requiring the same amount of radiation as 1 square foot of glass. Table 1 is as satisfactory perhaps as any that can be devised, but no table can be followed absolutely under all conditions. The geographical location, the exposure of the house to winds, the tightness of the houses themselves, and other factors must be taken into consideration in figuring radiation. The amount of radiation required must be determined in accordance with the temperature to be maintained in the house and in accordance with probable outside temperatures, proper allowance being made for any unusual conditions.

TABLE 1.—*Temperature to be maintained and number of linear feet of pipe required per 1,000 feet of glass or equivalent to supply this temperature under varying outside conditions* [1]

Temperature to be maintained in house (° F.)	Low-pressure steam system using—											
	1¼-inch pipe for a probable outside temperature of—						1½-inch pipe for a probable outside temperature of —					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	132	190	249	309	366	425	115	166	217	270	319	371
45 to 50	169	230	291	352	413	474	148	201	254	307	361	414
50 to 55	207	270	333	397	459	523	181	236	291	347	401	457
55 to 60	245	314	377	440	508	571	215	274	329	384	443	498
60 to 65	289	358	425	493	562	629	252	313	371	430	491	549
65 to 70	335	406	478	549	621	690	292	354	417	479	542	602
70 to 75	394	469	546	621	699	769	345	409	477	542	610	671

Temperature to be maintained in house (° F.)	Gravity-circulation hot-water system using—											
	2-inch pipe for a probable outside temperature of—						3½-inch pipe for a probable outside temperature of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	189	272	357	442	523	609	116	167	219	272	323	374
45 to 50	242	330	418	505	592	680	150	205	258	312	366	422
50 to 55	304	397	490	581	676	769	188	245	302	360	418	474
55 to 60	368	472	568	662	763	862	231	296	356	415	481	540
60 to 65	446	549	654	757	862	971	278	342	408	472	540	606
65 to 70	529	641	752	869	980	1,087	333	403	476	549	617	685
70 to 75	613	735	855	971	1,099	1,205	391	467	543	617	694	763

[1] This table is based on the use of 1¼- and 1½-inch pipe for low-pressure steam and on 2- and 3½-inch pipe for gravity-circulation hot-water heat. The data in this table are suitable for well-constructed houses in good repair. For poorly constructed houses or those in bad repair or under other unusual conditions more radiation should be added.

1,000 square feet of glass exposed can readily be determined by taking fractional parts of the amount necessary for each 1,000 square feet or by taking one tenth of the amount necessary for each 1,000 square feet and multiplying this by the number of hundred square feet of glass exposed. In practice it is always desirable to use one size of pipe for the mains and another size for the radiating coils.

Table 2 gives the number of linear feet of pipe of different sizes that mains of given sizes will supply. In most cases it is a good plan to figure the radiation needed and supply it in the coils, disregarding that supplied in the mains.

TABLE 2.—*Length of pipe radiation to be served by new, clean mains with ends reamed when combined length of supply and return mains does not exceed 200 feet*

Size of main (inches)	Length of radiation pipe			Size of main (inches)	Length of radiation pipe		
	1¼-inch gravity steam	2-inch gravity hot water	3½-inch gravity hot water		1¼-inch gravity steam	2-inch gravity hot water	3½-inch gravity hot water
	Linear feet	*Linear feet*	*Linear feet*		*Linear feet*	*Linear feet*	*Linear feet*
1¼	183	80	50	3	1,740	1,100	660
1½	285	140	80	3½	2,610	1,700	1,000
2	577	320	190	4	3,680	2,600	1,500
2½	953	650	380				

As an example, suppose that a certain house has the equivalent of 1,000 square feet of glass exposure and is to be maintained at 60° to 65° F. inside temperature against zero outside temperature by a gravity hot-water system using 2-inch radiation pipe. By referring to tables 1 and 2 it will be found that 650 feet of 2-inch pipe will give the desired amount of radiation, and that a 2½-inch main will supply it. The amount of radiation and the size main for any moderate-sized house can be determined in the same manner.

HOT-WATER BOILERS

Many types of hot-water boilers are available for gravity hot-water heating systems, but the cast-iron sectional boiler is largely employed in plants requiring not over 10,000 feet of radiation. Some manufacturers recommend two or more boilers for this amount of radiation. In the larger plants steel boilers are usually employed, either the ordinary fire-tube type or the Scotch marine. In some of the later and more up-to-date plants water-tube boilers fitted with mechanical stokers are employed. The type of boiler should be adapted to the conditions rather than selected because of its being of any particular type or material. For the best results the boiler should have a greater rating than is theoretically required to maintain the desired temperature. In planning the heating system, the first step is to determine the amount of radiation needed to maintain this temperature. The boiler-grate areas required to serve various amounts of hot-water or steam radiation are shown in table 3. In greenhouse practice it is often impracticable to have a fire- than is absolutely needed for the work will usually give more satisfactory results than a small one that must be forced.

TABLE 3.—*Grate areas, sizes of chimney flue linings, and heights of chimneys recommended for flat-grate boilers burning bituminous coal*

Radiation supplied (linear feet of pipe coils)				Grate area	Size of chimney-flue lining [1]		Height of chimney above grate
Hot water		Steam			Round (diameter)	Rectangular	
2-inch	3½-inch	1¼-inch	1½-inch				
				Square feet	*Inches*	*Inches*	*Feet*
400	240	350	300	2	11¾	8½ by 13	24
675	400	575	500	3	13	13 by 13	26
940	560	800	700	4	13	do	30
1,270	755	1,090	950	5	13	do	32
1,675	1,000	1,440	1,250	6	17¼	18 by 18	30
2,000	1,190	1,725	1,500	7	20½	20 by 20	32
2,400	1,430	2,070	1,800	8	20½	do	35
2,950	1,750	2,530	2,200	9	20½	do	38
3,425	2,025	2,925	2,550	10	20½	do	40

[1] Approximate outside dimensions of commercial flue linings.

