PLENUM FLOOR SYSTEM FOR BASEMENTLESS HOUSES

BY

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BUILDING RESEARCH

THE PENNSYLVANIA STATE UNIVERSITY

COLLEGE OF ENGINEERING AND ARCHITECTURE

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PLENUM FLOOR SYSTEM FOR BASEMENTLESS HOUSES

SUMMARY

The plenum floor system for on-grade house construction combines desirable features of crawl space and slab on ground. In this unusual arrangement the floor is supported above a slab, leaving space between for the heating plenum and utilities. Joists may be supported by several methods, some of which any builder can use without purchasing special materials.

The underfloor plenum offers cost-saving advantages for on-grade construction. It eliminates most of the home buyers' objections to basementless houses. It produces warm floors made of attractive conventional materials, provides a location for plumbing where it will not freeze, and employs a simple, inexpensive but efficient and effective heating system. Construction costs can be reduced still more by packaging the heating system with other utilities in a "core," thereby eliminating most of the on-site labor involved in installing utilities.

There is nothing radically different or difficult about this new system of construction, but it requires a different schedule of on-site operations, which the builder can turn to a profit in reduced over-all construction time.

BASIC PRINCIPLES OF THE PLENUM FLOOR SYSTEM

Houses without basements have not met with favor in parts of the United States where furnace heat is needed. Good construction is often considered too expensive, and cheap construction has failed to produce comfortable homes of acceptable quality. In many places such houses simply will not sell.

Most of the home buyers' objections relate to comfort. Several "cures" have been advocated, such as insulated slabs, heated slabs, crawl-space plenums, perimeter-loop warm air systems, baseboard radiation, and wall-to-wall carpeting, but none of these have adequately overcome the objections. Home buyers still feel that the economies of basementless construction will result in uncomfortable living.

In the autumn of 1958 the writer proposed the plenum floor system, a new method of flooring basementless houses, derived from observations in old steam-heated houses. The basements of these buildings were always much warmer than the rooms above. Bare steam pipes near the basement ceiling often transmitted temperatures as high as 90 to 100° F. to the wood floor above the ceiling, with the result that the warm floor served essentially as a radiant heating panel. Radiators therefore had steam in them rarely, even in coldest weather. Yet the flooring never became uncomfortably warm, nor did the heat affect the wood adversely.

These observations led to the belief that a system could be devised which would force warm air under finished flooring laid over a slab, to produce conditions comparable to those in the old steam-heated homes. This would make it possible to build comfortable basementless houses with
conventional floors, eliminating many of the objections to such houses in general.

During the winter of 1958 the details of the new system were worked out and scale models were developed. The following summer a small single-story duplex house was built in State College, Pennsylvania, with plenum floors throughout. The structure has now gone through a full heating season, with results so satisfactory that builders in Pennsylvania and elsewhere have requested information.

In its present state of development the plenum floor is little more than a new way of combining old ideas, some of which are adapted from heating arrangements in the public baths of ancient Rome, with modern materials, equipment, and construction methods. Its heat source is the downflow or counterflow warm air furnace commonly used to force air into under-slab ductwork. But for maximum economy of construction and fuel consumption the plenum must be shallow and unobstructed. This rules out interior bearing walls and calls for a different treatment of floor joists from that used in houses with basements or crawl space.

Besides the downflow or counterflow furnace, three other recent developments have contributed to the design of the new system. The use of trussed rafters in home construction eliminates the need for interior bearing walls and related masonry or other supports through the center of the structure. Prefabricated chimneys and fireplaces do not require masonry footings. Hence, if the finished floor is supported on the slab by a method that permits nondirectional air circulation, the space under the floor can be essentially open. Improved materials and methods of insulation reduce the amount of heat that must ever be supplied to the house.

The principle of the plenum floor is relatively simple. Instead of warm air from the furnace being distributed through ducts and liberated directly into living rooms, it is discharged into a shallow subfloor space, the underfloor plenum. There it moves in all directions, and as it does so, loses part of its heat to the flooring before being discharged into rooms. The warm floor gives off heat slowly, smoothing out the "first warm, then cold" effects which are a common complaint about warm air heating systems. Actual performance is something like a hot water system rather than warm air. The floors are never appreciably warm to occupants. Even within 12 inches of the warm air outlet of the furnace and with outdoor temperatures in the zero range, floor temperatures above 90° F. have not been observed.

To secure the advantages of the shallow plenum, floors must be supported on a light slab of concrete. Conventional heavy joists, stringers or girders cannot be used. This is the most distinctive difference between the plenum floor and other types of construction. House contents and floor literally float on the slab, which bears the entire load. The floor supports must be such that they permit essentially unimpeded circulation of air through the plenum.

