Rev. 1740

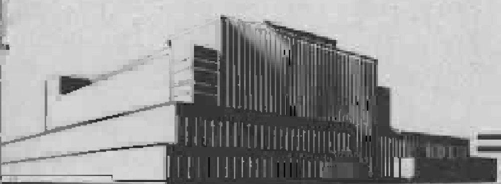
THERMAL INSULATION MADE OF WOOD-BASE MATERIALS

Its Application and Use in Houses

Revised October 1958

(Report)

No. 1740



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FOREST SERVICE
In Cooperation with the University of Wisconsin

FOREWORD

Today, the need for factual information on wood-base insulation is greater than at any earlier period. Architects, builders, and owners of homes have need of basic information on the most efficient insulation for their houses. The Forest Products Laboratory, during the course of its engineering investigations and allied studies extending over the past 48 years, has obtained much basic information on the thermal insulation of wood and wood-base materials, including their influence on fuel economy, comfort of occupants, attic ventilation, vapor barriers, fire hazard, and cold weather condensation. It is the purpose of this publication to present such information, together with procedures necessary for calculating the thickness of insulation required for a specified installation. The fullest efficiency to be derived from the use of insulation, as with any material, is in large part dependent on how it is used. The selection of the wrong materials, the use of improper thicknesses of materials, or faulty installation methods can constitute a severe drain on the home owner's income as well as on the Nation's resources.

This publication is intended to aid all who want to acquire a basis for independent judgment regarding the insulation they are buying. To such prudent buyers, a knowledge of the fact that they are using insulation is insufficient. Accordingly, this publication aims to assist in a careful estimation of where, when, and why insulation is needed; to show how the different wood-base materials meet specific requirements; and to emphasize some of the principles frequently overlooked that should be followed in the proper installation of insulation.

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THERMAL INSULATION MADE OF WOOD-BASE MATERIALS

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Introduction

One of the most important developments in modern construction practices is the increasing use of thermal insulation in all types of houses and particularly in the intermediate and low-cost dwellings. Comfort is the basic objective establishing the need for insulation, but fuel economy may often be the motivating factor justifying the added first cost involved in applying insulation. During cold weather, houses must be heated to maintain comfortable indoor temperatures, and insulation plays an important part in obtaining the uniformity of temperature that establishes comfortable conditions. During hot weather, insulation helps to keep indoor temperatures cooler than they would be in an uninsulated house. Even these advantages would not necessarily justify the use of insulation were it not for the fact that in cold climates there is a material saving in fuel, smaller heating plants can be used, and cleaning and decorating expense may be reduced. These savings will in themselves return the added cost of the insulation in a relatively short time.

Materials used in construction are selected to suit the needs of the service they are expected to perform. For example, in a conventional frame wall, the exterior may be wood siding over wood or fiberboard sheathing fastened to the studs, which act as structural supports for the wall. The inner wall surface may be lath and plaster or other suitable wall covering. All these materials offer resistance to the transmission of heat from one side to the other, and the heat transmission is proportional to the differences in temperature on opposite sides of the wall. Stucco or brick or stone veneer may be used in place of wood for exterior wall covering. Other materials may also be used for walls, such as brick, tile, concrete blocks, or stone with the interior surface furred, lathed, and plastered. Such walls, as commonly constructed in the usual thicknesses, will transmit more heat than will conventional frame walls. Where prefabricated construction is used, the wall panels may be made of light framing members covered on both sides with plywood or other suitable materials. The heat transfer through any of the wall types described can be

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

reduced by increasing the thickness of the basic materials. For example, 2 thicknesses of wood sheathing could be used in place of the 1 thickness generally used, or the thickness of a masonry wall could be increased above that required for minimum strength. Generally speaking, however, this means of decreasing heat loss is expensive without being very effective, and there are better means of accomplishing the desired purpose.

The materials used in construction are generally selected on a basis of first-cost, availability, building code requirements, appearance, fire hazard, and similar factors. In some cases, the materials may be selected because they are more resistive to heat transfer than others. For example, fiberboard products may be used in place of wood sheathing, as a plaster base in place of other plaster-base materials, and sometimes as wall or ceiling surfacing materials in place of plaster.

Structural and finish materials vary widely in thermal properties. Wood is much more resistive to heat transmission than is masonry. In this respect, 1 inch of Douglas-fir is equal in resistance to heat transmission to about 12 inches of concrete or stone, but it would take about 3 inches of the wood to equal 1 inch of fiberboard.

Thermal Insulation

Those materials that have high resistance to heat transmission are called thermal insulators or more commonly, insulation. Since wood has better thermal properties than most other building materials, such as brick, stone, concrete, or plaster, it might be called insulation. However, when the wood is made into fibrous products of low-to-moderate density, it becomes far superior to solid wood in thermal properties. The term "insulation" is, therefore, generally applied to materials, including wood-base materials, that have thermal properties superior to that of solid wood. Even among the materials called insulation, there are variations in thermal properties, since some types of insulation are more resistive than others. Commercial insulation is manufactured in a variety of forms and types, each having certain advantages for specific uses and no one type being best for all applications. This report is concerned only with those obtained from wood.

For purposes of description, the various kinds of materials (fig. 1) used commonly for insulation may be grouped within the following general classes: A, rigid insulation, (1) structural, (2) nonstructural; B, flexible insulation; C, fill insulation; and D, miscellaneous types.

Rigid Insulation

Structural.--Structural insulating board is a term generally applied to a type of product made by reducing wood, cane, or other vegetable fibers to a pulp and then assembling the fibrous material into large lightweight or low-density boards that combine strength with heat- and sound-insulating properties. Such material may also be used for decorative purposes. The finished board as generally made is 6 to 12 feet long, 4 feet wide, and 1/2 to 1 inch thick. Greater thicknesses are also furnished, usually by laminating the material of standard thickness to obtain the final thickness desired. Fiberboard products can be used for numerous purposes and consequently are furnished in a variety of sizes and finishes. The most common products are building board, sheathing, roof insulation board, roof slabs, factory-finished interior board, insulated siding base, insulating form board, shingle backer, and others.

Building board.--Building board is a general purpose insulating board supplied in widths of 4 feet, in lengths from 6 to 12 feet, and in thicknesses of 1/2 to 1 inch.

Sheathing.--Sheathing as the name implies, is intended for use as sheathing on walls and is sometimes used for roof sheathing on pitched roofs. It is furnished in widths of 2 and 4 feet, lengths of 8 to 12 feet, and thicknesses of 1/2 and 25/32 inches. It may be obtained with a natural finish or with surface coatings, generally of asphaltic material.

Interior board.--Factory-finished interior board is subdivided into four subtypes, (1) board, (2) plain tile, (3) acoustical tile, and (4) other subtypes. The board or plank is made in widths of 8 to 16 inches and lengths of 8 to 12 feet for use on interior walls.

Tile and acoustical tile.--Tile and acoustical tile are made in small squares or rectangular patterns generally with interlocking edges, and are used for interior finish, particularly on ceilings. It is available in a variety of sizes from 12 by 12 to 16 by 32 inches and in thicknesses of 3/8 and 1/2 inch.

Plank.--Plank is another type of interior finish frequently used in conjunction with tile board. It is made in widths ranging from 8 to 16 inches, lengths from 8 to 12 feet, and thicknesses of 3/8 and 1/2 inch. Tile board and plank may be obtained with natural finish or with a factory-applied surfacing. These materials are generally used if a decorative finish is desired, if the insulating properties are of secondary importance, and are also sometimes combined with sound insulation.

Roof insulation.--Roof insulation is made from fiberboard for use on flat roofs under composition roofing and under certain types of roofing on pitched roofs. It is also used under concrete floors. It is made in widths of 23 to 24 inches, 47 to 48 inches long, and 1/2 to 2 inches thick.

Insulating roof deck slabs.--Insulating roof deck slabs for roof decking are made up in panels 2- by 8-foot and in nominal thicknesses of 1-1/2, 2, and 3 inches. The lower face is of 1/2-inch, factory-finish interior board and the remaining layers are of sheathing-quality board. A vapor barrier is incorporated between the interior and sheathing quality boards when condensation control is desired.

The insulating roof deck slab is manufactured to provide the structural strength and rigidity for the roof construction as well as the desired thermal insulation. Each manufacturer furnishes the insulating roof deck in slightly more than nominal thickness, so that roofs constructed with it will have "C" factor values of 0.24, 0.18, and 0.12 British thermal units per hour per square foot per ° F. difference in temperature for heat flow up (winter heating) for the respective thicknesses of 1-1/2, 2, and 3 inches.

For most areas, design requirements are met structurally if the 1-1/2-inch decking is used where spans do not exceed 24 inches, the 2-inch decking where spans do not exceed 32 inches, and the 3-inch decking where spans do not exceed 48 inches.

Insulated siding base.--Insulated siding is sheathing-type board that is manufactured for use as siding, usually applied in the same way as bevel siding. It has slate, stone, or other granules on the exposed surface.

Insulating form board.--Insulating form board serves as the bottom form for light-weight, poured-in-place roof deck. Since it is not removed, it provides part of the thermal insulation and contributes to the strength of the deck.

Shingle backer.--Shingle backer is a product, usually 3/8 inch thick, used for backing of coursed shingle siding. It adds some insulation, a shadow line that enhances appearance, and, when properly used, eliminates the need for nailing strips over insulation board sheathing.

Nonstructural.--Nonstructural rigid insulation is often called "slab insulation." The slabs or blocks are small, rigid units sometimes 1 inch thick but generally thicker and vary in size up to 24 by 48 inches. The types made from wood-base materials are cork blocks, wood fiber bonded with Portland cement, magnesite, or other adhesive, and fiberboard slabs.

Cork blocks.--Cork blocks are made by bonding small pieces of cork together in blocks or slabs ranging from 12 by 36 inches to 36 by 36 inches and from 1 to 6 inches in thickness. It is used widely for cold storage insulation and for insulating the flat roofs of industrial and commercial buildings.

Wood-fiber blocks.--Wood-fiber blocks are made by bonding wood fibers, similar to excelsior but coarser, with some suitable bonding agent, such as cement. They are made in thicknesses of 1 to 3 inches and in various sizes. The principal uses are as roof deck insulation in industrial buildings, structural floor and ceiling slabs, and for nonbearing partitions.

Fiberboard slabs.--Fiberboard slabs are made by laminating fiberboard products to produce rigid blocks that are used generally for cold storage insulation.

Special high-density sheathing.--Most sheathing-grade insulating board is manufactured in a density range of 16 to 18 pounds per cubic foot. The thermal conductance values shown in table 2 for insulating board of sheathing type, either impregnated or coated, is for that material.

Recently many manufacturers of insulating board have developed a special sheathing with a density more nearly at 25 pounds per cubic foot. For many uses contemplated for the new product, thermal insulation efficiency is not considered so important as structural strength, because other insulation, such as blanket or batt, is included in the roof or wall construction. Coefficients or k values for heat-flow calculations should be obtained from the manufacturer when these new materials are used.

Flexible Insulation

Flexible insulation is manufactured in two classes or types: (1) blanket or quilt, and (2) fill. Blanket insulation is generally furnished in rolls or strips of convenient length and in various widths suited to standard stud and joist spacing. The usual thicknesses range from about 1/2 inch to 2 inches. It may be made of loosely felted mats of wood fiber or chemically treated wood-fiber products. The fibers used are generally chemically treated to make them resistive to fire, decay, and vermin. Quilts may also be made of multiple layers of newspapers stitched together. Most blanket insulating materials are supplied with a covering sheet of paper on one or both sides, and this covering material has tabs on the sides of the blanket used for fastening it in place. The covering sheet on one side may be of a type intended to serve as a vapor barrier. In some cases the covering sheet may be surfaced with aluminum foil or other materials known as reflective insulation.

Blanket insulations are also manufactured without the paper covering, the fibers having sufficient strength to hold the material in the intended form and shape.

Fill Insulation

Loose, fill-type insulation is generally composed of materials used in bulk form, usually supplied in bags or bales and intended to be poured or blown into place or packed by hand. It is used to fill stud spaces or to build up any desired thickness on horizontal surfaces. Wood products most commonly used are wood fiber, granulated cork, shredded redwood bark, ground or macerated newsprint, sawdust, and shavings.

Reflective Insulation

Most materials reflect radiant heat, and certain ones have this property to a high degree. For reflective insulation, high reflectivity and low emissivity are required, as provided by aluminum foil, sheet metal with polished surface coating, and paper products coated with reflective materials. Reflective insulation is available in a variety of forms, usually as foil or coatings mounted on paper backing and on the back of gypsum lath and wall board. It is sometimes used in combination with blanket insulation as the surface cover of one or both faces. Reflective insulation, to be effective, must be installed with the reflective surfaces facing or exposed to an air space preferably 3/4 inch or more in width. Reflective materials in contact with other surfaces lose their reflective properties.

Emissivity, as used here, applies to the emission or radiation of radiant heat from a surface on the warm side of an air space, and reflectivity applies to the reflection of radiant heat from a surface on the cold side of an air space.

Miscellaneous Insulating Materials

There are, of course, insulation materials that do not fit into the classification described, such as (1) confetti-like material mixed with adhesive and sprayed on the surface to be insulated, (2) multiple layers of corrugated paper, and (3) shredded wood-fiber bonded with magnesite cement.

Influence of Insulation on Comfort

The primary function of insulation is to retard the transfer of heat, either from within a building to the outside or from the outside to within a building. The question naturally arises as to how much insulation should be used. The answer to this question depends somewhat upon whether the dwelling is in a cold climate or a hot one. Houses are heated in cold weather to establish temperatures inside that are most conducive to comfort and health. Regardless of the variations in outside temperatures, comfort requires that inside temperatures be controlled within comparatively narrow limits.

Most adults are comfortable at temperatures from 70° to 72° F. in mild winter weather, but during severe weather, they prefer higher temperatures. The comfort of a person at rest is affected to a marked extent by exchange of radiant heat between the body and surrounding surfaces. Conditions most conducive to comfort are found where the surface temperatures of the enclosing walls, ceiling, and floor are very close to that of the air, and where this condition is attained, a temperature of 70° F. is considered comfortable. If such surrounding surfaces are several degrees below 70° F., however, comfort demands that the air temperature be raised to compensate. In cold weather and in inadequately insulated homes, the householder finds it necessary to raise the temperature above that acceptable in mild weather in an effort to acquire equal comfort. Even this practice does not fully accomplish the desired effect, since the variations in temperature between the cold surfaces, particularly the walls, create uncomfortable drafts making some parts of a room much less comfortable than others.

While no standard has been so far established for the surface temperature of enclosing walls, ceilings, and floors, it is generally accepted that temperatures of these surfaces that are more than 10° F. below the average air temperature are a cause of discomfort. To meet the minimum requirements for insulation of side walls established by the Federal Housing Administration, the calculated surface temperature would be about 9° F. below room temperature. A standard difference of about 6° F. between the air and enclosing wall surfaces and of 4° F. for ceilings under unheated attics or roofs at design temperature conditions for the zone where the building is located is suggested as reasonable, from the standpoint of comfort; practical, from the standpoint of the availability and cost of insulating materials; and economical, from the standpoint of fuel consumption. A difference of 6° F. as suggested would hardly be acceptable for average conditions, but that value is used for extremely cold weather; in normally cold weather, the difference would be less. Windows and doors are sources of greater heat loss than most wall materials, and the surface temperatures in cold weather will be below the standard suggested, even when they are protected by storm sash and storm doors. The physical discomfort caused by the colder surfaces and the drafts they produce should be offset as far as possible by limiting the heat transfer through other areas.

Insulation may be used to retard the inflow of heat, particularly through roof and wall surfaces exposed to the direct rays of the sun. Under such exposure, these surfaces become hotter than outdoor air temperatures. When outdoor air temperatures are about 90° F., the roof surface may have a temperature of 150° F. or higher. Since the transfer of heat through materials is proportional to the difference in surface temperature, it is the outside surface temperature, rather than the air temperature, that establishes the rate of heat flow into the structure and explains why an attic or roof space may have a temperature much higher than the outdoor air temperature. Heat from the attic or roof space can be transmitted through the ceiling to the rooms below. Attic spaces often remain at a high temperature long after the sun has set and supply heat that makes the rooms below uncomfortably hot all night. Insulation between the occupied rooms and the attic or roof space retards the heat flow and adds materially to the comfort of the occupants of the rooms. Side wall insulation, particularly on those sides exposed to the direct rays of the sun, is also helpful in reducing room temperatures.

Relation of Climate to Insulation

Enough insulation should be provided to assure comfort and economical heating in the coldest weather expected where the house will be erected. Because winter temperatures vary materially in different parts of the country, buildings in the cold zones require more insulation than do those where winters are less severe. This principle is recognized by heating engineers, and for design purposes, they use outside temperatures established for each major city or area. These temperatures are generally selected at about 15° F. above the lowest recorded temperature for the location or are based on the average minimum temperature for that location or on established local practice. Actual design temperatures, particularly in the mountain areas, may differ locally as much as 20° F. from the design temperatures shown in figure 2, and local weather records should be examined to adjust them accordingly.

Insulation Requirements

It is comparatively simple to determine the amount of insulation required to accomplish a desired result. The thermal properties of most building materials are known, and the coefficient of transmission, or U value, for most combinations of construction and insulation can be calculated. The U value represents the overall coefficient of heat transmission and is the amount of heat expressed in British thermal units transmitted in 1 hour through 1 square foot of surface per 1° F. difference in temperature between the inside and outside air. It is also comparatively easy to determine the calculated temperature of a surface when the U value and the temperature of the air on opposite faces of a wall, floor, or ceiling are known or assumed. If some minimum acceptable difference between inside air and surface temperature is established at some assumed outdoor temperature, the U value necessary to meet this requirement can be determined. The amount of insulation required to obtain the desired U value can then be determined for any combination of construction. The U values for a number of combinations of construction with and without insulation are given in table 1.

Figure 3 offers a convenient means of determining the U value required for walls, floors, and ceilings for various climatic conditions and various differences between inside air and surface temperatures. To use figure 3, first determine the zone where the building will be located from figure 2. Decide upon the acceptable difference between inside air and surface temperatures and subtract this figure from 70° F., which is assumed to be the air temperature. This value represents the surface temperature as shown on the bottom scale of figure 3. Follow this temperature up to the point where it intersects the zone line; then follow across at a right angle to obtain the required U value at the left of the chart.

Example: Assume that a house will be built in zone F and the minimum wall surface temperature should not be more than 6° F. below the air temperature in the rooms. This establishes the surface temperature at 64° F., and where the 64° line intersects the line for zone F, we find the U value to be 0.110. In zone C, the U value would be about 0.165 and in zone H, 0.090. These differences in U values explain why more insulation is needed in the colder zones than in the warmer zones to provide the same standards of comfort in cold weather. For basementless houses setting on a foundation wall, the crawl space between the floor and the ground will have an average temperature above that of the air out-of-doors. To determine the U value for such floors, it would be reasonable to use the method described for walls but to assume a temperature 30° higher than the zone temperature. For example, in zone F, use the values for zone C in figure 3 to determine the U value.

Assuming an air-to-surface temperature difference of 4° F. for the ceiling, the U value for zone F would be about 0.072 and for zone C, 0.11.

It should be understood that the calculated surface temperatures will not necessarily represent the true surface temperature at any one time, particularly on a wall. Air at the ceiling will invariably be at a higher temperature than air at the floor, and the actual wall surface temperatures will vary accordingly from ceiling to floor. The calculated surface temperatures represent the order of difference between the air and surface temperatures.

It should also be appreciated that the surface temperatures have been calculated on a basis of extremely cold weather and that during normal cold weather temperature, differences would be less. In fact it is questionable if true comfort conditions will be attained when the differences are as much as 6°, but the outside temperatures will seldom drop as low as the zone temperature, and then only for short periods.

As previously explained, most adults are comfortable at temperatures of 70° to 72° F. in mild winter weather when the surface temperatures are close to room temperature. In colder weather, however, when surface temperatures are lower, occupants will raise the air temperature 2° to 4° F. in an effort to attain equal comfort. However, temperatures are not equal in all parts of the room, being lower near exposed walls and higher near inner walls. Temperature differences also cause those drafts that make some parts of the room particularly uncomfortable. The use of adequate insulation to minimize differences in temperature between the enclosing surfaces and air temperature, not only makes it possible to be comfortable at lower air temperature, but results in a material saving of fuel by (1) reducing heat loss and (2) maintaining lower temperatures.

In the colder climates, the insulation provided for winter conditions will generally be adequate for summer conditions, but in the warm climates, where little or no insulation is required for cold weather, it may be essential in warm weather to establish reasonable comfort conditions. Its greatest value will be below the roof and above the occupied rooms to retard the inflow of heat from the more or less direct rays of the sun. It will also be of some value in the walls exposed to the sun, and it will be of the least value in those walls not exposed to the sun, such as the north wall and walls protected by porches, other buildings, or trees.

Where it is customary to close all windows and doors and draw the shades during the hottest part of the day and to open the house to cool it off at night, insulation is of value in all walls, as it retards the inflow of heat during the period when outdoor temperatures are above indoor temperatures. Insulation is also of value if air cooling systems are used.

As explained previously, the direct rays of the sun on a roof raise the surface roof temperature very much above that of the air. Thus the surface temperature of the roof may raise the temperature of the closed roof and attic as much as 50° or more above outdoor temperatures, and the roof space then holds heat long after the sun has set. Insulation between this roof space and the ceiling below will retard, but not stop, the heat flow. Ventilation of the roof space can carry away some part of the heat that is otherwise trapped there and may lower the temperature of the roof space from 20° to 30° F. It also hastens the cooling of the roof space after the sun has set. A combination of adequate roof space ventilation and insulation will be very effective in retarding the inflow of heat through the roof and roof space into the occupied rooms below.

The amount of insulation that should be used is largely a matter of judgment, but if comfort during hot weather is the justification for insulation, the following maximum U values are suggested: for side walls, 0.20; for ceilings under pitched roofs, 0.15; and for flat roofs, 0.10. Where mechanical cooling systems are used, lower values would be desirable.

