CONDENSATION PROBLEMS:

THEIR PREVENTION AND SOLUTION

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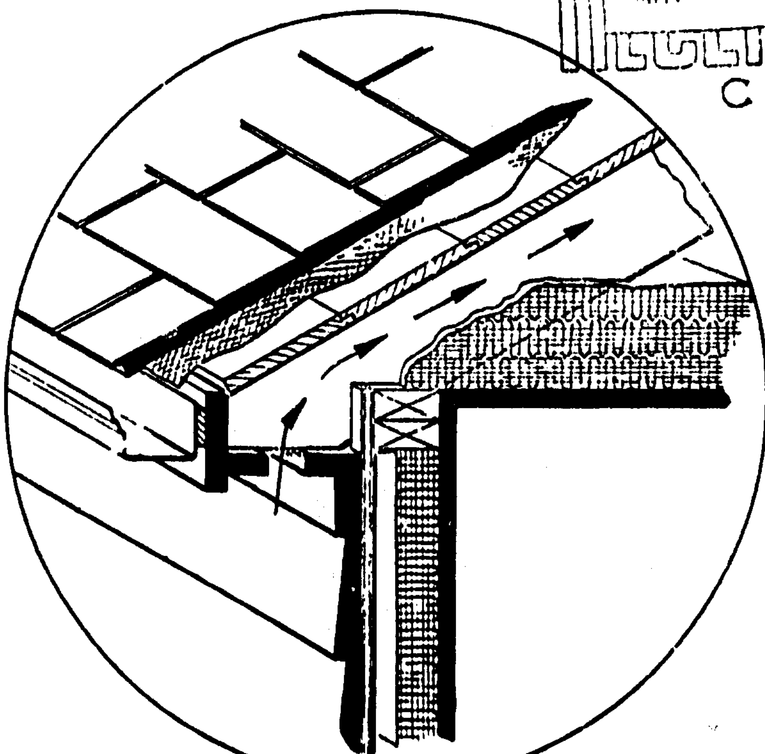

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ABSTRACT

Excessive moisture in some form is often the cause of condensation problems in a house or other structure. Perhaps the most aggravating and also the most easily prevented are those caused by the movement of water vapor through walls or ceilings. Such problems may result in excessive maintenance costs, such as the need for frequent repainting. However, properly installed vapor barriers, in conjunction with proper use of insulation, and adequate ventilation will avoid most of such difficulties.

The results of many years of research by Forest Products Laboratory and other scientists, together with their field experience in solving condensation problems, have provided much valuable information. This publication contains recommendations based on these data. In addition to good practices in the use of vapor barriers, insulation, and ventilation, other construction details are also described and illustrated. Such practices followed in the construction of a new home can pay for themselves many times over in reduced maintenance costs.

Foreword

Vapor barriers of adequate resistance, properly installed, are the most important factors in reducing the movement of water vapor through the walls and ceilings of a home. In cold weather, without some means of eliminating this movement that results from vapor pressure differences, water vapor moving through the wall or ceiling will condense on a cold surface. Such condensation in the form of moisture or frost often causes problems which result in increased maintenance costs.

This publication shows how to control condensation and minimize problems by the proper use of good vapor barrier materials and by adequate ventilation practices. The modern house is well insulated, has weatherstripped windows, and is much tighter than the houses our fathers lived in. The vapor and air resistance of exterior wall materials being used in modern construction often trap condensed moisture in wall cavities. In homes having heating units which do not aid in ventilation of the living area, cold weather condensation problems may be amplified because of humidity buildup. Furthermore, many heating units have humidifiers which increase the relative humidities in the home. A combination of such conditions makes it even more important that condensation control be practiced in order to reduce the problems associated with inadequate protection.

Because wood is so important a part of American homes, the research program of the Forest Products Laboratory has included studies related to proper use of wood-based materials. In addition to the results of recent research, this publication contains information from other papers now out of print. Included are U.S. Forest Products Laboratory reports originally prepared by L. V. Teesdale:

FPL Report 1710, "Remedial Measures for Building Condensation Difficulties." (1947)

FPL Report 1196, "Condensation Problems in Modern Buildings." (1939)

Data are also included from "Condensation Control in Dwelling Construction," originally prepared by M. E. Dunlap in 1949 for the Housing and Home Finance Agency, Washington, D.C.

Some current publications of particular value are listed in the "Selected Bibliography" at the end of this report. Prominent here is the ASHRAE "Handbook of Fundamentals, Heating, Refrigerating, Ventilating and Air Conditioning."

A glossary of some condensation and housing terms is also included at the end of the report for the convenience of readers.

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INTRODUCTION

Purpose and Scope

This publication is intended to serve as a guide for homeowners--not only as a means of preventing condensation problems, but also to better understand their cause. It contains information and recommendations for correct methods of installing vapor barriers, thermal insulation, and inlet and outlet ventilators in new homes. Methods which can be used to correct moisture problems in existing houses are also included.

The majority of the suggestions and recommendations are applicable to the typical wood-frame house. This publication illustrates use of typical materials and does not imply that other materials of equal quality and arrangement cannot be used successfully. Principles involved and procedures used to minimize the problem are equally applicable to commercial and farm buildings where conditions are similar to those in a home.

Information is based both on research by Laboratory and other scientists and engineers as well as experiences provided by the building industries and homeowners.

Background

In the colder regions of the United States--notably where the January temperature averages 35° F. or lower--the first signs of spring may include dark stains on house siding and blistered, peeling paint. These often indicate a cold weather condensation problem. The formation of icicles or an ice dam at the cornice of a house after a heavy snowfall indicates another type of moisture problem that requires correction. In each instance the culprit is condensation.

Condensation can be described as the change in moisture from a vapor to a liquid state. In homes not properly protected, condensation caused by high humidities often results in inconvenience and in many cases excessive maintenance costs. Water vapor within the house, when unrestricted, can move through the wall or ceiling during the heating season to some cold surface where it condenses, collecting generally in the form of ice or frost. During warm periods the frost melts. When conditions are severe, the water from melting ice in the attic may drip to the ceiling below and cause damage to the finish.

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

Moisture can also soak into the roof sheathing or rafters and set up conditions which could lead to decay. In walls, water from melting frost may run out between the siding laps and cause staining or soak into the siding and cause paint blistering and peeling.

Many of the wood and wood-base materials used for sheathing and panel siding may swell from this added moisture and result in bowing, cupping, or buckling. Thermal insulation may also become wet and provide less resistance to heat loss. Water held in the wall for long periods can also cause decay in the studs or wood sheathing. Efflorescence may occur on brick or stone of an exterior wall because of such condensation.

The cost of painting and redecorating, and excessive maintenance and repair caused by cold weather condensation can be easily reduced or eliminated when proper construction details are used.

Condensation problems are not new but changes in house design, materials, and construction methods since the midthirties have accentuated the problems. Additionally, the relative humidity within newer houses is generally higher than in those houses built many years ago. Old houses were usually large with high ceilings, had windows that were not weather-stripped, and their construction details allowed air loss and air infiltration. New types of weather stripping, storm sash, and sheet materials for sheathing in new houses provide tight and air-resistant construction. Thus, homes have not only become generally smaller with less atmosphere to hold moisture but are also tighter.

Estimates have been made that a typical family of four converts 25 pounds[2] of water into water vapor per day. Unless this water vapor is removed in some way (ventilation usually), it will either increase the humidity or condense on cold surfaces such as window glass. More serious, however, it can move in or through the construction, often condensing within the wall, roof, or floor cavities. Heating systems equipped with winter air-conditioning systems also increase the humidity.

In colder climates, new houses have from 2 to 3-1/2 inches of insulation in the walls and 6 or more inches in the ceilings. However, this insulation causes the outer portions of the wall, for example, to be colder because of lower heat loss. Moisture is attracted to cold surfaces and, unless moisture movement is restricted, it will condense or form as frost or ice on cold surfaces. Unfortunately from the standpoint of condensation, the more efficient the insulation is in retarding heat transfer, the colder the outer surfaces become and the greater the attraction for moisture.

Inexpensive methods of preventing condensation problems are available. They mainly involve the proper use of vapor barriers and good ventilating practices. Naturally it is simpler, more inexpensive, and more effective to employ these during the construction of a house than to add them to existing homes.

FACTORS IN THE CONDENSATION PROBLEM

Condensation will take place anytime the temperature drops below dewpoint (100 percent saturation of the air with water vapor). Commonly, under such conditions, some surface accessible to the moisture in the air is cooler than the dewpoint and the moisture condenses on that surface.

Types of Condensation

Two types of cold weather condensation normally occur within a house. They can be classed as (a) visible and (b) concealed. During cold weather, visible condensation is usually first noticed on window glass but may also be discovered on cold surfaces of closet walls and ceilings. Visible condensation might also occur in attic spaces on rafters or roof boards near the cold cornice area (fig. 1) or form as frost. Such condensation or melting frost can result in excessive maintenance such as the need for refinishing of window sash and trim or even decay. Water from melting frost in the attic can also damage ceilings below.

Another area where visible condensation can occur is in crawl spaces under occupied rooms. This area usually differs from those on the interior of the house and in the attic because the source of the moisture is usually from the soil or from warm moisture-laden air which enters through

[2] Approximately 3 gallons.

foundation ventilators. Moisture vapor then condenses on the cooler surfaces in the crawl space (fig. 2). Such conditions often occur during warm periods in late spring.

Another factor in surface condensation is the relative humidity of the air near the condensing surface. When the relative humidity of the inside atmosphere is increased, surface condensation

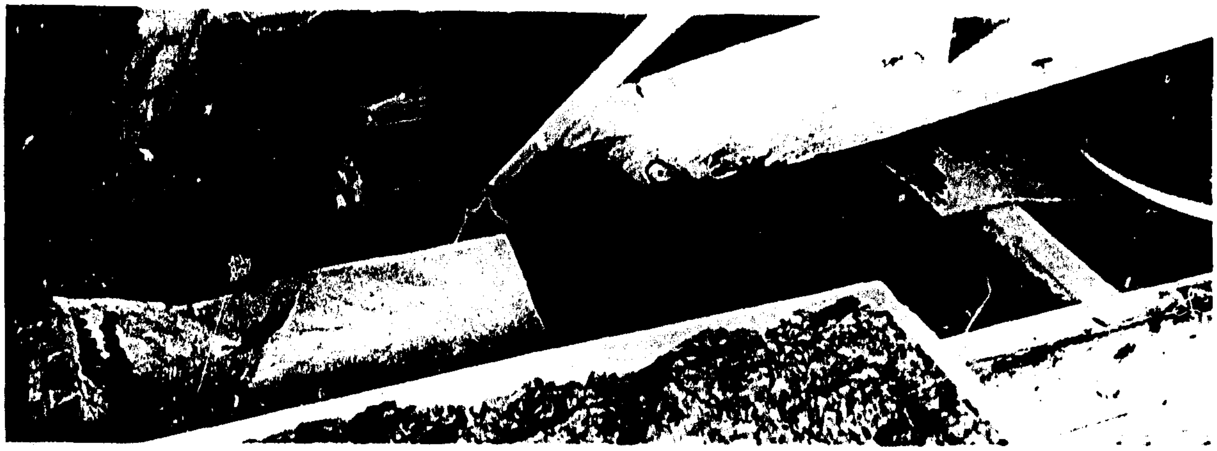

Figure 1.--Darkened areas on roof boards and rafters in attic area indicate stain that stemmed from condensation. This usually could be prevented by vapor barrier in the ceiling and good attic ventilation. M 32640 F

Figure 2.--Surface condensation on floor joists in crawl space. A vapor barrier ground cover can prevent this because it restricts water vapor movement from the soil and thus avoids high humidity of crawl space and subsequent surface condensation. M 105 308

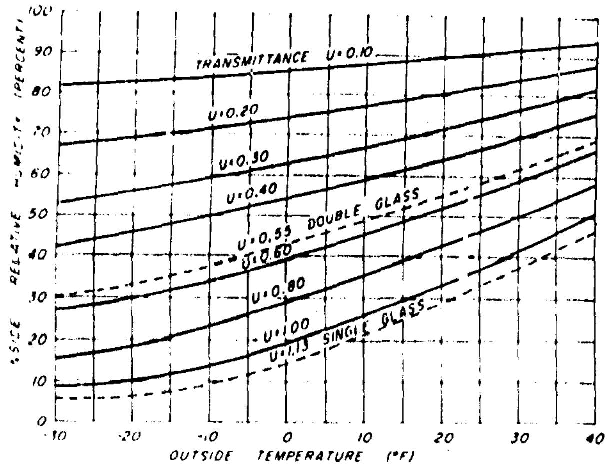

Figure 3.--Relative humidity at which visible condensation will appear on inside surface at a room temperature of 70° F. M 139 218

will occur at a higher outside temperature. This is illustrated by figure 3. For example, when inside temperature is 70° F., surface condensation will occur on a single glass window (U = 1.13) when outside temperature is about -10° F. and inside relative humidity is 10 percent. When inside relative humidity is 20 percent, condensation will not occur on the single glass until outside temperature falls to about +7° F. When a storm window is added or insulated glass is used (U = 0.55), surface condensation will not occur until the relative humidity has reached 38 percent when the outdoor temperature is -10° F. The above conditions apply only where storm windows are tight and there is good circulation of air on the inside surface of the window. Where drapes restrict circulation of air, storm windows are not tight, or lower temperatures are maintained in such areas as bedrooms, condensation will occur at a higher outside temperature.

Condensation in concealed areas, such as wall spaces, is usually more harmful than visible condensation. Such problems often are first noticed by stains on the siding or by paint peeling after the heating season. Water vapor moving through permeable walls and ceilings is normally responsible for such damage. Water vapor also escapes from houses by constant outleakage through cracks and crevices, around doors and windows, and by ventilation, but this moisture-vapor loss is usually insufficient to eliminate condensation problems.

Moisture Sources

Interior.--Moisture, which is produced in or which enters a home, changes the relative humidity of the interior atmosphere. Ordinary household functions which generate a good share of the total amount of water vapor include dishwashing, cooking, bathing, and laundry work, to say nothing of human respiration and evaporation from plants. Houses may also be equipped with central winter air conditioners or room water-evaporators. Still another source of moisture may be from unvented or poorly vented clothes dryers. Several sources and their effect in adding water vapor to the interior of the house are:

	Pounds of water
Plants	- 1.8 for each plant in 24 hours
Showers	- 0.5 for each shower and
	- 0.12 for each bath
Floor mopping	- 3.0 per 100 square feet, each washing
Kettles and cooking	- 5.7 per day
Clothes (washing, steam ironing, drying)	- 30.7 per week

Crawl space.--Water vapor from the soil of crawl-space houses does not normally affect the occupied areas. However, without good construction practices or proper precautions it can be a factor in causing problems in exterior walls over the area as well as in the crawl space itself. It is another source of moisture that must be considered in providing protection.

Water from construction.--People moving into a newly constructed house in the fall or early winter sometimes experience temporary moisture problems. Surface condensation on windows, damp areas on cold closet walls where air movement is restricted, and even stained siding--all indicate an excessive amount of moisture. Such conditions can often be traced to water used in the construction of a house.

Basement floors, concrete walls, and plastered walls and ceilings require a tremendous amount of water during their construction. While much of this water has evaporated from the surface after a month or so, the addition of heat aids in driving off more moisture as these elements reach moisture equilibrium with the surrounding atmosphere. This moisture creates higher than normal humidities, and increased vapor pressures move the water vapor to colder areas in attics or in the walls.

A concrete floor in the basement of a small home contains more than 2,000 pounds of water when it is poured. The concrete basement walls of this same home contain over 4,000 pounds of water. If the house is plastered, over 2,500 pounds of water are used. Thus, it is often a common occurrence to have some moisture problems when a house is just completed. These are normally corrected after the first heating season. However, several methods may be used to reduce this excessive moisture. Perhaps the simplest is to heat and ventilate a new house so that excessive moisture is dissipated outdoors before the occupants move in.

Miscellaneous.--There are other sources of moisture, often unsuspected, which could be the cause of condensation problems. One such source can be a gas-fired furnace. It is desirable to maintain flue-gas temperatures within the recommended limits throughout the appliance, in the flue, the connecting vent, and other areas; otherwise excessive condensation problems can result. If all sources of excessive moisture have been exhausted in determining the reasons for a condensation problem, it is well to have the heating unit examined by a competent heating engineer.

One factor which can influence combustion in a heating unit is the amount of air required. Without an ample supply of oxygen, gas (or other types of fuel) cannot be completely burned. In the tight modern house it is considered good practice, in forced air heating systems, to reduce relative humidity buildup by introducing low-moisture outside air into cold air return ducts.

Influences of Construction on Condensation

There is a distinct relationship in all homes between indoor relative humidity and outdoor temperature. The humidity is generally high indoors when outdoor temperatures are high and decreases as outdoor temperatures drop. This relationship is shown in figure 4 for (a) an old house (loosely constructed), (b) an average house, and (c) a modern house (tightly constructed). In other words, because of construction details and other factors it would be much more difficult to maintain a high relative humidity in an older house than a tight modern house. In houses where winter air conditioners are used, automatic controls maintain the desired relative humidity. The older, loosely constructed house has more areas which allow the escape of moisture and consequently it would be more difficult to maintain a particular relative humidity level within it.

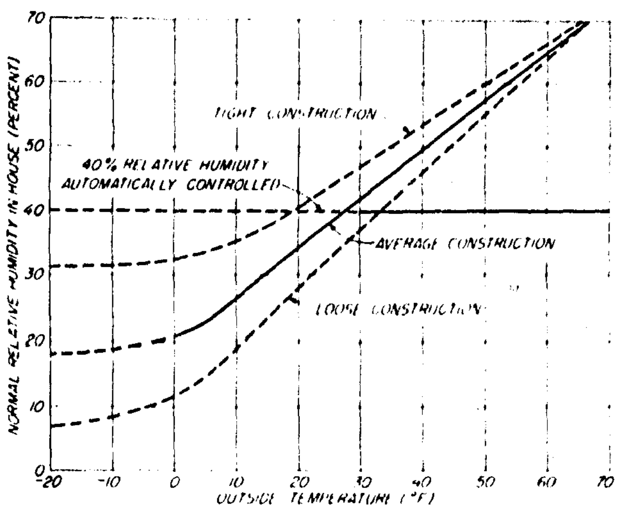

Figure 4.--Relation of normal humidity within a house to outside temperature.
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Vapor Barriers

Many materials used as interior coverings for exposed walls and ceiling, such as plaster, dry wall, wood paneling, and plywood, permit water vapor to pass slowly through them during cold weather. Temperatures of the sheathing or siding on the outside of the wall are often low enough to cause condensation of water vapor within the cavities of a framed wall. When the relative humidity or vapor pressure within the house at the surface of an unprotected wall is greater than that within the wall, water vapor will migrate through the plaster or other finish into the stud space; there it will condense if it comes in contact with surfaces below its dewpoint. Vapor barriers are used to resist this movement of water vapor or moisture in various areas of the house.