Satisfactory and economical plenum floor construction depends mainly on three things: (1) foundation walls and slab should be simple and therefore inexpensive; (2) floor supports must hold the floor secure and
firm while still not channeling the warm air; (3) the plenum must be shallow (small volume) and its structural parts must have relatively low heat capacity so that the heating system is quick to respond, but it should be deep enough so that other utilities, especially plumbing, can be installed in it.

EVALUATION OF THE PLENUM FLOOR SYSTEM

In a sense the new system is a hybrid or compromise, a kind of cross between crawl space and slab on ground, combining features of each into a single system. Naturally, the cost of some things goes up, but other costs go down. There is no claim that it offers the cheapest construction nor the ultimate in desirability. It is, however, a marked improvement over other floor systems now used for basementless homes.

Since the plenum floor is a compromise or hybrid, costs are intermediate. As time goes on and greater advantage is taken of prefabrication and other opportunities for savings, over-all costs should approach those of slab on ground. With these comments in mind, the advantages and disadvantages of the plenum floor can be weighed as they appear at the present time.

Advantages. In broad terms, the chief advantages of the system can be summed up as comfort, effective heating, and adaptability.

1. Floors are comfortably warm, having neither the cold sensation of hard concrete nor the coldness of wood floors over a crawl space.

2. Floors can be built of conventional materials and finished, covered, or carpeted as customers prefer.

3. The cost of installing the heating system is lower than for any other type of construction.

4. The heating system responds quickly to demand for heat, even with a furnace of minimum capacity.

5. Forced warm air means circulated filtered air. The room air is never "stagnant."

6. Because the warm floor structure has hold-over heat capacity, occupants of rooms are not conscious of whether the furnace is running.

7. The slight warmth of the floor panel does away with the "cold 70" sensation.

8. The system can be adapted for use with electric heat (electric furnace or heat pump).

9. Plenum floor should be satisfactory for air conditioning.

10. Water lines to plumbing fixtures pass through the plenum, reducing the chance of freezing.

11. Plumbing piping is installed above the slab before joists and finished floor are laid.
12. Where codes permit, electric wiring may be run through the plenum, saving time and materials.

13. Since no "rough-in" is needed for the heating system, it can be delivered and installed as a packaged unit. This is the only house construction system that permits such a simple and inexpensive heating installation.

14. The electric shock hazard generally encountered with concrete floors is minimized.

**Disadvantages.** The foregoing advantages are important but there are also some disadvantages, especially at present stage of development. These should not be overlooked by prospective users.

1. Floor construction is more expensive than asphalt tile on slab.

2. While studies indicate that a "perimeter slot" arrangement of warm air outlets provides the most uniform room heating, such outlet air equipment is not yet generally available.

3. The advantages of the plenum floor will not be fully realized unless plumbing and wiring systems are designed specifically for use with the underfloor plenum.

4. Devices to facilitate inexpensive and rapid assembly of the floor supporting system are not yet on the market.

**RULES FOR SATISFACTORY CONSTRUCTION**

In some respects the requirements for good plenum floor construction are simpler and less exacting than those for slab on ground, but careful attention must be given to the following details during the initial stages.

1. Foundation walls, whether of the grade-beam and pier or the continuous-footer type, should be at least 4 in. thick, with the top approximately 6 in. above the top level of the slab that will be poured.

2. The slab of concrete need not be more than 2 to 2 1/2 in. thick, and reinforcing or other special treatment appears to be unnecessary.

3. In cold climates the inside of the foundation wall and the perimeter of the slab must be insulated.

4. Because there is a slight positive pressure in the plenum when the heating system fan is running, the joint between the concrete foundation wall and the wood sill should be sealed against leakage of warm air.

5. The supports holding the joists or "stringers" up off the slab should (a) leave the plenum relatively free of obstructions, (b) provide adequate floor support to meet requirements for dwelling house construction, (c) require no materials or supplies that cannot be purchased readily.
6. Plumbing must be specified that can be fitted into the plenum above the slab.

7. Finish flooring and underlayment for kitchen and bathroom floors should be selected with reference to how it will be installed over joists and plenum.

8. The furnace should be standard downflow or counterflow equipment with a special base for mounting on combustible floors.

FOUNDATION WALLS AND SLAB

The plenum floor system is a modern system designed for modern homes. It demands the use of up-to-date materials and methods of construction. Builders should use trussed rafters to eliminate bearing walls within the house. No piers or other masonry should obstruct the plenum, and adequate insulation and joint seals should be used to control heat loss. Satisfactory performance of the system cannot be expected under other conditions.

Foundation Walls. Foundation walls are much the same as for slab on ground, the main difference being that the top of the finished slab should be approximately 6 in. below the top of the wall. This means that the wall must be higher or the slab must be lower, depending on the site.