Use of Tables of Calculated Coefficients of Transmission

Table 1 shows the calculated coefficients of transmission, or U values, for various types of walls, ceilings, and roofs of frame construction without insulation and with various combinations of insulation. No table is shown for an attic space between the ceiling and the roof, since the calculations for such attics are too involved for simple tabulating.

Tables 1, 2, 3, and 4 are useful in making comparisons between various types of construction and combinations of insulation. They show that the materials used for lath, sheathing, or for exterior finish have an important bearing upon the overall rate of heat transmission. They also show that, when insulation is added -- as, for example, blanket-type material in the stud spaces -- the rate of heat transmission decreases as the thickness of insulation increases but not in direct relation to the increase. The first inch reduces the coefficient of heat transmission more than the second inch, and the second inch, more than the third inch. For example, in a frame wall having a U value of 0.25 without insulation, the addition of 1 inch of blanket insulation in the stud space lowers the U value to 0.13, or by 48 percent, the second inch lowers the U value to 0.094, or by 62 percent, and the third inch to 0.076, or by 70 percent. If the cost of insulation were proportional to the thickness, the first inch would show the best return for the investment. However, the cost of blanket insulation is not proportional to its thickness, the second inch costing in both labor and material appreciably less than the first inch. Fill types of insulation, on the other hand, are sold in bulk, and the cost of the material is proportional to the thickness used, hence the labor cost for installation would be nearly proportional to the thickness.

If the materials used for structural and covering purposes in walls and roofs do not provide the desired amount of resistance to heat transmission, insulating materials may be added. In frame construction, the insulation is usually placed in the stud spaces in side walls and between joists in the attic or roof. In new construction, the insulation used in side walls is generally of a blanket type, and the same type may also be used in the roof. In level ceilings the fill type may be used. For existing buildings the fill type is commonly used in the stud spaces of side walls.

Methods of Heat Transfer

Heat seeks to attain a balance with the surrounding conditions, just as water will flow from a high to a low level or gases will flow from a high- to a low-pressure area. When outside temperatures are low, heat is supplied in houses and other similarly occupied buildings to maintain the inside temperatures in the comfort range. Under such conditions, with a difference in temperature between the inside and outside there will be a transfer of heat through the walls, floors, ceiling, and through windows and doors at a rate that bears some relation to the temperature differences and to the resistance to heat flow of intervening materials. To maintain a constant inside temperature when outside temperatures are constant and below inside temperatures will require a constant supply of heat, and the heat supply or inflow in this case equals the heat loss or outflow. The amount of heat required at any fixed temperature depends upon the rate that the heat will be transmitted through intervening materials used on the construction of the enclosing units.

The transfer of heat may take place by one or more of three methods -- conduction, convection, and radiation (fig. 4).

Heat is transmitted through solid materials by conduction. In a steam-heated radiator, the steam heats the inner surface of the radiator walls, and this heat flows through the walls to the outer surface by conduction.

Heat transfer by convection applies to heat carried by air currents from a warm zone to a cold zone. Air in contact with the warm outer surface of a radiator becomes heated above the temperature of the surrounding atmosphere, and rises, being replaced by colder air. Thus a circulation of air over the heated surface carries heat from the radiator to raise the temperature of the surrounding atmosphere.

Heat may be transmitted from a warm body to a cold one by wave motion through space; the process is called radiation, as it represents radiant energy. The waves do not heat the space through which they move, but when they come in contact with a colder surface or object, a part of the radiant energy is absorbed and converted into heat and part is reflected. For example, when one is standing near a radiator or an open fire, those surfaces of the body toward the source of heat are warmed by radiation and those surfaces away from the source of heat do not feel the radiant heat. The air temperature would be essentially the same in both types of exposure.

Heat transfer through a structural unit composed of a variety of materials may include any one or more of the three methods described. In the case of a frame house having an exterior wall consisting of plaster, gypsum lath, 2- by 4-inch studs 16 inches on centers, 3/4-inch wood sheathing, sheathing paper, and bevel siding, heat is transferred from the room atmosphere to the plaster by radiation, convection and through the lath and plaster by conduction. Heat transfer across the stud space by radiation from the back of the lath to the colder sheathing and by convection, since the air warmed by the lath moves upward on the warm side of the stud space and air cooled by the sheathing moves downward on the cold side. Heat transfer through the sheathing, sheathing paper, and siding will be by conduction. Some minor air spaces will be found behind bevel siding, and the heat transfer across these spaces will be principally by radiation. The heat transfer through the studs from the lath to the sheathing will be by conduction. The heat transfer from the outer surface of the wall to the atmosphere will be principally by convection and radiation.

Heat transfer by radiation across an air space is affected by the character of the surfaces. A dull black body or surface absorbs all the radiant waves that strike it but other types of surface reflect some part of the radiant heat. In general, bright metallic surfaces have high reflective properties whereas most nonmetallic materials used in building construction have low reflective properties.

The emission of radiant heat from a surface, emissivity, is in direct proportion to the amount of absorption. The transfer of heat by radiation across an air space is affected by the emissivity of the boundary surfaces.

Thermal Properties of Materials

Where necessary to determine the U value for a given combination of building materials with greatest accuracy, tests would be made on full-sized panels of the construction unit represented in a guarded hot box. Few research organizations are equipped to make hot-box tests, and the tests are expensive. It would hardly be practical to make tests on all combinations of construction and insulation that may occur in buildings. Nevertheless, for design purposes there is need for a simple and practical method of determining U values of construction assemblies so that the thermal properties of different combinations of construction and insulation may be compared.

Tests have been made and coefficients of heat transmission have been established for the usual materials used in construction or insulating materials. Materials of a homogenous character, such as wood, fiberboard, fiberous insulation and similar materials, are generally tested by the hot-plate method, but materials of irregular shape, such as concrete block and hollow tile, are tested by the guarded-box method. By proper use of the coefficients established for the various materials used in a construction assembly, the overall U value can be determined by calculation. The results obtained by calculation should agree reasonably well with those obtained by test in the guarded hot box.

Standard test procedure by the hot-plate method requires that the test material be ovendried. Therefore the conductivity values as given in most tables are based on dry material. Under service conditions, some building materials may contain more or less moisture, and the moisture may affect the overall heat transmission. For most design purposes, however, the U values obtained by computation based on dry materials will be sufficiently accurate.

Values recommended for use in computing the thermal properties of building units are given in table 2. Values that may be used for reflective insulation are given in table 3. Values for reflectivity, emissivity, and effective emissivity of air space are shown in table 4.

The Forest Products Laboratory has made careful determinations of the thermal conductivity of wood at various values of moisture content. These tests furnished sufficient data on the relationship between conductivity, specific gravity, and moisture content to make it possible to compute the approximate thermal conductivity across the grain for any wood for which the specific gravity is known and for which the moisture content can be determined or assumed.

Heat conductivity, represented by the symbol k, is defined as the amount of heat in British thermal units that will pass in 1 hour through 1 square foot of material 1 inch thick per 1° F. temperature difference between faces of the material. Table 5 gives the average specific gravity of ovendry specimens of most commercial species and the k value at 0 percent moisture content. Also given are the R value per inch of thickness and the R value for nominal material, 25/32 inch thick. For some purposes, the calculated thermal properties of materials should be based on the moisture content attained in service. The thermal conductivity of a given wood at a known or assumed moisture content can be determined from figure 5. To use this chart, obtain the average specific gravity from table 5 for the wood under consideration. Determine or assume the moisture content of the wood. When the actual moisture content is not known, assume it is 15 percent for wood siding or sheathing and 7 percent for inside woodwork or finish. On the chart, follow a vertical line corresponding to the moisture content of the wood upward until it intersects the sloping line corresponding to the specific gravity of the wood. The reading on the vertical scale at the left of this intersection point is the desired thermal conductivity, k, for the wood at the assumed moisture content.

The specific gravity data of table 5 are average values for the species listed. There are, of course, appreciable variations in specific gravity between boards and even between shipments of the same species. Infiltrated substance, such as gums, resins, and others, found in some species, and defects such as checks, knots, and irregular grains may also have some influence on conductivity, but for purpose of calculation, those factors may be ignored.

The conductivity value for plywood is essentially the same as that for solid wood of the same thickness.

Values for corrugated paper of the type developed at the Forest Products Laboratory for use as core stock in sandwich construction are given in table 6. Corrugated paper products with various combinations of surfacing materials and of different thicknesses are also among the materials used as insulation in conventional frame construction. These data are based on paper treated with 15 percent of water-soluble phenolic resin before the paper was corrugated with "A" flute rolls. Figure 6 shows a number of different methods of assembling, some with flutes parallel with the covering faces, some with flutes perpendicular, some with simple cells with the nodes of opposing corrugations in contact, and others with an interliner between corrugated sheets. As made, there are about 3-1/2 corrugations per inch. The k value applies to the corrugated material without the covering sheet of plywood shown.

In table 7 are given the effects of foamed resin and fill insulation on thermal properties of honeycomb cores.

Method of Computing Thermal Conductivities

The rate of heat transfer through various combinations of the materials and air spaces of walls and roofs can be obtained by comparing the overall coefficient of heat transmission, or U value, of the construction assembly. To determine the U value by test would, in most cases, be impracticable, but it is a simple matter to calculate this value for most combinations of materials of the type commonly used in building construction.

Table 2 gives conductivities and conductances with corresponding resistances and resistivities commonly used in calculating the thermal properties of construction units.

To compute the U value, add the resistance of each material, exposed surface and air space in the given section, using values given in table 2. The sum of these resistances divided into 1 (reciprocal of the sum) gives the coefficient (U). Where reflective insulation is used, the value in the table includes the air space.

Example: The overall U value through the stud space of a conventional frame wall consisting of plaster, gypsum lath, air space, wood sheathing and sheathing paper, and siding where heat flow is horizontal is calculated as follows:

Interior surface resistance	0.68
Plaster (1/2 inch of sand aggregate)	.09
Gypsum lath (3/8 inch)	.32
Air space	.97
Wood sheathing (25/32 hemlock)	1.00
Sheathing paper	.06
Bevel siding (1/2- by 8-inches)	.81
Exterior surface resistance (15 m.p.h. wind movement)	.17
Overall resistance	4.10

The overall coefficient of thermal transmission through the stud space becomes:

$$U = \frac{1}{4.10} = 0.244$$

For a U value through the stud, substitute the resistivity of wood based on the depth of the stud for the resistance value of the air space. For example, assume a species of wood that has a k value of 0.9, the resistivity would be 1.11. The depth of a standard 2- by 4-inch stud would be 3-5/8 inches.

$$3\text{-}5/8 \times 1.11 = 4.02$$

Substituting the value of 4.02 for the air-space value of 0.97 gives an overall resistance value of 7.15 or a U value of 0.140. Assuming the area of the stud represents 15 percent of the wall area, the corrected transmission value becomes $\frac{(0.244 \times 85) + (0.140 \times 15)}{100} = 0.228$

If insulation is used in the stud space, the values for the air space are changed accordingly. For example, assume that if 1-inch blanket-type insulation is to be used and so installed between the studs that there will be an air space of 3/4 inch between the lath and the blanket and another air space between the blanket and the sheathing of about 1-7/8 inches, the values will be as follows:

Interior surface resistance	0.68
Plaster (1/2 inch of sand aggregate)	.09
Gypsum lath (3/8 inch)	.32
Air space	.97
1-inch-blanket insulation (wood fiber)	4.00
Air space	.97
Wood sheathing	1.00
Sheathing paper	.06
Siding bevel (3/4 by 10 inches)	1.05
Exterior surface resistance	.17
Overall resistance	9.31

$$U = \frac{1}{9.31} = .107$$

The U value for the stud space and the stud would be
$\frac{(0.107 \times 85) + (0.135 \times 15)}{100} = 0.112$

If a 2-inch blanket is used in the center of the stud space, the U value becomes 0.075 and for stud space and stud, is 0.085.

Where fiberboard sheathing is used in place of wood sheathing, the computation through the stud space would be made as follows:

Interior surface resistance	0.68
Plaster and gypsum lath	.41
Air space	.97
Fiberboard sheathing (25/32 inch)	2.06
Wood siding, bevel (3/4 by 10 inches)	1.05
Exterior surface resistance	.17
Overall resistance	5.34

$$U = \frac{1}{5.34} = 0.186$$

The U value for the stud and stud space would be

$$\frac{(0.186 \times 85) + (0.162 \times 15)}{100} = 0.182$$

The application of the formula for heat transmission to top floor ceilings is done in the same manner as for side walls, but the coefficients used for surface and air space resistances depend upon the direction of heat flow.

If insulation is used, there should be provision for ventilation between the insulation and roof sheathing, as shown in figure 18. In computing heat flow, the roof sheathing, roofing, and exterior surface resistances are not included, but the resistance value used for the air space between the insulation and roof sheathing is the same as that used for a closed air space.

For a flat deck having a composition roof, wood sheathing, 10-inch-roof joist with a 2-inch blanket set between the joists, with an air space above and below the insulation, and with a ceiling of 1/2-inch gypsum board, the computation would be as follows:

	Heat flow up	Heat flow down
	Winter	Summer
Interior surface resistance	.61	.92
Gypusum board ceiling (1/2 inch)	.45	.45
Air space (3/4 inch)	.85	.93
Blanket insulation (2 by 3.70)	7.40	7.40
Air space (6 inches)	.85	.99
Overall resistance	10.16	10.69
U =	$\frac{1}{10.16} = 0.098$	$\frac{1}{10.69} = 0.093$

The difference in overall U value between heat flow up and heat flow down is not significant in the case of insulated roofs. Where the U value is 0.15 or lower but is significant where higher U values occur. If the covering sheet of the insulation, facing the 3/4-inch air space were of a reflective material having an effective emissivity value of 0.05, the R value 2.44 (see table 3) could be substituted for the R value 0.85 for heat flow up changing the U value from 0.098 to 0.085. For heat flow down, the R value of 0.93 for the 3/4-inch air space would be changed to 3.23, changing the U value to 0.079.

The method of computing the U value for floors over unheated crawl spaces in basementless houses is the same as that used for roofs; that is, the values set up for heat flow down are used. The surface resistance value for the surface facing the crawl space would be that used for still air (0.92). For concrete slab floors laid on the ground, heat is transmitted through the floor to the ground below and from the ground below the slab through the foundation wall to the ground outside. The heat transfer through the floor to the ground is not uniform over the whole area, being greatest near the outside walls. Heat is also transmitted through the slab to the foundation wall and to the outside both above and below grade. Accurate methods of determining the heat transfer are very involved and beyond the scope of this article. Tests made by the National Bureau of Standards on concrete slab floors (reference BMS 103) have shown that the heat loss may be calculated as proportional to the linear length of the exposed edge rather than total floor area and that insulation between the floor and the foundation wall around the perimeter of the building will reduce the heat loss at this point very appreciably.

The heat loss through doors and windows is generally much greater than that through walls, ceilings, or floors. The coefficients of transmission, or U values, generally used for doors are given in table 8.

These values are for solid doors of the thickness indicated and glazed storm doors. The losses of heat through doors having glass or wood panels can be computed, assuming a U value of 1.13 for glass or thin wood panels.

The U values commonly used for windows are:

Type of Window	
Single window	1.13
Double (storm sash)	.53
Double glazing (2 thicknesses of glass 1/4 inch apart)	.61
Glass blocks 7-3/4 by 7-3/4 by 3-7/8 inches thick	.56
11-3/4 by 11-3/4 by 3-7/8 inches thick	.52

Doors and windows represent about 20 percent of the surface of exterior walls. The loss of heat through unprotected glass and door surfaces is several times as great per unit of area as that through the walls and ceilings. The cold glass surface can also be the cause of considerable discomfort because of radiation from the body to the glass. Condensation collecting on the windows not only obscures the outlook but also wets the sash and window stool, stains the walls, and may also cause decay in the window sash and frame.

Installing storm doors and storm or double-glazed sash reduces the heat losses through these surfaces by approximately one-half. Protecting doors and windows in this way raises the temperatures of their inside surfaces and thereby eliminates condensation and adds materially to comfort. Protection against cold weather offered by the installation of storm doors and storm sash should be included in all houses in zones D, E, F, G, and H, (figs. 2 and 3) and in any zone where condensation on windows in cold weather creates a real nuisance or damage.

Inside Surface Temperature

The temperature of any inside surface may be computed by the following formulas:

For horizontal heat flow, as through walls:

$$T_s = t_i - \frac{U}{1.46}(t_i - t_o) \qquad (1)$$

For vertical heat flow upward, as through ceilings in winter:

$$T_s = t_i - \frac{U}{1.63}(t_i - t_o) \qquad (2)$$

For vertical heat flow downward, as through ceilings in summer or through floors in winter:

$$T_s = t_i - \frac{U}{1.08}(t_i - t_o) \qquad (3)$$

Where t_i is the temperature of the inside air, generally assumed at 70° F., t_o is the temperature of the outside air, $(t_i - t_o)$ is the difference between the temperature of the inside and outside air, and T_s is the temperature of the inside surface. The values 1.46, 1.63, and 1.08 are the surface conductances for walls, ceilings, and floors.

Temperatures for other surfaces in a composite structural unit can be computed by adding the respective resistances of intervening materials and substituting the reciprocal of this sum for the surface conductances used in the foregoing formulas.

Where to Insulate

Insulation is used to retard the flow of heat through ceilings, walls, and floors where wide temperature differences occur on opposite sides of those surfaces. In unheated attics, the insulation should be placed over the ceiling of the rooms below, but in heated attic spaces, the insulation should be located in the attic ceiling and down the slope of the roof to the wall plate (fig. 7). Where a dwarf wall is used between the floor and slope of the roof and the space behind the wall is not used, the insulation may be placed in the dwarf wall and across the ceiling below to the wall plate. Walls and ceilings of dormers and the gable ends of the attic should also be insulated if the space is heated. It is desirable to insulate the walls and undersides of stairways leading to unheated attics.

In flat and pitched roofs of frame buildings, where the insulation is placed over the ceiling and below the roof, it should be so installed that there is an air space between the insulation and the roof sheathing for air circulation, as shown in figure 18. In flat-roofed buildings, insulation may be placed on top of the roof deck. If this is done, there should be a vapor barrier below the insulation. No outside ventilation should be provided in the roof space below the insulation.

All exterior walls should be insulated including walls between heated rooms and unheated garages, porches, and similar spaces.

The floors over unheated garages, porches, and floors over crawl spaces or unheated basements should also be insulated.

Insulation of basement and cellar walls is generally less important than in the walls of rooms above grade; nevertheless, there are circumstances where insulation should be considered.

Basements used only for work space, laundry, and storage may have temperatures 10° F. or more below those acceptable for living rooms. If basements are too cold for comfort or if water pipes freeze because of excessive heat loss through the basement walls, insulation may be used to reduce the heat loss. Such conditions will be found more frequently in basements having a large part of the exterior walls above grade than where only a small part is above grade. Space in basements used for living rooms or play rooms should have insulation in exterior walls.

Where water or plumbing pipes, such as those near a kitchen sink, are located in exterior walls, the pipes should be as close as possible to the inside wall, and no insulation should be used between the pipes and the inside wall. All insulation should be on the cold side of the pipes to give maximum protection against freezing.

In hot climates, insulation can be used effectively to improve comfort conditions within the house. Those surfaces exposed to the direct rays of the sun may attain temperatures 50° or more above temperatures in the shade and, of course, tend to transfer this heat toward the inside of the house. Insulation in roofs and walls retards the flow of heat, and consequently, less heat is transmitted through these exposed surfaces to heat the atmosphere inside of the house.

Where any system of cooling the air inside of the house is employed insulation should be used in all exposed ceilings and walls in the same manner as that used for houses in cold regions. In such installations, it is presumed that all windows and doors in the house will be closed during those periods when the outdoor temperatures are above the temperature inside. It is important that windows exposed to the sun be shaded with awnings or that drapes or curtains be drawn to reduce the flow of heat through the glass surfaces.

Ventilation of attics and roof spaces is an important adjunct to insulation. On a bright sunshiny day when outdoor temperatures are about 90° F., the temperature in a closed attic space may be 150° F., but with ventilation, the attic temperature may be reduced to about 120° or 125° F. Obviously, less heat will be transmitted through the ceiling to the rooms below where the attic temperature is 125° than where it is 150° F. Moreover, the closed attic remains hot for many hours after the sun has set, but the ventilated attic cools off more rapidly.

Methods of ventilation suggested for protection against condensation during cold weather apply equally well for protection against excessive roof temperatures during hot weather.

Reducing Heat Loss in Existing Buildings

Owners of existing houses are often concerned with ways and means of reducing heat loss and improving comfort conditions in their homes. It is necessary, of course, to first determine the nature and importance of the various causes of heat loss and to consider the most practical means of reducing them. Each house must be considered as an individual problem, and each principal source of heat loss must be considered separately as it affects that house.

The heat transfer through each square foot of window surface and exposed door surface is many times that through most wall materials. In conventional construction and design, the area represented may be about 15 percent of the total exterior wall surface, but in some houses, the area is much greater than in others. Weather strips around windows and doors will reduce air infiltration. Storm sash and storm doors will also reduce air infiltration and, in addition, reduce heat transfer by 50 percent or more through the exposed surfaces. Though condensation or frost may collect on single windows in mild weather, it is unlikely to form on windows protected by storm sash except at very low outside temperature and under unusual conditions.

The transfer of heat and the corresponding losses of heat that occur through uninsulated ceilings and walls or between heated and unheated spaces can be reduced by insulation. Attics and roof spaces are often of a type that are easy to insulate, but side walls may present a problem. Table 1 may be used to estimate the extent to which it is possible to reduce the heat transfer through walls and ceilings of different types.