The amount of condensation that can develop within a wall depends upon (a) the resistance of the intervening materials to vapor transfusion,

(b) differences in vapor pressure, and (c) time. Plastered walls or ordinary dry walls have little resistance to vapor movement. However, when the surfaces are painted, the resistance is increased. High indoor temperatures and relative humidities result in high indoor vapor pressures. Low outdoor vapor pressures always exist at low temperatures. Thus, a combination of high inside temperatures and humidities and low outside temperatures will normally result in vapor movement into the wall if no vapor barrier is present. Long periods of severe weather will result in condensation problems. Though fewer homes are affected by condensation in mild winter weather, many problems have been reported. Where information is available, it appears that the minimum relative humidities in the affected homes are 35 percent or higher.

Vapor barrier requirements are sometimes satisfied by one of the materials used in a construction. In addition to integral vapor barriers which are a part of many types of insulation, such materials as plastic-faced hardboard and similar interior coverings may have sufficient resistance when the permeability of the exterior construction is not too low. The permeability of the surface to such vapor movement is usually expressed in "perms," which are grains of water vapor passing through a square foot of material per hour per inch of mercury difference in vapor pressure. A material with a low perm value is a barrier, while one with a high perm value is a "breather."

The perm value of the cold side materials should be several times greater than those on the warm side. A ratio of 1 to 5 or greater from inside to outside is sometimes used in selecting materials and finish. When this is not possible because of virtually impermeable outside construction (such as a built-up roof or resistant exterior wall membranes), research has indicated the need to ventilate the space between the insulation and the outer covering. However, few specific data are available on ventilation requirements for walls.

Areas of vapor barrier use.--Vapor barriers are used in three general areas of the house to minimize condensation or moisture problems:

Walls, ceilings, floors.--Vapor barriers used on the warm side of all exposed walls, ceilings, and floors greatly reduce movement of water vapor to colder surfaces where harmful condensation can occur. For such uses it is good practice to select materials with perm values of 0.25 or less, table 1. Such vapor barriers can be a part of the insulation or a separate film. Commonly used materials are (a) asphalt-coated or laminated papers, (b) kraft-backed aluminum foil, and (c) plastic films such as polyethylene, and others. Foil-backed gypsum board and various coatings also serve as vapor barriers, table 1. Oil-base or aluminum paints, or similar coatings are often used in houses which did not have other vapor barriers installed during their construction.

Concrete slabs.--Vapor barriers under concrete slabs resist the movement of moisture through the concrete and into living areas. Such vapor barriers should normally have a maximum perm value of 0.50. But the material must also have adequate resistance to the hazards of pouring concrete. Thus, a satisfactory material must be heavy enough to withstand such damage and at the same time have an adequate perm value. Heavy asphalt laminated papers, papers with laminated films, roll roofing, heavy films such as polyethylene and other materials are commonly used as vapor barriers under slabs, table 1.

Crawl space covers.--Vapor barriers in crawl spaces prevent ground moisture from moving up and condensing on wood members, figure 2. A perm value of 1.0 or less is considered satisfactory for such use, table 1. Asphalt laminated paper, polyethylene, and similar materials are commonly used. Strength and resistance of crawl space covering to mechanical damage can be lower than that for vapor barriers used under concrete slabs.

Moisture Content Relationship

An illustration of the effect of a vapor barrier in an outside wall was brought out in an exposure test conducted at the Forest Products Laboratory. It had been found that an excellent method of measuring condensation conditions was by determining the moisture accumulation in wood sheathing. A small test house contained sections of sheathing installed in such a way that they could be removed for moisture content determination and observation. The wood sheathing was conditioned to 6 percent moisture content before installation. Readings were made at the top and bottom of each panel, as more moisture collects in the sheathing at the bottom of uninsulated walls than at the top of stud spaces. In insulated walls, the

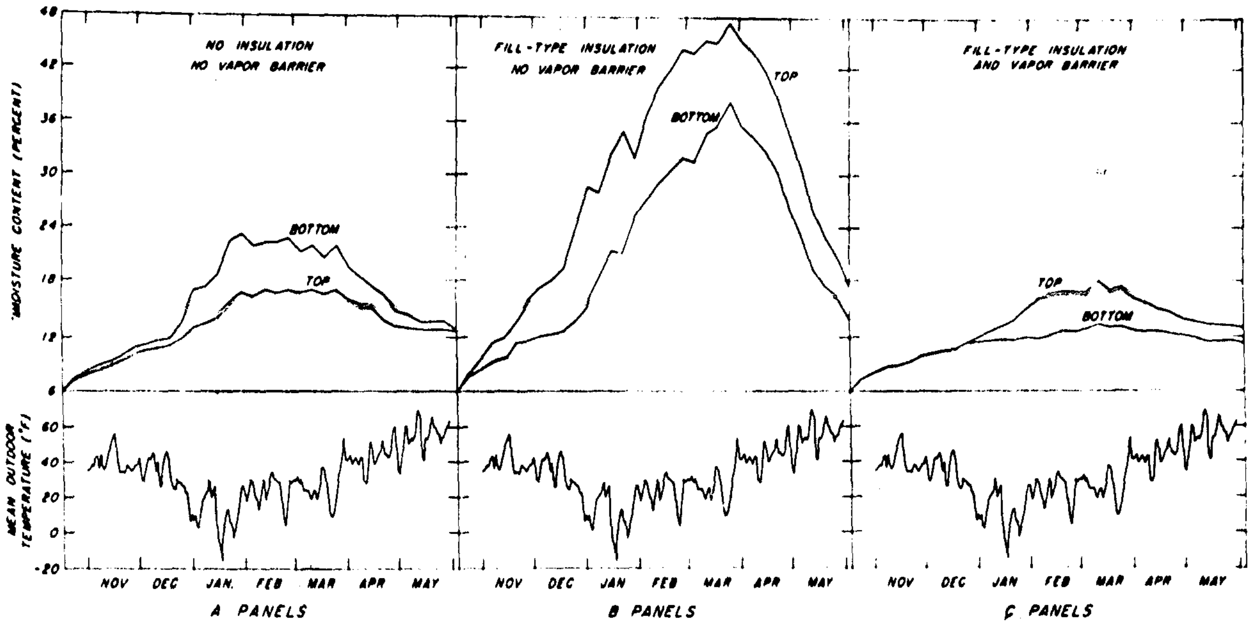

Figure 5.--Moisture content of wood sheathing at the top and bottom of wall panels in the Laboratory test house. The temperature within the house was maintained at 70° F. and the relative humidity at 40 percent. M 139 213

higher moisture contents are found to be at the top of the stud spaces.

Figure 5 shows the average moisture contents of the test house sheathing from October to June in three sets of typical wall panels. The walls were of conventional wood-frame construction with gypsum lath and plaster, wood sheathing, asphalt-felt sheathing paper, and bevel wood siding with two coats of exterior paint. Three panels had no insulation and no vapor barrier in the stud space (A panels); three had fill-type insulation with no vapor barrier (B panels); and three had fill-type insulation with a vapor barrier (C panels). Three panels of each variable were used to obtain average moisture contents. The perm value for the vapor barrier was about 0.21 and for the sheathing paper about 2.5.

The sheathing in panels reached an average moisture content of about 12 percent by December. However, the sheathing near the bottom of the wall reached values well over 20 percent in the next 2 months. Sheathing in B panels reached an average moisture content as high as 47 percent and remained above 20 percent for over 4 months. C panels, with insulation and vapor barrier, performed well as the sheathing did not reach 18 percent moisture content. It is likely that a better vapor barrier with a perm value of 0.10 or less would result in even lower moisture pickup by the sheathing. This indicates the need for a vapor barrier on exposed walls even when no insulation is used in the stud spaces.

Exterior Materials

Materials used on the exterior of walls, such as sheathing, sheathing paper, siding, and paint coatings, have an influence on the escape of water vapor which might reach the stud spaces. It is desirable to use materials and coatings in this location that will allow moisture to escape rather than hold it in. Exterior cover materials should be far more permeable than interior covering unless the stud space is ventilated.

Some of the materials normally used on the outside of a house, and which can be considered as having a low resistance to vapor movements, are:

- Sheathing paper such as red rosin or low asphalt content felt (breathing types).
- Wood siding, shingles, or shakes with stained finishes.
- Wood sheathing or sheathing-grade plywood sheathing (except those assembled with exterior glue).

Table 1.--Permeance and permeability of materials to water vapor[1,2]

Material	Permeance (Perm)			Permeability (Perm-inch)		
	Dry cup	Wet cup	Other	Dry cup	Wet cup	Other
MATERIALS USED IN CONSTRUCTION						
Concrete (1:2:4 mix)	--	--	--	--	3.2	--
Brick masonry (4 in. thick)	--	--	0.8	--	--	--
Concrete block (8 in. cored, limestone aggregate)	--	--	2.4	--	--	--
Asbestos-cement board (0.2 in. thick)	0.54	--	--	--	--	--
Plaster on plain gypsum lath (with studs)	--	--	20	--	--	--
Gypsum wallboard (3/8 in. plain)	--	--	50	--	--	--
Gypsum sheathing (1/2 in. asphalt impregnate)	--	--	--	20		
Structural insulating board (sheathing quality)	--	--	--	--	--	20-50
Structural insulating board (interior, uncoated 1/2 in.)	--	--	50-90	--	--	--
Hardboard (1/8 in. standard)	--	--	11	--	--	--
Hardboard (1/8 in. tempered)	--	--	5	--	--	--
Built-up roofing (hot-mopped)	0.0	--	--	--	--	--
Wood, sugar pine	--	--	--	--	--	[3]0.4-5.4
Plywood (Douglas-fir, exterior glue 1/4 in. thick)	--	--	0.7	--	--	--
Plywood (Douglas-fir, interior glue 1/4 in. thick)	--	--	1.9	--	--	--
Polyester, glass-fiber-reinforced sheet, 48 mil	0.05	--	--	--	--	--
THERMAL INSULATIONS						
Cellular glass	--	--	--	0.0	--	--
Corkboard	--	--	--	2.1-2.6	9.5	--
Mineral wool (unprotected)	--	--	--	--	116	--
Expanded polyurethane (R-11 blown)	--	--	--	0.4-1.6	--	--
Expanded polystyrene--extruded	--	--	--	1.2	--	--
Unicellular synthetic flexible rubber foam	--	--	--	0.02-0.15	--	--
PLASTIC AND METAL FOILS AND FILMS[4]						
Aluminum foil (1 mil)	0.0	--	--	--	--	--
Aluminum foil (0.35 mil)	0.05	--	--	--	--	--
Polyethylene (2 mil)	0.16	--	--	--	--	--
Polyethylene (4 mil)	0.08	--	--	--	--	--
Polyethylene (6 mil)	0.06	--	--	--	--	--
Polyethylene (8 mil)	0.04	--	--	--	--	--
Polyethylene (10 mil)	0.03	--	--	--	--	--
Polyester (1 mil)	0.7	--	--	--	--	--
Cellulose acetate (10 mil)	0.46	--	--	--	--	--
Polyvinylchloride, unplasticized (2 mil)	0.68	--	--	--	--	--

BUILDING PAPERS, FELTS, ROOFING PAPERS[5]

Duplex sheet, asphalt laminated, aluminum foil one side (43)[6]	0.002	0.176	--	--	--	--
Saturated and coated roll roofing (326)[6]	0.05	0.24	--	--	--	--
Blanket thermal insulation back-up paper, asphalt coated: (31)[6]	0.4	0.6-4.2	--	--	--	--
Asphalt-saturated and coated vapor-barrier paper (43)[4]	0.2-0.3	0.6	--	--	--	--
Asphalt-saturated but not coated sheathing paper (22)[4]	3.3	20.2	--	--	--	--
15-lb. asphalt felt (70)[4]	1.0	5.6	--	--	--	--
15-lb. tar felt (70)[4]	4.0	18.2	--	--	--	--
LIQUID-APPLIED COATING MATERIALS						
Paint--2 coats						
Asphalt paint on plywood	--	0.4	--	--	--	--
Aluminum varnish on wood	0.3-0.5	--	--	--	--	--
Enamels in smooth plaster	--	--	0.5-1.5	--	--	--
Primers and sealers on interior insulation board	--	--	0.9-2.1	--	--	--
Various primers plus 1 coat flat oil paint on plaster	--	--	1.6-3.0	--	--	--
Flat paint on interior insulation board	--	--	4	--	--	--
Water emulsion on interior insulation board	--	--	30-85	--	--	--
Paint--3 coats						
Exterior paint, white lead and oil on wood siding	0.3-1.0	--	--	--	--	--
Exterior paint, white lead-zinc oxide and oil on wood	0.9	--	--	--	--	--
Styrene-butadiene latex coating, 2 oz./sq. ft.	11	--	--	--	--	--
Polyvinyl acetate latex coating, 4 oz./sq. ft.	5.5	--	--	--	--	--
Asphalt cut-back mastic, 1/16 in. dry	0.14	--	--	--	--	--
3/16 in. dry	0.0	--	--	--	--	--

[1] Adapted from the 1967 ASHRAE Handbook on Fundamentals

[2] Table I gives the water vapor transmission rates of some representative materials. The data are provided to permit comparisons of materials; but in the selection of vapor barrier materials, exact values for permeance or permeability should be obtained from the manufacturer of the materials under consideration or secured as a result of laboratory tests. A range of values shown in the table indicated variations among mean values for materials that are similar but of different density, orientation, lot or source. The values are intended for design guidance and should not be used as design or specification data. The compilation is from a number of sources; values from dry-cup and wet-cup methods were usually obtained from investigations using ASTM E96 and C355; values shown under Other were obtained from investigations using such techniques as two-temperature, special cell, and air-velocity.

[3] Depending on construction and direction of vapor flow.

[4] Usually installed as vapor barriers, although sometimes used as exterior finish and elsewhere near cold side where special considerations are then required for warm side barrier effectiveness.

[5] Low permeance sheets used as vapor barriers. High permeance used elsewhere in construction.

[6] Basis weight in lb. per 500 sq. ft.

Insulation board sheathing with light asphalt coating or light impregnation.
Gypsum board sheathing.
Masonry veneer (without coatings).

Materials which can be considered to have moderate to high resistance to the escape of water vapor are as follows:

Wood siding with low-perm paint finish (2 to 3 coats of white-lead base paint).
Exterior grade or paper-overlaid plywood with paint coatings.
Metal or plastic sidings.
Aluminum foil, plastic films, or asphalt-laminated sheathing papers (nonbreathing types).
Any wood-base panel siding with high quality nonbreathing paint or film finish.

The perm values for some of these low, moderate, and highly permeable materials and coatings are listed in table 1.

It is not always possible, because of design, material selection, and other reasons, to have a combination of exterior materials which allow the escape of water vapor. However, this can be compensated to a great extent by the proper use of a vapor barrier with a very low perm value.

Thermal Insulation

Heat movement.--Thermal insulation has a major influence on the need for vapor barriers. The inner face of the wall sheathing in an insulated wall, for example, is colder than the sheathing face in an uninsulated wall and consequently has a greater attraction to moisture. Thus there is greater need for a vapor barrier in an insulated wall than in an uninsulated wall.

Heat is transferred through a wall or other building component by (a) conduction, (b) convection, and (c) radiation.[3] Heat loss through a wall may be by all three methods.

In the winter, thermal insulation reduces the rate of flow of heat from the home and thereby reduces the amount of fuel required. This provides more comfortable living quarters than an uninsulated house and uses smaller, lower cost heating equipment. Furthermore, during the summer, thermal insulation provides greater summer comfort by slowing the movement of heat into interior areas. This will also result in a lower air-conditioning load when such equipment is used.

Types of insulation.--Normally, any combination of building materials provides some insulation, especially those used in wood-frame construction. While plywood, conventional boards, siding, and other wood-base materials are usually much better insulators than many nonwood structural elements, the use of these materials alone is usually not sufficient in preventing excessive heat loss. Thus, some type of thermal insulation should be provided in walls, ceilings, and also in floors of houses with unheated crawl-spaces.[3] However, it is not enough to say that a wall is insulated because it contains some material sold for insulation; it is the quality and insulating value of the assembly that counts.

The relative value of thermal insulations is based on their heat conductivity, represented by the symbol k. This 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. Flexible insulation in blanket and batt form is often marked with the total resistance value represented by the symbol R. R is the resistance to heat flow and the reciprocal of conductance. Thus, knowing the k value of an insulation, the total R value for it can be found by the formula:

$$R = \frac{1}{k} \times \text{thickness of the insulation in inches}$$

Such values are used in determining the total U or overall heat transmission coefficient.[2]

The most common insulations used in the construction of houses are as follows:

Fill insulation.--Fill insulation consists of granular fibrous materials used in bulk form, intended to be poured or blown into place. It is commonly used in attic spaces above living areas and can also be poured or blown into wall cavities of existing houses. A vapor barrier of some type should be used under these conditions. Fill insulating materials include vermiculite, rock

[3] Lewis, Wayne C. Thermal Insulation from Wood for Buildings: Effects of Moisture and Its Control. U.S.D.A. Forest Service Research Paper FPL 86, Forest Products Laboratory, July 1968.

or glass wool, and wood fiber.

Flexible insulation.--Flexible insulation is supplied in blankets or batt form for use between framing members spaced 16 or 24 inches on center. Blanket insulation most often used in walls has a vapor barrier on one face and a light covering on the other. Batt insulation usually has a vapor barrier on one face with the insulation exposed on the other. Thickness may vary from 1 to 3-1/2 inches for the blanket and 4 to 6 inches for the batt insulation. Materials include cotton or wood fibers and mineral or glass wool.

A friction-type batt, usually supplied without coverings, is designed to fit lightly between frame members. Separate vapor barriers are required when this type insulation is used.

Rigid insulation.--Rigid insulation consists of insulating board, expanded plastic board, rigid glass board, and similar materials. Insulating board in thicknesses of 1/2 and 25/32 inch is commonly used for sheathing. It is also used as above deck insulation in 2- and 3-inch thicknesses.