The most economical way to build foundation walls is the grade-beam and pier method, spacing the piers at proper distances to support the beam as described in Better Building Report No. 1, "Slab-on-Ground Construction for Homes." The piers are poured a day or two earlier than the beam. Each pier is reinforced with a steel rod. The beam should have two horizontal steel reinforcing rods, one near the top and the other near the bottom. These rods are tied or wired to the vertical rods in the piers to keep them in place while the wall is being poured. Weight of the floor, interior partitions, and contents of the house rests on the slab, not on the foundation walls.

The sill is a standard 2 x 4 laid flat on top of the foundation wall, flush with the outside of the foundation, as shown in Fig. 1. It must be bolted or otherwise fastened down securely. Half-inch (diameter) bolts about 8 to 10 in. long may be placed in the concrete before it sets, about 48 in. apart and deep enough so that heads can be countersunk and will not interfere with panels or studs set onto the sill. Or the sill may be attached to the wall with steel pins driven into the concrete with a cartridge-actuated driver.

The joint between wall and sill should be well sealed against loss of air. If spongy sealing strips are used, they should be applied before the sill is bolted in place. One firm manufactures a special type of thin insulation pad suitable for sealing.

Since the bottom edge of the grade beam is on soil, piping can be installed after the beam is poured. Water supply and sewer connections to street are usually roughed in after the foundation walls have been completed, but they should be installed before the slab is poured.
The Concrete Slab. For regular slab-on-ground construction 4 in. floors are recommended, but a somewhat lighter slab can be used when weight is equally distributed. A slab 2 to 2 1/2 in. thick without reinforcement appears adequate, provided the location is well drained and the coarse base is firmly compacted. It is important that the base under the slab consists of a good grade of rock that will compact well. The total amount of fill required is roughly equal to the quantity of topsoil removed. Usually, however, a slightly larger volume of coarse fill is needed in order to raise the floor level an inch or more above the 8 in. minimum required by FHA. In some places, because of slope of the ground, one part of the area may need more fill than another. Fill soil and rock should be thoroughly compacted before the slab is poured.

Most builders put a sheet of polyethylene over the coarse rock layer before pouring the concrete. This film prevents the concrete mix from running down into the rock, and also serves as barrier to keep vapor and capillary water from coming up through the concrete.

The surface of the concrete slab need not be troweled or floated. It must be reasonably level, however, which can be accomplished by regular screening. Before anything is placed on the slab, the surface is allowed to dry or "cure" and is then covered with a layer of heavy building paper or cheap roll roofing. This prevents any contact of metal or wood to concrete.

In addition to the paper or roll roofing covering the slab, a layer of heavy foil or a thin sheet of metal (48 by 48 in. or larger) is placed on top of the paper at the location where warm air will be discharged from the furnace into the plenum, or the paper may be cut away in that area. To satisfy code requirements, wood joists in the vicinity of the air opening can be protected with metal insulation or asbestos paper, though there is no evidence that such protection is needed.

INSULATION

As mentioned previously, plenum floors should not be put into houses that are not well built and properly insulated according to modern standards. Efficient operation of the heating system calls for a superstructure with relatively low heat demand and a furnace of small capacity. Adequate insulation alone is not enough. Excessive loss of heat and infiltration of cold air should be prevented throughout the structure.

Builders generally have adopted rules of thumb or formulas for insulation. For houses to be heated with coal, gas, or oil, with Btu's costing not more than $0.20 per therm, they use a 3-2-1 formula: 3 in. of insulation in ceilings, 2 in. for sidewalls, and 1 in. under floors or around foundation walls. (A therm is 100,000 Btu, approximately the amount of heat obtained from 1 gal. of fuel oil, 1.40 cu. ft. of natural gas, or 30 kilowatts of electricity.) This rule applies to most houses built in the northern United States. Less insulation is used in southern states though it is needed, especially in ceilings, against summer heat.

For electric heating, Btu's regularly cost two to three times as much as for gas or oil. At 2 cents per kilowatt hour, the cost per therm is about 60 cents, but electric heating offers many advantages and is becoming
FIG. 1. Plenum floor construction on grade-beam and pier foundation, with conventional frame exterior walls. Note 6 in. strip insulation on grade beam, 24 in. perimeter insulation. In this example, floor joists are supported on 2 x 4 wood blocks, floor register supplies warm air direct from plenum.
Fig. 2. Plenum floor construction on continuous-footer foundation with 10 in. concrete block wall and brick veneer exterior wall. In this example, foundation wall insulation is applied vertically, floor joists are supported on standard bricks, floor register supplies warm air from plenum.
more popular. Obviously the cost of electric heating would be excessive if heat losses were not cut to a minimum. This means extra insulation, double or triple glazing of windows and doors, and tight construction throughout. The insulation formula recommended for electrically heated homes is 6-4-2, double the amount recommended for other types of heating.

