II.

Basics of Moisture: Sources, Mechanics, Problems

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MOISTURE IN BUILDINGS

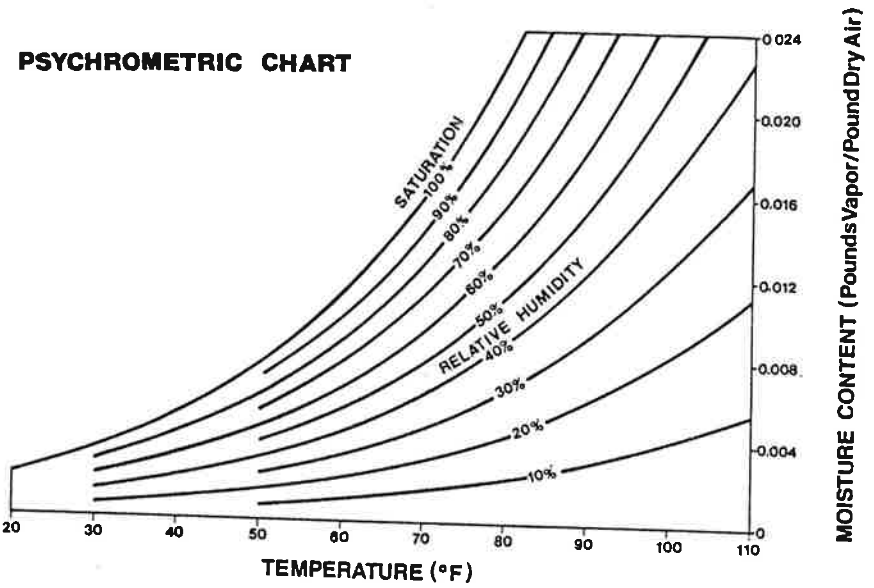
- SOURCES OF MOISTURE
  - INTERIOR

    PEOPLE (BREATHING/PERSPIRING)
    PLANTS
    BATHING/SHOWERING
    FLOOR WASHING
    COOKING
    DISH WASHING
    CLOTHES WASHING/DRYING
    UNVENTED COMBUSTION
      GAS (E.G. STOVE), OIL, KEROSENE, PROPANE
    HUMIDIFIERS, (CENTRAL, PORTABLE)
    GREENHOUSES
    HOT TUBS, SAUNAS, WHIRLPOOL BATHS, INDOOR POOLS
    FIREWOOD
    WET NEW BUILDING CONSTRUCTION MATERIALS
      WOOD, CONCRETE, MASONRY, SHEETROCK
      TYPICALLY MAJOR MOISTURE SOURCE DURING FIRST YEAR OR TWO
    BATHROOM, KITCHEN PLUMBING LEAKS
  - EXTERIOR

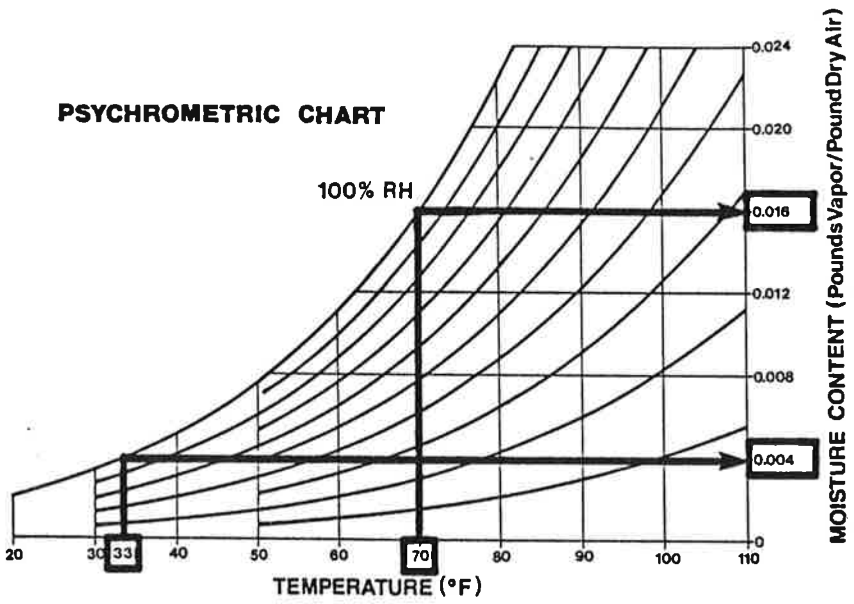
    LEAKS INTO BUILDING - RAIN, ICE, SNOW PENETRATION
      ROOF, WINDOW, SIDING LEAKS, ETC.
    SOIL (CRAWL SPACE)
    CONCRETE FLOOR SLAB, CONCRETE BASEMENT/FOUNDATION WALLS
    SURFACE RUNOFF, FLOODED CRAWLSPACE OR BASEMENT
    DRAINAGE SYSTEMS