Expanded plastic insulations are 1/2 to 2 inches thick and are commonly used for perimeter insulation around concrete slabs, as plaster base over concrete block, and for roof deck insulation.

Reflective insulation.--Reflective insulations are those that reflect heat to a high degree. Perhaps the most common is aluminum foil or foil coatings on other materials. These reflective surfaces must face an air space of at least 3/4 inch to be fully effective. A paper-reinforced sheet with aluminum foil on one or two sides, foil-backed gypsum board, and foldout accordion sections are the most common forms of this type of insulation.

Ventilation

Ventilation used in proper amounts and locations is a recognized means of controlling condensation in buildings. Inlet and outlet ventilators in attic spaces, ventilation of rafter spaces in flat roofs and crawl space ventilation aid in preventing condensation in those areas. By introducing fresh air into living quarters during the winter, some humid air is forced out of the house while the incoming air has a low water vapor content. Well installed vapor barriers may increase the need for ventilation because little of the moisture generated can get out. RH actually builds up.

The use of both inlet and outlet ventilators in attic spaces aids in keeping the air moving and preventing the accumulation of frost or condensation on roof boards in cold areas. "Dead" air pockets in the attic can normally be prevented by good distribution of inlet ventilators in the soffit areas. However, there is still a need for vapor barriers in the ceiling; ventilation alone, when insulation is used, does not prevent condensation problems. A good vapor barrier is especially needed under the insulation in a flat roof where ventilation can normally be provided only in the overhang.

Crawl space moisture, which results in high moisture content of the wood members, can be almost entirely eliminated by a vapor barrier over the soil. When such protection is used, the need for ventilation is usually reduced to only 10 percent of that required when a soil cover is not present.

During warm damp periods in early summer, moisture often condenses on basement walls or around the perimeter of the floor in concrete slab houses. Soil temperatures in the northern part of the United States remain quite low until summer, and surface temperatures of the floor or wall are often below dewpoint. When the concrete reaches normal temperature and the atmosphere changes, such problems are normally reduced or eliminated.

GOOD PRACTICE RECOMMENDATIONS

Condensation Control Zones

The control of condensation through the use of vapor barriers and ventilation should be practiced regardless of the amount of insulation used. Normally, winter condensation problems occur in those parts of the United States where the average January temperature is 35° F. or lower. Figure 6 illustrates this condensation zone. The northern half of the condensation zone has a lower average winter temperature and, of course, more severe conditions than the southern portion. Areas outside this zone, such as the southeast and west coastal areas and the southern states, seldom have condensation problems. Vapor barriers should be installed at the time of construction in all new houses built within the condensation zone outlined in figure 6 and proper ventilation pro-

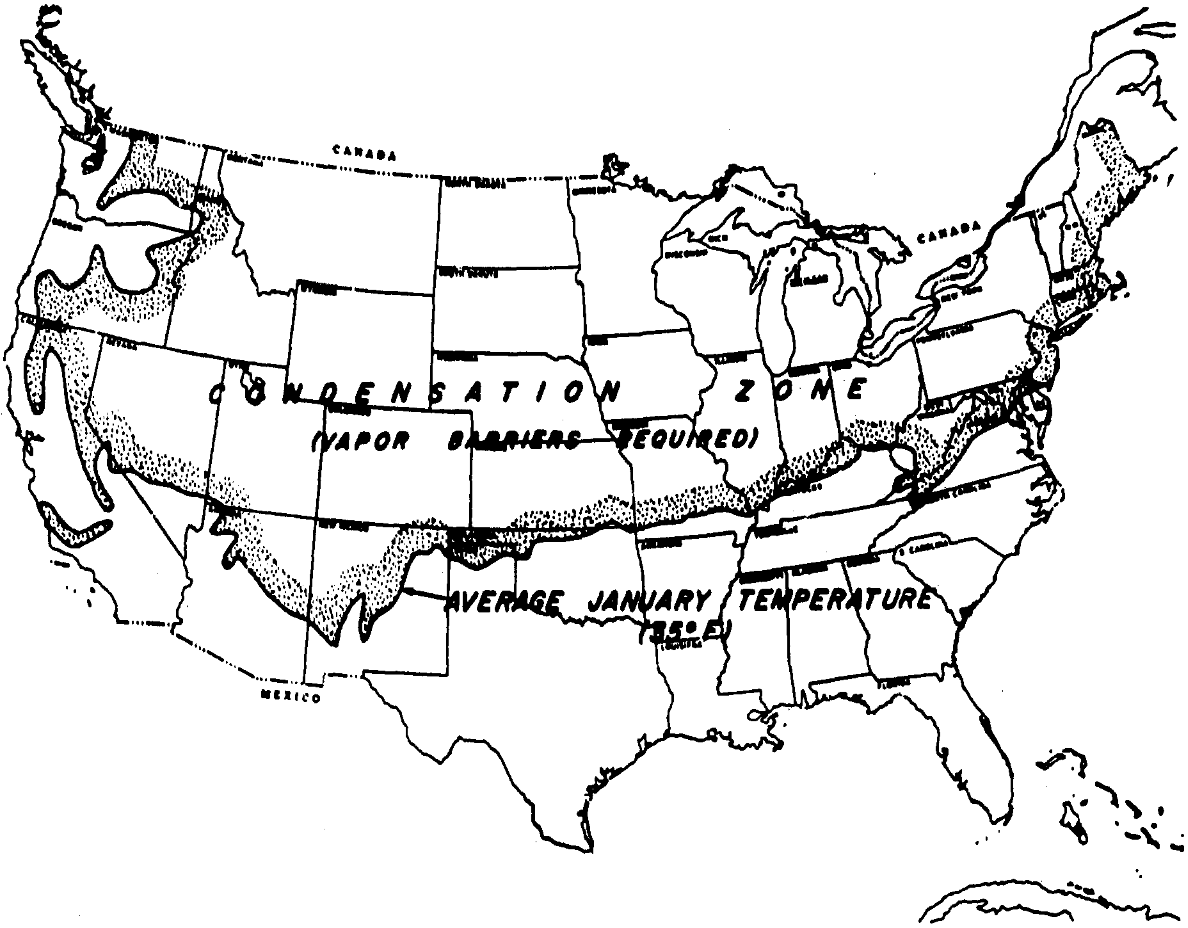

Figure 6.--Winter condensation problems occur where the average temperature for January is 35° F. or lower. M 139 490

cedures should be followed. These will insure control over normal condensation problems.

Location of Vapor Barriers

A good general rule to keep in mind when installing vapor barriers in a house is as follows: "Place the vapor barrier as close as possible to the interior or warm surface of all exposed walls, ceilings, and floors." This normally means placing the vapor barrier (separately or as a part of the insulation) on (a) the inside edge of the studs just under the rock lath or dry wall finish, (b) on the under side of the ceiling joists of a one-story house or the second floor ceiling joists of a two-story house, and (c) between the subfloor and finish floor (or just under the subfloor of a house with an unheated crawlspace in addition to the one placed on the ground). The insulation, of course, is normally placed between studs or other frame members on the outside of the vapor barrier. The exception is the insulation used in concrete floor slabs where a barrier is used under the insulation to protect it from ground moisture.

Placement of vapor barriers and insulation in one-story houses are shown in figure 7 (flat roof and concrete floor slab) and figure 8 (pitched roof and crawl space). Figure 9 shows barriers and insulation in a 1-1/2-story house with full basement. Figure 10 depicts a two-story house with full basement. Other combinations of slabs, crawl spaces, and basements in houses with 1, 1-1/2, or 2 stories, should follow the same general recommendations. Detailed descriptions

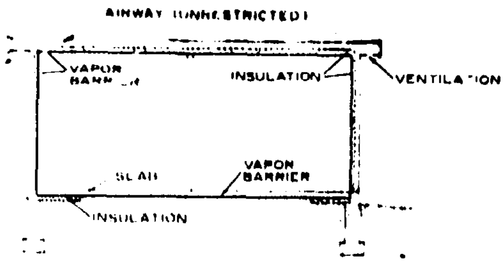

Figure 7.--Location of vapor barriers and insulation in concrete slab and flat-deck roof. M 139 236

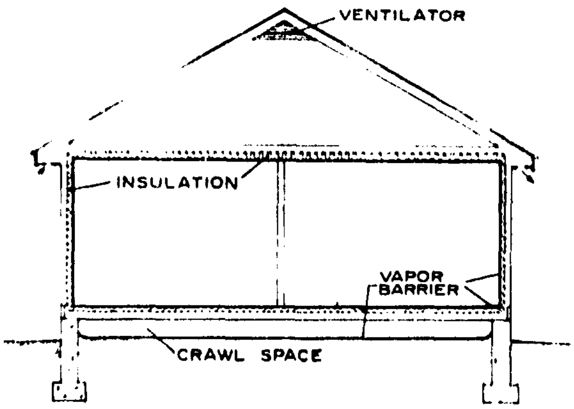

Figure 8.--location of vapor barriers and insulation in crawl space of another one-story house. M 139 237

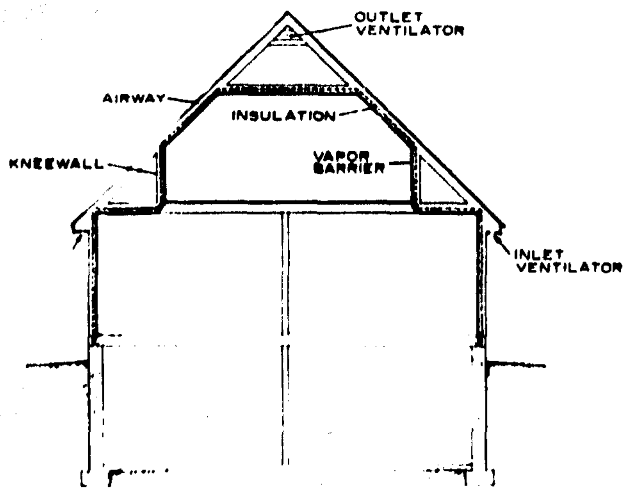

Figure 9.--Location of vapor barriers and insulation in 1-1/2-story house with basement. M 139 234

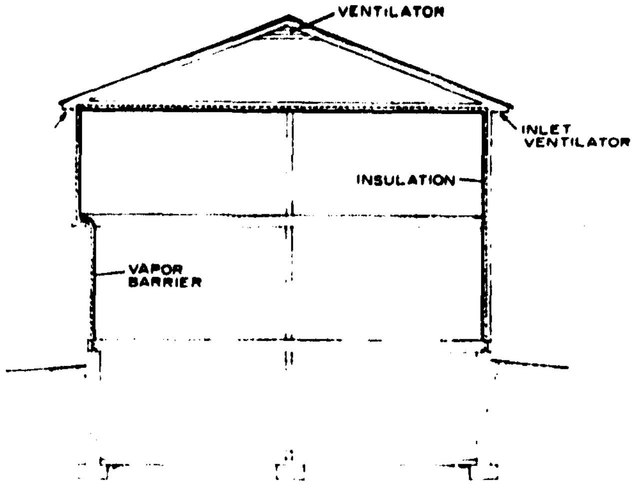

Figure 10.--Location of vapor barriers and insulation in full two-story house with basement. M 139 226

in the use of vapor barriers will be covered in the following sections.

Concrete Slabs

A house constructed over a concrete slab must be protected from soil moisture which may enter the slab. Protection is normally provided by a vapor barrier, which completely isolates the concrete and perimeter insulation from the soil. Thermal insulation of some type is required around the house perimeter in the colder climates, not only to reduce heat loss but also to minimize condensation on the colder concrete surfaces. Some type of rigid insulation impervious to moisture absorption should be used. Expanded plastic insulation such as polystyrene is commonly used.

One method of installing this insulation is shown in figure 11. Another method consists of placing it vertically along the inside of the foundation wall. Both methods require insulation at the slab notch of[3] the wall. In moderate climates the minimum R value of the insulation should be at least 2.0; in colder climates where temperatures reach -20° F., an R value of at least 3.0 is recommended. If the insulation is placed vertically, it should extend a minimum of 12 inches below the outside finish grade. In the colder climates a minimum 24-inch width or depth should be used.

In late spring or early summer, periods of high humidity may cause surface condensation on exposed concrete slabs or on coverings such as resilient tile before the concrete has reached normal temperatures. A fully insulated slab or a wood floor installed over wood furring strips minimizes if not eliminates such problems.

Because the vapor barriers slow the curing process of the concrete, final steel troweling of the surface is somewhat delayed. Do not punch holes through the barrier to hasten the curing process!

Crawl Spaces

Enclosed crawl spaces require some protection to prevent problems caused by excessive soil moisture. In an unheated crawl space this usually consists of a vapor barrier over the soil, together with foundation ventilators. In heated crawl spaces, a vapor barrier and perimeter insulation is used but foundation ventilators are eliminated.

Unheated crawl space.--To provide complete protection from condensation problems, the conventional unheated crawl space usually contains (a) foundation ventilators, (b) a ground cover (vapor barrier), and (c) thermal insulation between the floor joists. Foundation ventilators are normally located near the top of the masonry wall. In concrete block foundations, the ventilator is often made in a size to replace a full block, figure 12.

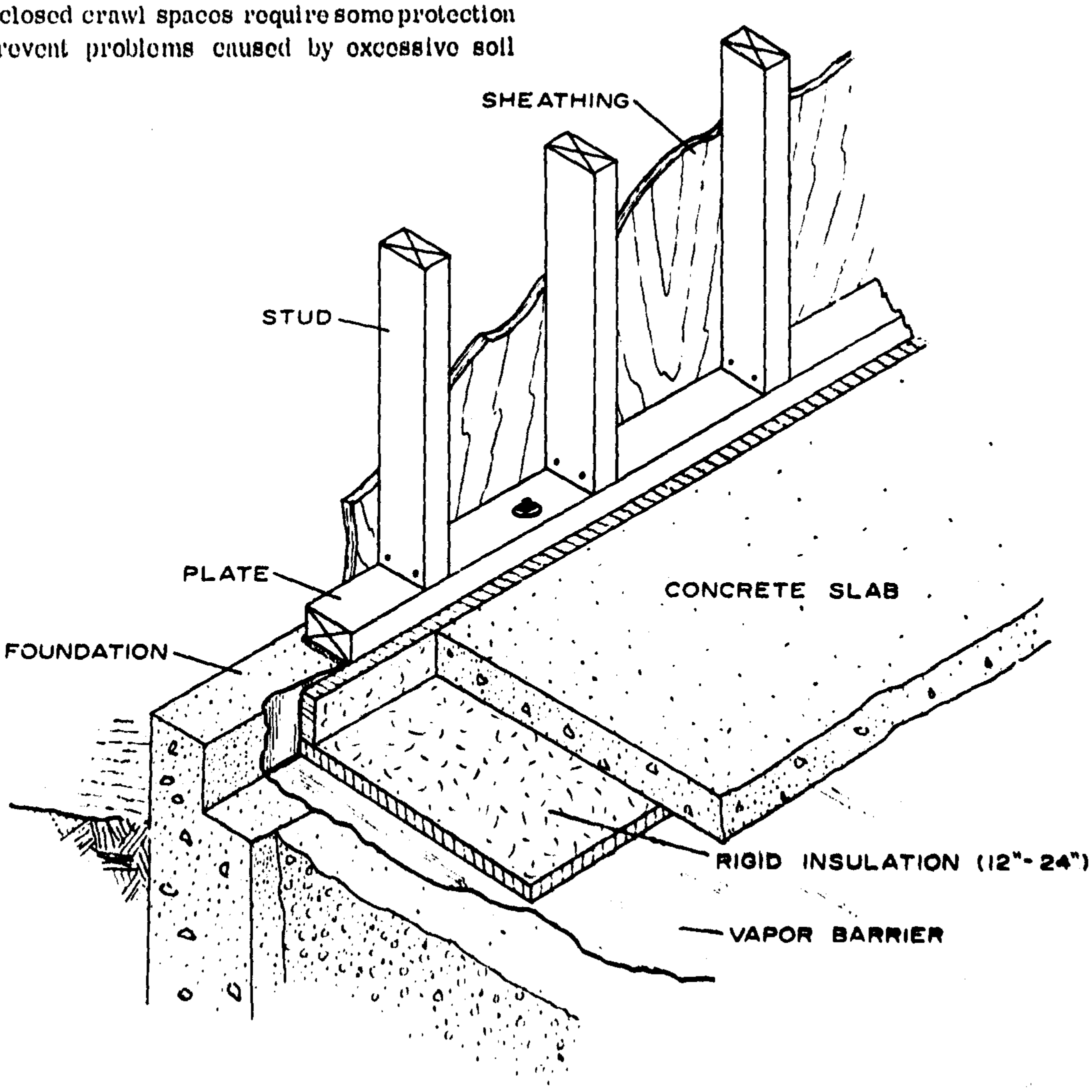

Figure 11.--Installation of vapor barrier under concrete slab. M 139 235

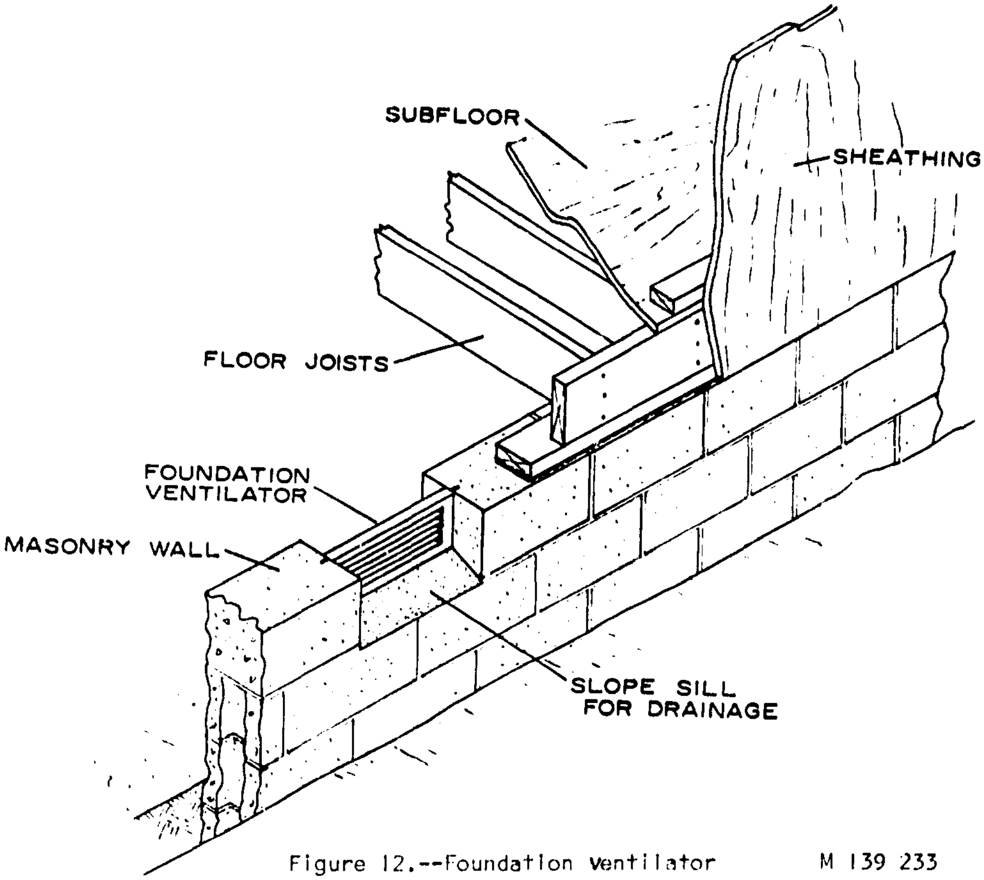

Figure 12.--Foundation Ventilator M 139 233

The amount of ventilation required for a crawl space is based on the total area of the house in square feet and the presence of a vapor barrier soil cover. Table 2 lists the recommended net ventilating areas for crawl space with or without vapor barriers.