Wall and ceiling insulation can be installed in any approved manner, but the plenum floor requires special treatment of foundation and slab. Because concrete is a good conductor of heat, even the 6 in. of exposed foundation will permit too much heat loss if it is not well insulated. Any semirigid or rigid insulation can be applied in the vertical position inside the wall. Examples of different positioning are shown in Figs. 1 and 2. If it is installed vertically so that it insulates the slab from the foundation wall as shown in Fig. 2, a high-grade material must be used. Any good foamed plastic or similar material, cut in strips 6 in. wide and beveled, can be installed as shown in Fig. 1. It can be cemented to the wall or otherwise held in place. A strip of batt or blanket insulation 1 or 2 in. thick and 6 in. wide can be stapled in position and will serve the purpose.

When the heating system is operating, warm plenum air constantly passes over the slab and some heat is conducted downward. Heat movement through soil is so slow that slab areas a distance away from the perimeter lose very little heat. Most of the heat that passes downward returns to the plenum. Around the perimeter of the slab, however, heat can pass downward and through or under the grade beam to the outdoors. When green grass is seen growing in winter near foundations of slab-on-ground houses, it indicates that insulation was inadequate.

The slab perimeter can be protected with batt or blanket insulation. Usually a 2 in. thickness is preferred. The joist supports simply rest on and compress the soft insulation. It is important to select inert material so that any condensation on the slab itself will not decompose the insulation. In theory, a blanket 24 in. wide around the perimeter should be sufficient, but more can be used. In electrically heated houses, the perimeter strip should be at least 48 in. wide.

METHODS OF SUPPORTING FLOOR JOISTS

Plenum floor construction requires special means for supporting the floor joists above the slab, to provide space for air circulation and installation of utilities.

For several reasons the space between slab and flooring should be as shallow as possible. A 2 in. height would probably be adequate or even an advantage for heating, because the volume of the plenum would be small and furnace response would be quick, but it is not sufficient for plumbing. If height between joist supports and slab -- that is, the open space under the joists -- is the same as the space in the house walls where 2 x 4's are used for studs, it will permit installing copper sewer pipe.

The simplest framework for flooring is 2 x 4's laid flat. Where spans do not exceed 24 in., 2 x 4's placed flat have adequate supporting strength and they are cheaper than the usual 2 x 8 or 2 x 10 joists. The difference in lumber cost partially cancels the cost of supports needed to hold
them up off the concrete. Therefore, all of the following methods for supporting plenum floors assume that the joists used are 2 x 4's laid flat.

Bricks or concrete blocks may be laid on the slab under the joists. Common bricks, if they are about the same width as a 2 x 4, or 4 in. concrete blocks should be spaced 16 to 24 in. o.c., with joist spacings of 16 or 24 in. A pad of glass wool can be placed on top of each brick to reduce slight unevenness of slab. (See Fig. 2.)

Wood blocks may be used as supports for the joists. Short 2 x 4 blocks were used in one test (not on concrete slab). Since the width of a 2 x 4 is the proper height (3 5/8 in.) between joist and slab, short blocks can be used as temporary supports or even in conjunction with other supporting systems. Two methods are suggested: (a) saw 2 x 4's at right angles into lengths just long enough so that they will not split when nails are driven down into them through joists, and space them as specified for bricks or concrete blocks (this method is demonstrated in Fig. 1); (b) cut standard 2 x 4's at a 45 or 60 degree angle so that the blocks are wedge shape, and nail, staple, or glue the blocks to the underside of the joists to make a substantial and permanent structure (Fig. 3).

Perforated metal studs such as those now used as a substitute for 2 x 4's in constructing house walls might be used. The punched openings would permit air circulation. Edges of these studs are made so that nails can be driven into them. These supports would be laid edgewise on the slab, with paper or roofing material under them to cover the slab, and the 2 x 4 joists would be attached to them (Fig. 4). This method seems to have definite possibilities for plenum floor construction, but it has not been tested.

W-shaped metal trusses have been specially designed for the purpose of supporting joists in plenum floor construction. Stamped out of light sheet metal, they are so made that the ends of the W's are fastened to the joists and the center segment floats free to automatically compensate for slight irregularities in the slab surface (Fig. 5).

These W-trusses should be spaced so that there is one to each 2.0 to 4.0 sq. ft. of floor area, the exact spacing to be governed by the finish flooring. The most convenient arrangement is to space the joists 16 in. o.c., with trusses 24 in. o.c. on the joists. Each truss then supports 2 2/3 sq. ft. of floor, giving a safe load capacity of 300 to 400 lb. per square foot even for trusses of soft aluminum. "Half-hard" sheet aluminum has 50 per cent more strength, and for exceptionally heavy loads thicker aluminum or stainless steel trusses may be used.