- SEASONALLY STORED MOISTURE
  - MOISTURE IS CYCLICALLY STORED IN AND RELEASED FROM FURNISHING AND INTERIOR CONSTRUCTION MATERIALS
  - IN NORTHWEST, MATERIALS GAIN MOISTURE IN WINTER AND DRY OUT IN SUMMER
  - WOOD FRAMING MEMBERS CAN SAFELY STORE MANY MONTHS WORTH OF INTERNALLY GENERATED MOISTURE

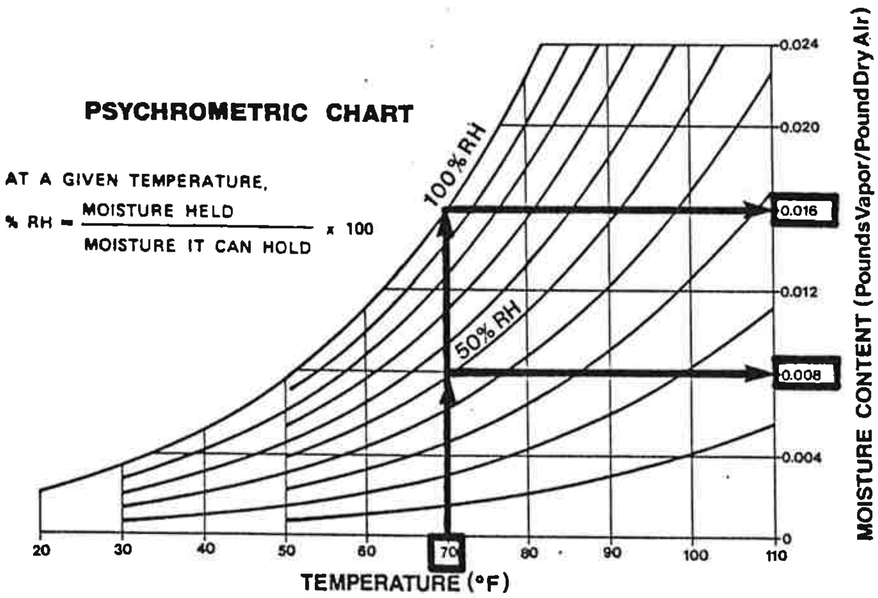
- <u>MOISTURE TRANSFER IN HOMES</u>
  - BASICS OF MOISTURE IN AIR