CHIMNEYS

If satisfactory results are to be secured from the heating system the boiler must be supplied with a chimney of proper capacity. The boiler is usually fitted with a smoke-pipe opening sufficiently large to carry off the products of combustion, and if a flue be built or stack erected with the same cross section as the fitting on the boiler and of such height that it will be above nearby objects, such as trees and buildings, the results will be satisfactory.

INSTALLATION OF THE GRAVITY HOT-WATER SYSTEM

After the proper amount of radiation and the size and location of the pipes have been determined and the boiler capacity needed to supply this radiation decided on, the whole success of the heating system depends on the way it is installed. For those not thoroughly familiar with heating problems, it is better to secure the services of a trained steam fitter rather than to attempt the work with inexperienced help. It is best to locate the boiler so that its top is at a lower level than the radiating pipes in the greenhouse. While the system will work as long as the bottom fitting of the boiler is below the radiating pipes, and even when the boiler is higher than the radiation, it is best to follow the plan suggested. Boilers are tapped or fitted for pipe that is large enough to care for all the radiation the boiler will supply. Unless the boiler is much larger than is actually required, these pipes should be of full size until the first branch is reached.

In branching hot-water pipes, abrupt turns should always be avoided. The pipes should be carried in the most direct route to each junction point, using pipe bends instead of fittings wherever possible. Every short turn in a hot-water line retards the flow of dependent on the care exercised in laying it out. As pointed out in an earlier paragraph, hot-water pipes must have a uniform grade or fall if good circulation is to be secured. If the pipes are uniformly graded, a fall of 4 inches in each 100 feet will give good circulation. The flow pipe leaving the top of the boiler is usually carried in a vertical direction to a point so high that there will be ample fall for the pipes to make the circuit of the houses and return with uniform grade to the bottom of the boiler. The distance between the top of the boiler and the point where the flow pipe starts in a horizontal direction varies according to conditions, but for large plants it is usually from 10 to 15 feet from the ground and in small houses just below the ridge of the house. The expansion tank as a rule is located in the boiler room and at a point somewhat higher than the highest point in the system. It is connected with the bottom of the boiler and fitted with an overflow, so that as the water expands it can rise into the expansion tank and finally overflow if the necessity arises. The type is known as an open expansion tank.

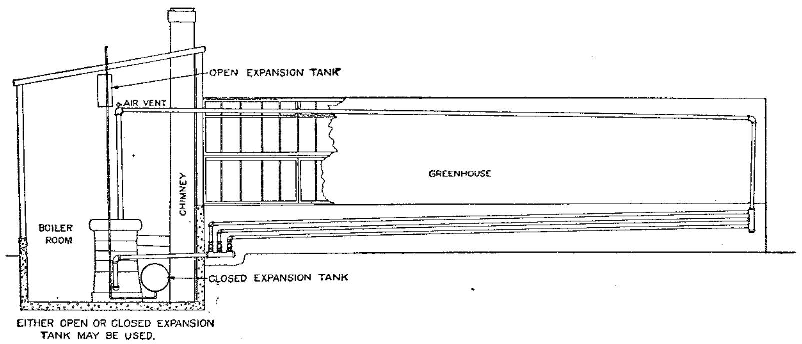

FIGURE 12.—The principle of hot-water circulation.

Another kind, known as the closed expansion tank, is merely a steel tank holding about one tenth the capacity of the heating system. It must be air-tight and fitted with a safety valve set to operate at a pressure below that which would be dangerous to the system. It should be connected with the heating system from the bottom of the boiler, and this connection must be through the bottom of the expansion tank. This type of expansion tank can be located at any convenient point, but no valves should be placed in the line connecting it with the boiler. As the water expands, it forces its way into the tank, compressing the air in the tank and putting the entire system under pressure. A typical arrangement of boiler, expansion tank, and radiating pipes is illustrated in figure 12. In this sketch both types of expansion tank are shown, but in actual practice only one is used.

Where several greenhouses are to be heated from the same boiler the arrangement is usually such that a common header supplied by the main flow pipe from the boiler runs along the end of the houses, preferably in the potting shed or workroom, where it will be protected from the elements, and this pipe is gradually reduced in size in accordance with the amount of radiation supplied each house. A is gradually increased in size as it nears the boiler until it reaches full size at the house nearest the boiler.

LOCATION AND ARRANGEMENT OF THE HEATING COILS

The location and arrangement of the piping system in the greenhouse must be planned to suit the particular house, and there are several well-defined arrangements to choose from. In general, the aim should be to secure uniform distribution of the heat and have the pipes out of the way. The usual arrangement is to have the mains or flow pipes overhead, with the radiating pipes under the benches or on the side walls or on the inside posts of wide houses. Pipes located along the side walls have a tendency to warm the cold air that enters through crevices, preventing its striking the tender plants. For small lean-to houses a good arrangement is to have the flow pipes overhead and branching into the returns at the end of the house away from the boiler, these being placed either on the side walls or under the bench. A suggested arrangement for this type of house is shown in figure 15. A system often used for small detached houses is to have the flow pipe under the ridge at such a height as to be out of the way and the return pipes placed on the side walls or under the benches. The arrangement is similar to that for the lean-to house, except that the main branches in two directions at the end of the house away from the boiler. The plans of the 10 by 50 foot house shown in figure 16 illustrate this system. In other cases the flow and return pipes are both placed overhead with the flow pipe at a higher level than the return. In wide houses, fitted with benches, the flow pipes, usually two or more in number, are carried overhead, and the radiating pipes are arranged part on the outside walls and part under the benches. There is some objection to having the flow pipes overhead, as they cast some shade and are also more or less unsightly, therefore they are sometimes placed in conduits under the walks.