The so-called "2.4.1 system" of plywood panel flooring, developed by the Douglas Fir Plywood Association, is adaptable to plenum floor construction with certain modifications. In this system, 4 x 8 ft. panels of extra-heavy plywood (1 1/8 in.) are laid over a framework of heavy joists or girders spaced 48 in. o.c. The joists are usually 4 in. timbers, or boxbeams 4 x 4 in., 4 x 6 in., or larger, depending on how closely the piers or supports are spaced. This kind of flooring can be laid quickly and accurately, and it is claimed that the new design of tongue-and-groove panels eliminates cross blocking.
FIG. 3. Method of supporting floor joists on wedge-shaped blocks cut from 2 x 4. Blocks are attached to joists with nails or screws and casein glue. Note also perimeter-slot warm air outlet from plenum, with damper control in metal baseboard-type register.

FIG. 4. Detail showing floor joists supported on perforated steel studs. Small pads of resilient material may be placed under studs if desired.
FIG. 5. Detail showing floor joists supported on small W-shaped trusses made of aluminum or steel. Note also perimeter-slot warm air outlet, formed by setting baseboard out from wall on 1/2 in. spacers. Inside of grade beam may be vertical instead of sloped as in Fig. 1.
When the 2.4.1 system is applied to plenum floors supported on a slab, the heavy joists are replaced by 2 x 4's laid flat in order to keep the plenum shallow. The load carrying capacity of the supported 2 x 4's is more than adequate, and they are considerably less expensive than 4 in. timbers. If the framing is spaced 48 in. o.c., the joist supports must be stronger or there must be less distance between them. Short 2 x 4 blocks used as supports should probably be placed no more than 16 in. apart. W-trusses should be spaced 16 in. o.c. or trusses made of heavier metal should be used.

The 2.4.1 system results in more concentrated loads on the slab directly under the joists. Extra supporting strength can be provided by pouring a kind of grade beam under each floor stringer. To do this, it is only necessary to dig shallow trenches in the subbase before pouring the slab, thereby making the slab thicker at those places. Reinforcing could also be used.

The heavy plywood underlay is an excellent base for wall-to-wall carpeting in the living areas, or for strip flooring or squares of vinyl, linoleum, rubber, or wood tile.

HEATING SYSTEM

Heating systems are of two broad types. Warm air furnaces with ductwork supply warm air to rooms to bring temperatures up to the comfort level. Other heating systems depend partly or almost wholly on producing a radiant effect (comparable to that of sunlight, a heat lamp, or a radiant electric heater) which counteracts loss of body heat to cold surfaces and at the same time raises the temperature of room air.

Warm air systems have some things in their favor, the most valid being lower first cost. Hence about four out of every five new homes have forced warm air heating. Forced circulation prevents stratification, and filters take out the dust. Air conditioning can usually be added with little change in the distribution system.

The most common radiant or partially radiant systems are hot water circulators, but electric heating also depends largely on the radiant principle. Radiators or panels are located under windows or wherever there is need to combat the effects of cold surfaces. One electric heating system employs resistance-wire heating elements embedded in the ceiling plaster. But for the cost, radiant systems of one kind or another would undoubtedly be used more widely in homes with on-grade floors.

None of today's heating systems, not even the most expensive, has every advantage or approaches the ideal even from the standpoint of comfort. Each represents a compromise. An ideal system should be low in first cost, economical to operate, low in upkeep, simple to adjust and control, and safe from hazards, and it should produce acceptable comfort at all times. The plenum-floor system comes closer than any other to meeting the ideal.

The principles involved in plenum floor heating are both old and simple. The idea of passing heated air or gas under the floor goes back
more than 2000 years. In the hypocaust system used by the ancient Romans in their public baths, floors were of hollow tile through which warm flue gases circulated, maintaining comfortable conditions. Early greenhouses also were flue-heated. An underfloor plenum for house heating is only a way of taking advantage of modern materials and construction, together with modern furnaces and equipment.

The heating system in a plenum floor house uses a counterflow furnace set over an opening in the floor. Warm air is forced downward from the bottom of the furnace into the subfloor space or plenum. Since the joist supports interfere very little with air circulation, the heated air moves in all directions. Heat is supplied to the living area above partly by the warmed floor itself and partly by liberating the warm circulated air directly into the rooms through perimeter slots (Figs. 3 and 5) or through floor registers (Figs. 1 and 2).

Counterflow furnaces perform somewhat differently from upflow types. No heat is supplied to the plenum till the fan starts. If bonnet switch setting (cut-in) is lowered, the fan starts at a lower air temperature. Usually a cut-in setting near 110°F is about right, resulting in output air never much above 120°F.

The bonnet switch setting should be adjusted so that the fan will run for a considerable time after the burner has stopped. For best performance, the fan should operate about twice as long as the burner, to equalize the temperature of wood structures near the furnace opening with that of more distant parts of the plenum. When cut-out and cut-in settings are low enough, heat coming up from the plenum will often start and operate the fan a second or third time. This is an ideal arrangement.