The flow of air through a ventilator is restricted by the presence of screening and by the louvers. This reduction varies with the size of the screening or mesh and by the type of louvers used. Louvers are sloped about 45° to shed rain when used in a vertical position. Table 3 outlines the amount by which the total calculated net area of the ventilators must be increased to compensate for screens and thickness of the louvers.

In placing the vapor barrier over the crawl-space soil, adjoining edges should be lapped slightly and ends turned up on the foundation wall (fig. 13). To prevent movement of the barrier, it is good practice to weight down laps and edges with bricks or other small masonry sections.

An unheated crawl space in cold climates offers insufficient protection to supply and disposal pipes during winter months. It is common practice to use a large vitrified or similar tile to enclose the water and sewer lines in the crawl space. Insulation is then placed within the tile to the floor level.

Insulating batts, with an attached vapor barrier, are normally located between the floor joists. They can be fastened by placing the tabs over the edge of the joists before the subfloor is installed when the cover (vapor barrier) is strong enough to support the insulation batt (fig. 13). However, there is often a hazard of the insulation becoming wet before the subfloor is installed and the house enclosed. Thus, it is advisable to use one of the following alternate methods:

Friction-type batt insulation is made to fit tightly between joists and may be installed from the crawl space as shown in figure 14,A. It is good practice to use small "dabs" of mastic adhesive to insure that it remains in place against the subfloor. When the vapor barrier is not a part of the insulation, a separate film should be placed between the subfloor and the finish floor.

When standard batt or blanket insulation containing an integral vapor barrier is not installed from above before the subfloor is applied, several alternate methods can be used. If the vapor barrier and enclosing paper wrap is strong enough it can be installed with a mastic adhesive in the same manner as the friction type (fig. 14,A). Floor

Table 2.--Crawl-space ventilation

Crawl space	Ratio of total net ventilating area to floor area[1]	Minimum number of ventilators[2]
Without vapor barrier	1/150	4
With vapor barrier	1/1500	2

[1]The actual area of the ventilators depends on the type of louvers and size of screen used--see table 3.

[2]Foundation ventilators should be distributed around foundation to provide best air movement. When two are used, place one toward the side of prevailing wind and the other on opposite side.

Table 3.--Ventilating area increase required if louvers and screening are used in crawl spaces and attics

Obstructions in ventilators--louvers and screens[1]	To determine total area of ventilators, multiply required net area in square feet by:[2]
1/4-inch-mesh hardware cloth	1
1/8-inch-mesh screen	1-1/4
No. 16-mesh insect screen (with or without plain metal louvers)	2
Wood louvers and 1/4-inch-mesh hardware cloth[3]	2
Wood louvers and 1/8-inch-mesh screen[3]	2-1/4
Wood louvers and No. 16-mesh insect screen[3]	[illegible]

[1]In crawl-space ventilators, screen openings should not be larger than 1/4 inch; in attic spaces, no larger than 1/8 inch.

[2]Net area for attics determined by ratios in figures 24, 25, and 27.

[3]If metal louvers have drip edges that reduce the opening, use same ratio as shown for wood louvers.

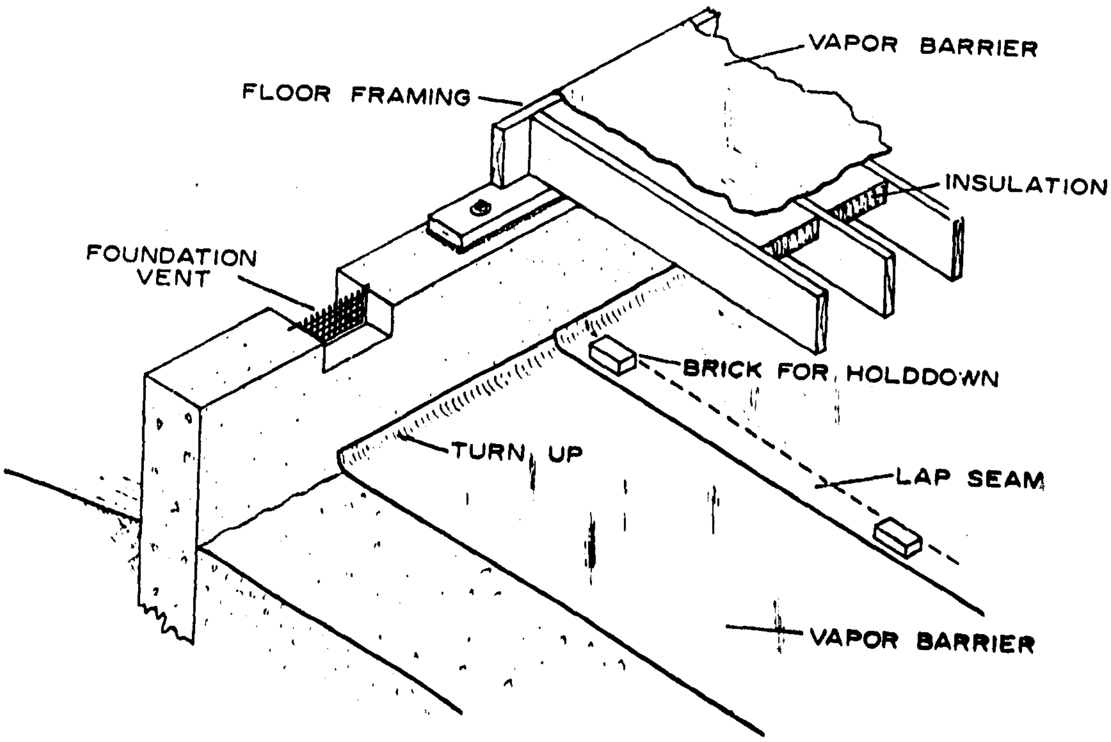

Figure 13.--Vapor barrier for crawl space (ground cover). M 139 225

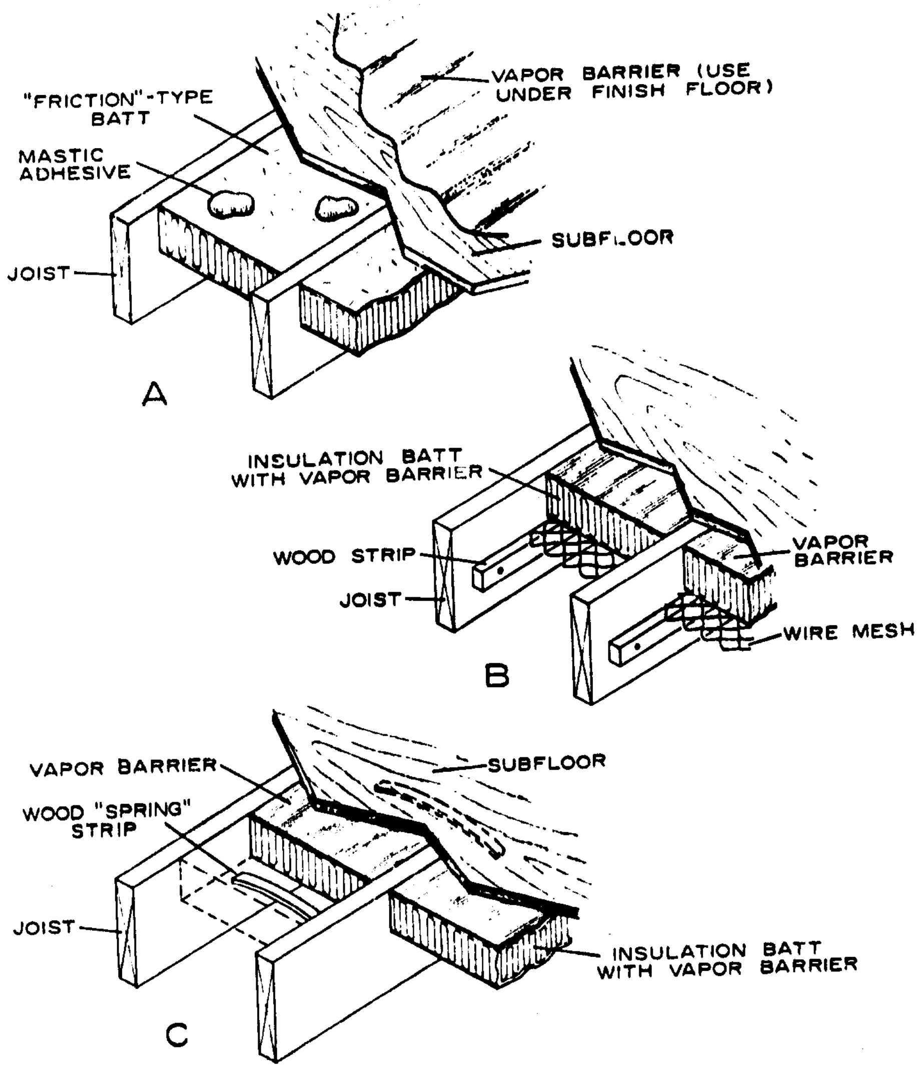

Figure 14.--Installation of vapor barriers and insulation in floor (unheated crawl space): A, Friction-type batts; B, wire mesh support; C, wood strip support. M 139 221

Insulation may also be supported by a wire mesh held in place by wood strips (fig. 14,B). A third method used to install the insulation from the crawl space consists of using small wood strips applied across the joist space (fig. 14,C). The strips are cut slightly longer than the width of the space and sprung in place so that they bear against the bottom of the insulation.

When only a small amount of insulation is required between the joists because of moderate climates, several other insulating materials can be used. One such material is reflective insulation which usually consists of a kraft paper with aluminum foil on each face. The reflective face must be placed at least 3/4 inch away from the underside of the subfloor or other facing to be fully effective (fig. 15,A). Multiple or expanded reflective insulation might also be used. A thin blanket insulation can also be used between the joists as shown in figure 15,B. This is installed in much the same manner as thicker insulations shown in figure 13 or 14. When vapor barriers are a part of the flexible insulation and properly installed, no additional vapor barrier is ordinarily required.

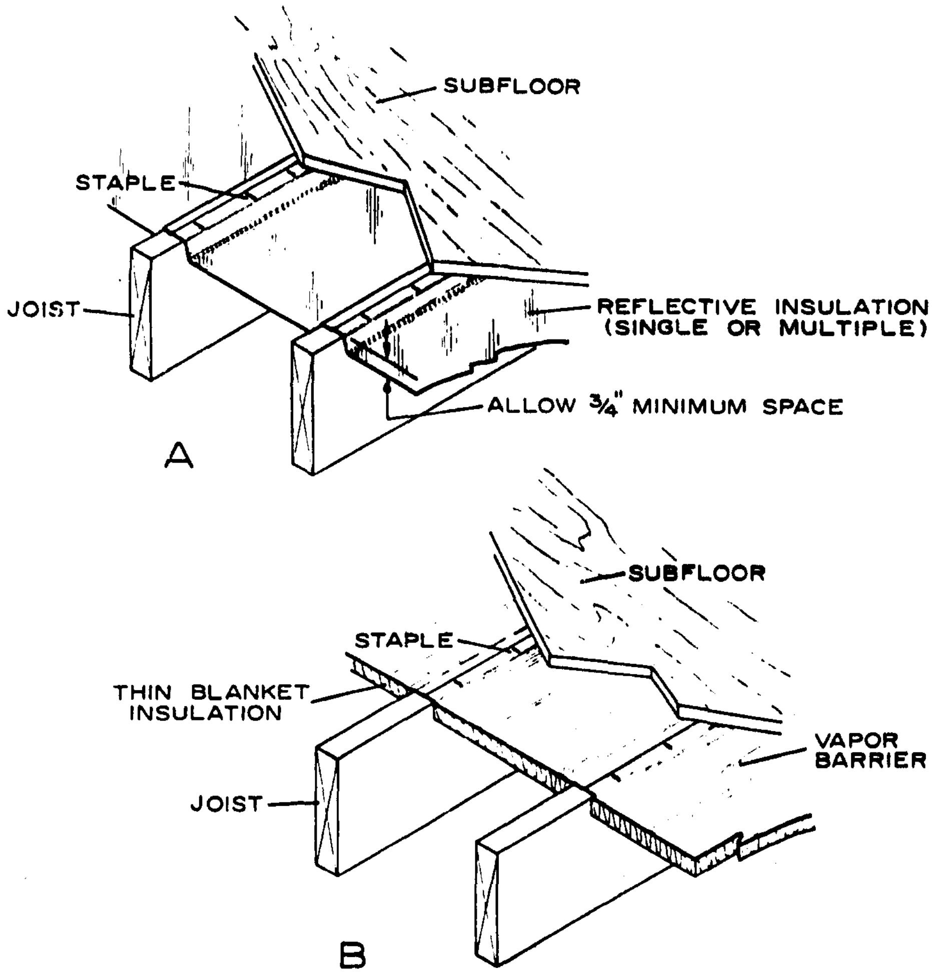

Figure 15.--Installation of vapor barriers and insulation over crawl space: A, Reflective insulation; and B, thin blanket insulation. M 139 229

Heated crawl space.--One method of heating which is sometimes used for crawl space houses, utilizes the crawl space as a plenum chamber. Warm air is forced into the crawl space, which is somewhat shallower than those normally used without heat, and through wall-floor registers, around the outer walls, into the rooms above. When such a system is used, insulation is placed along the perimeter walls as shown in figure 16. Flexible insulation, with the vapor barrier facing the interior, is used between joists at the top of the foundation wall. A rigid insulation such as expanded polystyrene is placed along the inside of the wall, extending below the groundline to reduce heat loss. Insulation may be held in place with an approved mastic adhesive. To protect the insulation from moisture and to prevent moisture entry into the crawl space from the soil, a vapor barrier is used over the insulation below the groundline, figure 16. Seams of the ground cover should be lapped and held in place with bricks or other bits of masonry. Some builders pour a thin concrete slab over the vapor barrier. The crawl space of such construction is seldom ventilated.

In crawl space houses, as well as other types, the finish grade outside the house should be sloped to drain water away from the foundation wall.

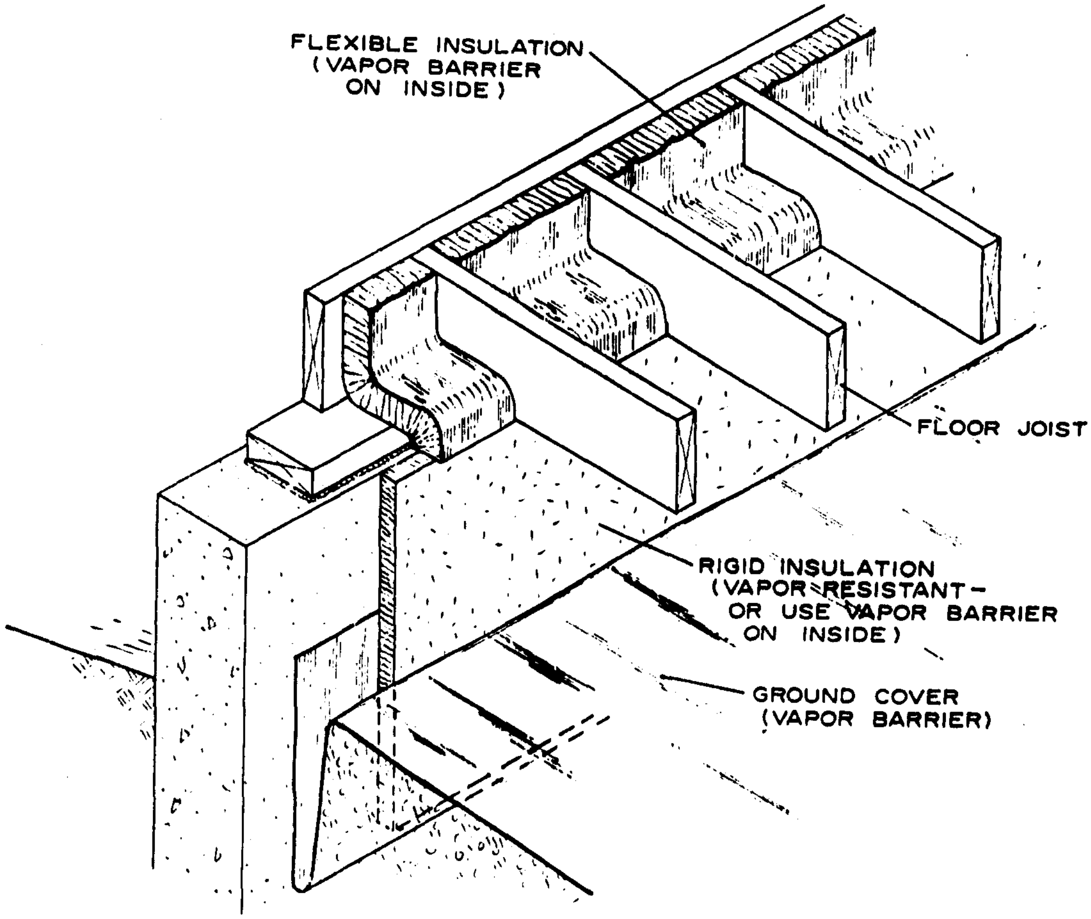

Figure 16.--Installation of vapor barrier and insulation in heated crawl space. M 139 239

Finished Basement Rooms

Finished rooms in basement areas with fully or partly exposed walls should be treated much the same as a framed wall with respect to the use of vapor barriers and insulation (fig. 17). When a full masonry wall is involved, several factors should be considered: (a) When drainage in the area is poor and soil is wet, drain tile should be installed on the outside of the footing for removing excess water; (b) in addition to an exterior wall coating, a waterproof coating should also be applied to the interior surface of the masonry to insure a dry wall; and (c) a vapor barrier should be used under the concrete floor slab to protect untreated wood sleepers or other materials from becoming wet.