Overhead flow pipes must be supported every few feet to prevent their sagging. Pieces of chain or regular pipe hangers are usually used, these being attached to the purlins or other strong parts of the greenhouse frame. It should be remembered that pipe expands about 1½ inches in each 100 feet when heated from ordinary temperatures to the temperature of steam or boiling water, and provision must be made to care for this expansion. Swing joints, or regular telescoping expansion joints can be employed to care for this expansion, as illustrated in figure 13. Flow pipes in conduits are usually carried on rollers, such as pieces of 1½-inch pipe slipped over other pieces of 1-inch pipe set crosswise in the conduit and embedded in the concrete walls of the conduit. These rollers allow free expansion and contraction of the flow pipe. Provision must be made somewhere in the flow line for this expansion and contraction, as in the case of the overhead flow pipe. Radiating pipes on the side walls or the center posts are usually carried on pipe hooks, and those under the benches rest on the bench supports. It should be remembered that the weight of the water necessary to fill the system is considerable and that pipes supplied with sufficient supports to keep them from sagging when empty may not have enough support when filled.

turned on or off as the necessity may arise. Although the first cost of good valves may be considerable, their installation is advisable.

Figure 13 illustrates some of the more important parts and fittings for steam and hot-water heating systems. The use of these fittings is well understood by most steam fitters, but some of them have been designed especially for greenhouse work. Either 90°, 45°, or re-

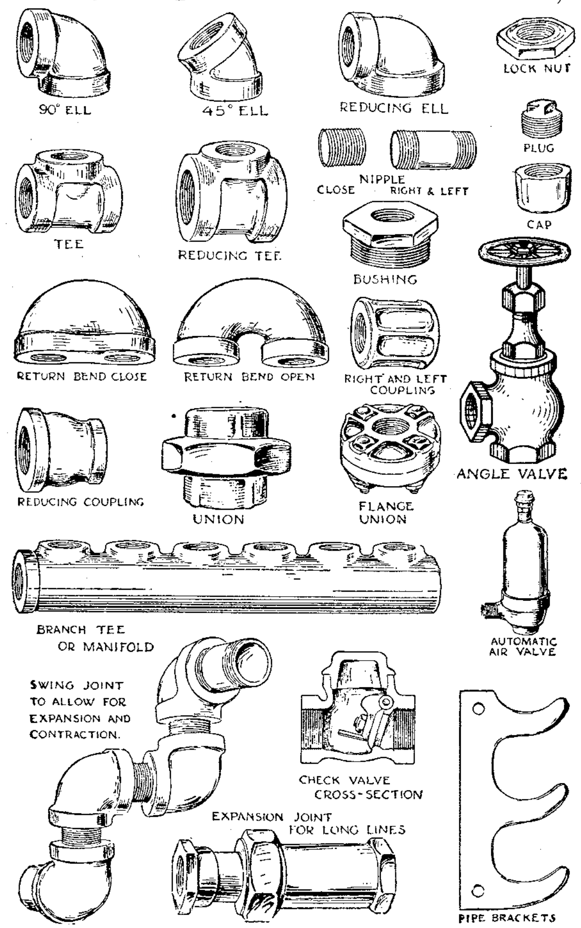

FIGURE 13.—Some of the fittings used in the steam and hot-water heating systems of greenhouses.

ducing ells are employed where it is necessary to make turns in the direction the pipe is being carried. Right-angle turns are to be avoided wherever it is possible to use pipe bends or 45° ells. Reducing ells are seldom used in hot-water systems but may properly be employed in the return lines of steam systems. The same is true of reducing couplings. Tees must be employed where it is desirable to take two lines from one pipe, but in hot-water systems they should be so used that the supply is not attached to the fitting on strikes the side of the tee. The supply from the boiler should be attached at one of the end fittings of the tee and the other two used for the branches. The right and left threaded coupling with the right and left threaded nipple and a lock washer are employed in some cases instead of an ordinary union or a flange union. Bushings have a very limited use in heating work and should be employed only where their use is absolutely necessary. It is far better to use reducing couplings, but the best method of all is to plan the system so that reducing tees can be employed in branching the lines, thus avoiding the necessity for employing either bushings or reducing couplings. Plugs and caps are properly employed only for the purpose of temporarily closing lines where extensions are to be made. Return bends are much employed for the making up of coils of pipe for installation on walls where the pipe is only a few feet long. The open pattern is to be preferred where sufficient room is available for its use.

For greenhouse work the ordinary ground joint threaded unions are used for small-sized pipe, but for pipe above 2 inches in diameter the flange union is usually employed. Right and left couplings are employed for moderate-sized pipe, but these are seldom used for pipe larger than 2 inches. Branch tees are used where it is desirable to install several lines of radiating pipes in close proximity to each other, such as on the side walls of the house between the floor and the ventilator sash. These tees cannot be used on both ends of long lines of pipe unless expansion joints are installed in each of these lines, as unequal expansion caused by some of the lines being hotter than the others will cause breakage. A method often followed to overcome this is to use one of these branch tees at one end of the radiating pipes, locating it so that the coils can be carried to a corner of the house where right- and left-hand ells are used to make the turn and running along the end of the house to a door where another branch tee is employed. The expansion of the pipe is cared for without placing a strain on the branch tees, but care must be taken to have the pipes far enough from the corner so they can move freely. The tee at one end of the line, usually the one near the door in the end of the house, is connected with the supply from the boiler through the tapping in the end of the tee, while the other tee is connected with the return system. Each radiating line should be fitted with a valve of the type best adapted to the conditions. The one shown in figure 13 is known as an angle valve, but other types are available. Every set of radiating pipes, whether for steam or hot water, should be fitted with suitable means for removing air from the system. Such valves should be at the highest point in the system in which they are installed. Check valves are used in the return lines of steam systems to prevent the condensation from backing up in the system.