- ABSOLUTE HUMIDITY IS POUNDS OF WATER VAPOR CONTENT PER POUND OF DRY AIR

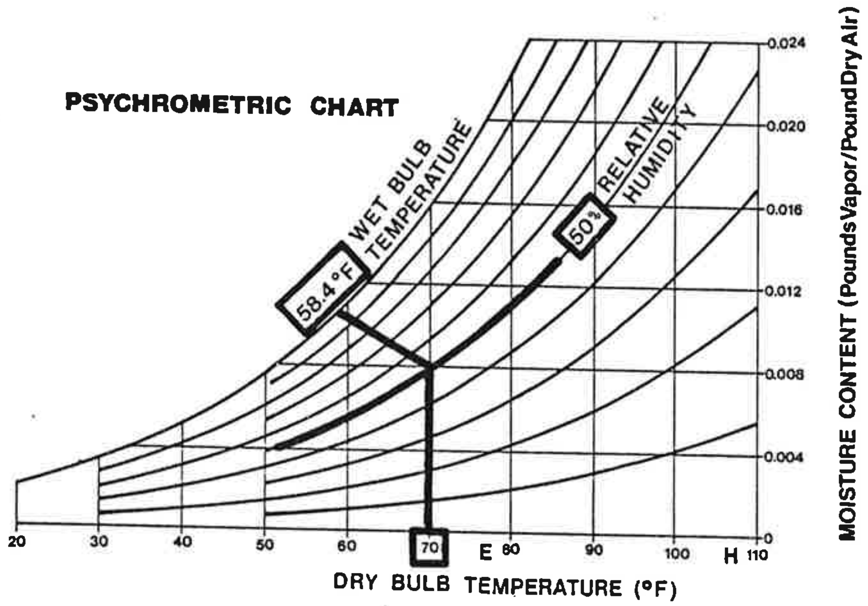


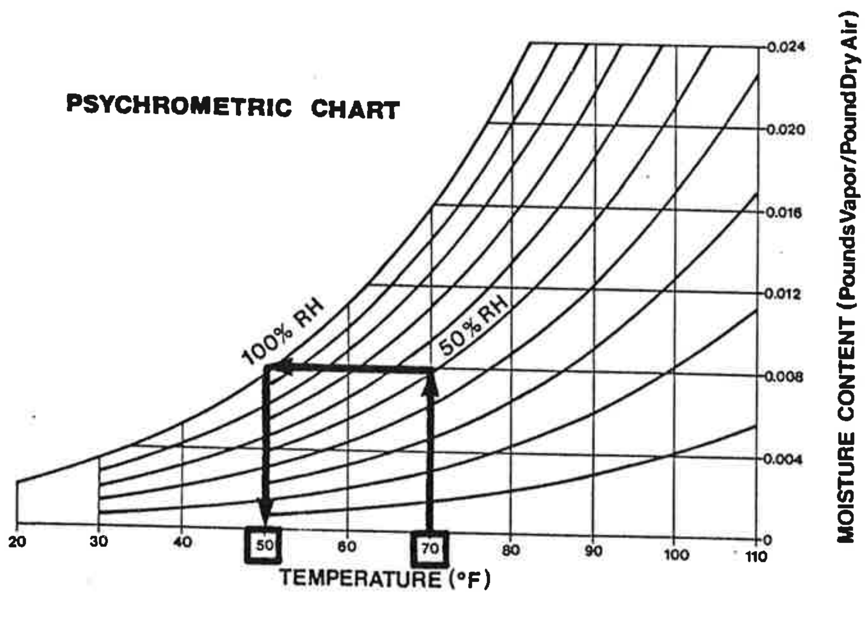
- WARM AIR CAN HOLD MORE MOISTURE THAN COLD AIR



- AT 100% RH, AIR IS SATURATED AND HOLDS THE MAXIMUM MOISTURE IT CAN HOLD IN VAPOR FORM

- PSYCHROMETER USED TO MEASURE WET AND DRY BULB AIR TEMPERATURES TO DETERMINE RELATIVE HUMIDITY
  - DRY BULB TEMPERATURE FROM DRY THERMOMETER
  - WET BULB TEMPERATURE FROM THERMOMETER WITH
    - WET WICK SURROUNDING BULB - EVAPORATION REDUCES TEMPERATURE OF WET BULB





- DEW POINT TEMPERATURE IS THE TEMPERATURE AT WHICH, WHEN MOIST AIR IS COOLED, THE AIR IS SATURATED WITH MOISTURE AND THE WATER VAPOR IN THE AIR BEGINS TO CONDENSE OR LIQUIFY OR FORM "DEW"