Insulation in Existing Buildings

In the application of insulation to existing buildings, there are certain limitations that do not apply for new construction. In an attic where the framing members are exposed, it should be possible to use any of the types that can be fitted between or over the framing members. Where the framing members are enclosed, it may be necessary to use blown insulation as described for side walls. In the side walls of a typical frame house, the framing members are covered on the outside with sheathing and some siding material and on the inside with plaster or other wall finish. It is impractical to introduce blanket or batt insulation to the stud space. It is possible, however, to fill the stud space with a fill-type insulation by making small openings in the outside wall through which the insulation may be blown or poured. This is the method generally used by insulation applicators or contractors equipped for such work.

On houses having wood siding, a piece of siding is removed at the top of the wall and below each window opening (fig. 1, F). Holes about 2 inches in diameter are cut through the sheathing into each stud space. The applicator uses a plumb bob to determine the depth of the stud space and cuts additional holes where necessary below the top hole and below windows, so that he will have access to the full height of the wall. By means of a blower, insulation is forced through a hose and nozzle into each opening under a slight pressure until the stud space is completely filled. The siding is then replaced. When properly applied, there should be little or no settling of the insulation.

The same general method is used for stucco, brick, and stone veneer walls. Blown insulation is also commonly used in attic and roof spaces, particularly where applied to a horizontal surface.

Some applicators follow a practice of leaving the hole in the sheathing open, claiming that such practice provides a means of escape of moisture from the wall and is a protection against condensation difficulties. Tests have been made, however, which show that the influence of such holes is very local in walls where condensation occurs and that they cannot be considered an effective protective measure against condensation.

Masonry walls of existing buildings, such as brick, stone, concrete, and tile, cannot be insulated by the method used for frame walls. Insulating materials can be applied to interior surfaces of exterior walls where conditions are such that the expense and loss of space in the room are justified. One method is to apply fiberboard 1/2-inch thick over the wall surface. It could be plastered or left exposed depending upon the finish desired. Thicker fiberboard can also be used and the resistance to heat loss increased accordingly. Another more effective method is to fur-over the old wall with 2- by 2-inch strips at 16-inch centers and apply 1-inch-blanket insulation over the strips and under the fiberboard, lath or wall finish. By employing thicker furring strips, it is possible to use thicker blanket insulation.

Fuel Savings

Since substantial savings of fuel can be effected by the proper use of insulation, the question naturally arises as to how much fuel might be saved for any given condition. No general statement of the percentages can be accurate. The most satisfactory method is to approach the problem by calculation, and while this method is not wholly satisfactory, it is reasonably accurate if the proper assumptions are used.

For an example, let us assume a 2-story, Colonial-type frame house about 26 by 32 feet in area, located in a suburb of Chicago. The walls have wood siding, wood sheathing, studs, wood or gypsum lath, and plaster. Such a wall has a calculated U value of 0.024. Assume that enough insulation is added to the stud space to reduce the U value to 0.09 thereby saving 0.15 British thermal units per square foot per hour per degree of difference in temperature on opposite sides of the wall. The area of the wall, exclusive of windows and doors, is about 1,700 square feet, and the total reduction per degree of difference in temperature would be 0.15 x 1,700 or 255 British thermal units per hour.

The next step is to determine the number of hours the house is heated during the year and the average difference in temperature between indoors and outdoors during the heating season. The Weather Bureau or local heating contractors can supply information regarding the average outdoor temperature for the heating season. If the inside temperature averages 72° F. for 16 hours and 60° F. for 8 hours, the average daily temperature would be about 68° F.

In Chicago, the heating season is generally assumed to start October 1 and end May 1, and the average outdoor temperature during this period is 36.4° F. If the indoor average is assumed to be 68° F., the difference between inside and outside temperatures becomes 31.6° F. The heating season is 212 days or 5,088 hours. The heat saved per heating season by reducing the rate of heat loss through the wall is 5,088 x 255 x 31.6 = 41,000,000 British thermal units.

To translate the British thermal units savings into fuel, coal, oil, or gas, further calculations must be made that are based on the heat content of the fuel and combustion efficiency of the heating unit. Table 9 gives approximate calorific values for fuel and combustion efficiency for various types of heating plants of the type used in homes.

For example, assume that oil is used in a heating plant having a combustion efficiency of 80 percent. The calculation becomes

$$\frac{41{,}000{,}000 \times 100}{140{,}000 \times 80} = 367 \text{ gallons}$$

the amount saved by the use of insulation as outlined.

Insulation as an Investment

If substantial fuel savings can be made, insulation will return good dividends to the householder. Using the above example, it may be assumed that the insulation including a vapor barrier could be installed for about \$0.14 per square foot or a total cost of \$228.00. The savings in fuel oil at \$0.175 per gallon would be 0.175 x 367 = \$64.22. The annual return would be $\frac{100 \times 64.22}{228.00}$ or 28.3 percent. It would appear that insulation will not only pay for itself in a very few years but represents an important item of fuel conservation.

Dirt Patterns

The dirt patterns marking the positions of studs and joists sometimes seen on the inside surfaces of exterior walls, on ceilings below unheated roof spaces, and on exterior walls of houses painted a light color are caused by slight differences in surface temperature that occur when the heat transfer through the framing member or other parts is not substantially the same as that through the space between the members. This difference of temperature leaves parts of the surface cooler than others, and the cool parts attract more dirt than do the warm parts. Differences of temperature sufficient to cause these dirt patterns can be very slight. Such marks on inside surfaces will be most pronounced where no insulation is used. They will be least in evidence when the coefficient of heat transmission through the framing members is the same as that through the space between members.

Very pronounced dirt patterns may appear on some surfaces in 1 to 2 years after these surfaces have been decorated. This may be taken as evidence that the heat transfer through these surfaces is high, affecting comfort, fuel economy, and maintenance. It may take 10 years or more for the same degree of pattern to develop on surfaces where some insulation has been used in the construction unit.

A comparison of temperatures may be determined by computation. Assume that a conventional frame wall having a U value of 0.244 through the stud space and 0.140 through the stud, an outside temperature of 0° F., and an inside temperature of 70° F. Using formulas given on page 18 for calculating surface temperatures, we find that the surface temperature over the stud space would be 70 - 11.7 or 58.3° F. and over the stud 70 - 6.7 or 63.3° F., a difference of 5.0° F.

If the wall at the stud space has a U value of 0.107, equivalent to the use of 1-inch-blanket insulation, the calculated surface temperature would be 70 - 5.0 or 65.0° F. For a stud space with a U value of 0.075 equivalent to the use of a 2-inch blanket, the calculated surface temperature would be 70 - 3.6 or 66.4° F. The temperature differences between the surface over the stud and the air between studs are 1.7 and 3.1, respectively, much less than for the uninsulated wall. Moreover, the greater the difference between room and surface temperature, the greater the air movement that carries the dirt particles to the surface.

Where dry wall construction is used, involving such materials as fiberboard, plywood, gypsum board, and similar material, the wall finish is often attached to the studs with nails through the face of the covering material. The nail is a better conductor of heat than the wall material and in consequence, a dirt pattern may outline each nailhead. The type of material used will in some cases establish the size and shape of the nail. Where the requirements of the material permit, short nails having small heads should be used. The nails should be set as deep as possible, to minimize the dirt pattern. Some types of material are attached with concealed clips, some are held in place with glue or mastic. By using these types of fastenings, the dirt pattern characteristic where nails are used will be avoided.

Condensation Within Walls and Roofs

The formulation of sweat or frost on the inner face of windows not protected by storm sash is a familiar example of how water vapor present in the air of a room condenses in cold weather. Most building materials are more or less permeable to water vapor, and when outdoor temperatures are low, such vapor under certain conditions will pass through inner surface materials and condense within a wall or roof space on some colder surface (figs. 8 and 9). Moisture that collects within walls during cold weather is a common cause of exterior paint failure (fig. 10) and may cause decay in the framing members and exterior wall covering (fig. 11). Moisture collecting in attics and under flat roofs as frost or ice (fig. 12) later will melt, part soaking into roof members, setting up conditions that favor decay; part dripping back on the ceiling below, wetting and loosening plaster, staining the finish, and causing other damage (fig. 13). Millions of dollars are spent every year in painting, redecoration, maintenance, and repairs caused by such cold weather condensation.

Vapor Sources

There is no mystery regarding the source of moisture. Water vapor is added to the atmosphere within a house from such ordinary functions as cooking, dishwashing, laundry work, bathing, respiration, and evaporation from plants. Moisture is liberated by unvented gas heaters and gas stoves. Often the humidity is raised in homes during cold weather by the evaporation of water from a furnace or radiator pan. Some houses are equipped with winter air-conditioning devices that automatically maintain the relative humidity at some selected condition that is presumed to be beneficial to health and comfort.

Water vapor escapes from houses during the winter in various ways. There is a constant outleakage through cracks and crevices, around doors and windows, through the heating plant which needs air for combustion, and through the ventilating system. Some water vapor escapes through walls and roofs of a permeable character, the amount lost depending upon the materials and type of construction used. Most condensation problems are related to this type of vapor loss.

Houses that were built before the early 1930's were so constructed that generally there was considerable air infiltration and outleakage, and as a result, the relative humidity in such houses today is consistently low during cold weather. It is common practice today, however, to build houses more airtight than those built before the depression, the reduction in air infiltration being accomplished partly by construction methods and materials used and partly by the more general use of weather strips and storm sash. Consequently, there is less opportunity for water vapor liberated in the house to escape from modern tightly built houses than from the older houses. Moreover, the modern homes are often smaller and more compact than the older houses, and therefore there is less volume of air available to hold moisture as well as less area through which the moisture can escape.

There is a characteristic relationship in all houses between indoor relative humidity and outdoor temperature.

The relative humidity indoors during warm weather follows the trends of outdoor humidity and, generally speaking, is comparatively high. It decreases as outdoor temperatures drop. The order of this relationship is shown in figure 14 for a loosely built house, an average house, and for a tightly constructed house. Higher humidities than shown are not uncommon in small tightly constructed homes. In houses where winter air conditioning involves automatic control of relative humidity, hygrostats are used to maintain some established minimum humidity. An example illustrating automatically controlled indoor relative humidity is also shown in figure 14 with the indoor humidity set at 40 percent.

These temperature-humidity relationships are by no means uniform. For various reasons they vary widely even among houses of similar construction. In building projects where a large number of houses of more or less identical construction are involved, some houses may show no evidence of condensation, others may show it only after unusually cold winters, and still others may show such evidence several times each winter or after each period of cold weather. These differences in otherwise comparable houses are due not to a variation in construction but to variations in custom or habits of the occupants. Aside from usual differences because of cooking, laundry, or evaporating water for humidification, babies with their needs for extra laundry, dishwashing, and sterilizing also contribute additional moisture. Some householders prefer to heat their houses to higher temperatures than others, an important contributing factor, particularly when temperatures higher than 75° F. are maintained.

Effect of Insulation on Condensation

Insulation does not "draw water," but it can contribute to the accumulation of condensation when conditions are favorable. The function of insulation is to reduce heat flow. Where insulation is used, the temperatures of those parts of a wall or roof on the cold side of the insulation will be lower during cold weather than if no insulation were used. This means that it is more likely that material on the cold side will be below the dewpoint temperature of the room, and hence there is likely to be more condensation on this material than when no insulation is used unless protection by means of a vapor barrier is provided on the warm side of the insulation. Insulation is important, however, as a means of conserving heat and creating comfortable living conditions and should not be condemned because of its influence on condensation.

The atmosphere always contains some moisture or water vapor. The maximum amount of moisture that can be present depends upon the temperature; it increases in amount as the temperature goes up. If the atmosphere is completely saturated with water vapor, it is at its dewpoint temperature and the relative humidity is 100 percent. If not completely saturated, it is above its dewpoint temperature, and its relative humidity is less than 100 percent. Raising the temperature of the air without changing the amount of moisture will decrease its relative humidity, but lowering the temperature will increase the relative humidity until the dewpoint temperature and saturation are reached. Further lowering of the temperature will cause progressive condensation of water vapor from the air.

Condensation on windows is a typical example of the effect of lowering the atmospheric temperature below its dewpoint temperature. When outside temperatures are below inside temperatures, heat loss through the glass lowers its temperature below the room temperature. Condensation forms on the glass when temperature differences are great enough to lower the surface temperature of the glass below the dewpoint temperature of the atmosphere in the room. If the glass temperature is below freezing, the condensation collects as frost.

Water vapor establishes a pressure, which is, of course proportional to the amount of water vapor present. Vapor pressure is commonly expressed in terms of inches of mercury or pounds per square inch. At 0° F., the atmosphere at 100 percent relative humidity would have a vapor pressure of 0.0377 inch of mercury (Hg), and at 70° F. and 100 percent relative humidity, the vapor pressure would be 0.739 inch Hg. The average relative humidity outside would be less than saturation so that it might be assumed to be 75 percent, which would mean a vapor pressure of 0.027 Hg. For the inside, a relative humidity of 35 percent might be assumed; then the vapor pressure would be 0.259 inch Hg. The vapor pressure inside is nearly 10 times as high as it is outside, and this difference in pressure causes vapor to move out through every available crack and crevice.

It also causes vapor to move through any materials used in the walls and ceilings that are permeable to vapor. Most building materials, such as plaster, fiberboard, wood, concrete, most kinds of brick and mortar, and many kinds of building papers, are permeable to vapor. The rate of vapor movement from one point to another is more or less proportional to the difference in vapor pressure between the points and inversely proportional to the resistance of the interposed materials.

Walls of conventional house construction are composed of materials varying in permeability. Moreover, the temperature gradients through a wall drop step by step according to the thermal properties of the material and the differences in temperature between the warm interior and the cold exterior. Should the temperature at any point within the wall, as for example, at the inner face of the sheathing, fall below the dewpoint of the atmosphere on the roomside of the wall, under certain conditions, condensation may take place at that point.

The relation of the forces and the influence of materials used can best be visualized by examples. Let us assume a conventional frame wall consisting of gypsum lath and plaster, stud space, wood sheathing, paper, and wood siding. By calculation, both the temperature gradient and the maximum vapor pressures for the calculated temperatures through the wall can be determined.

Example 1. Temperature outside, 0° F.; relative humidity, 75 percent; temperature inside, 70° F.; relative humidity, 35 percent.

Comparison of differences of vapor pressure through walls

	Not insulated In. Hg	Insulated 4-inch fill insulation In. Hg
Differences in vapor pressure between:		
Room and inside face of sheathing................	0.259 - 0.212 = 0.047	0.259 - 0.060 = 0.199
Inside face of sheathing and inside face of siding...................	.212 - .085 = .127	.060 - .041 = .019
Inside face of sheathing and outdoors.............	.212 - .027 = .185	.060 - .027 = .033
Inside face of siding and outdoors................	.085 - .027 = .058	.041 - .027 = .014

In the uninsulated wall of example 1 there is a drop in vapor pressure between the room and inside face of the sheathing, but the differences of vapor pressure between the inside face of the sheathing and inside face of the siding is more than 2-1/2 times as much, and between the room and the siding the difference is 3 times as much. We could expect with these differences that the moisture would be forced through the sheathing to the back of the siding. The difference in vapor pressures between the inside face of the siding and outdoors, however, is only about 45 percent of that between the sheathing and siding so that 45 percent of the moisture would be expected to reach the back of the siding and escape out-of-doors, and the balance would remain as condensation in the form of ice or frost (fig. 15). In explaining the forces that cause vapor movement, no consideration has been given the vapor resistance of intervening materials to vapor movement. These materials will have some influence both on the amount of vapor moving into the wall where it may condense and on the amount that may accumulate. The values as given, however, do show the intensity or magnitude of the forces, the influence of temperature and insulation, and where moisture is most likely to collect.

For an insulated wall, the stud space is assumed to be filled with some type of efficient fill insulation. Here the drop in vapor pressure between the room and inside face of the sheathing is found to be 10 times as great as the difference between the sheathing and the siding and more than 6 times the difference between the inside face of the sheathing and outdoors.

On a basis of the differences in pressure, it could be assumed that for each 6 parts of water vapor moving into the wall only 1 part would move out and 5 parts would remain as condensation, collecting on the inner face of the sheathing.

Example 2. Temperature outside, 0° F.; relative humidity, 75 percent; temperature inside, 80° F.; relative humidity, 35 percent.

	Not insulated	Insulated 4-inch fill insulation
	In. Hg	In. Hg
Differences in vapor pressure between:		
Room and inside face of sheathing................	0.361 - 0.268 = 0.093	0.361 - 0.063 = 0.298
Room and inside face of siding....................	.361 - .098 = .263	.361 - .049 = .312
Inside face of sheathing and inside face of siding....	.268 - .098 = .170	.063 - .049 = .014
Inside face of sheathing and outdoors................	.268 - .027 = .241	.063 - .027 = .036
Inside face of siding and outdoors................	.098 - .027 = .071	.049 - .027 = .022

In example 2, the conditions are similar to example 1 except that owing to the increased room temperature the differences of vapor pressure are materially increased. In the uninsulated wall, the difference between room and siding is 3.7 times the difference between siding and outdoors. In the insulated wall, the difference between room and sheathing is 8.3 times the difference between sheathing and outdoors.

Materials used in wall construction vary widely in resistance to vapor transmission. The comparative resistance of such materials is an important factor influencing vapor movement. Over a period of years, various investigators have tested the resistance of different materials to moisture movement by diffusion, conducting tests on wall sections having various combinations of materials and making observations in occupied homes. It has been found, for example, that most types of inside wall finishes, such as wallboard, plywood, fiberboard, and plaster on wood, gypsum, or metal lath, are low in resistance to vapor transmission. Some kinds of finishes over these materials may increase their resistance materially.

Wood, fiberboard, and gypsum board sheathing are also comparatively low in resistance. Some sheathing papers are very resistive, others very permeable.

Painted wood siding may be very resistive when the paint is new, but its resistance decreases as the paint ages. Some vapor undoubtedly escapes through the lap joints of siding. Some types of paint coatings on plaster are very resistive whereas other types of wall finishes may have little or no resistance.

While at first glance the marked differences in vapor transmission of different materials appear to complicate the problem of vapor control, these differences can in fact be employed to help solve it. As has been shown, differences of temperature and relative humidity between indoors and outdoors setup the vapor pressures that cause moisture to diffuse outward through house walls. There is not much that can be done to control or eliminate these physical factors. The other important factor, the difference in vapor resistance of construction materials, thus becomes the factor that must be dealt with in seeking better control and eliminating the hazards of vapor condensation within walls.

Essentially, since differences in vapor pressure cause moisture to move into walls during periods of great differences of temperature faster than it moves out, the problem, at least in theory, becomes one of seeking a better balance between the rates of inflow and outflow.

That, in effect, is what is sought through the use of so-called "vapor barrier," or materials that are highly resistive to vapor transmission. Since vapor passes with comparative ease through the common building materials -- more easily, in many cases, through inside than through outside finish materials -- a suitable vapor barrier is necessarily an additional feature of wall construction. It is, in fact, a necessary companion of insulation if the more acute vapor problems created by insulation are to be met.

The location of the barrier is very important (figs. 16 and 17). It must be at or near the inner face of the wall so that the temperature of the barrier will always be above the dewpoint temperature of the room, in which case no condensation will take place on the barrier (fig. 14). Cold air return ducts are sometimes located in outside walls of frame buildings. Such returns, if not lined with metal, should be lined on the cold side with a vapor barrier. What is sought in a vapor barrier is a mechanical restriction to the amount of vapor that will flow into a wall despite great differences in vapor pressure between the warm side and the colder interior surfaces of the wall, such as the back of siding or the inside face of sheathing. The barrier will be serving its purpose if it reduces the inflow of vapor to an amount that can be moved through the outer wall materials under compulsion of the lesser vapor pressure setup by the difference in temperature between, say, the interior face of the sheathing and the outside siding surface.

In new construction, the barrier can be any one of several types, such as (1) a vapor-resistant membrane on the inner face of the studs or furring and under the lath or surface finishing material; (2) a vapor-resistant membrane or coating as an integral part of the lath or covering material; (3) vapor-resistant covering materials on the inner or warm side of insulation; or (4) reflective insulation made of vapor-resistant materials.

Vapor barriers may be either incorporated with or installed separately from other materials of the wall structure. Barriers of type 1 are separately installed; those of types 2 and 3 are integrated with other wall materials by the manufacturer; and those of type 4 are in effect dual-purpose materials, since the same material provides both the insulation and the vapor barrier.

Among the materials suitable as separate vapor barriers of type 1 are polyethylene membrane 2 mils or more in thickness, asphalt-impregnated and surface-coated kraft papers sold in rolls of 500 square feet and weighing about 50 pounds per roll, and duplex or laminated paper in which 2 sheets of kraft paper are cemented together with asphalt. Type 2 barriers would include gypsum lath with aluminum foil backing, vapor-resistive fiberboard lath, and painted plaster or plywood used for inner wall surfaces. Blanket insulation with vapor-resistive paper covers is an example of a type 3 barrier. Reflective insulation is an illustration of a type 4 barrier.

Type 1 barrier materials should be fastened to the inner face of the stud, below the lath or other wall finishing material. Type 2 is automatically located in the proper position. Type 3 should have the vapor-resistant surface faced towards the inside of the house with the insulation toward the outside. Type 4 should have the reflective face toward the inside of the house.

Paint coatings on plaster may be very effective as vapor barriers if materials are properly chosen and applied. Of these, 2 coats of aluminum primer followed by 2 decorative coats of flat paint, or 1 coat of pigmented primer and sealer paint (not glue size), followed by decorative finish coats, offer fair resistance and may be satisfactory in older houses, though it is below the standard desired for new construction. For dry-wall construction where plywood, fiberboard, or other wall materials are used in place of plaster, paint coatings may be applied to the back or to the face. Asphalt coatings on the back of plywood, for example, make an excellent barrier. Two coats, or enough to make a bright shiny finish, are required. It is also important that outflow of vapor from a wall should not be impeded by materials of relatively high resistance on the cold side of the vapor barrier. Sheathing paper should be of a type that is waterproof but not vapor proof, such as tarred felt. Coated fiberboard sheathing may also interfere with outleakage.