Furring strips (2- by 2- or 2- by 3-inch members) used on the wall provide (a) space for the blanket insulation with the attached vapor barrier and (b) nailing surfaces for interior finish, figure 17. One- or 1-1/2-inch thicknesses of friction-type insulation with a vapor barrier of plastic film such as 4-mil polyethylene or other materials might also be used for the walls.

Other materials which are used over masonry walls consist of rigid insulation such as expanded polystyrene. These are installed with a thin slurry of cement mortar and the wall completed with a plaster finish. The expanded plastic insulations normally have moderate resistance to vapor movement and require no other vapor barrier.

When a vapor barrier has not been used under the concrete slab, it is good practice to place

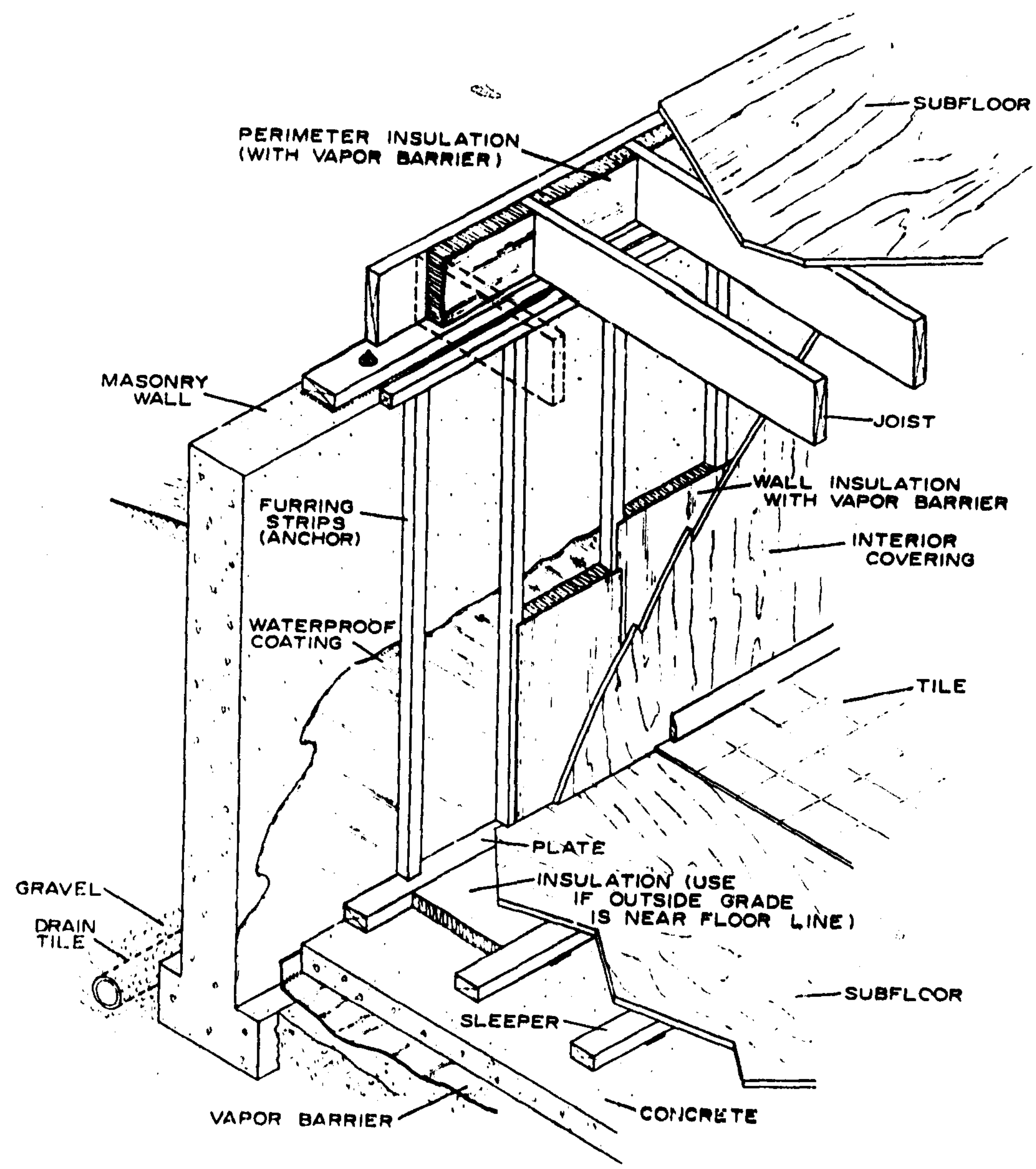

Figure 17.--Installing vapor barrier in floor and wall of finished basement. M 139 216

some type over the slab itself before applying the sleepers. One such system for unprotected in-place slabs involves the use of treated 1- by 4-inch sleepers fastened to the slab with a mastic. This is followed by the vapor barrier and further by second sets of 1- by 4-inch sleepers placed over and nailed to the first set. Subfloor and finish floor are then applied over the sleepers.

When the outside finish grade is near the level of the basement floor, it is usually good practice to use perimeter insulation around the exposed edges (fig. 17).

To prevent heat loss and minimize escape of water vapor, blanket or batt insulation with attached vapor barriers should be used around the perimeter of the floor framing above the foundation wall (fig. 17). Place the insulation between the joists or along stringer joists with the vapor barrier facing the basement side. The vapor barrier should fit tightly against the joists and subfloor.

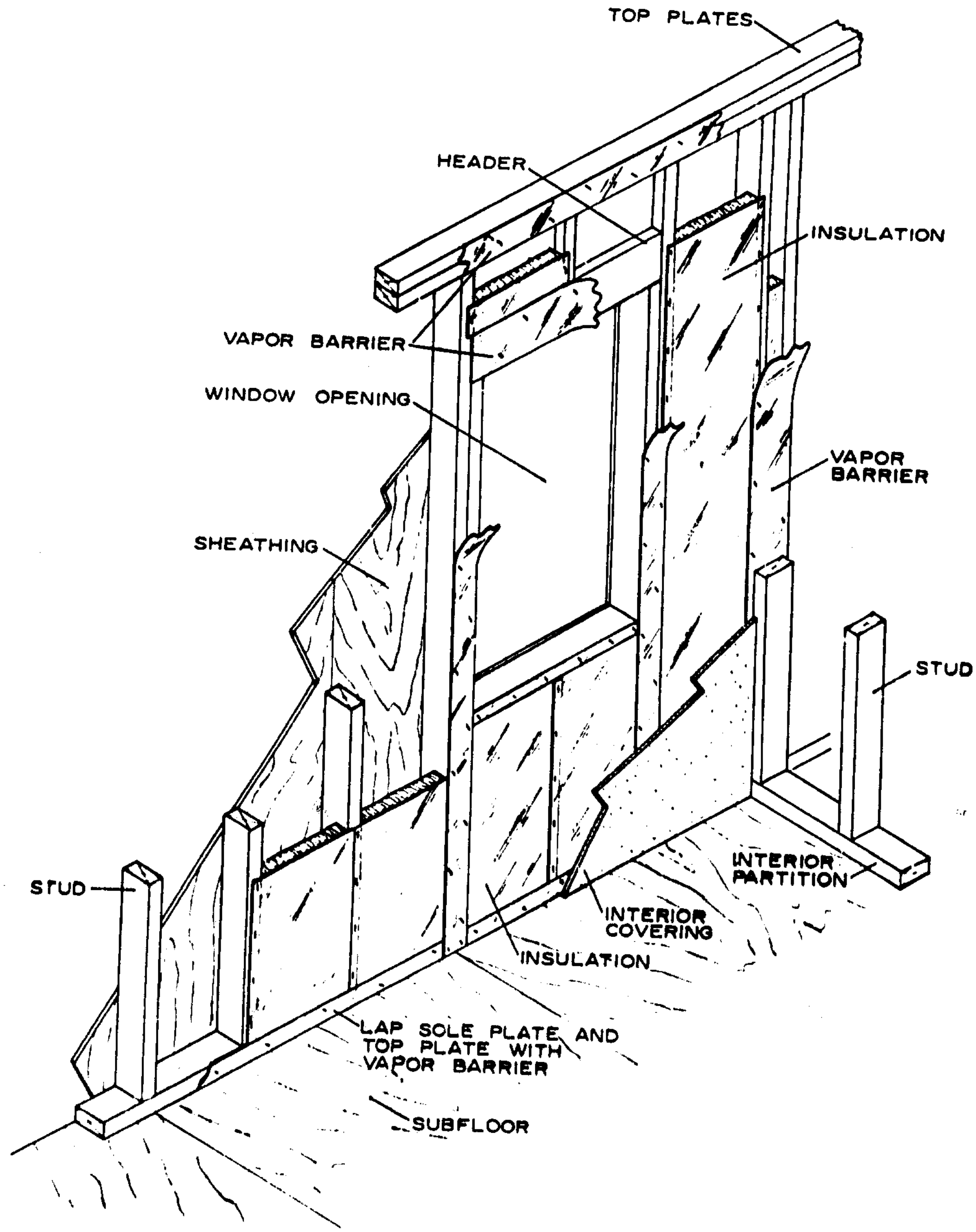

Figure 18.--Installing blanket insulation and vapor barriers in exterior wall. M 139 219

Walls

Blanket insulation.--Flexible insulation in blanket or batt form is normally manufactured with a vapor barrier. These vapor barriers contain tabs at each side, which are stapled to the frame members. To minimize vapor loss and possible condensation problems, the best method of attaching consists of stapling the tabs over the edge of the studs (fig. 18). However, many contractors do not follow this procedure because it is more difficult and may cause some problems in nailing of the rock lath or dry wall to the studs. Consequently, in many cases, the tabs are fastened to the inner faces of the studs. This usually results in some openings along the edge of the vapor barrier and, of course, a chance for vapor to escape and cause problems. When insulation is placed in this manner, it is well to use a vapor barrier over the entire wall. This method is described in the next section.

Another factor in the use of flexible insulation having an integral vapor barrier is the protection required around window and door openings. Where the vapor barrier on the insulation does not cover doubled studs and header areas, additional vapor barrier materials should be used for protection (fig. 18). Most well-informed contractors include such details in the application of their insulation.

At junctions of interior partitions with exterior walls, care should be taken to cover this intersection with some type of vapor barrier. For best protection, insulating the space between the doubled exterior wall studs and the application of a vapor barrier should be done before the corner post is assembled (fig. 18). However, the vapor barrier should at least cover the stud intersections at each side of the partition wall.

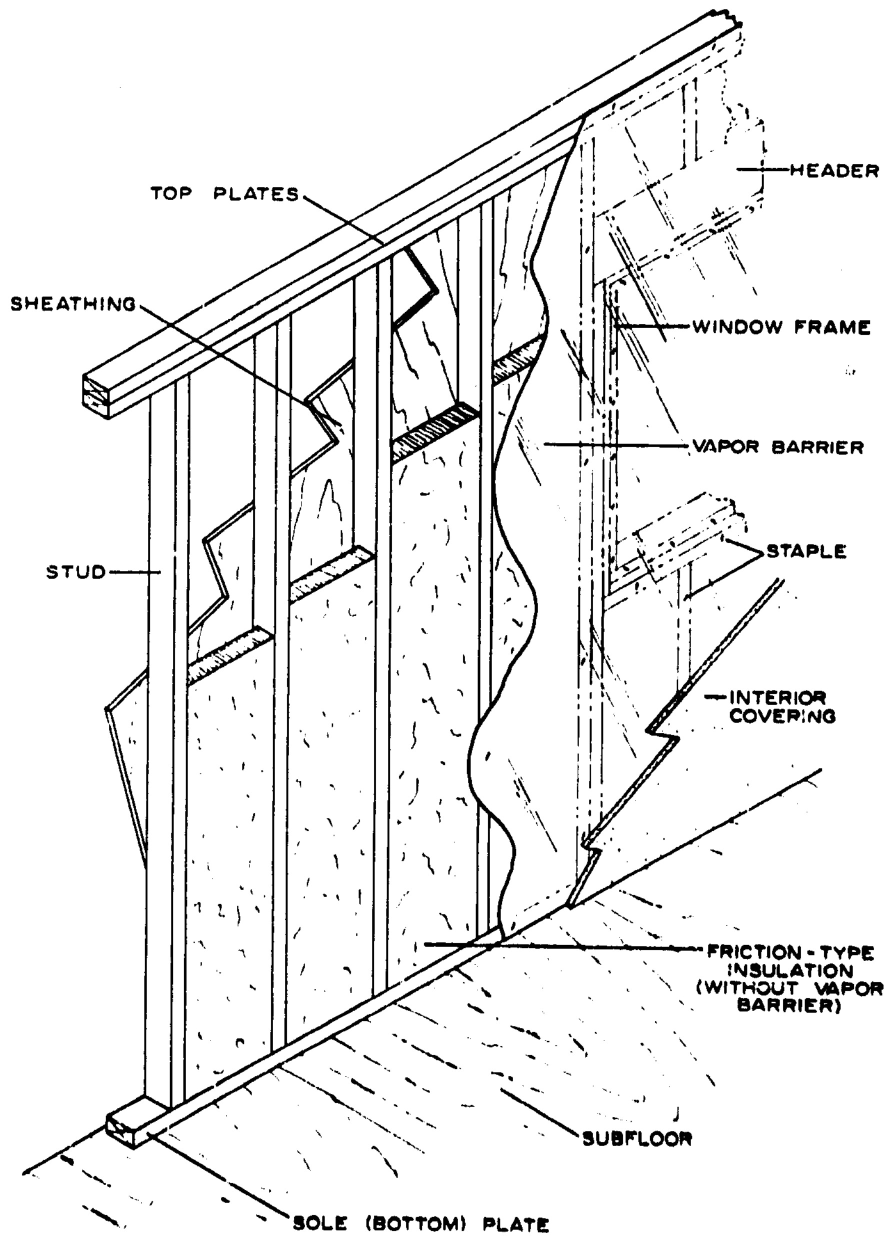

Figure 19.--Installing vapor barrier over friction-type insulation (enveloping). M 139 223

Friction-type insulation.--Some of the newer insulation forms, such as the friction-type without covers, have resulted in the development of a new process of installing insulation and vapor barriers so as to practically eliminate condensation problems in the walls. An unfaced friction-type insulation batt is ordinarily supplied without a vapor barrier, is semi-rigid, and made to fit tightly between frame members spaced 16 or 24 inches on center. "Enveloping" is a process of installing a vapor barrier over the entire wall (fig. 19). This type vapor barrier often consists of 4-mil or thicker polyethylene or similar material used in 8-foot-wide rolls. After insulation has been placed, rough wiring or duct work finished, and window frames installed, the vapor barrier is placed over the entire wall, stapling when necessary to hold it in place. Window and door headers, top and bottom plates, and other framing are completely covered (fig. 19). After rock lath plaster base or dry-wall finish is installed, the vapor barrier can be trimmed around window openings.

Reflective insulations.--Reflective insulations ordinarily consist of either a kraft sheet faced on two sides with aluminum foil, figure 20,A, or

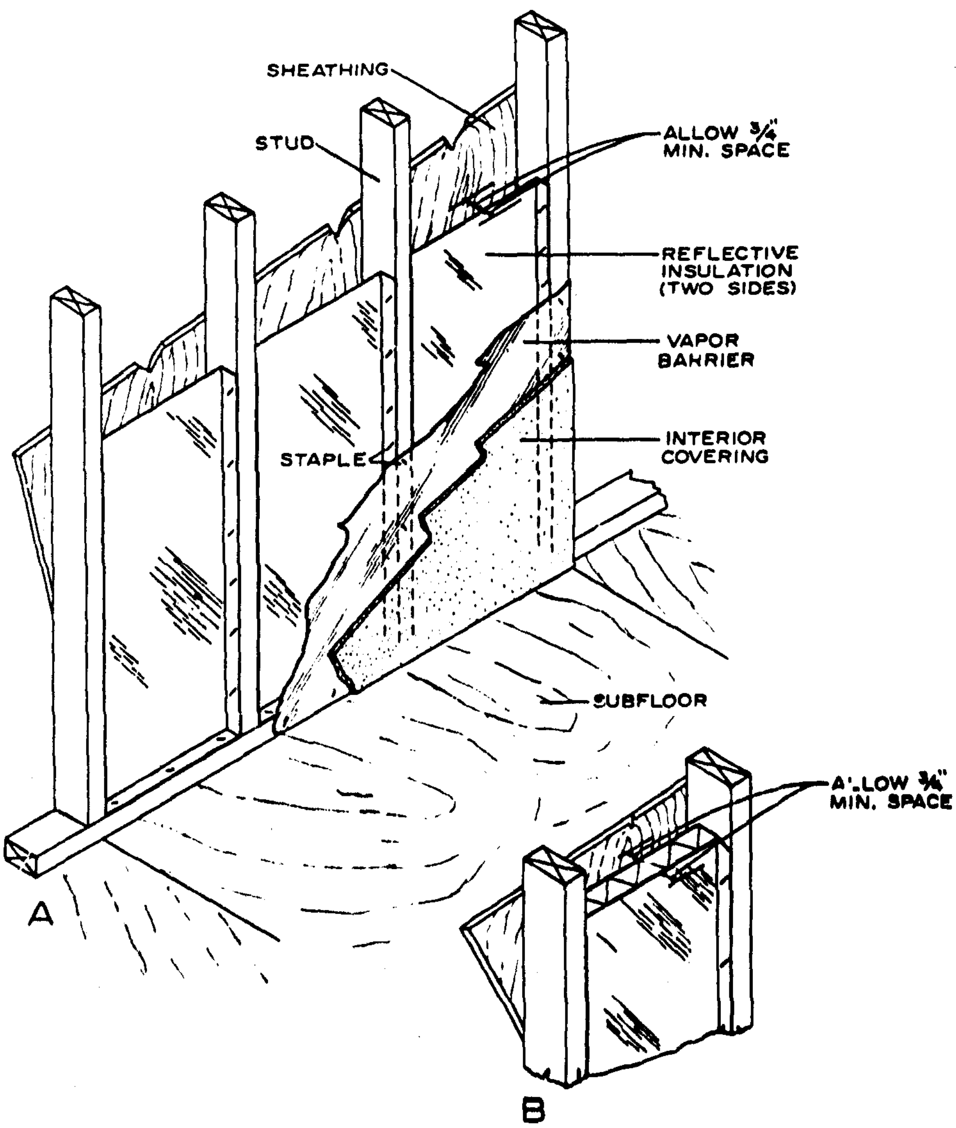

Figure 20.--Installing reflective insulation: A, Single sheet, reflective two sides; B, multiple reflective insulation.
M 139 222

the multiple-reflective "accordion" type, figure 20,B. Both are made to use between studs or joists. To be effective, it is important in using such insulation that there is at least a 3/4-inch space between the reflective surface and the wall, floor, or ceiling surface. When a reflective insulation is used, it is good practice to use a vapor barrier over the studs or joists. The barrier should be placed over the frame members just under the dry wall or plaster base (fig. 20,A). Gypsum board commonly used as a dry wall finish can be obtained with an aluminum foil on the inside face which serves as a vapor barrier. When such material is used, the need for a separate vapor barrier is eliminated.