FORCED-CIRCULATION HOT-WATER HEATING SYSTEMS

The forced-circulation hot-water heating system takes its name from the use of pumps to circulate the water through the mains and radiating pipes. The general arrangement of the pipes is the same as for the gravity system, except that the mains and radiating pipes may be run level if desired. Plants originally installed as gravity tiveness by the installation of some suitable device for hastening the circulation. With forced circulation it is possible to maintain a given temperature with much less heating surface and usually with a lessened first cost. It should be remembered, however, that any device for hastening the circulation will necessitate the use of a boiler much larger than that theoretically required for the amount of radiation installed. The pump used may be of any suitable type, such as the rotary or the centrifugal, and may be operated by an electric motor, a steam engine, or a gas engine, or in cases where high-pressure steam is available for their operation the direct-acting steam pump may be used. It is not ordinarily feasible to use this type in small plants, as steam is seldom available for their operation.

Improved circulation can be had, however, through the installation just above the boiler of a simple and inexpensive circulator made

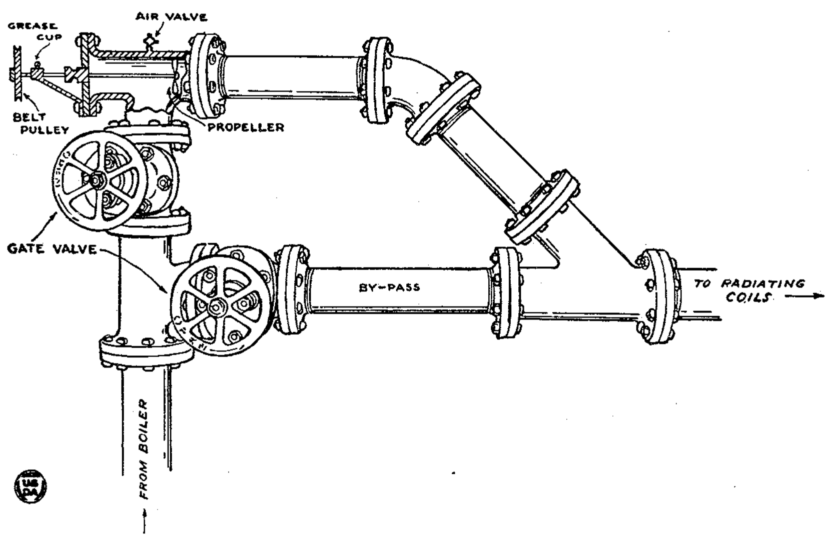

FIGURE 14.—A simple hot-water circulator made of pipe and operated by power, such as an engine or a motor.

of ordinary pipe fittings of the size of the flow pipe in which the device is installed. Figure 14 shows in cross section the essential parts of the circulator. It can be made by any steam fitter, and the cost of its operation is small, especially when a small electric motor is used. As will be noted in the illustration, the stuffing box consists of the bonnet of an ordinary globe steam valve from which the valve and stem have been removed and the shaft bearing the propeller slipped through in its place. The shaft should extend out of the stuffing box far enough to give room for the bearings, collars, and the driving pulley. The bearings may be supported by a bracket attached to the riser pipe. When a motor is used to operate the circulator, it may be mounted on another bracket on the riser pipe. In assembling the circulator care should be taken to have the pulley marked so the propeller will drive the water in the correct direction. A one fourth horsepower motor will operate the device at sufficient

When high speed, with consequent increase in the rapidity of the circulation is desired, more power may be necessary. The device is fitted with a by-pass, so that it can be used or not as desired. Reliable small circulators may be purchased at small cost, often less than that of the home-made device just described. More complete information on forced-circulation hot-water systems may be found in Circular 254 previously referred to.

STEAM, VAPOR, AND VACUUM HEATING SYSTEMS

When steam is employed for heating, tables 1, 2, and 3 can be used for figuring the radiation and the size of the boiler and chimney. The same general principle holds as to the arrangement of the mains and radiating pipes, while the returns connecting the radiating coils in the houses to the boiler can be of small size, as they carry only condensed steam from the heating coils. More care must be exercised in the design and installation of steam systems, as the changes in temperature and the expansion is greater than is usually the case with hot water. With steam systems at least 2 feet vertical clearance must be provided between the return tap of the lowest radiator and the water line in the boiler. In small systems the circulation of the steam and the return of the condensation is by gravity, whereas in large systems pumps are usually employed to insure return of the water to the boiler. Many different types of steam-heating apparatus, such as vapor and vacuum and ordinary low-pressure systems, are in use. In any of these it is necessary that the system be kept free from air. In the vacuum and the vapor systems this is usually accomplished automatically and in the case of steam systems by either automatic or hand-operated valves. In installing any form of heating system it is wise to provide plenty of air valves for freeing the system from air, as good circulation cannot be secured while there are air pockets.

WATER SUPPLY

Large quantities of water are required by greenhouse crops, and its supply should be one of the first considerations in locating and building a greenhouse. In many locations it is more economical to use a city supply, as its use makes unnecessary an extensive investment in wells, pumps, tanks, etc. Whatever the supply, its absolute reliability must be assured. When a private system is employed the water may come from any suitable source, and sufficient storage capacity should be provided to meet the needs of a day or two at least. This may be a tank on a tower, a pressure tank in the boiler room, or a reservoir on some near-by hill. The necessity for providing an absolutely reliable water system cannot be overestimated.

The houses themselves should be piped so that all parts can be reached with a moderate length of hose. The supply pipes should be placed in position before the walks are laid, as it is much easier to perform the work at this time. Water pipes should not, however, be placed under concrete walks, as this necessitates breaking up the concrete when making repairs.

installed to good advantage, the use of such a system usually lessening the time spent in watering the crops. The necessary piping with inserted nozzles and other fixtures making up these systems can be installed on the pipe posts or other parts of the greenhouse structure, and the work can be done when the greenhouse is built, or if this is not practicable it can be performed at some later time.