Ventilation in Attics and Roofs

Condensation occurs in attic spaces and under flat roofs in the same manner as in walls. It collects as frost or ice on the roof boards, on projecting nails, and frequently between the roof sheathing and exterior coverage. On bright, sunshiny days, even at low temperatures, the frost melts and water drops to the ceiling below, where it causes stain and other damage. Stain and decay of roof members is quite common.

It has become almost standard practice for builders to install louvered openings in the gable ends of houses to provide ventilation through attic spaces (fig. 18). When these openings function properly, there is generally little evidence of condensation. Some, however, are too small, some do not face prevailing winds, and for numerous other reasons many fail to function as intended. They cannot be installed in all types of roofs, such as hip roofs and some flat roofs. Even where ventilation is provided by the builder, the householder may close the openings to conserve heat or for some other reason, and the intended protection is thus lost.

The moisture problem in attic spaces and on the underside of flat roofs is usually aggravated by the use of highly impermeable roofing, such as asphalt shingles or composition roofing.

Vapor barriers should be installed in the ceilings under attics and flat roofs in the same manner as for walls (fig. 16). It is to be expected that some vapor will work into the roof space through the barrier or through places not fully protected by a barrier, such as doors and around pipes and ducts. The amount is small and, if uniformly distributed over the roof, would no doubt be unimportant. However, the condensation tends to collect in the coldest parts, and the concentration of moisture may be enough to cause trouble. A combination of vapor barriers and ventilation is obviously the safest procedure.

Figure 18 shows recommended sizes of ventilators for various types of roofs expressed as a percentage of the ventilator area per square foot of projected ceiling area below the roof space. For roof spaces having no occupied rooms, the ceiling area may be assumed as the area within the exterior wall line. For attic space with occupied rooms, determine the projected ceiling area below the attic and add enough additional area to take care of the knee walls and sloping ceilings.

For gable-roof houses with open attics where there is little or no overhang of the roof at the eaves, louvered openings in the gabled ends having a ratio of 1 square foot of net opening to 300 square feet of ceiling area should be adequate. For attics with overhanging eaves or with occupied rooms, provide openings under the eaves and louvered openings in the gables having the ratio of opening to ceiling areas as shown in figure 18.

Hip roofs, where louvered openings cannot be used, can be vented by various means. Globe ventilators at or near the ridge with inlet openings under the cornice around the perimeter of the house are efficient. Special flues may be provided in chimneys with suitable openings into the attic or roof space. Rectangular hip roofs may be built with louvered openings at the peak. Minimum areas for such conbinations are shown in figure 18. Minimum areas do not provide for screen. Where 16-mesh screen is used, the minimum area of the screen should be at least double that of the area specified. In most cases, this can be accomplished by providing a frame of proper size inside of the opening to hold the screen.

Openings below overhanging eaves or in the soffit of cornices should preferably be continuous. In most cases, it would be practical to provide an opening back of a bed mould.

Ventilation in flat roofs should be provided in accordance with the roof framing. Where one solid member is used for both ceiling and roof joist, there is no intercommunication between joist spaces, and openings should be provided for each space. Flat roofs that overhang the wall below can often be provided with openings under the overhang. A continuous opening three-fourths inch wide should be sufficient for a house of average size.

The Forest Products Laboratory has been receiving reports of trouble with condensation in houses from various parts of the United States for many years. In normal or mild winters most of these are from areas north of the Ohio River, but after a severe winter, such as occurs every 4 or 5 years, the reports are more numerous and include many from areas farther south. On a basis of these reports, it has been well established that condensation problems may be expected in houses in those parts of the country where the average January temperature, according to Weather Bureau reports, is 35° F. or lower.

At the time it is built every new house north of the 35° January isotherm (fig. 19) should be provided with some positive form of protection against condensation. In the light of our present knowledge, vapor barriers on the warm side of the wall and under the roof seem to offer the most assured form of protection and are inexpensive. For existing houses, suitable paint coatings over the inside surfaces of exterior walls and ceilings will generally prove satisfactory. Tests have shown that, with suitable integral vapor barriers or suitable paint coatings, adequate protection is obtained in houses with or without insulation maintained at relative humidities as high as 40 percent in the coldest weather.

Effect of Humidity on Comfort and Health

Many householders are of the opinion that low humidities are unhealthful, because such humidities are responsible for dry nasal passages and increase the incidence of colds and sinus trouble. Some authorities claim that these difficulties may be minimized if the relative humidity is maintained at not less than 50 percent. Some authorities also claim that relative humidity has an important bearing upon physical comfort -- a debatable point if house temperatures are normal. Relative humidity, however, may affect physical comfort at either low temperatures or at temperatures high enough to cause sweating.

It is true, however, that if it were practical to maintain the relative humidity at about 60 percent during the heating season, the moisture content of interior woodwork, floors, and furniture would hardly change throughout the year, and practically all of the shrinking and swelling would be eliminated that normally occurs in the average heated house.

Though there may be good reasons why comparatively high relative humidities, such as 50 percent and higher, are desirable in homes during cold weather, there are also equally good reasons why they are undesirable because of the effect upon the structure. The higher the humidity the greater the hazards of condensation that may cause stain and decay in wood framing members and in window frames and sash, wet and loosened plaster, paint failures, dampness, and mold in clothes closets, on outside walls, and numerous other difficulties that cause damage and high maintenance costs.

Houses adequately protected with vapor barriers can be safely maintained at 40 percent relative humidity when outdoor temperatures are 0° to -20° F., but in houses without vapor barriers, the humidity should be 25 percent or less under the same outdoor temperature conditions.

Crawl Space

Basements and cellars under houses serve certain useful purposes, such as providing a space for the laundry, water heater and softener, storage, heating plant and fuel, and in some cases, for recreation and work space. Warm basements mean that floors above are warm and that water and sewer pipes will not freeze.

Changing styles in house design and equipment in recent years has reduced the value of basements as a place for household services and equipment. Modern heating plants do not depend upon gravity to circulate the heating medium, but mechanical methods of circulation are used instead, and therefore the heater can be located on the first floor level. Storage for fuel is no problem where gas, oil, or electricity is used. A small service room on the first floor level can be used for the heating plant, water heater and softener, and may include a washing machine and clothes drier. By removing the necessary services from the basement and sacrificing storage, work, and recreational space, the basement can be eliminated in most cases, it will cost less to add a small service room to the first floor than to build a basement with its excavation, deeper walls, and floor.

There are two common methods of construction used for basementless houses. For one, a concrete slab is laid over the ground and finishing is usually just a step above grade level. For the other, wood joists are used that are supported on masonry walls or on sills supported by piers. There is a space between the ground and the underside of the joists, called a crawl space, which may be only a foot high but is generally 18 inches or more in height. If foundation walls are made of masonry, the walls extend up to the underside of the joists and thereby enclose the crawl space. If the building is supported on piers or posts, it is common practice to provide between the grade and the joists a skirting of wood siding, asbestos cement board, or some similar material. This type of construction was widely used many years ago when stoves were used for heating, but with the advent of central heating plants of the gravity type, such practice gave way to the building of basements. Changes in the types of heating plants and other considerations have made this type of construction popular again.

Building codes set up certain requirements as safety measures for basementless structures. To reduce the decay and termite hazard, the joists should be not less than 18 inches above the ground, and there must be openings in the outside wall for ventilation of the crawl space. Federal Housing Agencies require a minimum total free area of not less than 1/160 of the ground area divided into four or more openings around the enclosing walls.

Moisture rising from the soil in these crawl spaces has created a serious situation in many buildings in spite of provisions for ventilation. In a survey of a large number of buildings, the investigators found decayed joists and sills, decayed floors, badly corroded steel girders and pipes, and underfloor insulation dropping down, and the occupants or managing personnel reported freezing of water in return heating lines, rodents, vermin, musty odors, and generally unhealthy conditions directly chargeable to the dampness in the crawl space.

In some cases, moisture from the crawl space works into the rooms above adding to the sources of moisture that create condensation problems in the walls and roof spaces (fig. 20). Instances have been found where moisture worked up pipe chases or other openings from the crawl space to the roof space.

Various reasons can be advanced as to why ventilation fails to give adequate protection. The ventilators may be closed in cold weather to prevent the freezing of water-pipe lines and also to prevent cold floors. Shrubbery or other external conditions may interfere with a free circulation of air. If vents are covered with fly screen, the screen may become clogged with lint and cobwebs. The ventilators may not be located to face prevailing winds. If the outside finish grade is above the level of the ground under the house, water from the downspouts may work into the crawl space.

Experiments with soil covers, which serve to reduce the amount of water liberated from the ground, have proven them effective in crawl spaces of buildings where the moisture was a problem (fig. 21).

Soil covers may consist of any suitable material that is durable and has a high degree of resistance to vapor transmission. Those tested in service were installed in houses after they had been built and occupied; therefore the experiments were limited to include only material that could be spread over the soil in the restricted space available. Roll roofing weighing 55 pounds per roll of 108 square feet appears to meet the requirements of high resistance, durability, low initial cost, and ease of installation. Smooth-surfaced material having no crushed stone imbedded in the surface is most convenient to handle. All coarse debris should be removed and the soil leveled where necessary. The soil cover should be laid so that it contacts the outside walls and has a lap of at least 2 inches on all edges and ends. Bricks or stones may be used for weights to hold the soil cover down and to prevent curling.

The investigations made to date indicate that much less ventilation through the crawl space is required where soil covers are used. Where soil covers are used, FHA permits the free opening area to be reduced to 1/10 that required where no soil cover is used.

Condensation on Interior Wall Surfaces

Surface condensation sometimes appears on the inside surfaces of exterior walls during cold weather. It is most likely to appear on uninsulated walls, on surfaces back of large pieces of furniture, in rooms that have no heat or in which the temperature is quite far below the average of the house, or in unheated closets adjacent to outside walls. Such condensation indicates that the surface temperature is below the dewpoint temperature of the atmosphere in the room. It can be eliminated by using some means of raising the surface temperature above the dewpoint temperature.

In some cases, insulation could be used in outside walls to raise the temperature of the inside surface. More heat in the room might be helpful. For temporary relief, an electric fan can be set up in a warm part of a room to blow air against a cold surface to raise its temperature above the dewpoint temperature.

Condensation sometimes appears on walls and ceilings of rooms during warm weather. Trouble from this source is quite common in the Southern States and not uncommon in the Northern States. It usually develops on warm damp days following a reasonably cool night and appears in parts of a room where there is little cross circulation. For temporary relief, electric fans can be used effectively, but otherwise the treatment suggested for cold weather condensation can oridnarily be used to raise surface temperatures.

Fire Hazard and Its Control[2]

The role of wood-base insulation as a contributor to the fire hazard of a home cannot be considered solely on the basis of the combustibility of the materials. Many factors are involved in the development and spread of fire other than the materials that constitute the structural elements of a house. This is apparent from two simple illustrations. Some of the most disastrous fires have occurred in so-called fireproof construction in which the structural elements contributed no fuel whatever to the fire but where the contents of the building furnished the fuel and structural defects aided in spreading the fire. On the other hand, there are thousands of homes constructed of wood-base materials containing combustible furnishings where no fires have occurred and simple, common-sense precautions minimize the fire hazard. In the discussion that follows, the more important elements pertaining to fire hazard in a home are presented together with suggestions for reducing the danger of fire.

Elements of Fire Hazard

Causes of fires.--Fires in a home start from many causes. The accompanying tabulation is based on an analysis of fires in dwellings made by the National Fire Protection Association.

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[2]This section was prepared originally by Arthur Van Kleeck, Chemist, Forest Products Laboratory and has subsequently been reviewed.

Causes of fires in dwellings[3]

	Percent	Percent
Smoking and matches		30
Heating defects		21
Defective flues and chimneys	12	
Defective or overheated appliances	6	
Inadequate clearance from combustible materials	2	
Miscellaneous	1	
Misuse of electricity		12
Fixed services	10	
Appliances or fixtures	2	
Exposure		8
Sparks on roof	6	
Other	2	
Inadequate rubbish disposal methods[4]		4
Kitchen hazards[5]		4
Hot ashes and coals		3
Flammable liquids[6]		2
Lightning		2
Spontaneous ignition[7]		2
Open fireplaces		2
Children with matches		2
Flammable decorations[8]		1
Candles and open flames other than from a stove		1
Incendiary		1
Vehicle fires		1
Defective hot-water tanks		1
Explosion (heat and power sources)		1
Miscellaneous		2
Total		100

[3]Data from N.F.P.A. Handbook of Fire Protection, Tenth Edition, p. 1246.

[4]Includes ignition from unknown causes at rubbish collection points.

[5]Including grease, fat, wax, flammable liquids, on stoves; open flames unattended; combustible materials falling into open flames.

[6]Including such things as home dry cleaning fluids, home paint removers, and home storing of fluids.

[7]Including oily rags, mixed rubbish, packing materials, painting supplies.

[8]Including Christmas trees, streamers, or paper shades in contact with electric light bulbs and subject to ignition from sparks or open flames.

Furnishings.--With the exception of a few metal items, such as stoves and refrigerators, the contents of the living quarters of a home contain such combustible furnishings as tables, chairs, bookcases, beds, and dressers of wood. In addition, other combustibles in the form of rugs, drapes, upholstery, bedding, clothing, magazines, newspapers, and books are present. If the home has an attic or basement, combustible items usually are present in these locations. If, for the present, attention is focused on the match or cigarette as the cause of a fire, some one item of the furnishings provides the next step in the progress of the fire. It may be the bedding, a curtain, or a waste paper basket. The fire once started gathers momentum within the furnishings of the room and, regardless of whether the walls and ceilings are combustible or not, the furnishings provide substantial fuel for a disastrous fire.

Type of construction.--The details of construction that provide for maximum safety against the start and spread of fire are well known in locations or communities where good building codes are in effect and are rigidly enforced. It may be noted from the foregoing tabulation that such faults in construction as defective flues and chimneys, inadequate clearance from combustible materials, and defective electrical wiring constitute 24 percent of the causes of fire.

After a fire is once started, it spreads not only by direct contact of the flames with combustibles but also by the movement of high-temperature air and gases through every open channel. In addition to moving through halls, stairways, and other large spaces, these heated gases follow the concealed spaces between floor joists and between studs in partitions and walls of wood-frame construction. In the best types of construction, fire stops are provided to prevent the movement of hot gases both laterally and vertically. The fire stop may consist of 2-inch lumber cut to fit tightly in the rectangular space between studs or joists, or it may be of incombustible material such as concrete, hollow tile, or brick. If fire stops are not installed, fire damage to a home is usually faster and much greater than if fire stops are present.

Exposure of wood-base materials to fire.--Referring again to the foregoing tabulation of causes of fire, it may be noted that most fires start in the exposed parts of the home.

In this type of fire, therefore, the potential fire hazard of wood-base materials can be evaluated from the standpoint of whether or not they are exposed to the earlier stages of the fire. Materials that are concealed, such as sheathing, lath, studs, joists, and flexible and fill insulation contribute little or no fuel to the fire until the interior convering is burned through or sufficient heat is developed to cause spontaneous ignition. Materials in these locations, therefore, present much less of a potential fire hazard than those that are exposed.

Typical of wood-base materials that are exposed are interior fiberboard walls and ceilings, plywood walls and ceilings, wood floors and trim, and wood in the form of roof boards and rafters in attics and the subflooring and joists in the basement. The stage of a fire at which these materials would contribute fuel is in large measure dependent on the location of the start of the fire. If this location is away from the walls, the wall and ceiling materials would contribute no fuel until such time as they were exposed to direct flames or until the temperature of the room rose sufficiently high to cause ignition. The significance of this is that, in many cases, a severe fire develops from the furnishings alone with combustible walls or ceilings contributing nothing to the fuel until the fire has already reached a dangerous stage. On the other hand, if the fire starts in a location adjacent to the walls or in the corner of a room covered with combustible finish, the wall coverings can be expected to contribute fuel at an earlier stage of the fire. All factory-finished insulation board now manufactured in the U. S. is finished with a fire-resistant intumescent paint to retard the spread of flame on walls and ceilings of that material.

Control of Fire Hazard

In the pages immediately preceding, a number of the potential fire hazards in a home have been indicated regardless of the types of materials used for construction of the dwelling. The mere mention of these hazards are related to the causes of fire shown in the preceding tabulation suggests some common-sense methods to either reduce or eliminate them. Such things as attention to details of construction of a new dwelling, observance of safety precautions about the home, and the development of the habit of good housekeeping in such places as basements, attics, and garages will help minimize fire hazards in the home.

If all these safety practices were carefully observed, the fact that a home contains wood-base materials in its construction would be of little concern from the standpoint of fire hazard. Unfortunately, accidents can and do occur and, as an extra measure of safety, either of the following steps can be taken: (a) fire-retardant coated board (Class F, as specified in Commercial Standard CS 42-49) can be used or (b) the exposed surfaces of wall and ceiling panels can be coated with a fire-retardant paint. Realizing the need for such coatings, the Forest Products Laboratory has done considerable research in this field and has developed several effective fire-retarding coating formulations. These formulations are given in Forest Products Laboratory Report R1280. Satisfactory proprietary preparations also are now available.

As previously indicated, there is less need for protection against fire of the unexposed wood-base materials. However, it is the practice of the manufacturers of flexible insulation to treat their materials with fire-retardant chemicals to reduce the fire hazard. Some of the fill types of insulation, also, are so treated. Methods are given in Forest Products Laboratory Report R1092 that enable the home owner to treat such materials as sawdust and shavings to give them added fire protection.

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Table 1.--Coefficients[1] of heat transmission (U) for frame walls[2,3]

Exterior finish	Interior finish	No insulation between studs						Blanket insulation: 1-inch thick, 2 air spaces				Blanket insulation: 2-inch thick, 2 air spaces				Blanket insulation: 3-inch thick, Air space neglected			
		Sheathing						Sheathing				Sheathing				Sheathing			
		None	5/16-inch plywood	25/32-inch wood	1/2-inch fiberboard	25/32-inch fiberboard	1/2-inch gypsum board	None	5/16-inch plywood	25/32-inch wood	25/32-inch fiberboard	None	5/16-inch plywood	25/32-inch wood	25/32-inch fiberboard	None	5/16-inch plywood	25/32-inch wood	25/32-inch fiberboard
3/4 by 10 inch wood siding	Gypsum lath, 3/8-inch, plastered		0.272	0.235	0.217	0.188	0.269		0.120	0.112	0.100		0.083	0.079	0.073		0.072	0.069	0.065
3/4 by 10 inch wood siding	Gypsum board, 3 8-inch, decorated		.279	.240	.222	.191	.275		.121	.113	.101		.084	.080	.074		.073	.070	.065
3/4 by 10 inch wood siding	Plywood, 1/4-inch		.280	.240	.222	.192	.276		.121	.113	.101		.084	.080	.074		.073	.070	.065
3/4 by 10 inch wood siding	Insulation board, 1/2-inch		.213	.189	.178	.158	.211		.107	.101	.091		.077	.073	.068		.067	.065	.061
3/4 by 10 inch wood siding	Metal lath and plaster		.295	.251	.231	.198	.291		.124	.116	.103		.085	.081	.075		.074	.071	.066
1/2- by 6- or 8-inch siding	Gypsum lath and plaster		.292	.249	.229	.197	.287		.123	.115	.103								
1-inch drop siding	None (garage wall)	0.610																	
1-inch drop siding	Gypsum lath and plaster	.331						0.130				0.088				0.076			

(Sheet 1 of 2)

Table 1.--Coefficients[1] of heat transmission (U) for frame walls[2,3] (Continued)

Exterior finish	Interior finish	No insulation between studs						Blanket insulation											
								1-inch thick				2-inch thick				3-inch thick			
								2 air spaces				2 air spaces				Air space neglected			
		Sheathing						Sheathing				Sheathing				Sheathing			
		None	5/16-inch plywood	25/32-inch wood	1/2-inch fiberboard	25/32-inch fiberboard	1/2-inch gypsum board	None	5/16-inch plywood	25/32-inch fiberboard	25/32-inch fiberboard	None	5/16-inch plywood	25/32-inch wood	25/32-inch fiberboard	None	5/16-inch plywood	25/32-inch wood	25/32-inch fiberboard
Wood shingles (16-inch)[4] 7-1/2-inch exposure	Gypsum lath and plaster		.287	.245	.186	.164	.222		.123	.114	.093		.084	.080	.069		.073	.070	.062
Wood shingles, double[4] 12-inch exposure (same for 3/4-inch insulating siding)	Gypsum lath and plaster		.262	.227	.175	.156	.207		.118	.110	.090		.082	.078	.068		.072	.069	.060
Wood shingles, with 3/4-inch[4] insulating backerboard	Gypsum lath and plaster		.249	.217	.169	.151	.198		.115	.108	.088		.081	.077	.067		.071	.068	.060
Plywood, 3/8-inch, lapped (same for 4-inch brick veneer)	Gypsum lath and plaster		.312	.263	.242	.205	.307		.127	.118	.105		.086	.082	.076		.075	.072	.067
Stuco, 1-inch (same for asbestos-cement shingles)	Gypsum lath and plaster		.353	.292	.266	.223	.347		.133	.124	.109		.089	.085	.078		.077	.074	.068

[1]Coefficients are expressed in British Thermal Units per hour per square foot per degree of difference in temperature on the two sides and are based on an outside wind velocity of 15 miles per hour.

[2]Table based chiefly on data from 1957 Heating, Ventilating, and Air Conditioning Guide.

[3]Values are for spaces between studs. Where net U values are desired, correction should be made for influence of the studs on overall U values.

[4]Furring strips for nailing included between wood shingles and insulating board or gypsum sheathing.