The small amount of residual heat in the floor structure cannot override the thermostat setting, but it is sufficient to smooth out temperature effects between burner cycles. Room occupants are rarely conscious of whether the burner or fan is operating, because the temperatures of room and floor remain so constant. In this respect the system behaves much like a radiant panel of low heat capacity (which it really is), with the desirable features of a warm air system. The holdover effect between burner cycles is provided by the warm floor structure.

Research by the National Warm Air Heating Association shows that a perimeter-slot air outlet produces the most uniformly comfortable conditions, but this arrangement has not been used extensively because of difficulties in construction. The slab-supported plenum floor makes it possible to leave a slot all around the perimeter, thus easily providing an adequate air outlet.

A slot 1/2 to 3/4 in. wide should be allowed between the edge of the finished floor and the outer wall (see Fig. 5). This slot should be covered with a strip of insect screening, stapled in place. A combination baseboard-wiring raceway or a common baseboard can then be set out from the wall on 1/2 in. spacers, the opening back of this baseboard serving as a channel for warm air. Little or no adjustment of the heat flow is necessary in a house of the "open plan" type.
Since there is a slight positive pressure throughout the plenum when the furnace fan is running, registers can be installed in openings made anywhere in the floor. FHA specifies closable registers in bedrooms. Floor registers with controls should be installed in those rooms even though a perimeter slot is used in the rest of the house.

PLUMBING AND WIRING

Plumbing. In a plenum floor house the space above the slab is a "utility" space, not just a heating plenum. Its depth is adequate for plumbing, wiring, and fuel and air conditioning lines. Because the space is warm, there is no danger that water lines will freeze.

The above-slab plenum has an advantage over slab-on-ground construction in that plumbing can be roughed-in after the slab is in place. Pouring the slab can wait until the house is under roof (see Fig. 6). The only basic operation that has to be completed before putting up studs, trussed rafters, and permanent roof is to pour the grade-beam and pier foundation. Everything else, even the water and sewer connections to the street, can be done afterward. Hence wet weather, which together with a clay soil often makes building difficult, need not delay construction once the house is closed in.

Since the partition walls where plumbing goes are supported on the slab, they should be put in place first. Holes for water pipes and drain lines (see Fig. 7) may be made before the walls are set up, or better still, the whole plumbing wall can be shop-fabricated. Ready-built plumbing walls for single or double bathrooms are already on the market.

If the plumbing wall extends at right angles to the floor joists, the bottom plate should be fastened to those joists, providing a nailing place for wall finishing materials. Because of the extra weight of fixtures, piping, and so forth, adequate supports must be placed under these joists. If the plumbing wall extends parallel to the joists, one or two short joists should be added, either under the wall or alongside the regular joists, not only for support but also to provide a place to nail flooring.

The small drain pipes (1 1/2 or 2 in.) from laundry, dishwasher, sink and garbage disposal, bathtubs, and lavatories can be run anywhere under the floor. When the paper covering is put on the slab, the location of joists and supports should be indicated on the paper with chalk. Then piping can be placed where it will not interfere with joists.

Plumbers often run hot and cold water lines parallel and with right angle bends in order to present a workmanlike appearance. This is unnecessary, and it requires more joints and fittings, leaves more chance for leaks, and takes more piping than if soft tubing is run the shortest distances between fixtures. This is especially true if plumbing and kitchen or laundry equipment units are shop-assembled and only the connections between them are made on the job.

Hot water supply pipes in the plenum may be insulated with blanket insulation. Bathtub and shower bases or stalls can be set directly on the joists. Warm air circulation beneath those fixtures is desirable.
FIG. 6. Plenum floor house under construction, with rock base for slab serving as work platform. Utilities will be roughed-in and slab will be poured after house is enclosed and roofed.

FIG. 7. Utility wall on joists supported by W-trusses. All plumbing lines are installed above slab, within plenum, except connections to street water supply and sewer.
Whether to provide a removable floor panel for access to plumbing is a matter of choice. An access hole can easily be arranged in the utility area, or small access panels under kitchen sink, bathroom cabinets, or in closets. If sections of flooring are put down with wood screws, they may be removed if necessary.

Wiring. Slab-on-ground houses have wiring difficulties because circuits must be carried overhead or through partitions. The above-slab space in plenum floor construction provides a place for many of the electric circuits. The main exception is wiring for ceiling fixtures, but the trend is toward eliminating such fixtures. Putting wiring under the floor offers an important saving, especially of heavy-duty wire for kitchen range, clothes dryer, water heater, or space heaters in electrically heated homes.

The first partition walls to go into place in the house are those of bathroom and utility areas. The wall of the utility area is the ideal location for the electrical distribution panel, making circuit breakers and other controls readily accessible.