BENCHES AND WALKS

Greenhouse benches are expensive to install and unless made of rot-resisting materials are short-lived. Benches of durable construction, such as those with pipe legs and cast-iron supports and bottoms, or with iron frame and tile bottom, or of concrete, are durable, but their cost is high. Wood benches are fairly satisfactory if made of cypress or other durable wood. At the present time there is a tendency to dispense with benches wherever it is possible to do so. Growers are finding that it is possible to grow many crops in ground beds, and the modern greenhouse, especially the vegetable house, is an enclosed area with only enough space occupied by walks to make it possible to handle the crops. For crops such as roses and carnations, where it is desirable that the plants be above the walks, in order that the crop may be more easily handled, this is often accomplished either by depressing the walks or by putting concrete curbs some 2 or 3 feet high along the sides of the walks and filling the beds with soil. The same results can be obtained by using boards along the walks, but such an arrangement is of a more or less temporary nature.

Greenhouse walks may be of any suitable material, such as cinders, brick, or even earth, but concrete walks are best, as these readily serve as a very satisfactory track for trucks and wheelbarrows used in handling material in the house. As little space as convenience permits should be devoted to walks, since it costs just as much to cover and heat the area occupied by walks as that in crops.

SOME GREENHOUSES SUITABLE FOR THE BEGINNER

The greenhouse plans given on the following pages are submitted only as suggestions, for the plans can be modified to suit conditions. All the houses suggested are practical structures and well adapted to many uses, but modifications to suit the location and the particular needs of the individual can readily be made. The materials used in their construction can be varied also.

A LEAN-TO HOUSE

The house shown in figure 15 is a simple, inexpensive structure that can readily be built against some existing building. It is 6 feet 8 inches wide, or wide enough to make room for a walk 2½ feet wide and a bed 3½ or 4 feet wide. The house shown is 48 feet long, but it can be shortened or lengthened as desired. The house may be built as illustrated or the walk may be excavated to such a depth that the natural surface of the ground will be the right height to be used as a bench. This method will make the whole structure lower and will possibly lessen the cost. As figured, the house is con-

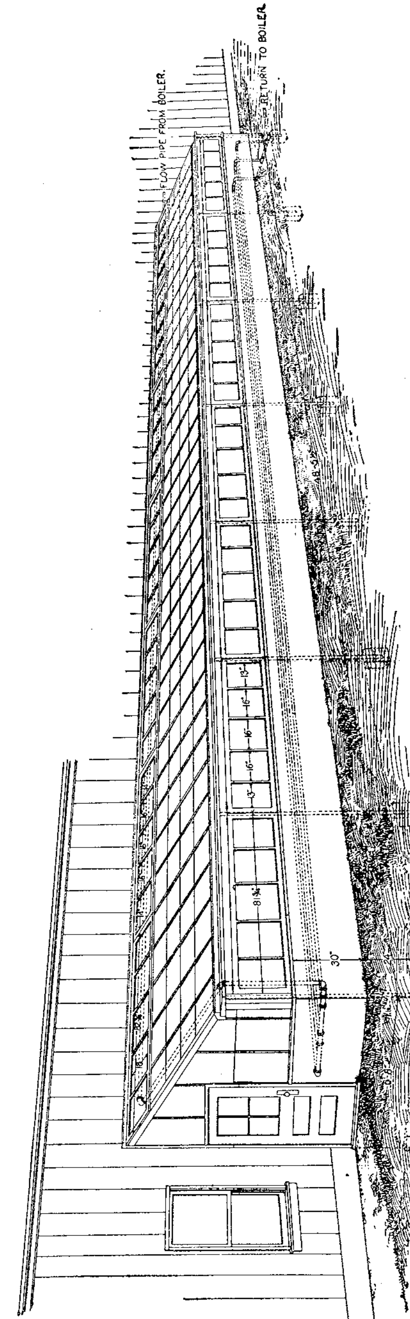

FIGURE 15.—A lean-to greenhouse built against a building. This house is 6 feet 8 inches wide and may be made any reasonable length.

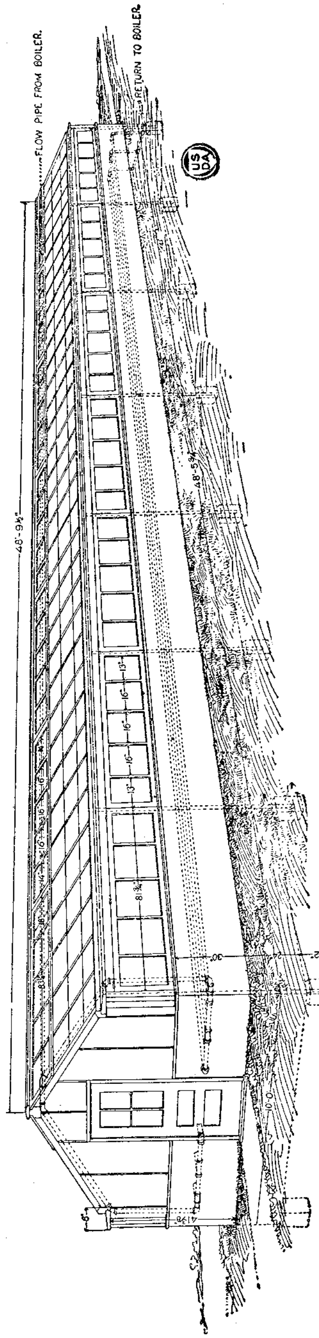

FIGURE 16.—A 10-foot detached house well suited to the needs of the beginner.

embedded 2-inch iron-pipe posts fitted with special post-top fittings to which is attached a wooden gutter. The construction can be modified so as to use wooden posts or to use the angle-iron eave-plate type of construction. The materials entering into the construction of such a house are simple and can be secured from firms making a specialty of such equipment.