(Sheet 2 of 2)

Table 2.--Conductivities (k), conductances (C), and resistances (R) of building and insulating materials (design values)[1,2]

Material	Description	Thickness	Density	Conductivity or conductance: (k)	Conductivity or conductance: (C)	Resistance (R): $\frac{1}{k}$	Resistance (R): $\frac{1}{C}$
		Inches	Pound per cubic foot				
Air spaces[3]	Horizontal position; heat flow up (winter)	3/4 to 4			1.18		0.85
	Horizontal position; heat flow up (summer)	3/4 to 4			1.28		.78
	Horizontal position; heat flow down (winter)	3/4			.98		1.02
	Horizontal position; heat flow down (winter)	1-1/2			.87		1.15
	Horizontal position; heat flow down (winter)	4			.81		1.23
	Horizontal position; heat flow down (winter)	8			.80		1.25
	Horizontal position; heat flow down (summer)	3/4			1.18		.85
	Horizontal position; heat flow down (summer)	1-1/2			1.07		.93
	Horizontal position; heat flow down (summer)	4			1.01		.99
	Sloping, 45° position; heat flow up (winter)	3/4 to 4			1.11		.90
	Sloping, 45° position; heat flow down (summer)	3/4 to 4			1.12		.89
	Vertical position; heat flow horizontal (winter)	3/4 to 4			1.03		.97
	Vertical position; heat flow horizontal (summer)	3/4 to 4			1.16		.86
Air surfaces[4] Still air	Horizontal position; heat flow up				1.63		.61
	Up sloping, 45° position; heat flow up				1.60		.62
	Vertical position; heat flow horizontal				1.46		.68
	Sloping, 45° position; heat flow down				1.32		.76
	Horizontal position; heat flow down				1.08		.93
15 miles per hour wind	Any position; heat flow any direction (for winter)				6.00		.17
7-1/2 miles per hour wind	Any position; heat flow any direction (for summer)				4.00		.25
Building board[5] Boards, panels, sheathing, etc.	Asbestos-cement board		120	4.0		.25	
	Asbestos-cement board	1/8			33.		.03
	Gypsum or plaster board	3/8	50		3.10		.32
	Gypsum or plaster board	1/2	50		2.25		.44
	Plywood		34	.80		1.25	
	Plywood	1/4	34		3.20		.31
	Plywood	3/8	34		2.12		.47
	Plywood	1/2	34		1.60		.62
	Plywood or wood panels	3/4			1.07		.93
	Wood fiberboard, laminated or homogeneous		26	.42		2.	
			31	.50		2.00	
	Wood fiber, hardboard type		65	1.40		.71	
	Wood fiber, hardboard type	1/4	65		5.60		.18
	Wood-fir or pine sheathing	25/32			1.02		.98
	Wood-fir or pine	1-5/8			.49		2.04
Building paper	Vapor-permeable felt				16.70		.06
	Vapor seal, 2 layers of mopped 15-lb. felt				8.35		.12
	Vapor seal, plastic film						Negligible

Table 2.--Conductivities (k), conductances (C), and resistances (R) of building and insulating materials (design values)[1, 2] (continued)

Material	Description	Thickness	Density	Conductivity or conductance (k)	Conductivity or conductance (C)	Resistance (R) $\frac{1}{k}$	Resistance (R) $\frac{1}{C}$
		Inches	Pound per cubic foot				
Flooring materials	Asphalt tile	1/8	120		24.80		0.04
	Carpet and fibrous pad				.48		2.08
	Carpet and rubber pad				.81		1.23
	Ceramic tile	1			12.50		.08
	Cork tile		25	0.45		2.22	
	Cork tile	1/8			3.60		.28
	Felt, flooring				16.70		.06
	Floor tile or linoleum, average value	1/8			20.00		.05
	Linoleum .	1/8	80		12.00		.08
	Plywood subfloor	5/8			1.28		.78
	Rubber or plastic tile	1/8	110		42.40		.02
	Terrazzo	1			12.50		.08
	Wood subfloor	25/32			1.02		.98
	Wood, hardwood finish	3/4			1.47		.68
Insulating materials Blanket and batt	Cotton fiber[6]		0.8- 2.0	.26		3.85	
	Mineral wool, fibrous form, processed from rock, slag or glass[6]		1.5- 4.0	.27		3.70	
	Wood fiber[6]		3.2- 3.6	.25		4.00	
	Wood fiber, multilayer, stitched expanding[6]		1.5- 2.0	.27		3.70	
Insulating materials, board	Glass fiber		9.5	.25		4.00	
	Wood or cane fiber						
	Acoustical tile[7]	1/2			.84		1.19
	Acoustical tile[7]	3/4			.56		1.79
	Interior finish (plank, tile, lath)		15.0	.35		2.86	
	Interior finish (plank, tile, lath)	1/2	15.0		.70		1.43
	Roof deck slab						
	Approximate	1-1/2			.24		4.17
	Approximate	2			.18		5.56
	Approximate	3			.12		8.33
	Sheathing (impregnated or coated)		20.0	.38		2.63	
	Sheathing (impregnated or coated)	1/2	20.0		.76		1.32
	Sheathing (impregnated or coated)	25/32	20.0		.49		2.04
Board and slabs	Cellular glass		9.0	.40		2.50	
	Cork board (without added binder)		6.5- 8.0	.27		3.70	
	Hog hair (with asphalt binder)		8.5	.33		3.03	
	Plastic (foamed)		1.62	.29		3.45	
	Wood shredded (cemented in preformed slabs)		22.0	.55		1.82	
Loose fill	Macerated paper or pulp products		2.5- 3.5	.28		3.57	
	Mineral wool (glass, slag, or rock)		2.0- 5.0	.30		3.33	
	Sawdust or shavings		8.0-15.0	.45		2.22	
	Vermiculite (expanded)		7.0	.48		2.08	
	Wood fiber: redwood, hemlock, or fir		2.0- 3.5	.30		3.33	

Table 2.--Conductivities (k), conductances (C), and resistances (R) of building and insulating materials (design values)[1,2] (continued)

Material	Description	Thickness	Density	Conductivity or conductance: (k)	Conductivity or conductance: (C)	Resistance (R): $\frac{1}{k}$	Resistance (R): $\frac{1}{C}$
		Inches	Pound per cubic foot				
Roof insulation	All types[8]						
	Preformed, for use above deck						
	Approximate	1/2			0.72		1.39
	Approximate	1			.36		2.78
	Approximate	1-1/2			.24		4.17
	Approximate	2			.19		5.26
	Approximate	2-1/2			.15		6.67
	Approximate	3			.12		8.33
Masonry materials Concretes	Cement mortar		116	5.0		0.2	
	Gypsum-fiber concrete 87-1/2 percent gypsum, 12-1/2 percent wood chips		51	1.66		.60	
	Lightweight aggregates including expanded shale, clay, or slate; expanded slags, cinders, pumice, perlite, vermiculite; also cellular concretes		120	5.2		.19	
			100	3.6		.28	
			80	2.5		.40	
			60	1.7		.59	
			40	1.15		.87	
			30	.90		1.11	
			20	.70		1.43	
	Sand and gravel or stone aggregate (ovendried)		140	9.0		.11	
	Sand and gravel or stone aggregate (not dried)		140	12.0		.08	
	Stucco		116	5.0		.20	
Masonry units	Brick, common		120	5.0		.20	
	Brick, face		130	9.0		.11	
	Clay tile, hollow						
	1 cell deep	3			1.25		.80
	1 cell deep	4			.90		1.11
	2 cells deep	6			.66		1.52
	2 cells deep	8			.54		1.85
	2 cells deep	10			.45		2.22
	3 cells deep	12			.40		2.50
	Concrete blocks, three oval core:						
	Sand and gravel aggregate	4			1.40		.71
		8			.90		1.11
		12			.78		1.28
	Cinder aggregate	3			1.16		.86
		4			.90		1.11
		8			.58		1.72
		12			.53		1.89
	Gypsum partition tile						
	3 by 12 by 30 inches, solid				.79		1.27
	3 by 12 by 30 inches, 4-cell				.74		1.35
	4 by 12 by 30 inches, 3-cell				.60		1.67
	Lightweight aggregate (expanded shale, clay, slate or slag, pumice)	3			.79		1.27
		4			.67		1.49
		8			.50		2.00
		12			.44		2.27
	Stone, lime or sand			12.50		.08	

Table 2.--Conductivities (k), conductances (C), and resistances (R) of building and insulating materials (design values)[1,2] (continued)

Material	Description	Thickness	Density	Conductivity or conductance (k)	Conductivity or conductance (C)	Resistance (R) $\frac{1}{k}$	Resistance (R) $\frac{1}{C}$
		Inches	Pound per cubic foot				
Metals	See Chapter 5, table 1 of 1957 Heating, Ventilating, and Air Conditioning Guide						
Plastering materials	Cement plaster						
	Sand aggregate		116	5.0		0.20	
	Sand aggregate	1/2			10.00		0.10
	Sand aggregate	3/4			6.66		.15
	Gypsum plaster						
	Lightweight aggregate	1/2	45		3.12		.32
	Lightweight aggregate	5/8	45		2.67		.37
	Lightweight aggregate on metal lath	3/4			2.13		.47
	Perlite aggregate		45	1.5		.67	
	Sand aggregate		105	5.6		.18	
	Sand aggregate	1/2	105		11.10		.09
	Sand aggregate	5/8	105		9.10		.11
	Sand aggregate on metal lath	3/4			7.70		.13
	Sand aggregate on wood lath				2.50		.40
	Vermiculate aggregate		45	1.7		.59	
Roofing	Asbestos-cement shingles		120		4.76		.21
	Asphalt roll roofing		70		6.50		.15
	Asphalt shingles		70		2.27		.44
	Built-up roofing	3/8	70		3.00		.33
	Slate	1/2			20.00		.05
	Sheet metal			400+		Negligible	
	Wood shingles				1.06		.94
Siding materials (on flat surface)	Shingles:						
	Wood, 16-inch, 7-1/2-inch exposure				1.15		.87
	Wood, double, 16-inch, 12-inch exposure				.84		1.19
	Wood, plus insulation backer board	5/16			.71		1.41
	Siding:						
	Asbestos-cement, 1/4 inch, lapped				4.76		.21
	Asphalt roll siding				6.50		.15
	Asphalt insulating siding (1/2 inch board)				.69		1.45
	Wood, drop, 1 by 8 inches				1.27		.79
	Wood, bevel, 1/2 by 8 inches, lapped				1.23		.81
	Wood, bevel, 3/4 by 10 inches, lapped				.95		1.05
	Wood, plywood, 3/8 inch, lapped				1.59		.63
	Structural glass				10.00		.10
Woods[8]	Maple and oak		43	1.11		.90	
	Douglas-fir		32	.88		1.14	

[1]Table based on data from 1957 Heating, Ventilating and Air Conditioning Guide.

[2]Representative values for dry materials at 75° F. mean temperature, intended as design, not specification, values.

[3]Air space resistance values are for spaces faced both sides with ordinary nonreflective surface.

[4]Surface resistance values shown are for ordinary nonreflective materials.

[5]See also insulating materials, board.

[6]Includes paper backing and facing, if any, having nonreflective surface.

[7]Insulating value of acoustical tile vary depending on density of the board and on the type, size, and depth of the perforations. An average conductivity k value is 0.42.

[8]Based on tests made at the Forest Products Laboratory. See table 5.

Table 3.--Thermal conductance and resistances of a plane air space

Position of air space	Heat flow	Air space			Thermal conductance (C) value of E[1]				Thermal resistance (R) value of E[1]			
		Thickness	Mean temperature	Temperature difference								
		Inches	° F.	° F.	0.05	0.2	0.5	0.82	0.05	0.2	0.5	0.82
Horizontal	Up	3/4 to 4	50	30	.54	.68	.95	1.24	1.84	1.47	1.05	.80
Sloping 45°	Up	3/4 to 4	50	30	.48	.62	.89	1.18	2.08	1.62	1.13	.85
Vertical	Horizontal	3/4 to 4	50	30	.38	.52	.79	1.08	2.64	1.94	1.27	.92
Sloping 45°	Down	3/4 to 4	50	30	.30	.43	.71	1.00	3.36	2.30	1.41	1.00
Horizontal	Down	3/4	50	20	.28	.42	.69	.98	3.57	2.38	1.45	1.02
Horizontal		1-1/2	50	20	.18	.31	.58	.87	5.56	3.23	1.73	1.15
Horizontal		4	50	20	.11	.25	.52	.81	8.94	4.03	1.92	1.25
Horizontal		3/4	90	20	.31	.48	.82	1.18	3.23	2.08	1.22	.85
Horizontal		1-1/2	90	20	.20	.37	.71	1.07	5.00	2.70	1.41	.93
Horizontal		4	90	20	.13	.30	.64	1.01	7.82	3.35	1.56	.99

[1]E is the effective emissivity of the two boundary surfaces of an air space.

Table 4.--Reflectivity and emissivity values of various surfaces and effective emissivities of air spaces

Surface	Reflectivity	Average surface emmisivity (e)[1]	Effective emmisivity (E)[1] of air space	
			With one surface having emissivity e and other 0.90	With both surfaces of emissivity e
	Percent			
Aluminum foil, bright	92 to 97	0.05	0.05	0.03
Aluminum-coated paper, polished	75 to 84	.20	.20	.11
Aluminum paint	30 to 70	.50	.47	.35
Building materials; wood, paper, glass, masonry, nonmetalic paints	5 to 15	.90	.82	.82

[1] e is the emissivity of a surface while E is the effective emissivity of the two boundry surfaces of an air space. Emissivity as used here applies to either surface of an air space, one of which radiates or emits heat from the warm side of the space and the other reflects some part of the radiant heat from the cold side. In this sense, emissivity and reflectivity are equal.

Table 5.--Average specific gravity, conductivity and resistance values of various species of hardwoods and softwoods

Species hardwoods	Specific gravity[1]	Conductivity k	Resistance $\frac{1}{k}$	Resistance [2]25/32
Ash:				
Black	0.531	0.903	1.11	0.87
Commercial white	.618	1.024	.98	.77
Aspen:				
Big tooth	.412	.738	1.36	1.06
Quaking	.401	.722	1.39	1.09
Basswood, American	.398	.718	1.39	1.09
Birch, American	.671	1.098	.91	.71
Birch:				
Sweet	.714	1.157	.86	.67
Yellow	.662	1.085	.92	.72
Cherry, black	.534	.907	1.10	.86
Chestnut, American	.454	.796	1.26	.98
Cottonwood:				
Black	.368	.677	1.48	1.16
Eastern	.433	.767	1.30	1.02
Elm:				
American	.554	.935	1.07	.84
Rock	.658	1.080	.93	.73
Slippery	.568	.955	1.05	.82
Hackberry	.558	.941	1.06	.83
Hickory:				
Pecan	.694	1.130	.88	.69
True	.787	1.259	.79	.62
Magnolia, southern	.530	.902	1.11	.87
Maple:				
Black	.620	1.027	.97	.76
Red	.546	.924	1.08	.84
Silver	.506	.868	1.15	.90
Sugar	.676	1.105	.90	.70
Oak:				
Commercial red	.676	1.105	.90	.70
Commercial white	.719	1.164	.86	.67
Sweetgum	.551	.931	1.07	.84
Sycamore, American	.539	.914	1.09	.85
Tupelo:				
Black	.552	.932	1.07	.84
Water	.524	.893	1.12	.88
Yellow poplar	.449	.789	1.27	.99

Species softwoods	Specific gravity[1]	Conductivity k	Resistance $\frac{1}{k}$	Resistance [2]25/32
Bald cypress	0.482	0.835	1.20	0.94
Cedar:				
Alaska	.465	.811	1.23	.96
Atlantic white	.352	.654	1.53	1.20
Northern white	.315	.603	1.66	1.30
Port Orford	.440	.777	1.29	1.01
Western redcedar	.342	.640	1.56	1.22
Douglas-fir:				
Coast-type	.508	.871	1.15	.90
Intermediate	.476	.827	1.21	.95
Rocky Mountain	.446	.785	1.27	.99
Fir:				
Balsam	.414	.740	1.35	1.05
Commercial white	.413	.739	1.35	1.05
Hemlock:				
Eastern	.429	.761	1.31	1.02
Western	.443	.781	1.28	1.00
Larch, western	.591	.986	1.01	.79
Pine:				
Eastern white	.367	.675	1.48	1.16
Loblolly	.545	.923	1.08	.84
Lodgepole	.434	.768	1.30	1.02
Longleaf	.623	1.031	.97	.76
Ponderosa	.420	.749	1.34	1.05
Red	.470	.818	1.22	.95
Shortleaf	.535	.909	1.10	.86
Slash	.661	1.084	.92	.72
Sugar	.378	.690	1.45	1.13
Western white	.418	.746	1.34	1.05
Redwood:				
Virgin growth	.416	.743	1.35	1.05
Second growth (openly grown)	.310	.596	1.68	1.31
Second growth (closely grown)	.361	.667	1.50	1.17
Spruce:				
Engelmann	.355	.658	1.52	1.19
Red	.413	.739	1.35	1.05
Sitka	.416	.743	1.35	1.05
White	.446	.785	1.27	.99

[1]Average specific gravity based on volume and weight of ovendry specimens.

[2]The thickness of nominal 1-inch boards is 25/32 inch.

Table 6.--Thermal conductivity of honeycomb cores with no fill insulation

Type of honeycomb core[1]	Weight of paper	Weight of core	Mean temperature	Conductivity value k
	Pounds per 3,000 square feet	Pounds per cubic foot	° F.	British thermal units per square foot per hour per inch per ° F.
Corrugated-PN	50	2.94	75.1	0.47
Corrugated-PNL	50	5.49	77.2	.59
Corrugated-XN	50	2.75	78.6	.45
Corrugated-XNL	50	5.30	76.4	.51
Corrugated-XN flatwise	50	2.75	74.9	.36
Corrugated-XNL flatwise	50	4.68	75.5	.29
Corrugated-PNL flatwise	50	4.25	75.5	.31
Corrugated-XN diagonal	50	2.69	76.9	.48
Corrugated-PNL	30	3.35	76.8	.47
Figure 8		2.89	76.0	.53

[1]For the corrugated core arrangements, see figure 6.

Table 7.--Effect of foamed resin and fill insulation on thermal properties of honeycomb cores

Type of honeycomb core	Added insulation	Weight per cubic foot	Mean temperature	Conductivity value k
		Pounds	° F.	British thermal units per square foot per hour per inch per ° F.
		FOAMED-IN-PLACE RESIN		
Corrugated-PN	None	3.48	77.9	0.58
Corrugated-PN	Foamed resin A	5.33	77.0	.40
Corrugated-PN	Foamed resin B	8.70	78.3	.41
Corrugated-PN	Foamed resin C	10.52	78.1	.51
Figure 8	None	2.89	76.0	.53
Figure 8	Foamed resin A	5.50	77.6	.38
Figure 8[1]	Foamed resin A	1.88	77.7	.31
		FILL INSULATION		
Corrugated-PN	None	3.48	77.9	.58
Corrugated-PN	Shredded urea foam	4.72	77.3	.37
Corrugated-PN	Silica aerogel	6.44	77.5	.35
Corrugated-PN	Puffed siliceous rock	10.68	78.1	.45
Corrugated-XN	None	2.75	78.6	.45
Corrugated-XN	Shredded urea foam	4.08	76.3	.35
Corrugated-PNL flatwise	None	4.68	74.9	.31
Corrugated-PNL flatwise	Silica aerogel	8.47	77.5	.27

[1]Large loops 1-1/4 inches in diameter made with 20-pound kraft paper.