- IF CONDENSATION APPEARS ON THE INSIDE SURFACE OF WINDOW GLASS, THEN FOR ROOM AIR AT 70°F AND 50% RH, THE TEMPERATURE OF THE GLASS MUST BE BELOW 50°F (THE AIR'S DEW POINT)

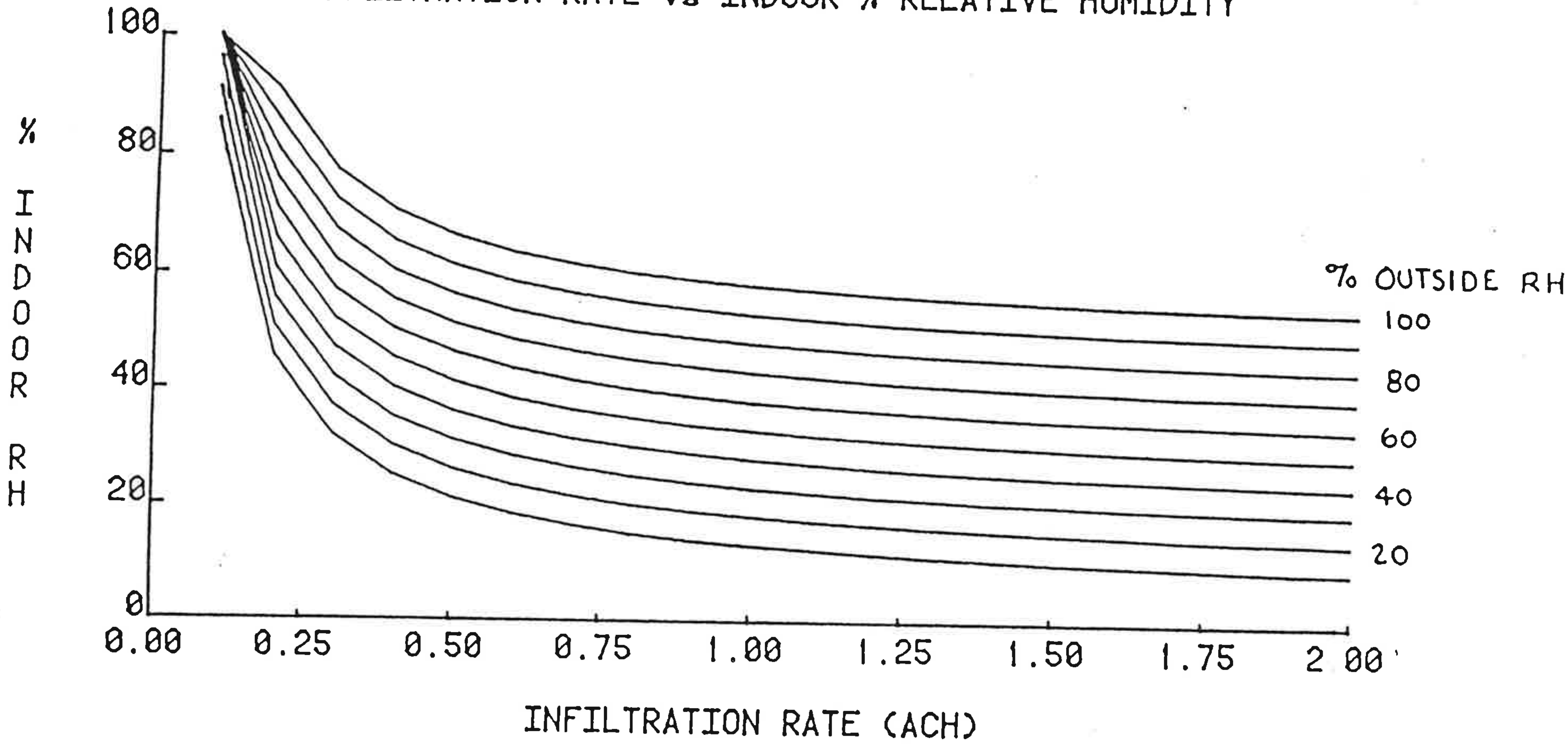
- OUTDOOR AIR AT TEMPERATURES BELOW 50°F IS ALWAYS "DRIER" THAN AIR AT 70°F AND 50% RH