Two-story house.--One of the areas of a two-story house where the requirement of a vapor barrier and insulation is often overlooked is at the perimeter area of the second floor floor joists. The space between the joists at the header and along the stringer joists should be protected by sections of batt insulation which contain a vapor barrier (fig. 21). The sections should fit tightly so that both the vapor barriers and the insulation fill the joist spaces.

A two-story house is sometimes designed so that part of the second floor projects beyond the first. This projection varies but is often about 12 inches. In such designs, the projections should be insulated and vapor barriers installed as shown

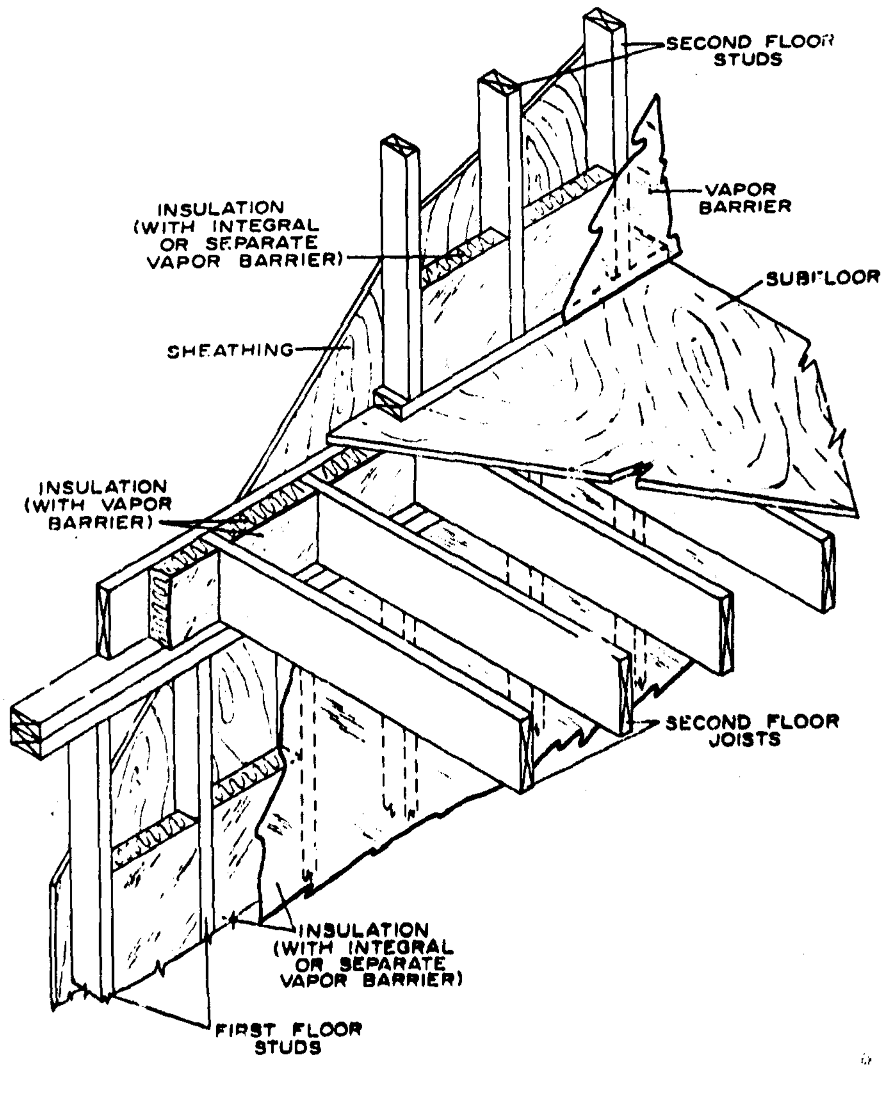

Figure 21.--Vapor barriers in walls and joist space of two-story house. M 139 220

in figure 22.

Insulation and vapor barriers in exposed second floor walls (fig. 21) should be installed in the same manner as for walls of single-story houses. This might include: (a) standard blanket insulation with its integral vapor barrier; (b) friction-type insulation with separate vapor barrier (fig. 19); or (c) reflective insulation with the protective vapor barrier (fig. 20).

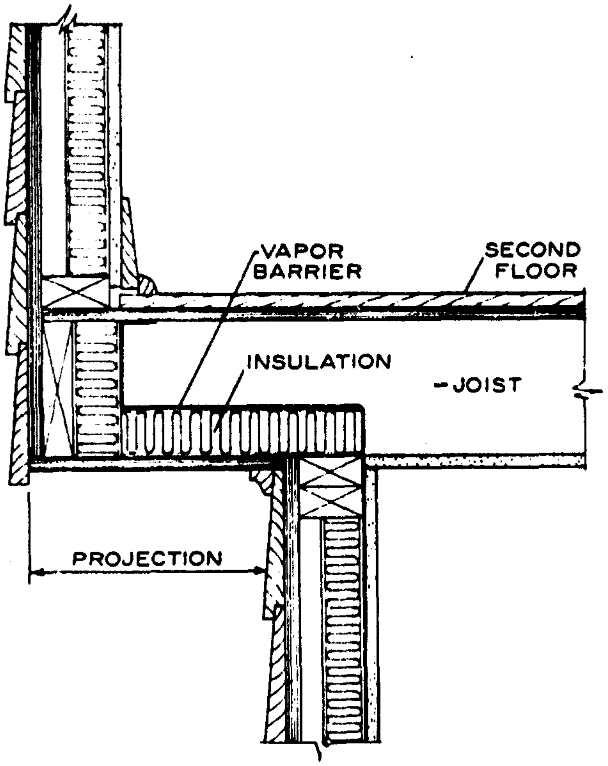

Figure 22.--Insulation and vapor barrier at second floor projection. M 139 227

Knee walls.--In 1-1/2-story houses containing bedrooms and other occupied rooms on the second floor, it is common practice to include knee walls. These are partial walls which extend from the floor to the rafters (fig. 23). Their height usually varies between 4 and 6 feet. Such areas must normally contain vapor barriers and insulation in the following areas: (a) In the first floor ceiling area, (b) at the knee wall, and (c) between the rafters. Insulation batts with the vapor barrier facing down should be placed between joists from the outside wall plate to the knee wall. The insulation should also fill the entire joist space directly under the knee wall (fig. 23). Care should be taken when placing the insulating batt to allow an airway for attic ventilation at the junction of the rafter and exterior wall.

Insulation in the knee wall can consist of blanket or batt-type insulation with integral vapor barrier or with separately applied vapor barriers, as described for first and second floor walls.

Batt or blanket insulation is commonly used between the rafters at the sloping portion of the heated room, figure 23. As in the application of all insulations, the vapor barrier should face the inner or warm side of the roof or wall. An airway should always be allowed between the top of the insulation and the roof sheathing at each rafter space. This should be at least 1-inch clear space without obstructions such as might occur with solid blocking. This will allow movement of air in the area behind the knee wall to the attic area above the second floor rooms (fig. 9).

Ceilings and Attics

Vapor barriers and insulation.--Insulation in ceiling areas normally consists of the batt or fill-type. However, to provide for good condensation control, a vapor barrier should always be provided (fig. 24,A). When an insulation batt is supplied with a vapor barrier on one face, no additional protection is normally required. Place the batts with barrier side down, so that they fit tightly between ceiling joists. Batts with the vapor barrier attached can also be stapled to the bottom edge of the joists before the ceiling finish is applied. At the junction of the outside walls and rafters, a space should always be left below the roof boards to provide a ventilating airway (fig. 24,B).

Ventilation.--Ventilation of attic spaces and roof areas is important in minimizing water vapor buildup. However, while good ventilation is important, there is still a need for vapor barriers in ceiling areas. This is especially true of the flat or low-slope roof where only a 1- to 3-inch space above the insulation might be available for ventilation.

In houses with attic spaces, the use of both inlet and outlet ventilation is recommended. Placing inlet ventilators in soffit or frieze-board areas of the cornice and outlet ventilators as near the ridge-line as possible will assure air movement through a "stack" effect. This is due to the difference in height between inlet and outlet

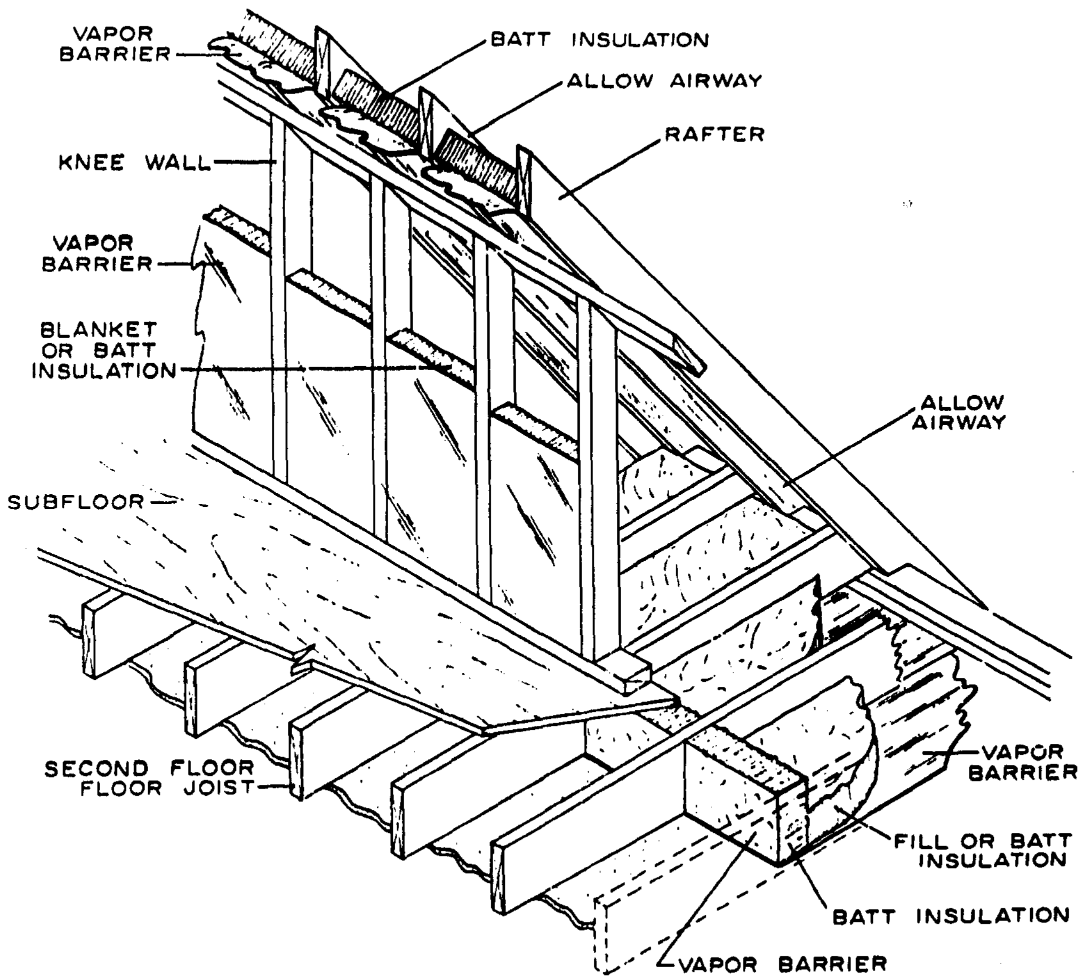

Figure 23.--Installing vapor barrier and insulation in knee-wall areas of 1-1/2-story house. M 139 232

ventilators and normally assures air movement even on windless days or nights.

Recommended ventilating areas.--The minimum amount of attic or roof space ventilation required is determined by the total ceiling area. These ratios are shown in figures 25, 26, and 27 for various types of roofs. The use of both inlet and outlet ventilators is recommended whenever possible. The total net area of ventilators is found by application of the ratios shown in figures 25, 26, and 27. The total area of the ventilators can be found by using the data in table 3. Divide this total area by the number of ventilators used to find the recommended square-foot area of each.

For example, a gable roof similar to figure 25,B with inlet and outlet ventilators has a minimum required total inlet and outlet ratio of 1/900 of the ceiling area. If the ceiling area of the house is 1,350 square feet, each net inlet and outlet ventilating area should be 1,350 divided by 900 or 1-1/2 square feet.

If ventilators are protected with No. 16-mesh insect screen and plain metal louvers, table 3, the gross area is 2 x 1-1/2 or 3 square feet. When one outlet ventilator is used at each gable end, each should have a gross area of 1-1/2 square feet (3 divided by 2). When distributing the soffit inlet ventilators to three on each side, for a small house (total of 6), each ventilator should have a gross area of 0.5 square feet. For long houses, use 6 or more on each side.

Inlet ventilators.--Inlet ventilators in the soffit may consist of several designs. It is good practice to distribute them as much as possible to prevent "dead" air pockets in the attic where moisture

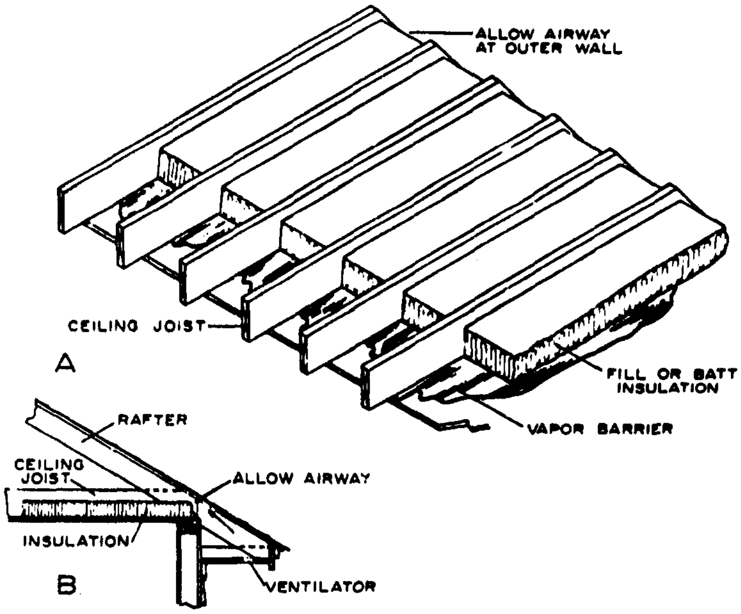

Figure 24.--Installing ceiling insulation and vapor barrier: A, Vapor barrier and insulation; and B, airway for ventilation. M 139 231

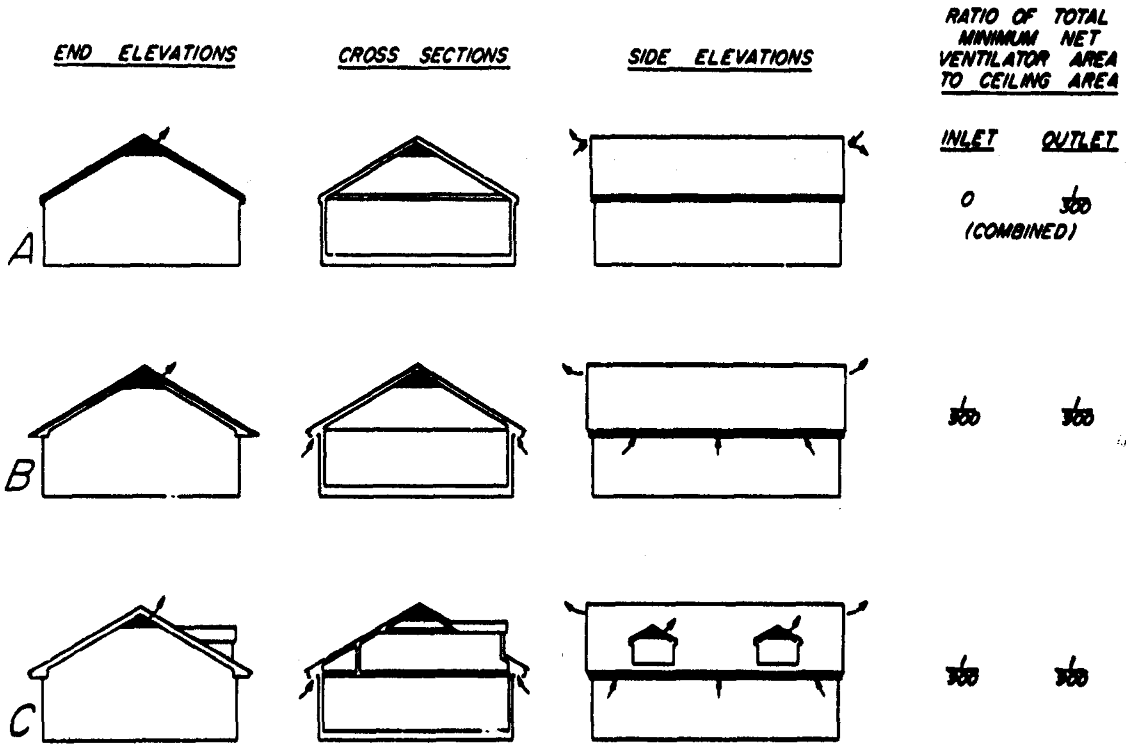

Figure 25.--Ventilating areas of gable roofs: A, Louvers in end walls; B, louvers in end walls with additional openings at eaves; C, louvers at end walls with additional openings at eaves and dormers. Cross section of C shows free opening for air movement between roof boards and ceiling insulation of attic room. M 87625 F