Wiring systems for complicated machines or equipment, for example the instrument panels of airplanes, have to be preassembled so that they can be installed in the assembly line without delays. Preassembly consists of attaching wires of correct length to go to each circuit and coiling them up (pigtailling) on the back of the panel. In final assembly, it is only necessary to uncoil those wires and connect them to the proper lights, motors, generators, and other equipment.

The logical solution for low cost and development housing is to preassemble the wiring as is done for the airplane instrument panel. A "wiring tree" has been developed for use in houses having similar floor plans. In a plenum floor house with the control panel in the utility area, the preassembled wires would simply be dropped down to the slab and then extended to outlets or fixtures. This operation could be completed quickly just before joists and finish flooring are put in place.

Baseboard-type raceways for wiring and electrical receptacles can serve a further purpose in plenum floor construction. Set out from the wall on half-inch spacers, they offer a neat finish for the perimeter-slot warm air outlets. Combination baseboard-raceway systems are now on the market, but there is room for improvement of their appearance. Some of the newer products, made of plastic and less expensive, may offer more attractive choices for this treatment.

FLOORING

A general idea of the floor construction system for a house with a subfloor plenum formed with W-trusses is shown in Fig. 8. The joist spacing shown is 16 in. o.c., and the prefinished panels of flooring (in this case parquet) are laid crosswise. This arrangement can be modified in many ways for other types of flooring.

If flooring over the plenum is conventional hardwood, the process of laying it differs little from that for regular frame construction. The flat 2 x 4 joists may be spaced to suit the flooring, but because of their
wide flat surfaces the unsupported span between them is 2 in. less, with the same on-center spacing, than when joists are set on edge.

Subflooring is usually unnecessary; the slab serves as a platform for workmen. However, for regular strip-type hardwood flooring (2 1/4 in. tongue and groove), a subfloor may be desirable if joists are farther apart than 12 in. There is too much chance for squeaks or cracks to develop from flexing of the short narrow pieces of hardwood.

Large panels of prefinished flooring are too expensive to use in addition to a subfloor, but when the latter can be eliminated they are economical. These panels are obtainable presanded, even prestained, varnished, and waxed. The whole floor can be laid in a few hours, completely finished, usually after all painting, plastering, trimming, and other finish work is done. If movable partitions, room dividers, and storage cabinet walls are to be installed over it, the surface can be protected with building paper or roll roofing.

Prefinished panels eliminate the dusty job of sanding and the laborious operations of applying filler, stain, varnish, and wax, all of which can be done at the factory. If minor painting or other work must be completed after the floors are laid, they can be covered with building paper or drop cloths.

The most efficient flooring system, measured by time and materials required, utilizes panels large enough for rapid installation, heavy enough to need no subflooring and prefinished to reduce on-site labor. Several types are obtainable, two of which are described here.

Hardwood floor panels are built up by gluing together four widths of 2 1/4 in. flooring to make "boards" 9 in. wide, and 48, 72, or 96 in. long. The pieces composing the boards are random length, and the appearance is that of regular oak or maple flooring. Tongued and grooved on sides and ends, these boards or panels are accurately dimensioned, sanded, and completely prefinished if desired. Laying that kind of floor in a 1000 sq. ft. house means handling only 150 to 200 pieces of material, as compared with 2000 to 3000 pieces of regular flooring.

The panels should be laid so that the joints break on joists, and the joints should be staggered to add strength to the entire structure. Since joints between boards are not blocked or otherwise supported, joist spacing should not be more than 16 in. This leaves not more than 12 in. unsupported between joists.

Parquet-style flooring, which many people prefer, is available as prefinished panels with either 8 or 12 in. squares of 1/8 in. wood "tile" bonded to 5/8 in. plywood. The 8 in. squares are made up into panels measuring 16 x 32 in. or 16 x 48 in. Panels with 12 in. squares are usually 24 x 48 in., but may be obtained as large as 48 x 96 in. Edges are accurately tongued and grooved.

The total thickness of these panels is 3/4 in. They are of what is known as "balanced" construction; that is, the bottom ply is of the same type of hardwood as the top surface to reduce the tendency to warp. When
FIG. 8. Section of floor showing arrangement of metal trusses, joist spacing (16 in. o.c.), and panels of finished flooring, either strip or parquet type, applied crosswise of joists.
bonded to the surface of 5/8 in. plywood the squares are 5/32 in. thick, but 1/32 in. is sanded off to leave a smooth surface ready for further finishing.

The spacing of joists for parquet-style flooring is determined by the size of the panels and the pattern of the squares. Joists cannot be spaced 16 in. o.c. if 12 in. squares are used, because the pattern will not match when joints are broken on the joists.