LAYING OUT AND ERECTING THE HOUSE

A lean-to house should have a southerly exposure, as otherwise it will be shaded for a considerable portion of the time. If built as a supplemental source of employment, when it is to receive but a portion of the operator's time, the location must be an accessible one. If the house is to be heated from some existing plant, the location must be such that this is possible. The laying out of greenhouses is similar to the laying out of other structures, and any good mechanic can readily perform the work.

The necessity for thorough workmanship cannot be overemphasized. Success or failure with the house is determined largely by the way it is built. The setting of the pipe posts and the pouring of the concrete around them are matters that require painstaking care. It is best to excavate the trenches for the concrete, set the posts in position, bore holes of the proper size in the plate, slip it over the top of the posts and block it at the proper height, then attach the post-top fittings and the gutter, lining it up and securing it in position before pouring the concrete in the forms previously prepared.

The placing of the ventilators, sash bars, glass, and other parts of the structure is in accordance with the suggestions made in earlier portions of this bulletin, to which the reader is referred.

THE HEATING SYSTEM

The house may be heated in any one of a number of ways, but a gravity hot-water system is suggested as being both simple and efficient. The heat may be supplied either from a separate boiler located in a separate enclosure at the end of the greenhouse, or it may be supplied from a boiler used for other purposes, such as the one serving the residence. In either case the pipe shown in figure 15 entering the house near the ridge will be attached to the line supplying the heat. As shown in this illustration, the house has about 500 square feet of wall surface taken up by the portions made up of concrete and the wall against which the house is built. The amount of radiation that should be allowed for this surface must be determined after taking into consideration the tightness of these walls and whether the building against which the house is constructed is heated or not. If heated, less radiation will be necessary, but figuring on a basis of 4 square feet of this wall surface as needing the same amount of radiation as 1 square foot of glass, this area of wall will be equivalent to 125 square feet of glass surface. The glass surface in this structure as figured in the plans is approximately 500 square feet, disregarding that contained in the ends of the structure. The radiation needed for the house, which could be determined from table 1, is given in table 4.

pipe needed to supply hot-water gravity-circulation radiation [illegible] *greenhouse*

[Dimensions, 6⅔ feet by 48 feet. The radiation in the flow pipe is disregarded]

Temperature to be maintained in house (°F.)	Gravity-circulation hot-water system using—											
	2-inch pipe for a probable outside temperature of—						3½-inch pipe for a probable outside temperature of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	113	163	214	265	314	365	70	100	131	163	194	224
45 to 50	145	198	251	303	355	408	90	123	155	187	220	253
50 to 55	182	238	294	349	406	461	113	147	181	216	251	284
55 to 60	221	283	341	397	458	517	139	178	214	249	289	324
60 to 65	268	329	392	454	517	583	167	205	245	283	324	364
65 to 70	317	385	451	521	588	652	200	242	286	329	370	411
70 to 75	368	441	513	583	659	723	235	280	326	370	416	458

In using table 4 always take full-length lines of pipe, even though this may give a little more radiation than theoretically is necessary. For instance, suppose it is the purpose to maintain a temperature of 45° to 50° F. against 0° outside temperature, and it is desired to use a 2-inch pipe; by referring to table 4, giving the linear feet of pipe necessary to heat this house, it will be found that 251 feet will be required. Five lines of 2-inch pipe, each the length of the house, will not give sufficient radiation, hence 6 lines should be employed. In cases where the length of pipe required is very close to that supplied by a given number of lines, it would be all right to ignore a small discrepancy. In figuring the radiation for these small houses it is usually advisable to disregard the radiation supplied by the main or flow pipe.

The heating coils themselves may be arranged in a number of ways, but in the house shown they are placed under the bench. The main is usually placed overhead and the radiating pipes either under the bench, as shown in the illustration, or along the wall back of the bed, or part in each location. The pipes should have ample fall and be uniformly graded so that good circulation will be secured.

A 10-FOOT DETACHED HOUSE

The small detached even-span house shown in figure 16 is well adapted to the needs of persons for whom the lean-to house is not suitable and yet who want a small, simple, and inexpensive structure. This house can be constructed with low side walls about 8 inches thick, with the walk excavated below the surface; but as figured, it is to be built entirely above ground. This house also can be modified to suit conditions and the needs of the owner. A good plan is to have a center walk 2 feet wide and two benches each 3 feet 4 inches wide. Whatever modifications are made in the size and shape of the structure, attention should be paid to the economical division of the space in the house. For houses fitted with benches there is no width between 10 feet and 20 feet that divides economically between walks and benches.

cast-iron or the angle-iron eave-plate construction, can be used. Likewise other materials than those suggested can be employed in the different parts of the structure.

There is nothing better than a gravity-circulation hot-water heating system for a house of this description. The amount of radiation for the house may readily be figured by referring to table 1. Table 5 gives the lengths of pipe of different sizes necessary to maintain the house at various temperatures with different outdoor conditions.