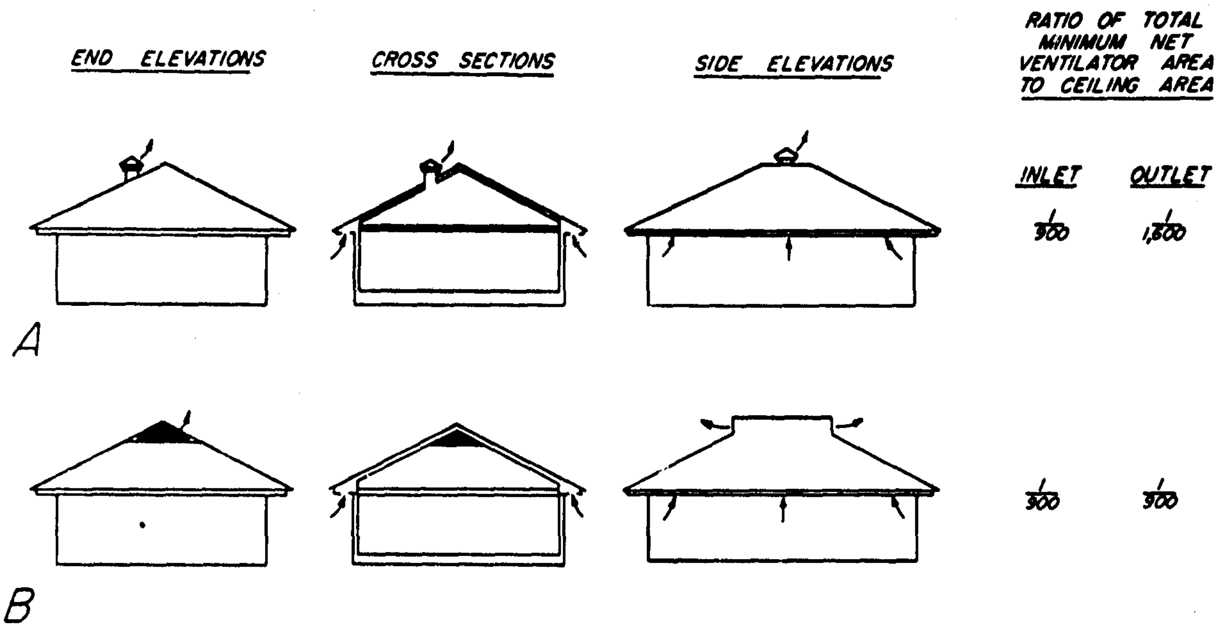

Figure 26.--Ventilating areas of hip roofs: A, inlet openings beneath eaves and outlet vent near peak; B, inlet openings beneath eaves and ridge outlets. M 87626 F

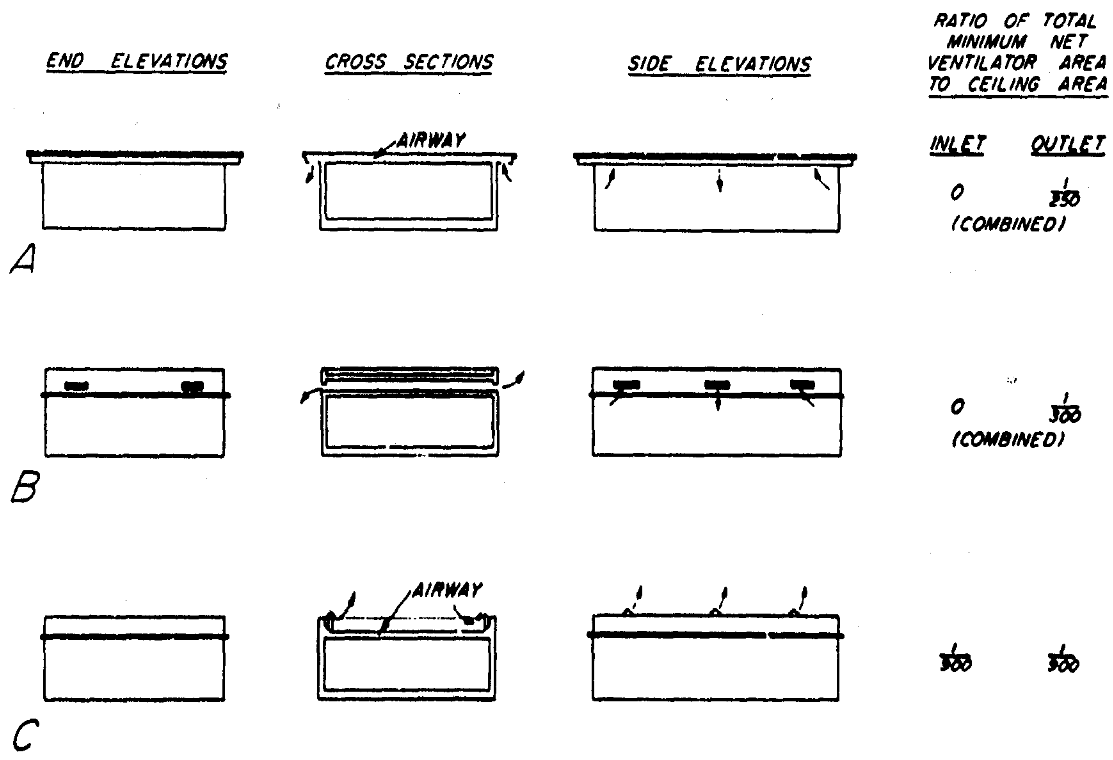

Figure 27.--Ventilating area of flat roofs: A, Ventilator openings under overhanging eaves where ceiling and roof joists are combined; B, for roof with a parapet where roof and ceiling joists are separate; C, for roof with a parapet where roof and ceiling joists are combined. M 87627 F

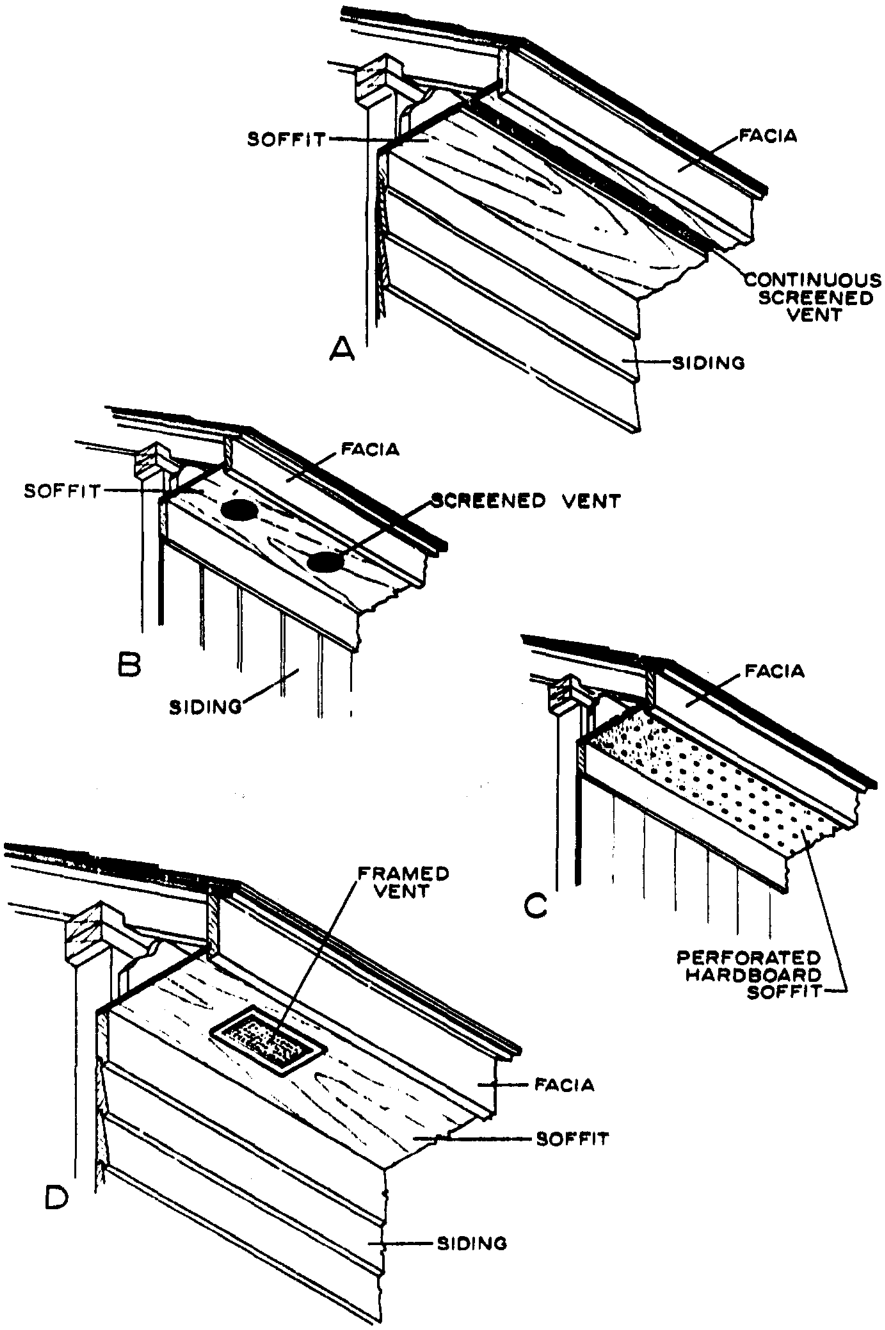

Figure 28.--Inlet ventilators in soffits: A, Continuous vent; B, round vents; C, perforated; D, single ventilator. M 139 214

might collect. A continuous screened slot, figure 28,A, satisfies this requirement. Small screened openings might also be used, figure 28,B. Continuous slots or individual ventilators between roof members should be used for flat-roof houses where roof members serve as both rafters and ceiling joists. Locate the openings away from the wall line to minimize the possible entry of wind-driven snow. A soffit consisting of perforated hardboard, figure 28,C, can also be used to advantage but holes should be no larger than

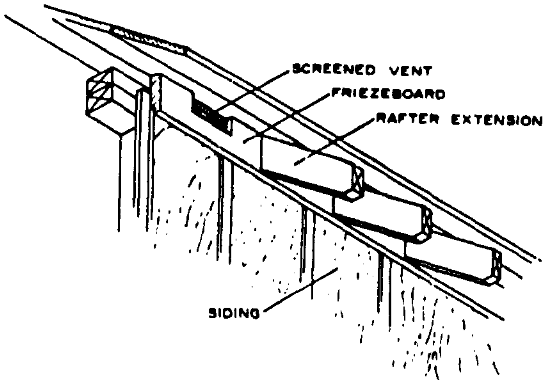

Figure 29.--Frieze ventilator (for open cornice). M 139 230

1/8 inch in diameter. Small metal frames with screened openings are also available and may be used in soffit areas, figure 28,D. For open cornice design, the use of a frieze board with screen ventilating slots would be satisfactory, figure 29. Perforated hardboard might also be used for this purpose. The recommended minimum inlet ventilating ratios shown in figures 25, 26, and 27 should be followed in determining total net ventilating areas for both inlet and outlet ventilators.

Outlet ventilators.--Outlet ventilators to be most effective should be located as close to the highest portion of the ridge as possible. They m be placed in the upper wall section of a gable-

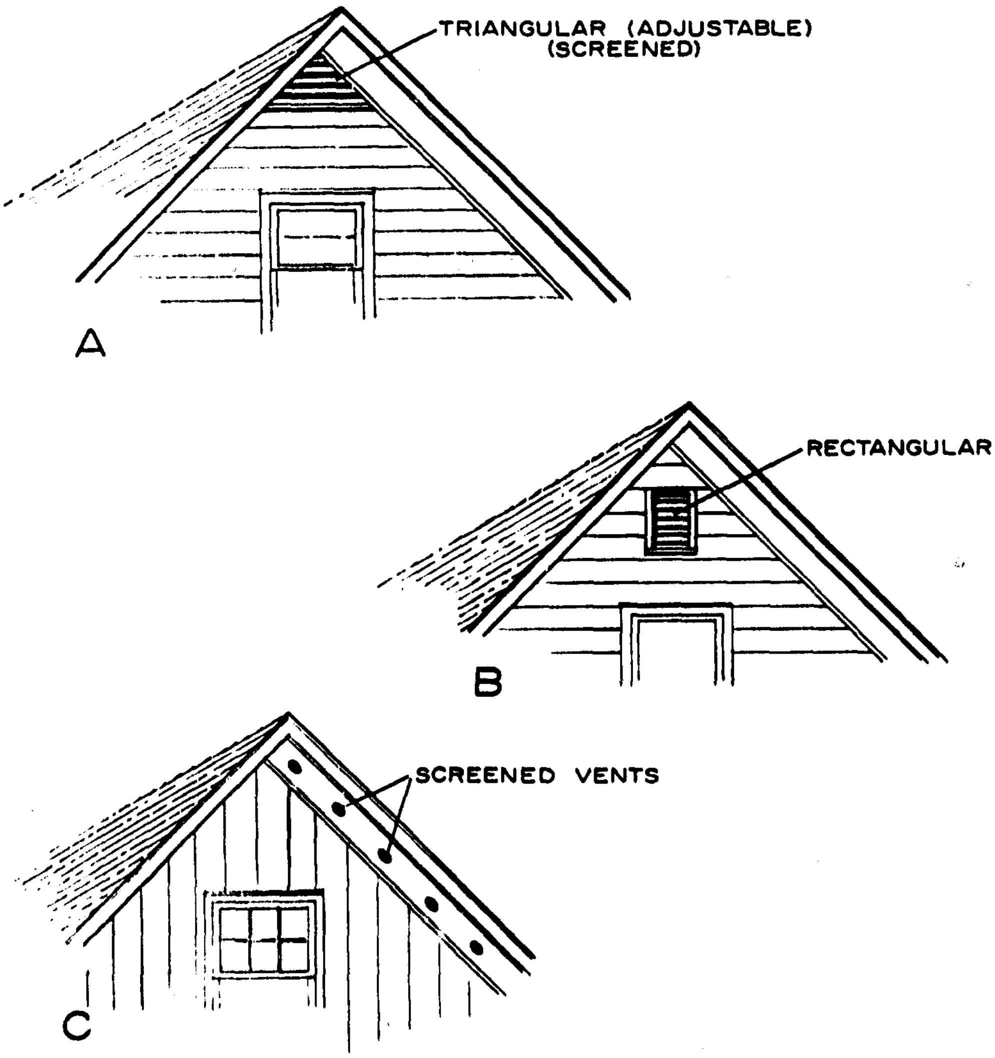

Figure 30.--Gable outlet ventilators: A, Triangular gable end ventilator; B, rectangular gable end ventilator; C soffit ventilators. M 139 228

roofed house in various forms as shown in figure 30,A and B. In wide gable-end overhangs with ladder framing, a number of screened openings can be located in the soffit area of the lookouts (fig. 30,C). Ventilating openings to the attic space should not be restricted by blocking. Outlet ventilators on gable or hip roofs might also consist of some type of roof ventilator (fig. 31,A and B). Hip roofs can utilize a ventilating gable (modified hip) (fig. 31,C). Protection from blowing snow must be considered, which often restricts the use of a continuous ridge vent. Locate the single roof ventilators (fig. 31,A and B) along the ridge toward the rear of the house so they are not visible from the front. Outlet ventilators might also be located in a chimney as a false flue which has a screened opening to the attic area.

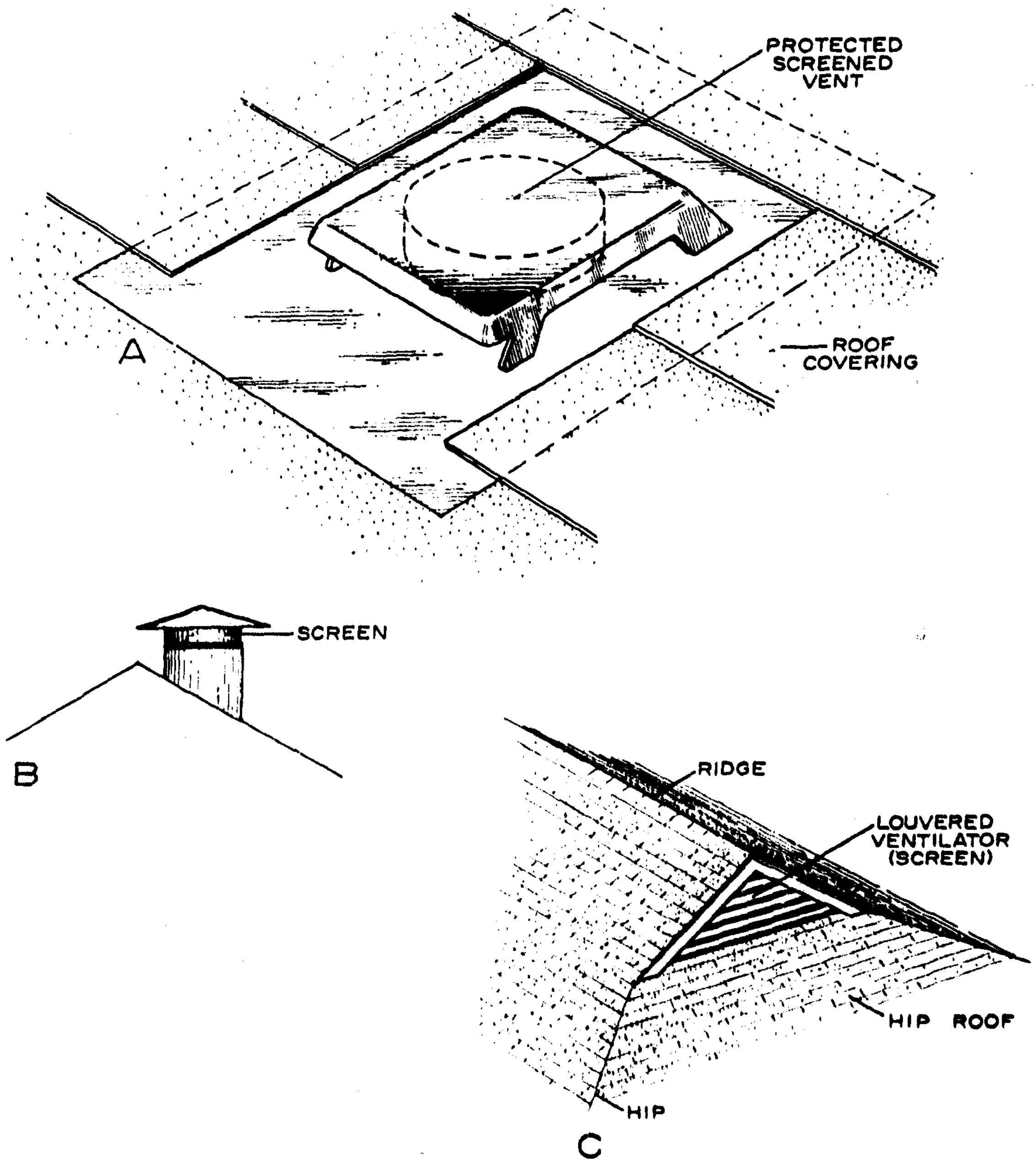

Figure 31.--Ridge outlet ventilators: A, Low silhouette type; B, pipe ventilator type; C, modified hip ventilator.
M 139 217

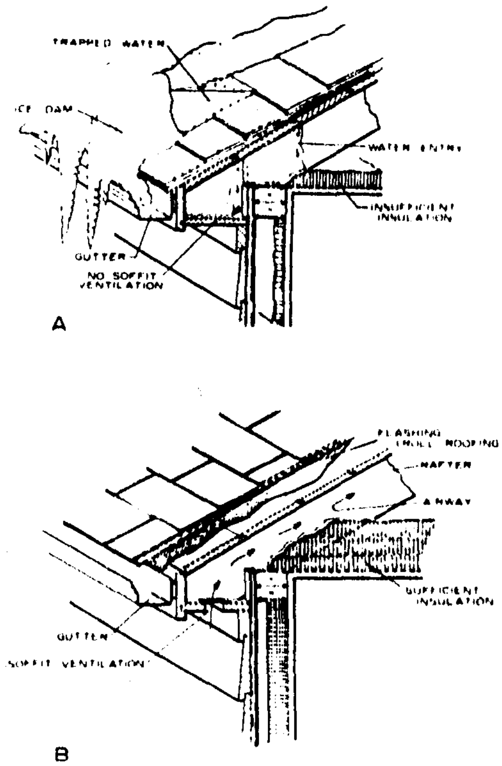

Figure 32.--Ice dams: A, Insufficient insulation and ventilation can cause ice dams and water damage; B, good ventilation, insulation, and roof flashing minimize problems. M 134 787

Other Protective Measures

Snow and ice dams.--Water leakage into walls and interiors of houses in the snow belt areas of the country is sometimes caused by ice dams and is often mistaken for condensation. Such problems occur after heavy snowfalls, followed by temperatures somewhat below freezing when there is sufficient heat loss from the living quarters to melt the snow along the roof surface. The water moves down the roof surface to the colder overhang of the roof where it freezes. This causes a ledge of ice and backs up water, which can enter the wall or drip down onto the ceiling finish (fig. 32,A).