Table 8.--Coefficients of thermal transmission through solid doors of different thicknesses with and without wood storm doors

Actual thickness	Without storm door	With storm door
1-1/16	0.55	0.34
1-3/8	.48	.31
1-5/8	.43	.28
2-1/8	.36	.26

Table 9.--Calorific values for fuel and combustion efficiency of small heating plants

Fuel	Unit	Type of firing	Approximate calorific value	Probable combustion efficiency
			British thermal units	
Coal	Pound	Hand fired	12,000	50 to 55
Coal	Pound	Stoker	12,000	55 to 65
Oil	Gallon	Conversion burner	140,000	55 to 65
Oil	Gallon	Oil design unit	140,000	75 to 80
Manufactured gas	Cubic foot	Conversion burner	535	60 to 70
Manufactured gas	Cubic foot	Gas designed unit	535	75 to 80
Natural gas	Cubic foot	Conversion burner	1,000	60 to 70
Natural gas	Cubic foot	Gas designed unit	1,000	75 to 80

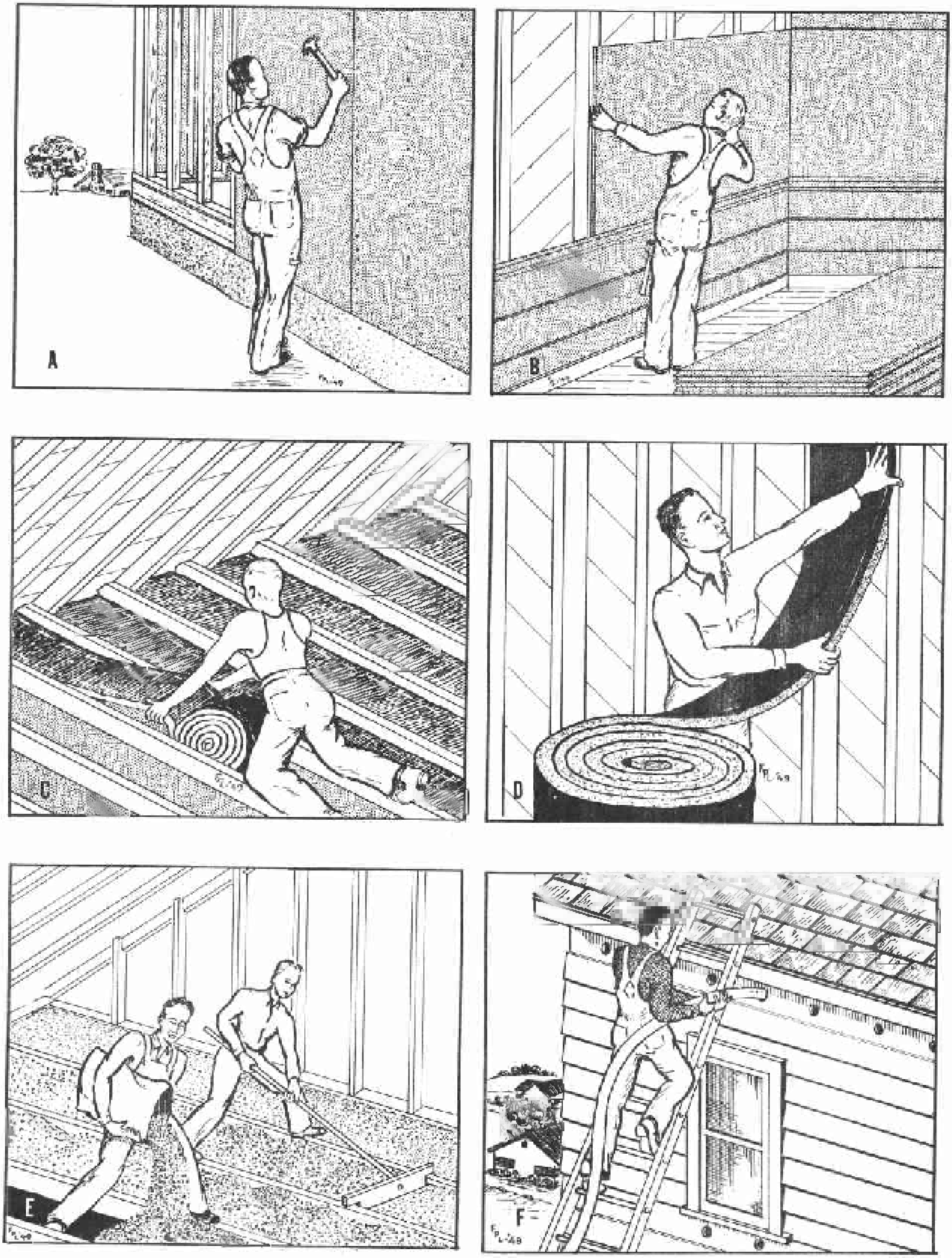

Figure 1.--Various kinds of insulation. A, application of structural insulating board sheathing to studs. B, application of fiberboard used as an interior wall surfacing material. The vapor barrier and interstud space insulation have been omitted for clarity of the illustration. C, installing blanket insulation in a ceiling below an attic. Blanket insulation may also be applied from below the ceiling before lath are applied. D, installing blanket insulation in a stud space of an outside wall. Most blanket materials have tabs on the edges used in fastening the blanket in place. E, pouring fill type insulation between ceiling joist and leveling to a uniform thickness. Note vapor barrier in part not yet covered. F, pneumatic method of insulating existing walls with fill type insulation.

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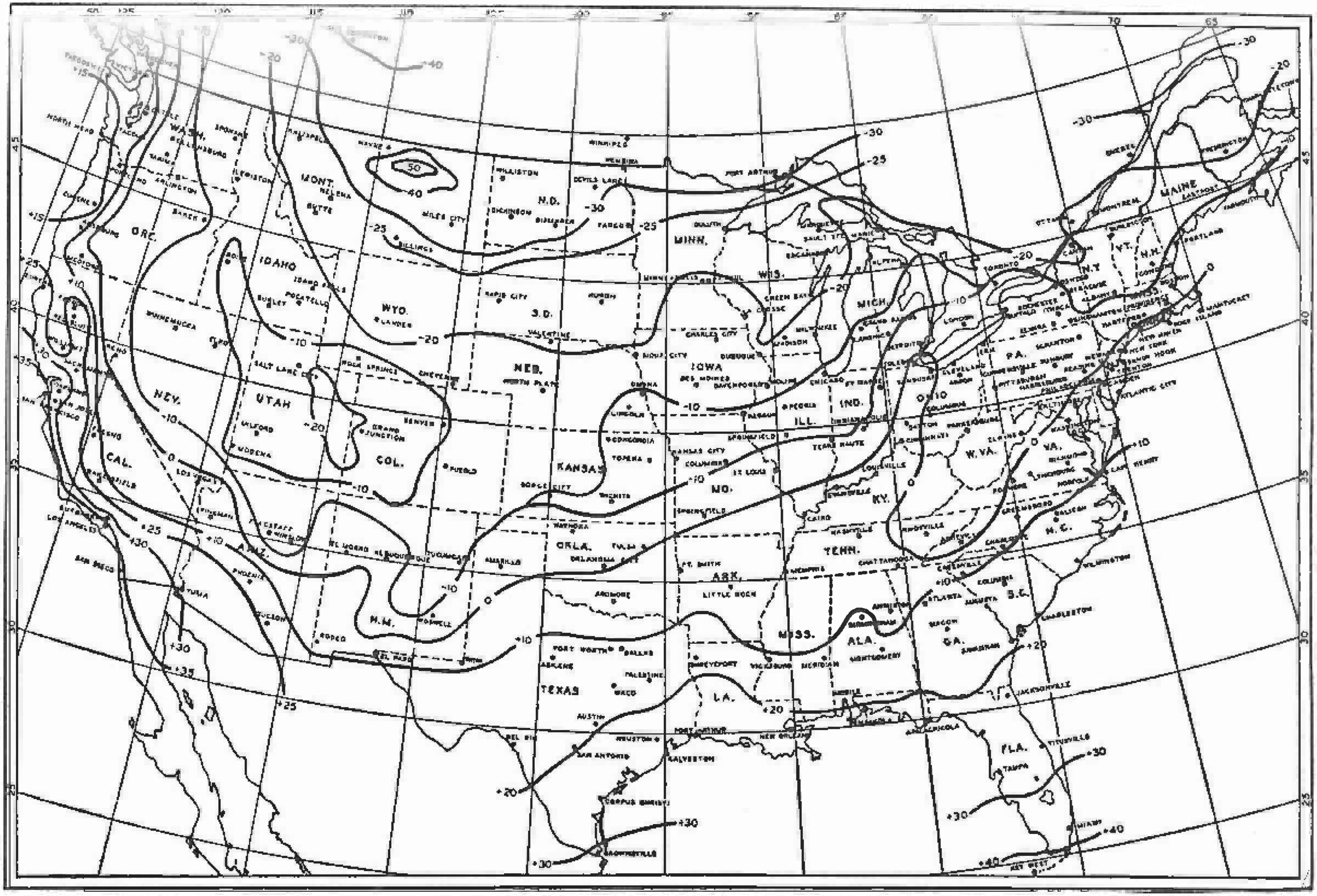

Figure 2.--Average outside design temperature zones of the United States. From 1948 Heating, Ventilating & Air Conditioning Guide.

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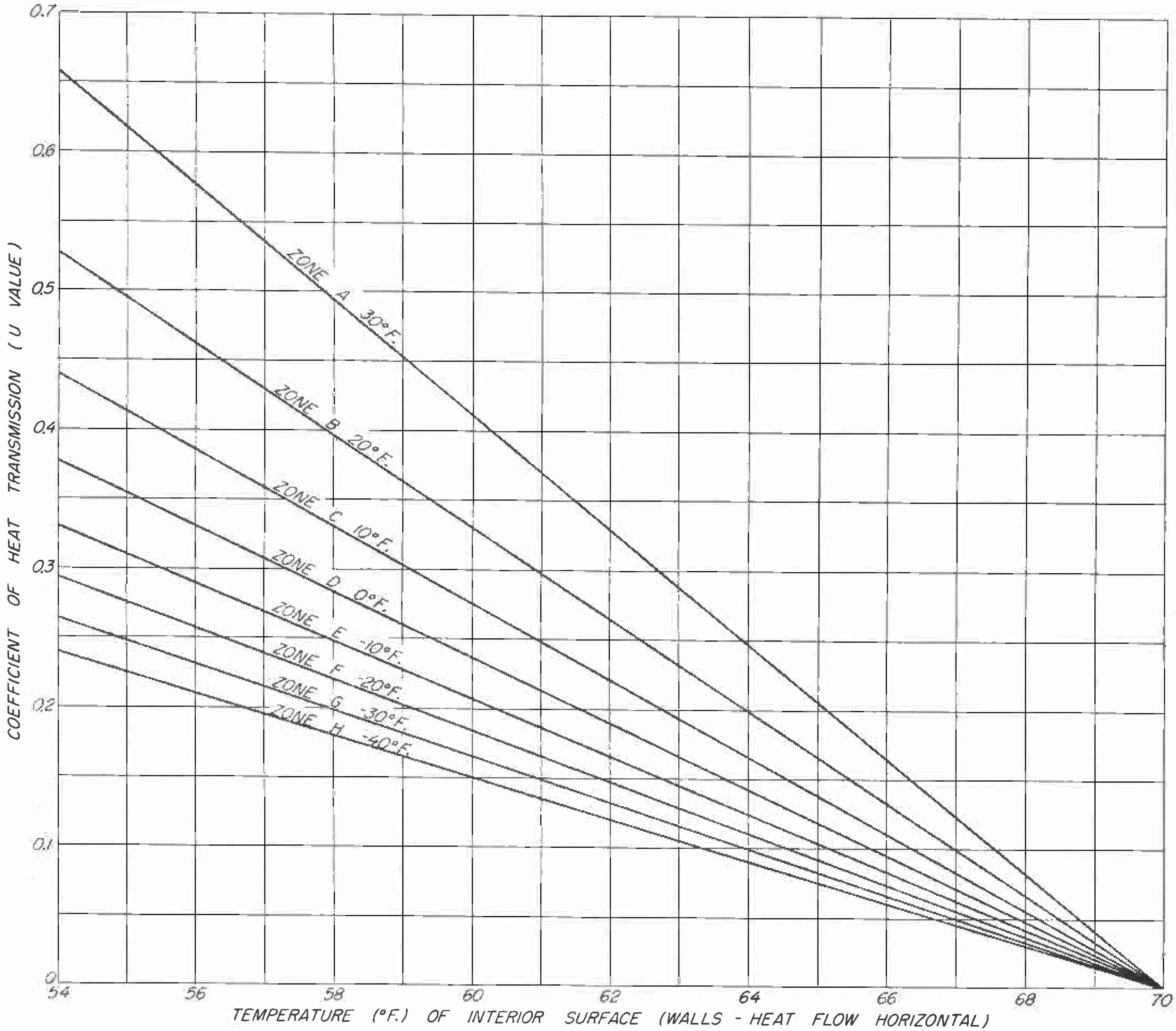

Figure 3.--Chart for determining the U value for walls, floors, and ceilings for various climatic conditions and differences between inside air and surface temperatures.

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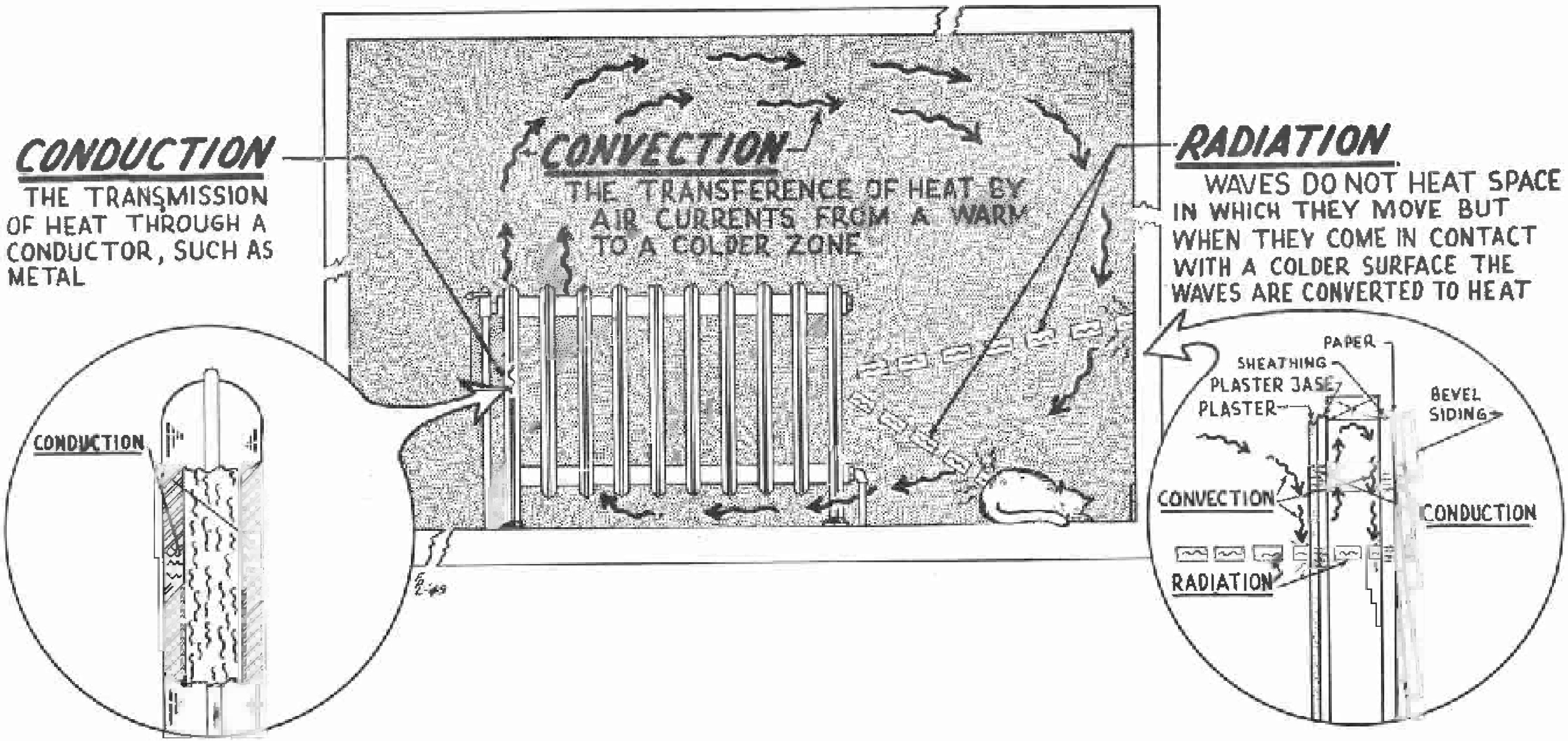

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Figure 4.--Methods of heat transfer.

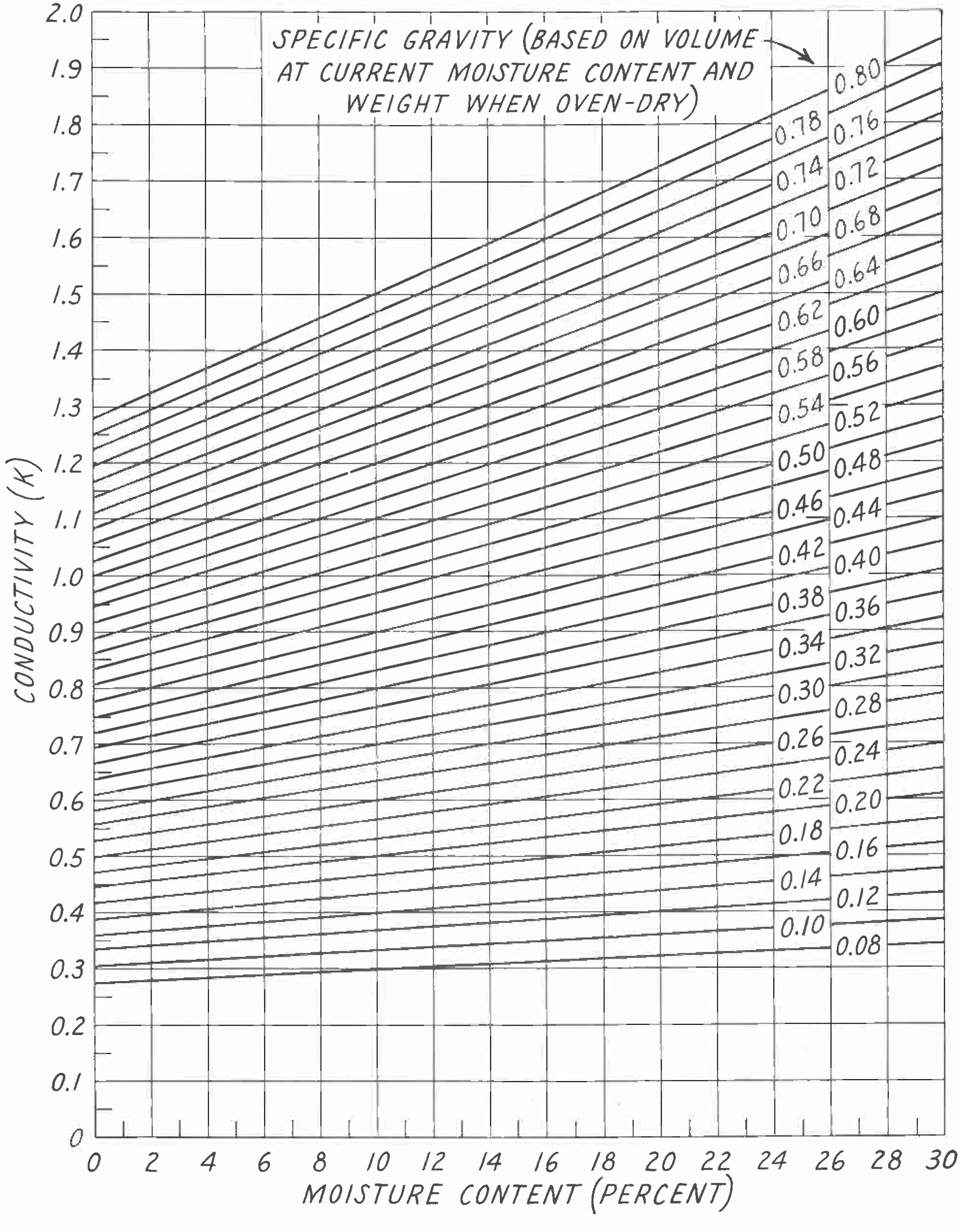

Figure 5.--Relation between computed conductivity and moisture content for wood having different specific gravity values. (Specific gravity based on volume at current moisture content and weight when ovendry. Conductivity computed from formula $K = S\,[1.39 + 0.028M] + 0.165$.)

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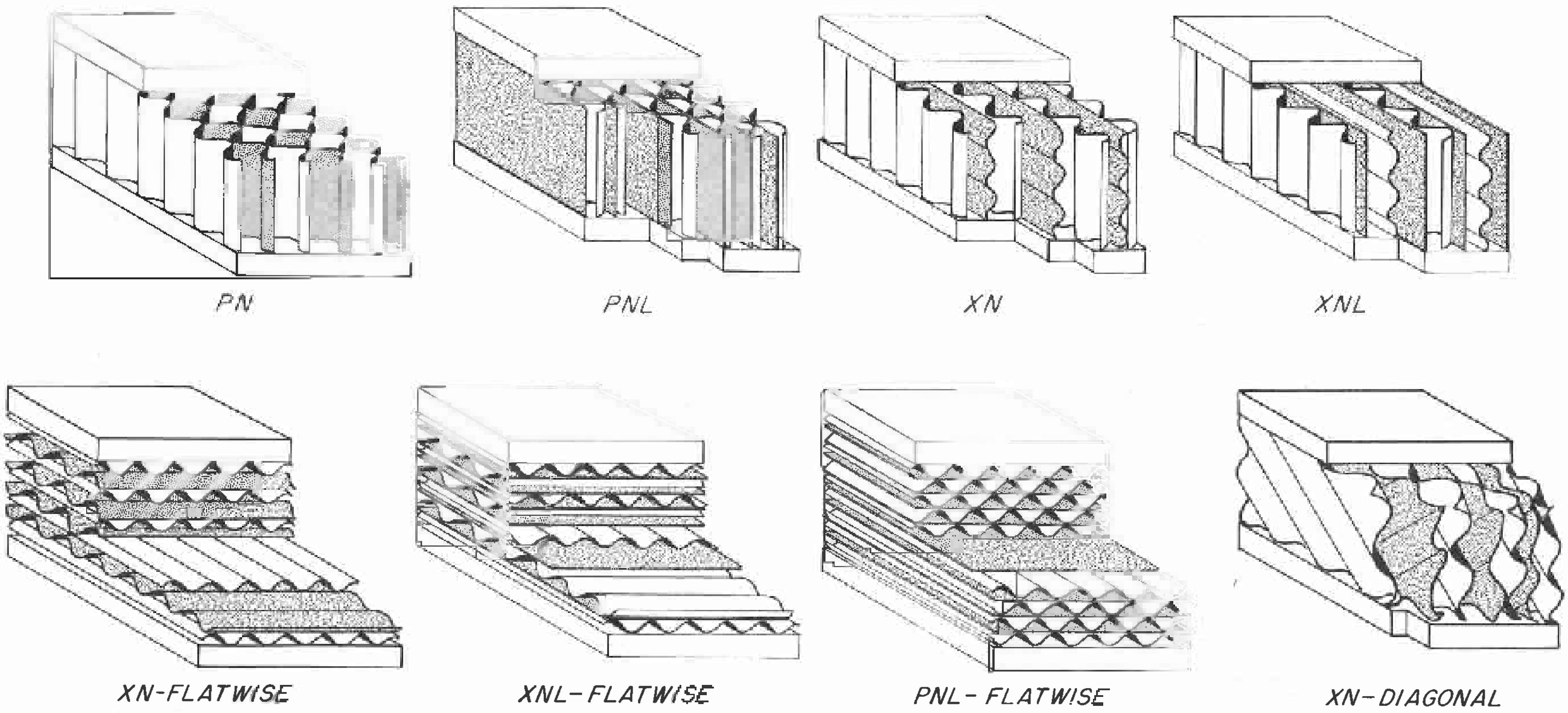

Figure 6.--Various types of corrugated-paper honeycomb cores.