TABLE 5.—*Temperatures to be maintained and length of 2-inch or 3½-inch pipe needed to supply hot-water gravity-circulation radiation for an even-span, detached greenhouse*

[Dimensions, 10 feet by 48 feet. The radiation in the flow pipe is disregarded]

Temperature to be maintained in house (° F.)	Gravity-circulation hot-water system using—											
	2-inch pipe for a probable outside temperature of—						3½-inch pipe for a probable outside temperature of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	159	228	300	371	439	512	97	140	184	228	271	314
45 to 50	203	277	351	424	497	571	126	172	217	262	307	354
50 to 55	255	333	412	488	568	646	158	206	254	302	351	398
55 to 60	309	396	477	556	641	724	194	249	299	349	404	454
60 to 65	375	461	549	636	724	816	233	287	343	396	454	509
65 to 70	444	538	632	730	823	914	280	338	400	461	518	575
70 to 75	515	617	718	816	923	1,012	328	392	456	518	583	641

In table 5 the number of lines of pipe of the size used that contains the number of feet of radiation nearest to that given in the table should be taken. It is always better to figure more rather than less radiation than is indicated as necessary by this table. For a house of the size specified the flow pipe should in most cases be placed under the ridge, this location making it possible to branch it in two directions at the end away from the boiler and to connect to the radiating pipes, which may be located under the benches, as shown in figure 16, or along the side walls, either below the benches or part in either location.

A 20-FOOT DETACHED HOUSE

Figure 17 shows a 20-foot house of semi-iron construction with two rows of inside posts. This house could be built with one row of pipe posts through the middle and with braces from these posts to the purlins, as brought out in figure 8, *B*. When constructed as shown in figure 17, with two rows of pipe posts, they are always tied together by pipe ties, the whole constituting what is sometimes termed the "giant arch." This house, with side walls about 8 inches thick, has space for two side benches, each about 3 feet 9 inches wide, two walks each about 2 feet wide, and a middle bench 7 feet wide. The exact width of the benches and the walks will be determined by varied to suit the needs of the operator. The suggested proportions are believed to be as good as any, as all these benches are about as wide as a workman can reach across and the aisles as wide as necessary for ordinary greenhouse needs. When the house is to be used for vegetable growing or for the production of other crops not needing benches, the type of construction shown in the lower part of figure 17 may be employed. The concrete walls are low, being but 12 inches above the surface of the ground, and the remainder of the space to the eaves is occupied by ventilators, or part by ventilators and part by sash-bar and glass construction.

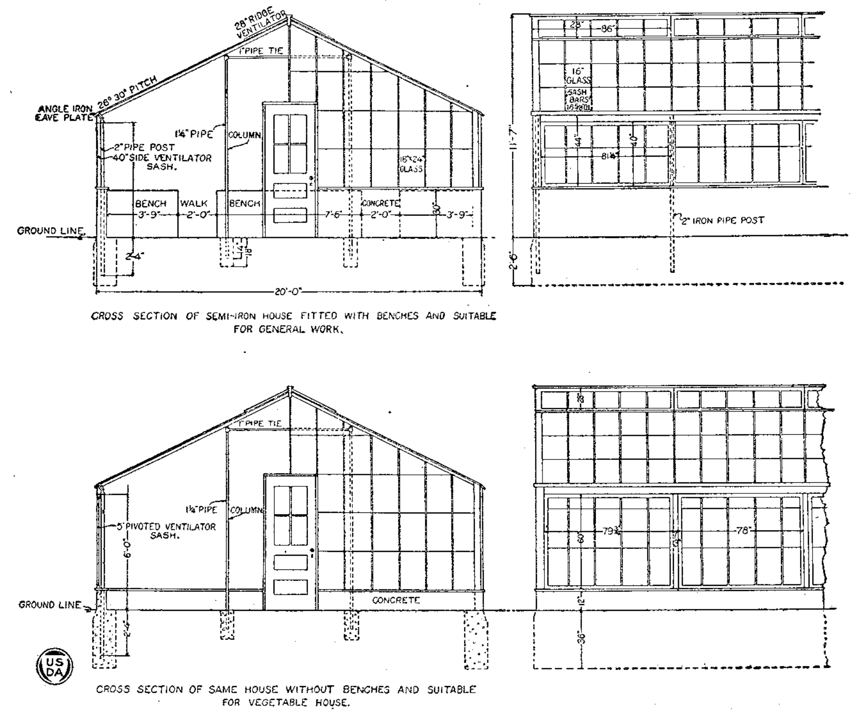

FIGURE 17.—A 20-foot pipe-post, angle-iron, eave-plate house suitable for the production of either flowers or vegetables.

This plan is offered only as a suggestion as to the general construction of a house of this size and description. For such a structure wooden gutters are seldom used, as the angle-iron eave-plate type of construction is greatly to be preferred. For the grower who wants a medium-sized house for general greenhouse work it is difficult to find a type of construction that is better than the semi-iron house illustrated in figure 17. Houses of this general type with two rows of inside posts can be built as wide as 50 feet and as long as necessary.

The tables given in this bulletin and in Circular 254 will enable anyone to figure the amount of radiation, either steam or hot water, necessary to heat this house to any desired temperature. For convenience, the accompanying table 6 is given.

needed to supply radiation for a 20- by 100-foot greenhouse containing 3,500 square feet of glass, or the equivalent

Temperature to be maintained in house (° F.)	Low-pressure steam system using—											
	1¼-inch pipe for a probable outside temperature of—						1½-inch pipe for a probable outside temperature of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	462	665	871	1,081	1,281	1,487	402	581	759	945	1,116	1,298
45 to 50	591	805	1,018	1,232	1,445	1,659	518	703	889	1,074	1,263	1,449
50 to 55	724	945	1,165	1,389	1,606	1,830	633	826	1,018	1,214	1,403	1,599
55 to 60	857	1,099	1,319	1,540	1,778	1,998	752	959	1,151	1,344	1,550	1,743
60 to 65	1,011	1,253	1,487	1,725	1,967	2,201	882	1,095	1,298	1,505	1,718	1,921
65 to 70	1,172	1,421	1,673	1,921	2,173	2,415	1,022	1,239	1,459	1,676	1,897	2,107
70 to 75	1,379	1,641	1,911	2,173	2,446	2,691	1,207	1,431	1,669	1,897	2,135	2,348