Ice dam problems can be minimized if not entirely eliminated. By reducing attic temperatures by adequate insulation and ventilation, snow melting at the roof surface is greatly reduced. Good insulation, 6 inches or more in the northern sections of the country, greatly reduces heat loss from the house proper. Adequate ventilation, in turn, tends to keep attic temperature only slightly above outdoor temperatures. This combination of good ventilation and insulation is the answer to reducing ice dam problems.

Another protective measure is provided by the use of a flashing material. A 36-inch width of 45-pound roll roofing along the eave line will provide such added protection (fig. 32,B).

Protection at unheated areas.--Walls and doors to unheated areas such as attic spaces should be treated to resist water vapor movement as well as to minimize heat loss. This includes the use of insulation and vapor barriers on all wall areas, adjacent to the cold attic (fig. 33). Vapor barriers should face the warm side of the room. In addition, some means should be used to prevent heat and vapor loss around the perimeter of the door. One method is through some type of weather strip (fig. 33). The door itself should be given several finish coats of paint or varnish which will resist the movement of water vapor. Table 1 lists a number of coatings which provide some vapor resistance.

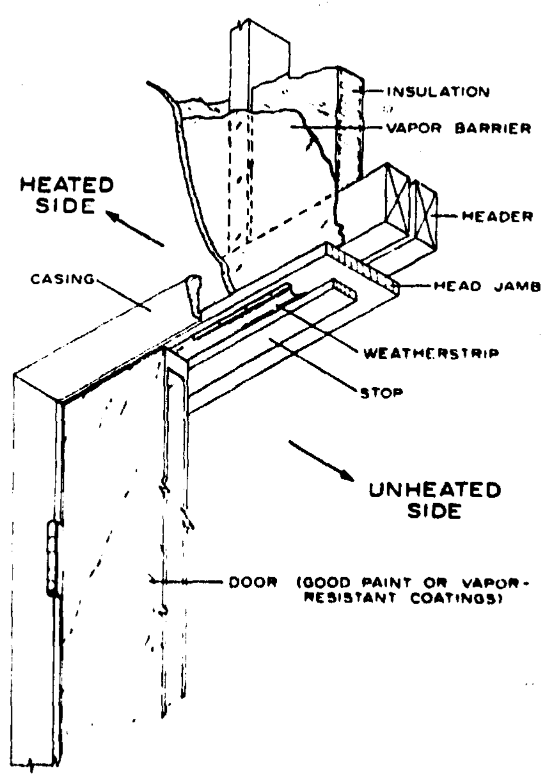

Figure 33.--Insulating door to unheated attic space. M 139 238

If further resistance to heat loss is desired, a covering of 1/2 inch or thicker rigid insulation, such as insulation board or foamed plastic, can be attached to the back of the door.

Protection at outlet boxes.--Outlet or switch boxes or other openings in exposed (cold) walls often are difficult to treat to prevent water vapor escape. Initially, whether the vapor barrier is a separate sheet or part of the insulation, as tight a fit as possible should be made when trimming the barrier around the box (fig. 34). This is less difficult when the barrier is separate. As an additional precaution, a bead of calking compound should be applied around the box after the dry wall or the plaster base has been installed (fig. 34). The same calking can be used around the cold-air return ducts or other openings in exterior walls. This type of sealing may appear unnecessary, but laboratory tests have shown that there is enough loss through the perimeter of an outlet box to form a large ball of frost on the back face during extended cold periods. Melting of this frost can affect the exterior paint films. In the colder areas of the country and in rooms where there is excess water vapor, such as the bath and kitchen, this added protection is good insurance from future problems. Some switch and junction boxes are more difficult to seal than others because of their makeup. A simple polyethylene bag or other enclosure around such boxes will provide some protection.

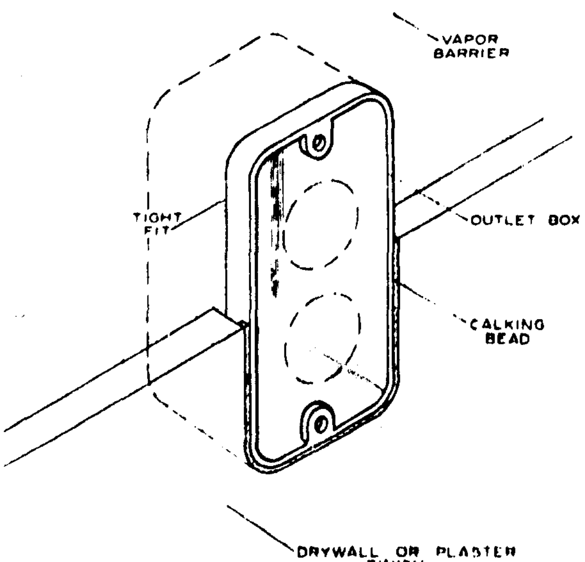

Figure 34.--Protection around outlet boxes in exposed walls. M 139 224

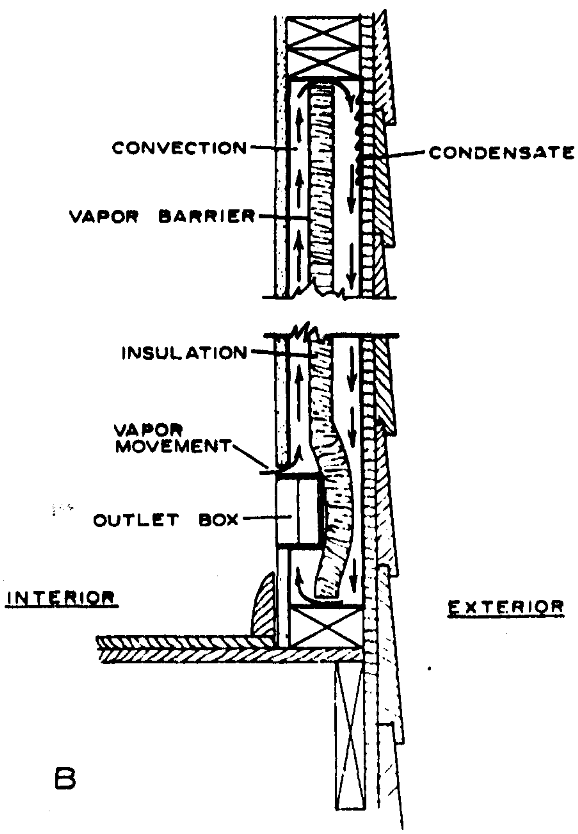

Figure 35.--Results of water vapor loss around outlet box. M 139 215

Condensation problems caused by water-vapor movement through unprotected outlet box areas in exposed walls are often due to poor workmanship during application of the insulation. Figure 35 shows a section of exterior wall with the vapor barrier loosely stapled to the face of the studs. Because of poor application, a small space is sometimes left at the top and bottom of the insulation in the stud space. Water vapor escaping through the unprotected outlet box travels by convection, on the warm side, to the top of the wall, where it moves to the cold side and condenses on the inner face of the colder siding or sheathing. Continued movement of vapor can saturate these materials and in severe conditions cause decay. Buckling of single panel siding, such as hardboard or similar materials, can result as moisture content of the material increases. Such problems can be minimized by "enveloping" of the inner face of exposed walls with a vapor barrier, as previously outlined (fig. 19). Sealing the outlet box in some manner will also aid in restricting water vapor movement into the wall cavity.

Other openings.--The same principles used in sealing outlet boxes should be applied to all openings in an outside wall or ceiling. Openings may include exhaust fans in the kitchen or the bathroom, hot air registers, cold air return registers, and plumbing. Openings are also required in ceilings for light fixtures, ventilation fans, and plumbing vents. Regardless of the type of opening, the vapor barrier should be trimmed to fit as tightly as possible.

HOW TO MINIMIZE EXISTING CONDENSATION PROBLEMS

Condensation problems can be eliminated by specifying proper construction details during planning of the house. Correct placement of vapor barriers, adequate insulation, the use of attic ventilation, and other good practices can be incorporated at this time. These recommendations have been outlined and illustrated in the preceding sections. However, when one or more of these details have not been included in an existing house and condensation problems occur, they are often more difficult to solve. Nevertheless, there are methods which can be used to minimize such condensation problems after the house has been constructed.

Visible Condensation

Glass surfaces.--Visible surface condensation on the interior glass surfaces of windows can be minimized by the use of storm windows or by replacing single glass with insulated glass. However, when this does not prevent condensation on the surface, the relative humidity in the room must be reduced. Drapes or curtains across the windows hinder rather than help. Not only do they increase surface condensation because of colder glass surfaces, but they also prevent the air movement that would warm the glass surface and aid in dispersing some of the moisture.

Attic areas.--Condensation or frost on protruding nails, on the surfaces of roof boards, or other members in attic areas normally indicates the escape of excessive amounts of water vapor from the heated rooms below. If a vapor barrier is not already present, place one between joists under the insulation. Make sure the vapor barrier fits tightly around ceiling lights and exhaust fans, calking if necessary. In addition, increase both inlet and outlet ventilators to conform to the minimum recommendations in figures 25, 26, and 27. Decreasing the amount of water vapor produced in the living areas is also helpful.

Crawl spaces.--Surface condensation in unheated crawl spaces is usually caused by excessive moisture from the soil or from warm humid air entering from outside the house. To eliminate this problem, place a vapor barrier over the soil as shown in figure 14; if necessary, use the proper amount of ventilation as recommended in table 2.

Concrete slabs.--Concrete slabs without radiant heat are sometimes subjected to surface condensation in late spring when warm humid air enters the house. Because the temperature of some areas of the concrete slab or its covering is below the dewpoint, surface condensation can occur. Keeping the windows closed during the day, using a dehumidifier, and raising the inside temperature aid in minimizing this problem. When the concrete slab reaches normal room temperatures, this inconvenience is eliminated.

Reducing Relative Humidity

Reducing high relative humidities within the house to permissible levels is often necessary to minimize condensation problems. Discontinuing the use of room-size humidifiers or reducing the output of automatic humidifiers until conditions are improved is helpful. The use of exhaust fans and dehumidifiers can also be of value in eliminating high relative humidities within the house. When possible, decreasing the activities which produce excessive moisture, as discussed in a previous section, is sometimes necessary. This is especially important for homes with electric heat.

Concealed condensation.--Concealed condensation is, in essence, a surface or similar condensation that takes place within a component such as a wall cavity when a condensing surface is below the dewpoint. In cold weather, condensation often forms as frost. Such conditions can cause staining of siding and peeling of the paint and often decay in severe and sustained conditions. These problems are usually not detected until spring after the heating season has ended. Installing a nonpermeable metal or plastic siding is not a solution, but only hides the symptoms. The remedies and solutions to the problems should be taken care of before repainting is attempted. Several methods might be used to correct this problem:

(1) Reduce or control the relative humidity within the house as previously discussed.

(2) Improve the vapor resistance of the wall and ceiling by adding a vapor barrier between the ceiling joists. Add a vapor-resistant paint coating to the interior of walls (table 1).

(3) Improve attic ventilation (figs. 25, 26, and 27).

(4) When repainting the outside of the house, use permeable paints which allow some vapor movement through them (table 1).

Ice dams.--Several methods can be used to minimize this problem caused by melting snow. By reducing the attic temperatures in the winter so that they are only slightly above outdoor temperatures, most ice dams can be eliminated. This can be accomplished in the following manner:

(1) Add insulation to the ceiling area in the attic to reduce heat loss from living areas below. This added insulation and ventilation will also be helpful by reducing summer temperatures in the living areas below.

(2) Provide additional inlet ventilation in the soffit area of the cornice as well as better outlet ventilation near the ridge.

(3) When reroofing, use a flashing strip of 36-inch-wide roll roofing paper of 45-pound weight along the eave line before reshingling. While this does not prevent ice dams, it is a worthwhile precaution.

(4) Under severe conditions, or when only some portions of a roof produce ice dams (such as at valleys), the use of electric-thermal wire laid in a zig-zag pattern and in gutters may prove effective. The wire is connected and heated during periods of snowfall and at other times as needed to maintain channels for drainage.

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GLOSSARY OF CONDENSATION AND HOUSING TERMS

Condensation.--Free water, frost, or ice extracted from the air and deposited on any cold surface. It may occur on the surface of a window glass, for example (surface condensation), or on a cold inner face of wall sheathing (concealed condensation), or within a material. Excessive condensation especially in the walls, can cause problems which often result in excessive maintenance.

Conduction, convection (see Energy transfer)

Crawl space.--A shallow space below the living quarters of a house. It is generally not excavated and may be constructed with a foundation wall or with piers and a skirt board enclosure.

Dew point.--The temperature at which the water vapor in space becomes saturated and can hold no more moisture. Water vapor cooled below the dew point appears in the atmosphere as fog and on the surface as dew or frost.

Energy transfer

- Conduction.--Transfer of heat or energy within and through a material (or gas) as a result of temperature gradient.
- Convection.--Transfer of heat energy by the circulatory motion that occurs in a fluid or gas at a non-uniform temperature owing to the variation of its density and the action of gravity.
- Radiation.--Transfer of heat energy in the form of waves or particles which have no effect on the medium through which they pass.

Humidifier.--A device designed to discharge water vapor into a confined space for the purpose of increasing or maintaining the relative humidity. It may be attached to the central heating plant or consist of small room-size units.

Ice dam.--Ice forming at the eave line from melting snow pocketing. Water which can enter walls and cornice.

Insulation.--Normally a low-density material used to reduce heat loss. It is made of wood fiber, cotton fiber, mineral or glass wool or fiber, vermiculite, expanded plastics, and others. It is made in several forms including:

- (a) Flexible.--In blanket or batt form.
- (b) Fill.--A loose form which can be poured or blown.
- (c) Rigid.--Includes insulating board or other materials in sheet or block form. Often used as sheathing material, as perimeter insulation, etc.
- (d) Reflective.--A polished surface such as aluminum foil which has high reflectivity and low emissivity.

k (see Thermal conductivity)

Perm.--A measure of vapor movement through a material, i.e. grains per square foot per hour per inch of mercury difference in vapor pressure at standard test conditions.

Permeance.--Rate of water vapor transmission through a material, measured in perms. Thus, the lower the permeance, the better the vapor barrier.

R.--Resistance of a substance or assembly to heat transfer.

Radiation (see Energy transfer)

Relative humidity.--The amount of water vapor expressed as a percentage of the maximum quantity that could be present in the atmosphere at a given temperature. (The actual amount of water vapor that can be held in space increases with the temperature.)

Roll roofing.--Roofing material composed of fiber saturated with asphalt and supplied in 36-inch-wide rolls which cover 100 square feet including a lap seam. It can be obtained in weights of 45 to 90 pounds per roll.

Sheathing paper.--A paper for use between wood board sheathing and the exterior covering to reduce air infiltration. Materials such as 15-pound asphalt felt or red rosin paper with a perm value of 5 or greater is commonly used.

Thermal conductivity (k).--The amount of heat expressed in British thermal units (B.T.U.) that will pass through 1 square foot of uniform material, 1 inch thick, in 1 hour when the temperature difference between surfaces of the material is 1° F. The lower this value the better the material is for insulating purposes.

U.--Overall heat transmission coefficient; the amount of heat expressed in British thermal units transmitted in 1 hour through 1 square foot of a building section for each degree temperature difference between air on the inside and air on the outside of the building section.

Vapor barrier.--A film, duplex paper, aluminum foil, paint coating or other materials which restrict the movement of water vapor from an area of high vapor pressure to one of lower pressure. Material with a perm value of 1.0 or less is normally considered a vapor barrier.

Vapor permeability.--The property of a material that allows the passage of water vapor.

Vapor, water.--Water vapor is an invisible gas present in varying amounts in the atmosphere. There is a maximum amount that can be held at a given temperature.

Ventilation.--The replacement, by outside air, of the air within the building.