- INFILTRATION OF COLD, DRY OUTDOOR AIR REDUCES INDOOR AIR RH; WHEN OUTDOOR AIR AT 42°F, 80% RH IS HEATED TO 70°F, ITS RH DROPS TO 30%

- DESIRABLE INDOOR RELATIVE HUMIDITY LEVEL
  50% RH FOR BEST HEALTH AND COMFORT
  LESS THAN 30% RH PRODUCES STATIC ELECTRICITY, DRY SKIN, AND NASAL DISCOMFORT
  GREATER THAN 70% PRODUCES MUSTINESS AND MOLD/MILDEW GROWTH
  LOWERING INDOOR RH LEVELS REDUCES OR ELIMINATES WINDOW CONDENSATION

- HOME MOISTURE BALANCE
  MOISTURE CONTINUOUSLY ADDED TO INTERIOR SPACE
  MOISTURE REMOVED BY EITHER NATURAL AIR LEAKAGE OR MECHANICAL VENTILATION SYSTEMS
  MOISTURE BALANCE: IF INDOOR RELATIVE HUMIDITY IS CONSTANT, MOISTURE INPUT RATE MUST EQUAL MOISTURE REMOVAL RATE
  EFFECT OF AIR LEAKAGE ON INDOOR RELATIVE HUMIDITY
  INDOOR RELATIVE HUMIDITY RISES SIGNIFICANTLY AS AIR LEAKAGE REDUCED BELOW ONE HALF AIR CHANGE PER HOUR

INFILTRATION RATE vs INDOOR % RELATIVE HUMIDITY



******************** INPUT DATA ********************

OUTSIDE TEMPERATURE = ... 47 F
ATMOSPHERIC PRESSURE = ... 14.7 PSI
INDOOR DESIGN TEMPERATURE = ... 68 F
INDOOR MOISTURE PRODUCTION RATE = . . 20 LB H2O/DAY
BUILDING'S FLOOR AREA = ... 1200 SQ. FT
BUILDING'S CEILING HEIGHT = ... 8 FT

- MECHANISMS OF MOISTURE MOVEMENT THROUGH WALLS
  - DIFFUSION
    - CAUSED BY VAPOR PRESSURE DIFFERENCE
    - HIGHER VAPOR PRESSURE INSIDE HOUSE CAUSES MOISTURE TO DIFFUSE TOWARDS OUTSIDE
  - AIR MOVEMENT (AIR CONVECTION OR AIR LEAKAGE)
    - INFILTRATION/EXFILTRATION RESULTS IN AIR MOVEMENT THROUGH WALL CAVITY
    - CAUSED BY:
      - WIND PRESSURE (MORE MOISTURE ON LEE SIDE)
      - HOUSE STACK EFFECT (WARM AIR RISING DRAWS IN COOLER OUTDOOR AIR)
      - CHIMNEY EFFECT (INFILTRATION RESULTS FROM SUCTION CAUSED BY CHIMNEY DRAFT)
    - CONVECTION IS MAJOR MECHANISM CAUSING MOISTURE TRANSFER THROUGH WALL CAVITY
  - CAPILLARY ACTION
    - LIQUID WATER MOVEMENT THROUGH POROUS MEDIUMS (E.G. SOIL, CONCRETE, WOOD, INSULATION)
  - MOISTURE STORAGE
    - WOOD CAN ADSORB/ABSORB AND STORE CONSIDERABLE MOISTURE
  - VARYING INDOOR AND OUTDOOR CONDITIONS (NONSTEADY EFFECTS)