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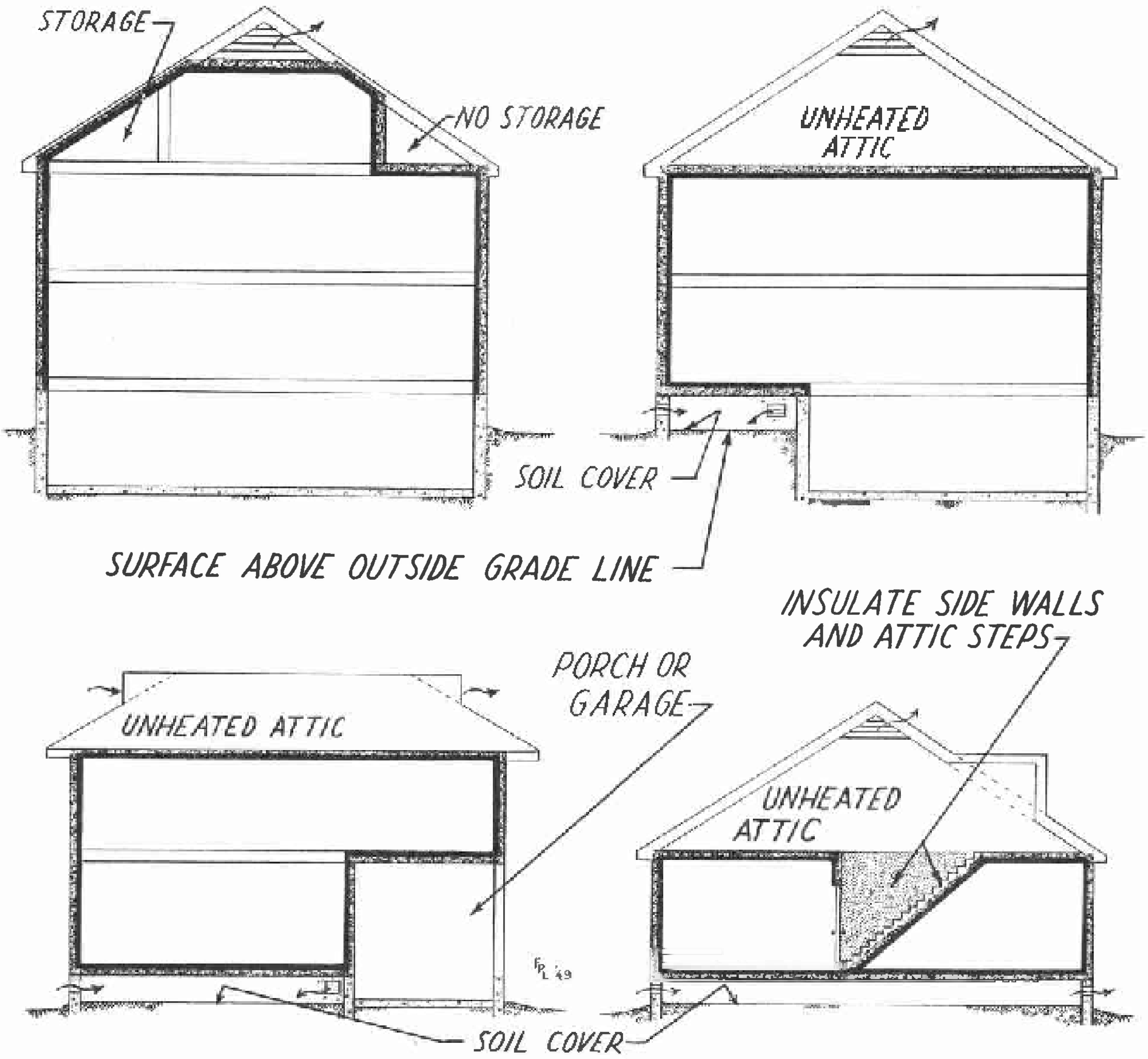

Figure 7.--Insulation should be installed in (1) side walls between heated rooms and outdoors, (2) in walls and floors between unheated garages and porches and heated rooms, (3) in floors of basementless houses, (4) in ceilings below unheated attics, (5) in roofs over heated rooms, (6) in side walls and below stairs leading to unheated attics.

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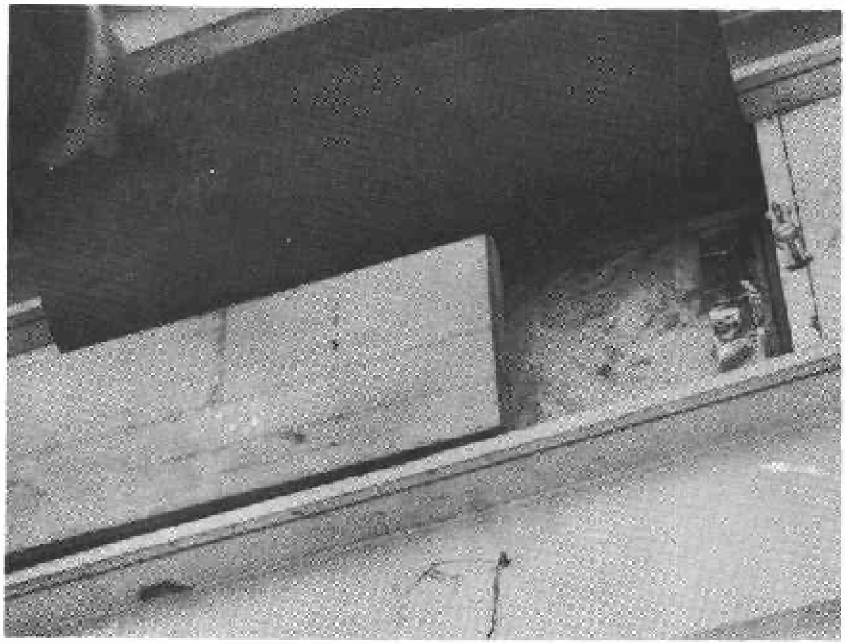

Figure 8.--Investigations made in Forest Products Laboratory test house show how vapor barriers prevent condensation in side walls. Sample of sheathing reversed. This insulated test panel had a vapor barrier on the warm side and no frost gathered on the sheathing or sheathing paper.

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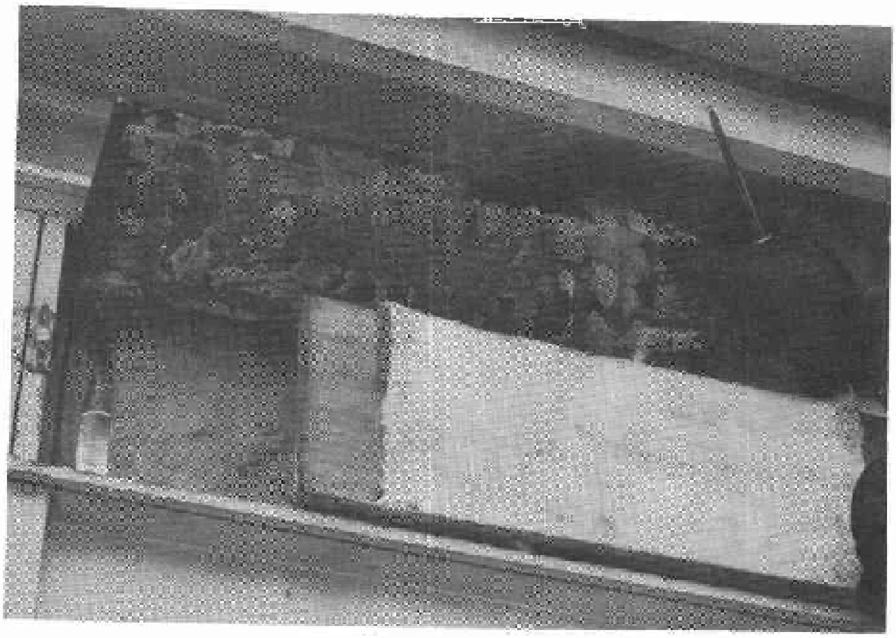

Figure 9.--Sample of sheathing in Forest Products Laboratory test house reversed to show collection of frost on inside surface of an insulated panel not protected with a vapor barrier. Frost also appears on inner face of sheathing paper.

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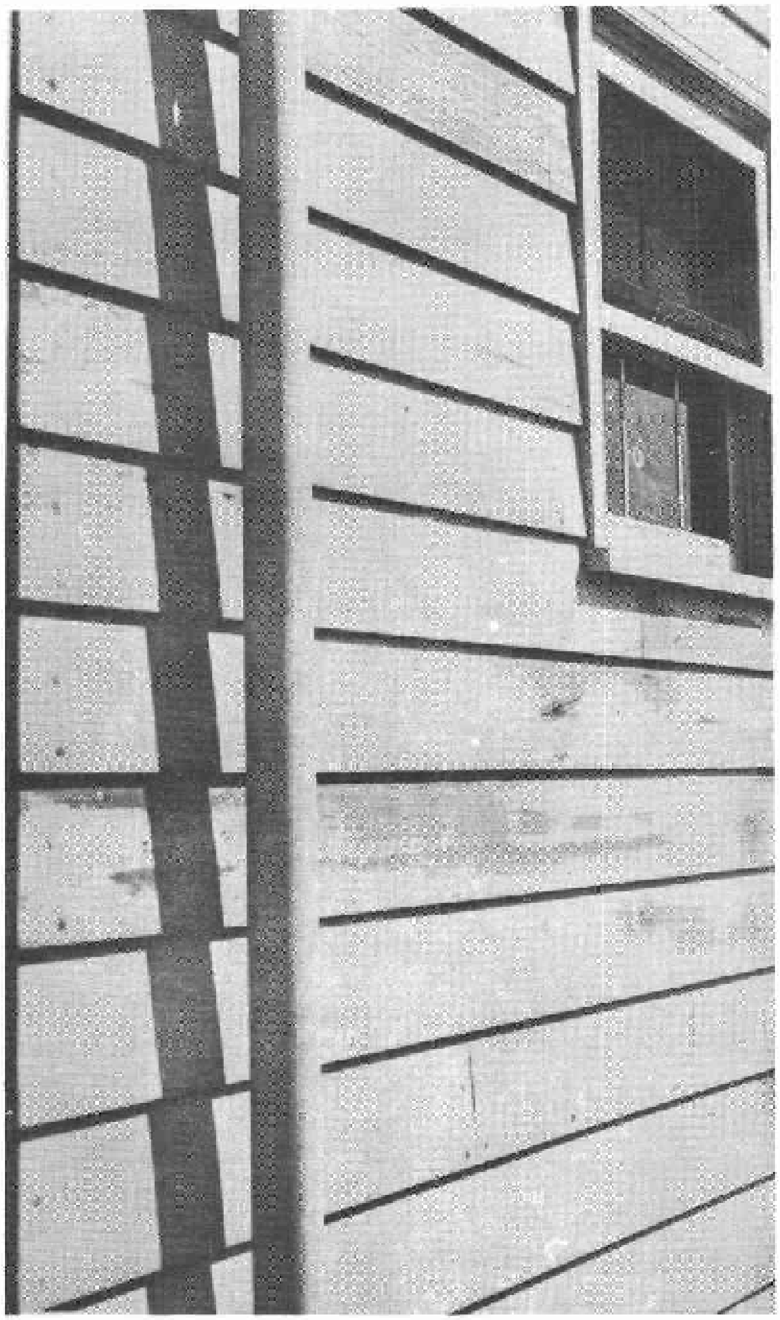

Figure 10.--Paint failures on siding caused by cold weather condensation.

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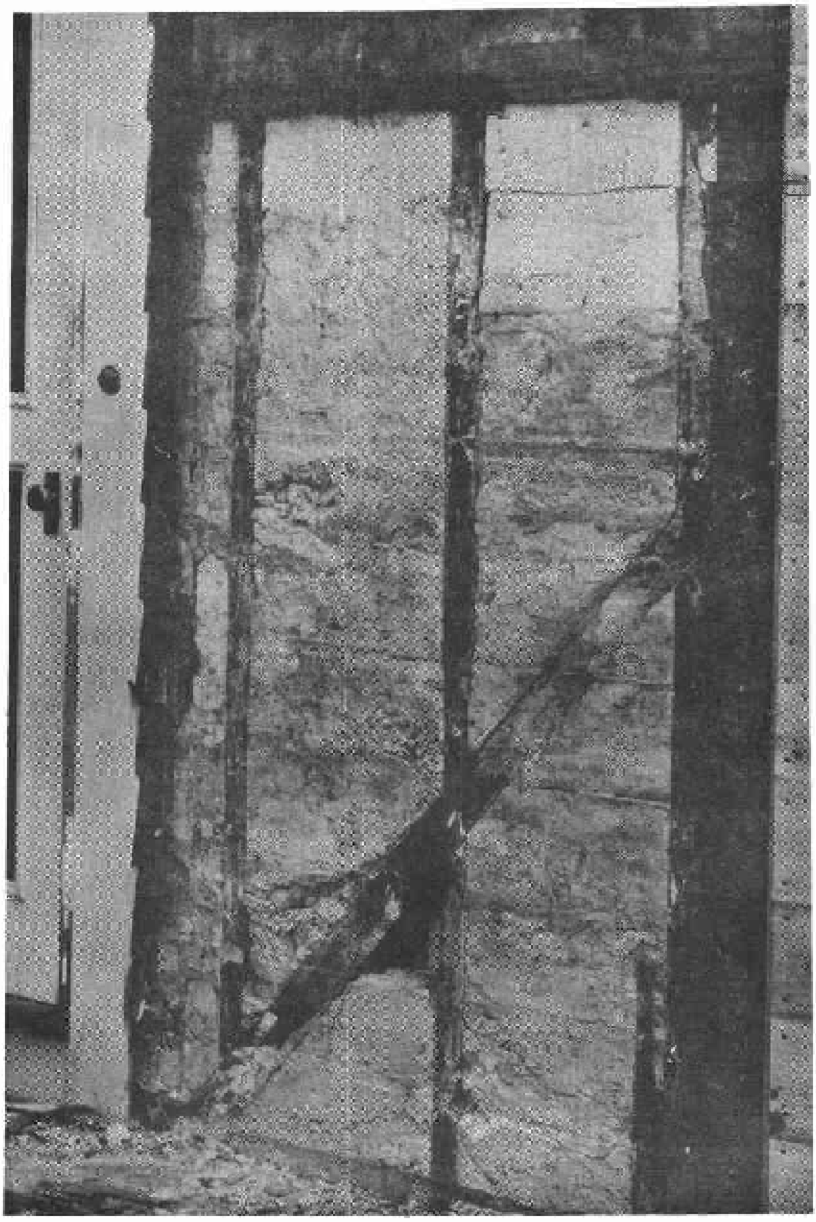

Figure 11.--Condensation in the wall caused decay in the sheathing and studs.

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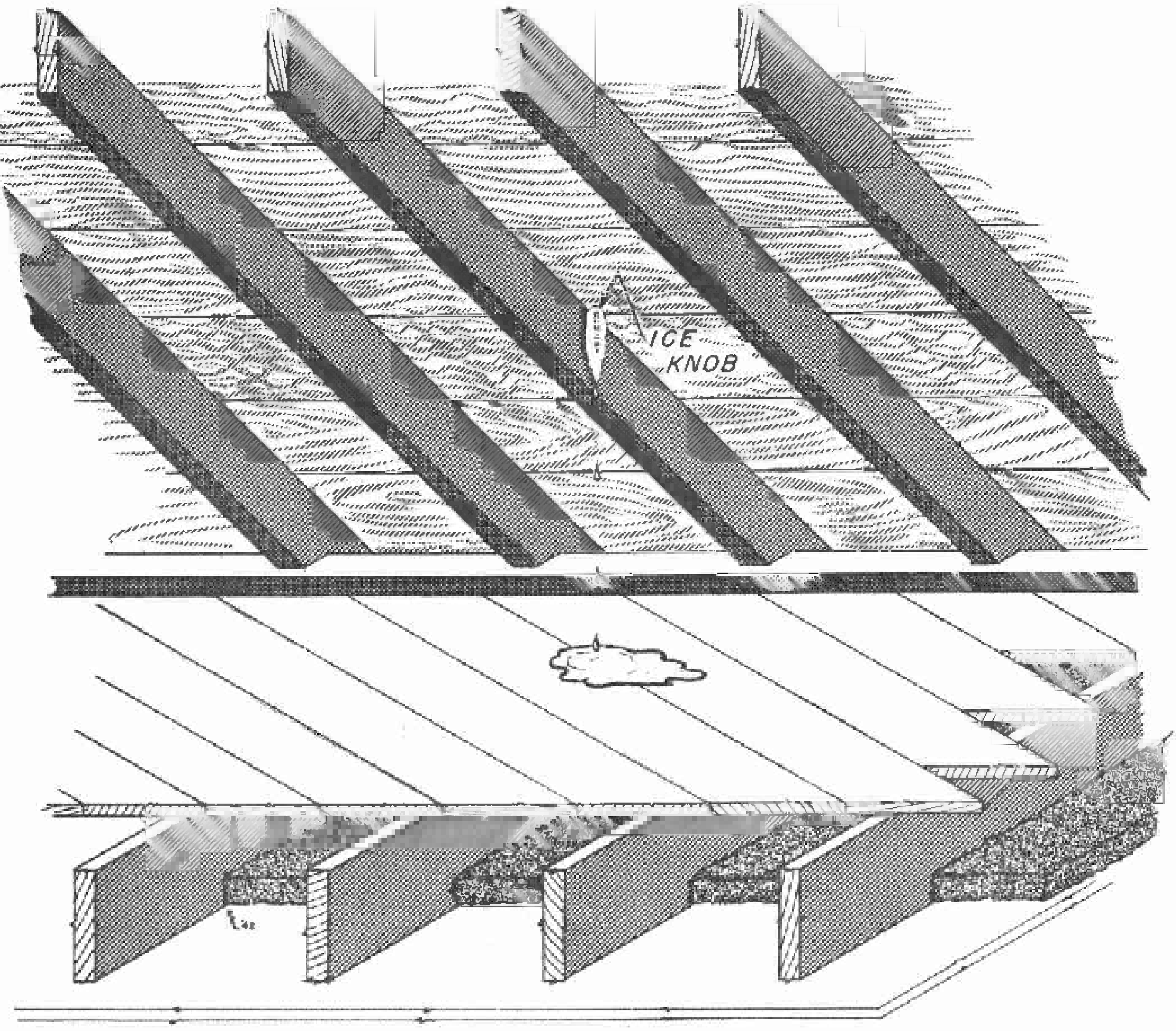

Figure 12.--Condensation collecting on the roof sheathing in an unventilated attic. Ice has collected on the tip of protruding nail (arrow). When outdoor temperatures rise after a cold spell or when the sun strikes the roof the ice melts and drips down to the ceiling below.

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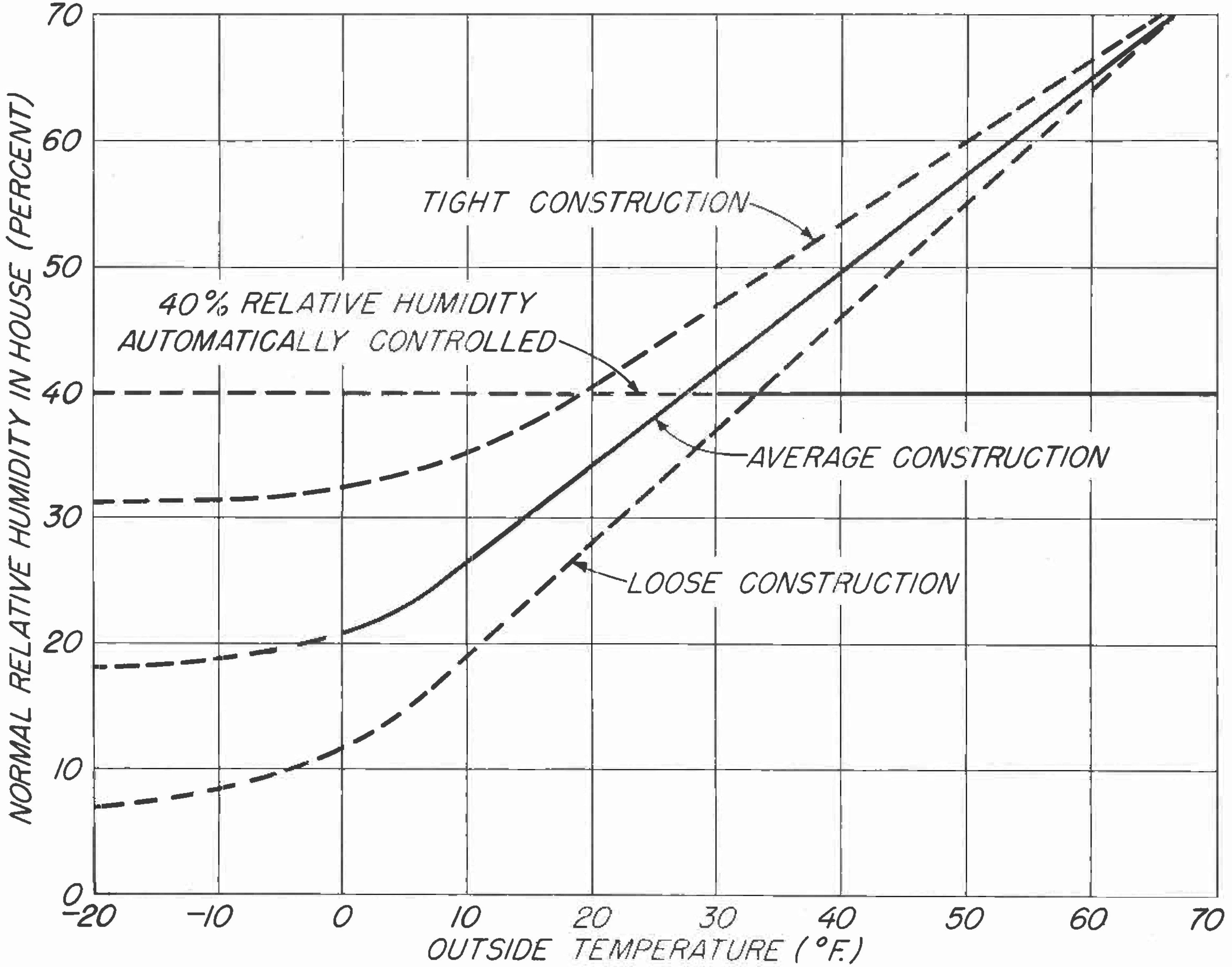

Figure 14.--Relation of relative humidity indoors to outdoor temperature for a loosely built, an average house, and a tightly constructed house.