Boards or panels are always more rigid if laid across rather than lengthwise of the joists, as shown in Fig. 8. When 16 x 32 in. or 16 x 48 in. panels are laid across joists spaced 16 in. o.c., the open span is only 12 in. and there is no need for blocking. But if panels 24 in. wide are laid across joists 24 in. o.c., the clear span is over 20 in. and blocking is required. Hence the 24 in. panels are more difficult to use in any construction scheme. If they must be used, it is probably best to space the joists only 12 in. o.c. Staggered joints will then break on joists every 12 in.

Manufactured panels of the straight board or the parquet type cost builders about 40 to 45 cents per square foot. If laid over a subfloor of 1/2 in. plywood, their cost would not be competitive with that of other wood flooring. In plenum floor construction the slab provides the work platform and the floor can be installed as almost the final operation. A prefinished panelized floor is therefore as cheap as any other, all things considered, and will save the time otherwise required for the floor finishers to complete their work.

SCHEDULING ON-SITE BUILDING OPERATIONS

For a house with basement, pouring footers and building basement walls are the next operations after digging the foundation. The basement floor may be left till the superstructure is well under way, even the roof, windows, siding, and doors in place. As soon as subflooring has been put on the first-floor joists, the building can be closed in and locked.

A different working schedule is used for slab-on-ground houses. The piers and grade beam or the continuous footers for walls are put in first, but the next job is to install the plumbing and heating rough-in that goes under the slab. Muddy ground or unfavorable weather may hold up that operation, and therefore all others, for days or even weeks. Above-slab plumbing systems have been devised in an attempt to get around this difficulty.

In plenum floor construction, walls may be set on the foundation before the slab is poured. In this respect, it is similar to building houses with crawl space or basement. But since there are no supporting walls within the floor area, there is no need for footers inside that area, and in this respect it resembles slab on ground. Because little of the plumbing and none of the heating rough-in is put in place before pouring the concrete slab, it is different from any other system and requires a new schedule of operations.
There is no need for a platform subfloor. The slab serves that purpose, and the compacted rock fill will do until the slab is poured (Fig. 6). Floor joists can wait until other rough work is finished. If interior walls require no plastering, the inner face of outside walls and the ceiling can be plastered, or gypsum board and insulation can be applied immediately. Even the furnace can be installed by putting down a few square feet of temporary joists and running the flue through the roof. Construction need not be delayed because of sheet metal or heating contractors.

Maximum savings, particularly of labor, will not be realized till the new construction system has been mastered and on-site operations are well organized. No set schedule can be developed or recommended, because much depends on choice of materials and finishes, flooring systems, and other details. Only a few generalizations can be made here. Some of the operations are entirely new, such as sealing the plenum, insulating the low foundation wall and slab, and attaching the joist supports. Others are familiar but must be fitted into the builders schedule somewhat differently.

As in any building system, foundation walls come first. Then coarse fill is spread over the soil as a base for the slab. Walking on the rock base as it serves as a temporary work platform helps to compact it.

Next, the sill is installed, and walls are framed (or paneled) up to the lintel or plate. Rafters then go into place, and the roof is completed. As soon as outside walls are sheathed and windows and doors are set in, the house can be closed to prevent theft and the furnace can be operated, though up to that point nothing has been done about rough-in of utilities.

Beyond that point, timing of construction operations is largely a matter of making arrangements that fit the materials being used. As soon as electric outlet boxes in the ceiling are fastened in place, insulation can be put in and paneling, rocklath, or gypsum board put up. Usually the last will be left till after pouring the slab.

Obviously, with the house enclosed and temporary heat provided, it is possible to finish the slab at most any convenient time. The only plumbing rough-ins that are needed before pouring the slab are water and sewer connections to the street mains. The soil pipe should be headed approximately level with the slab surface.

The stud walls for plumbing rough-in, or the prefabricated or shop-built plumbing walls, are erected next. They are set on sections of the joists, as shown in Fig. 7. Other joists should not be put in until plumbing and wiring rough-ins are finished. The electrical distribution panel may go into the utility wall, with its wires ready to be run overhead to ceiling fixtures or down and along the slab to other outlets.

If interior partitions of the house are movable, they will be set after the floors have been completed. Permanent interior walls are built on the joists in the same manner as the plumbing walls. Movable partition...
should be an important selling point, for the builder can adjust room sizes and closet arrangements to suit the buyer's needs.

Sanding and taping dry-wall joints or putting on rocklath and plaster are easily worked into the schedule. Naturally, if the interior walls are to be paneled and need no other finishing, partitions must be in place before the outer dry-walls and ceiling can be finished and painted.

Installing the joists and flooring is among the final operations. This coincides with putting on final trim, installing light fixtures, and completing the painting, hardware, and plumbing.

With good organization, builders using plenum floor construction can save considerable time between breaking ground and turning over the keys to the new owner. This is particularly true in areas where building is ordinarily hampered by winter weather. A small-scale builder whose operations do not justify the expense of "balloons" or other winter construction expedients can become almost independent of the seasons.