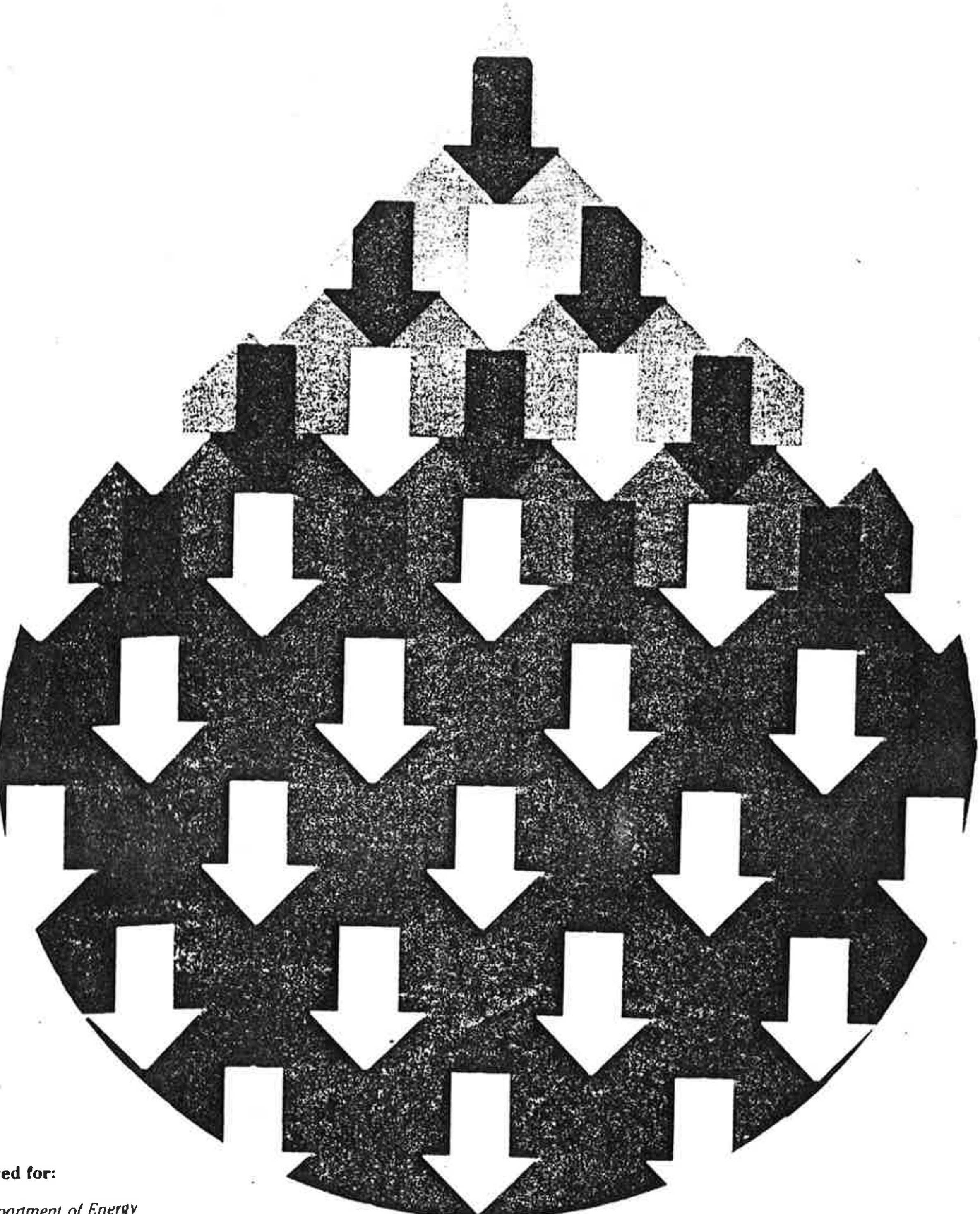
- EXCESS MOISTURE PROBLEMS
  - ODORS, MUSTINESS, DAMPNESS
  - WINDOW CONDENSATION/SWEATY PIPES, TOILETS
    - GOOD INDICATOR OF HIGH RELATIVE HUMIDITY
  - ATTIC CONDENSATION