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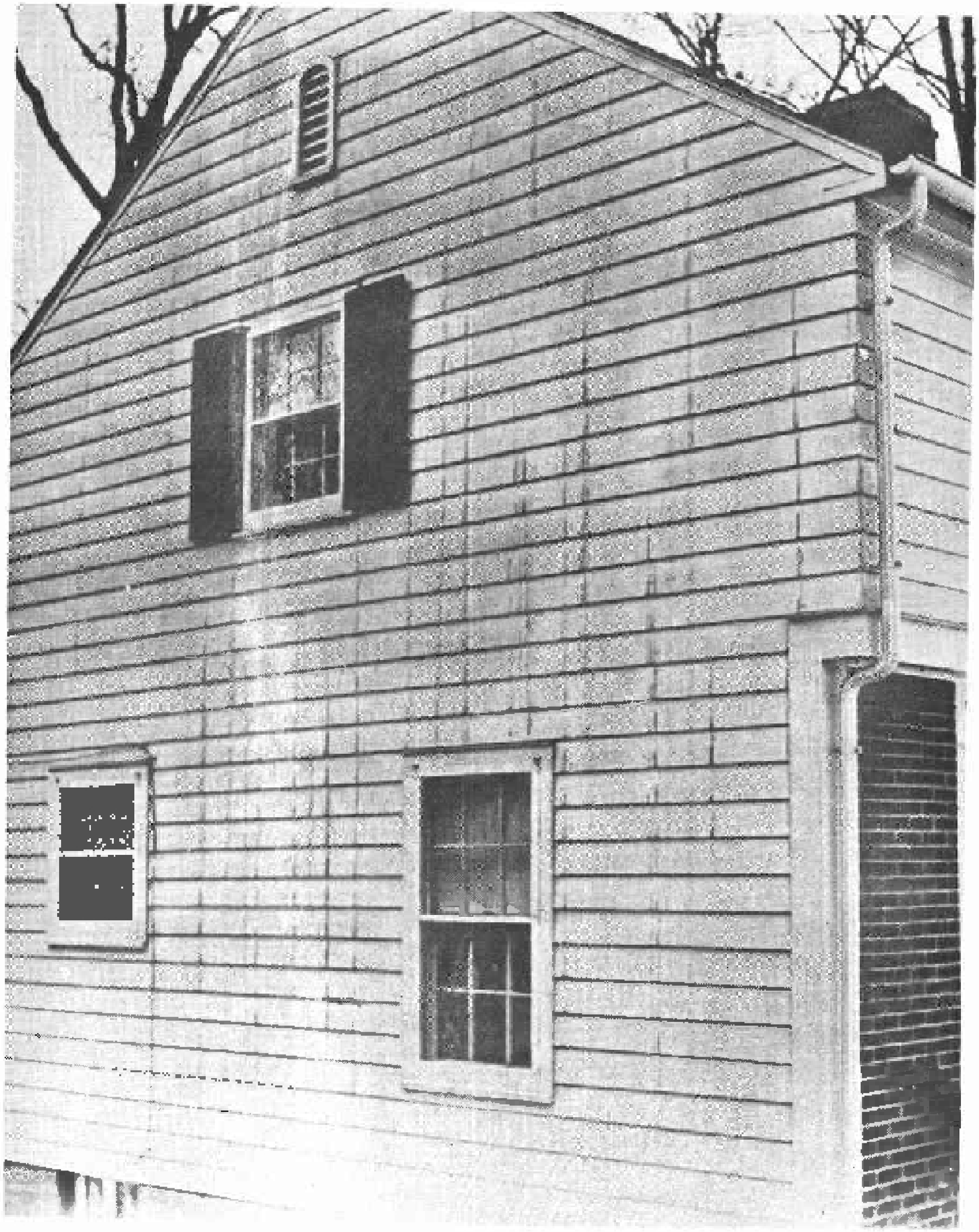

Figure 15.--Stains on a painted wall caused by condensation collecting behind siding in cold weather, as ice and melting when the weather moderated. The water drains out through the laps in the siding carrying water soluble extractives that cause the stain. This building, located in Wisconsin, had no vapor barrier.

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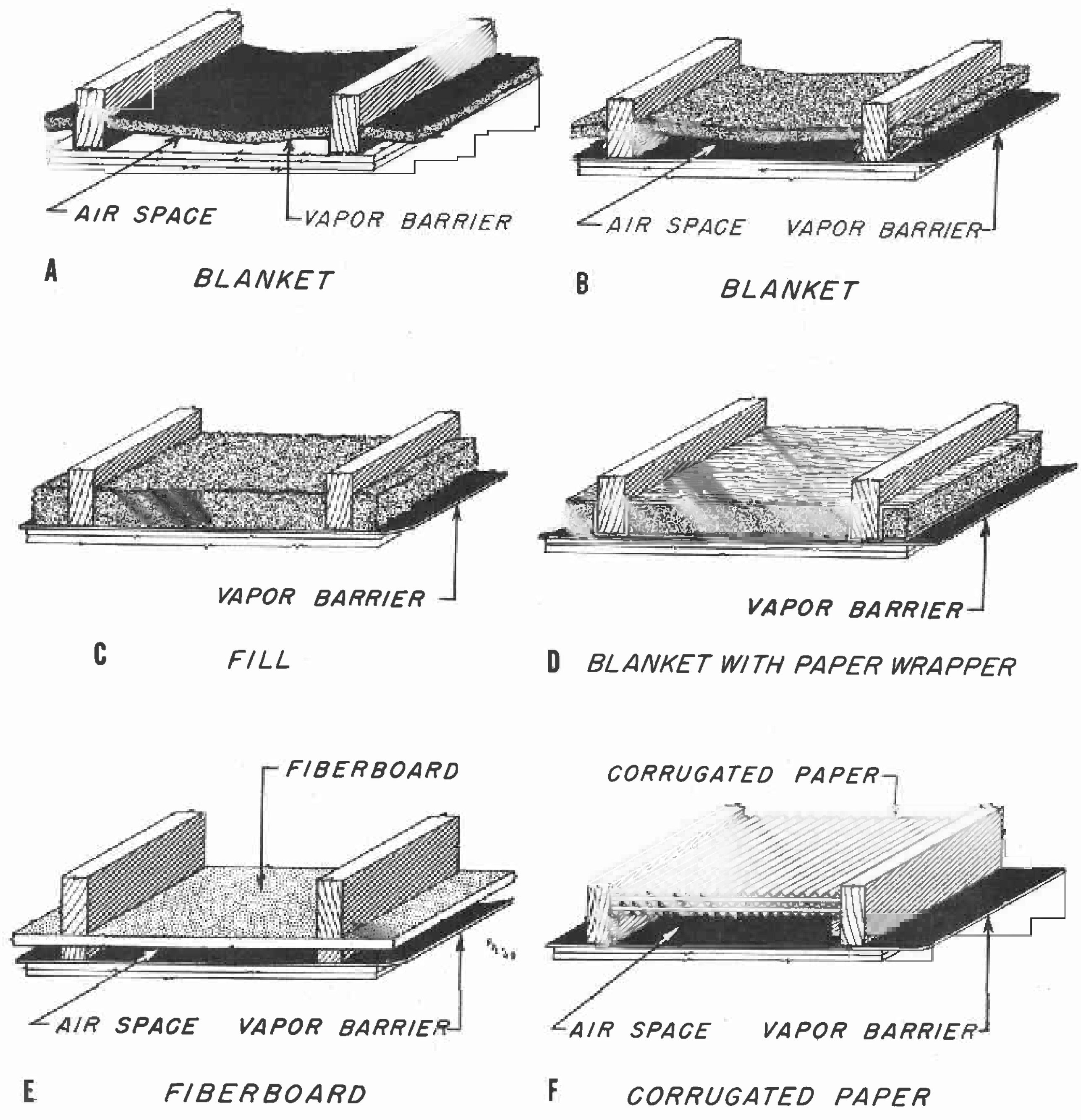

Figure 16.--Methods of insulating ceilings. The sketches show the use of vapor barriers for condensation control and the arrangement of several types of thermal insulation.

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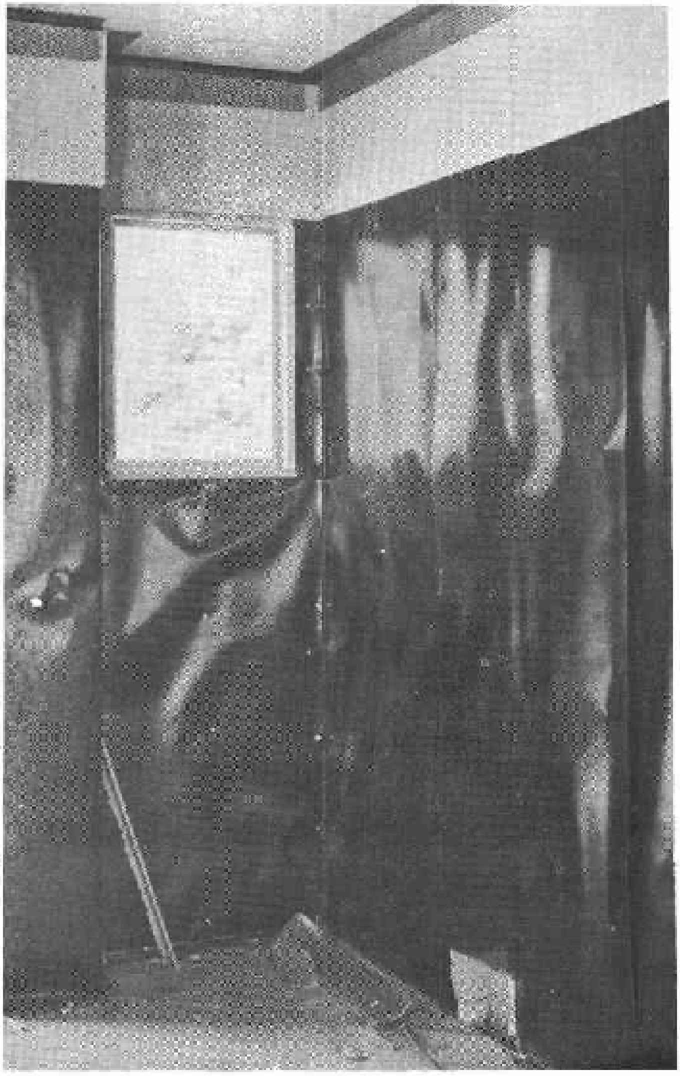

Figure 17.--Vapor barriers installed on the inner face of the studding. Lath placed over the barriers and nailed to the studding holds the paper tight at the laps and no special seal is required.

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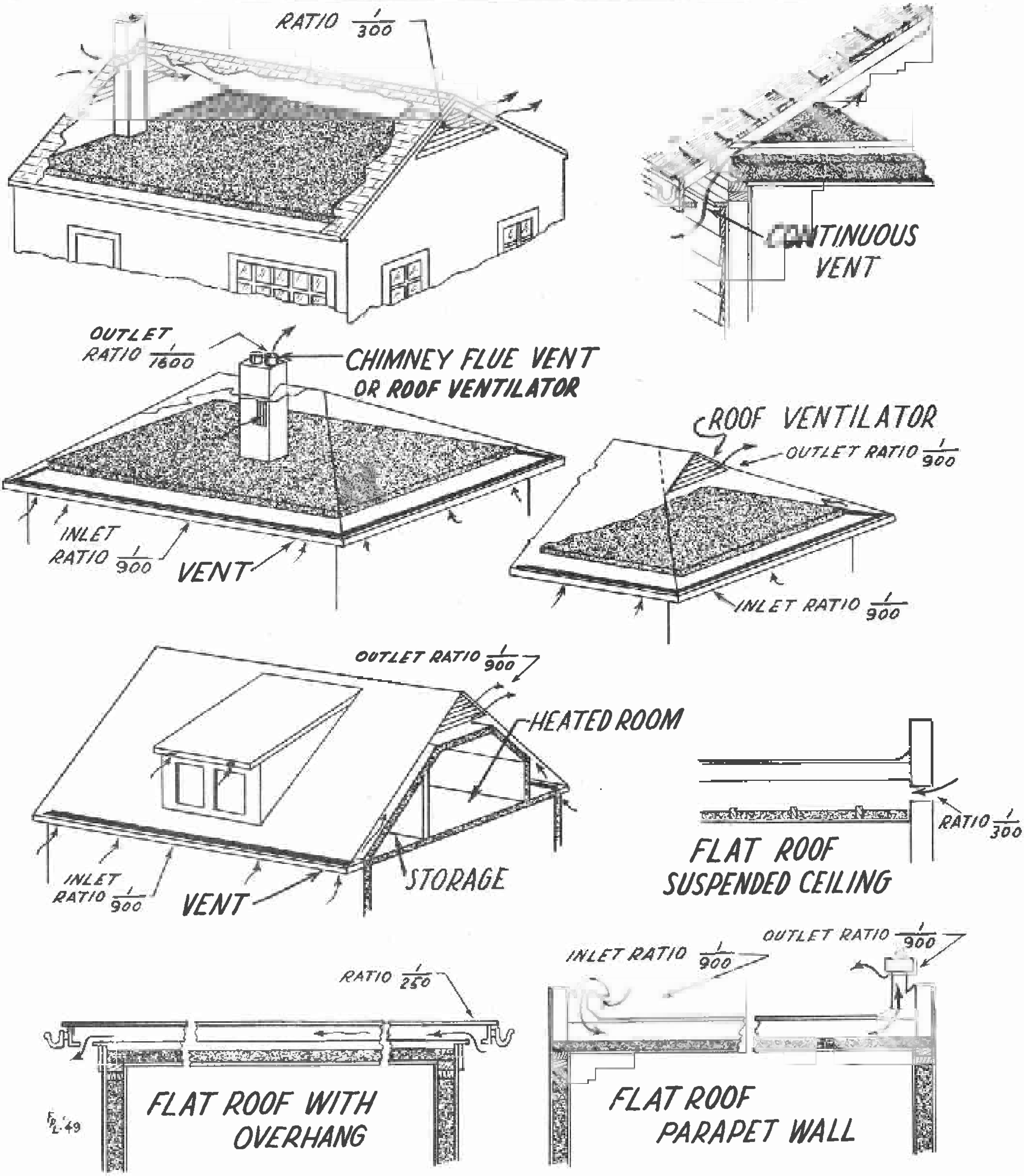

Figure 18.--Methods used to ventilate attics and roof spaces. Air inlet openings under the eaves of pitched roofs in addition to outlet openings near peak provide air movement independent of the effect of wind. For flat roofs where joists are used to support ceiling and roof, continuous vents, open to each joist space, are needed for both inlets and outlets. The dormer has inlets at eave and a roof space opens into attic. All dormers should be carefully framed to assure means of ventilation in the roof space. The figures show the ratio of free opening in louvers and vents to the area of the ceiling in the rooms below.

Figure 19.--Winter condensation problems generally occur in those parts of the country where the average temperature for January is 35° F. or lower. Vapor barriers should be installed at the time of construction in all new houses built in that area.

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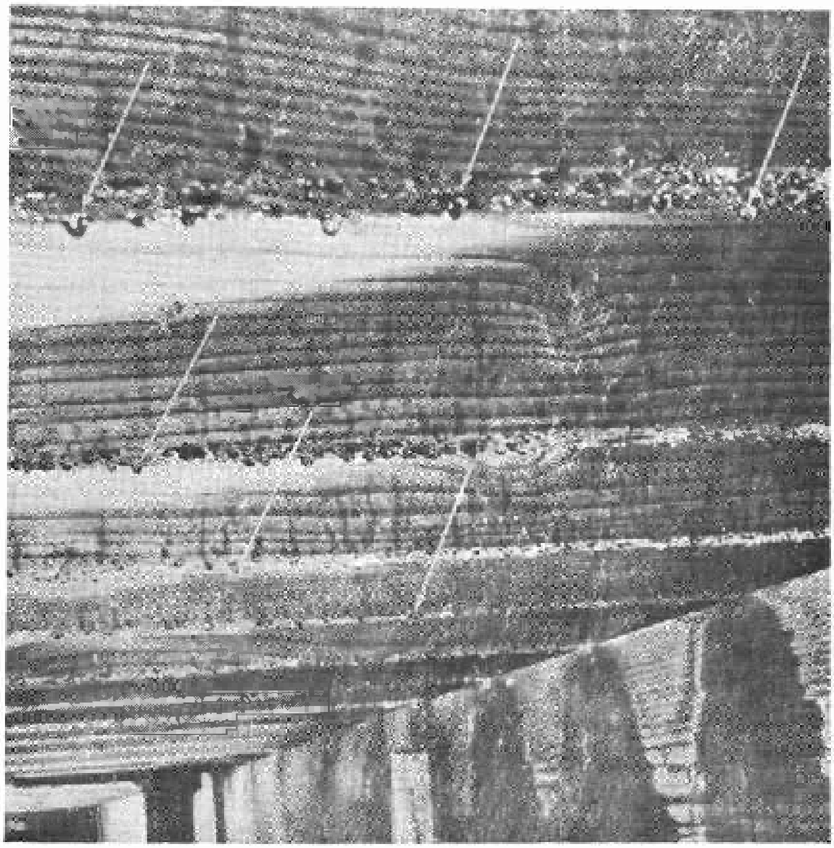

Figure 20.--Drops of condensation (arrows) formed on floor joists of a basementless house.

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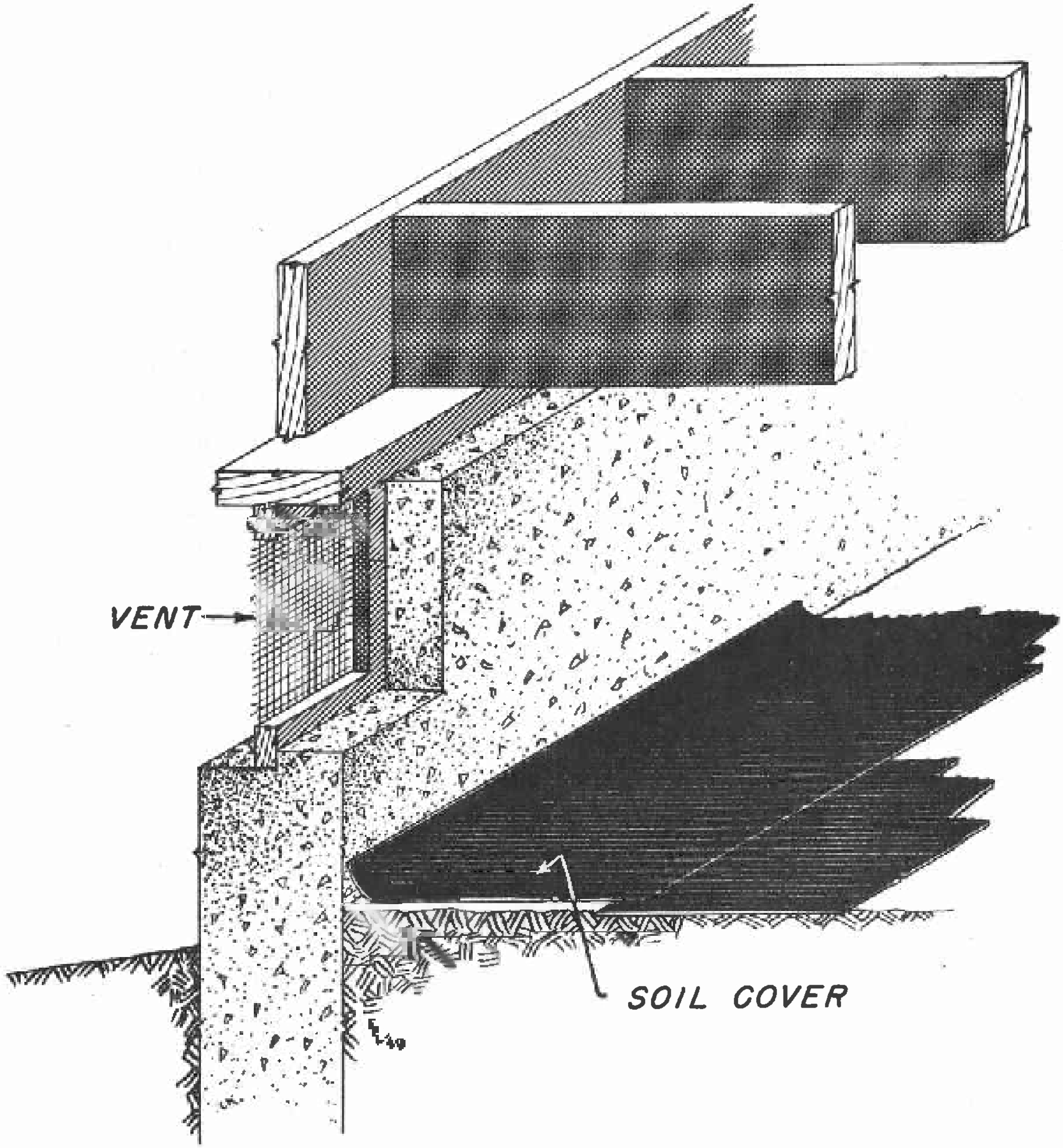

Figure 21.--The use of a suitable soil cover in crawl spaces has proved very effective in preventing condensation on the sills and joists above. The soil surface should be above the outside grade if there is any chance that water might get inside the foundation wall.

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