Temperature to be maintained in house (° F.)	Gravity-circulation hot-water system using—											
	2-inch pipe for a probable outside temperature of—						3½-inch pipe for a probable outside temperature of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Linear feet	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*	*Linear feet*
40 to 45	661	952	1,249	1,547	1,830	2,131	406	584	766	952	1,130	1,309
45 to 50	847	1,155	1,463	1,767	2,072	2,380	525	717	903	1,092	1,281	1,477
50 to 55	1,064	1,389	1,715	2,033	2,366	2,691	658	857	1,057	1,260	1,463	1,659
55 to 60	1,288	1,652	1,988	2,317	2,670	3,017	808	1,036	1,246	1,452	1,683	1,890
60 to 65	1,561	1,921	2,289	2,649	3,017	3,398	973	1,197	1,428	1,652	1,890	2,121
65 to 70	1,851	2,243	2,632	3,041	3,430	3,804	1,165	1,410	1,666	1,921	2,159	2,397
70 to 75	2,145	2,572	2,992	3,398	3,846	4,217	1,368	1,634	1,900	2,159	2,429	2,670

The arrangement of the radiating coils will be determined by the interior arrangement of the house. If the house is to be fitted with

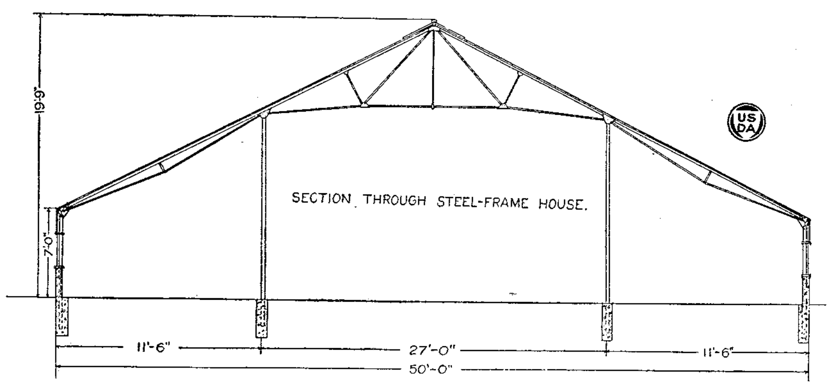

FIGURE 18.—End of a steel-frame house 50 feet wide and any desired length.

benches, as indicated in the upper part of the figure, the main or flow pipes may be placed advantageously overhead, suspended from the purlins, with the radiating coils along the side walls or under the benches, or part of them in each location. For a vegetable place for the radiating pipes is on the side walls.

A 50-FOOT STEEL-FRAME HOUSE

The construction of large steel-frame houses necessitates the employment of considerable engineering skill in designing, manufac-

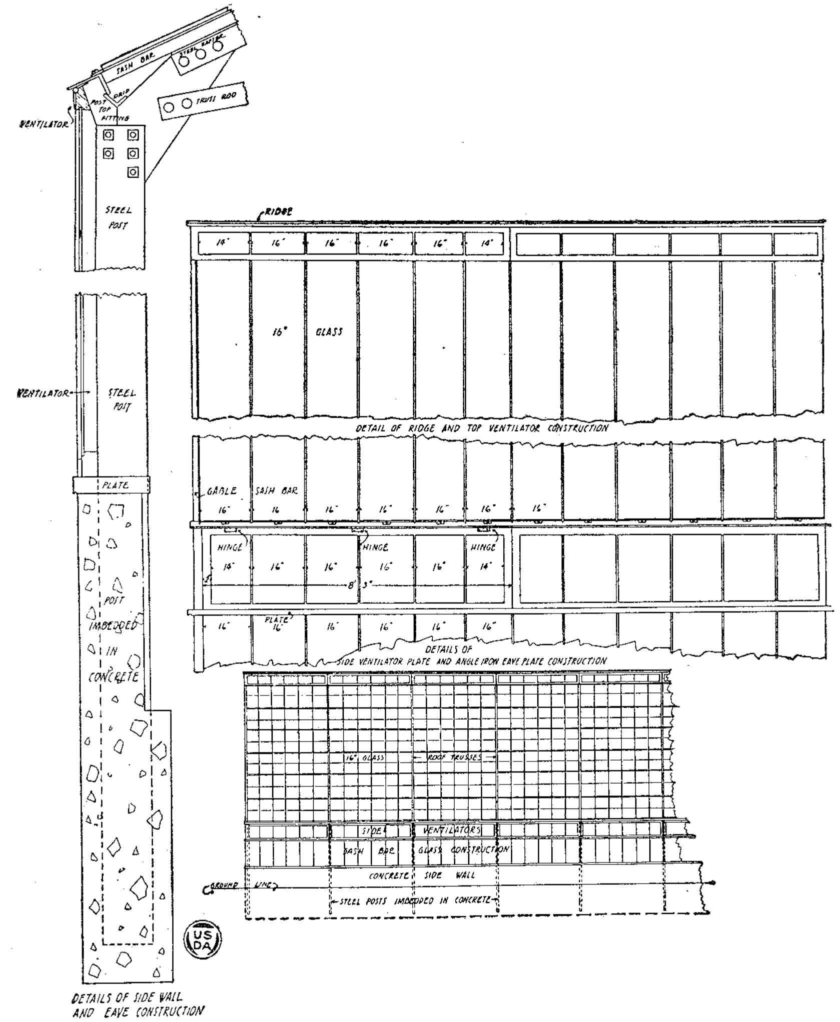

FIGURE 19.—Details of construction of the steel-frame house shown in figure 18.

turing, and erecting the structure. Figures 18 and 19 show the details of construction of a steel-frame house 50 feet wide, with two rows of inside posts. As figured, this house has 7-foot eaves, a 26½° pitch roof, and it may be as long as desired. These drawings are offered as a suggestion only, as the details of the construction can be changed to suit the conditions. As shown, the house