- MOLD/MILDEW/STAINS/DISCOLORATION
  - WHERE FOUND AND WHY
    - INSIDE SURFACES OF EXTERIOR WALLS/CEILINGS
      - HIGH RELATIVE HUMIDITY
      - COLD SURFACES DUE TO MISSING INSULATION OR THERMAL SHORT CIRCUITS
  - ESTHETIC AND POSSIBLY HEALTH PROBLEM
  - CAN BE OK - DIFFERENT FUNGI THAN DECAY FUNGI
- DRY ROT/WOOD DECAY
  - CAUSED BY FUNGAL GROWTH
  - REQUIRED CONDITIONS FOR GROWTH
    - WARM TEMPERATURES (75°-90°F OPTIMUM, NO GROWTH BELOW 50°F)
  - HIGH MOISTURE CONTENT (GREATER THAN FIBER SATURATION POINT - 30%; NO GROWTH BELOW 20%)
  - WOOD NORMALLY WILL NOT DECAY IN WINTER BECAUSE CONDITIONS NOT RIGHT; IN SUMMER WOOD NORMALLY DRIES OUT, EXCEPT FOR LEAKS OR LACK OF PROPER VENTILATION
- BLISTERING/PEELING PAINT
  - MOISTURE OFTEN BLAMED
  - MOST LIKELY DUE TO POOR SURFACE PREPARATION/PAINT
- WOOD SIDING SHRINKAGE, CUPPING, CRACKING
  - OCCURS WHEN MOIST WOOD DRIES OUT
- HARDBOARD SIDING BUCKLING
  - MOISTURE SOMETIMES BLAMED
  - NORMALLY CAUSED BY IMPROPER NAILING
- BASEMENT DAMPNESS AND LEAKAGE
  - OFTEN CAUSED BY LEAKY FOUNDATION WALLS, POOR FLASHING DETAILS, OR INADEQUATE FOUNDATION DRAINAGE

September 1983

MOISTURE AND HOME ENERGY CONSERVATION

How to Detect, Solve and Avoid Related Problems



Prepared for:

U.S. Department of Energy
Assistant Secretary, Conservation and Renewable Energy
Small Scale Technology Branch
Appropriate Technology Program
Under Contract No. DE-AC01-82CE15095

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PREFACE

From 1978 to 1981, the Department of Energy (DOE) awarded more than 2,000 small grants to individuals, organizations and small businesses across the nation to research and demonstrate appropriate technologies. Grants were given in the general areas of conservation, solar, biomass, wind, geothermal, and hydro power. During 1983, the National Center for Appropriate Technology (NCAT) was placed under contract to review final reports from each DOE grantee in an effort to extract new ideas and other proven concepts that could be of value to the public in their search for methods to apply appropriate technologies to their energy problems.

This booklet is only one in a series of publications that focuses on appropriate technologies and their application in the home and the work place. These publications combine a qualitative assessment of the DOE grant projects by the NCAT technical staff along with the results of current research for the particular technology highlighted in this document. At the back of this publication there is a list of pertinent projects reviewed in preparation of this document.

Prepared By

Ncat the National Center for Appropriate Technology

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MOISTURE AND HOME ENERGY CONSERVATION

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INTRODUCTION

As Americans work to save energy at home with conservation improvements, the potential for moisture damage is often overlooked. And, contractors, weatherization specialists and energy auditors are often at a loss to explain, prevent or correct moisture problems that stand in the way of their work.

During 1978-1981, the U.S. Department of Energy (DOE) funded a wide range of energy conservation research and demonstration projects through its Appropriate Technology Small Grants Program. A review of many projects reveals that as new techniques are employed to save home heating or cooling energy, special attention must be given to preventing moisture problems.

Grantees developed a variety of energy-conserving designs for new construction and retrofit, some of which represent improvements in the way moisture is controlled. Others tried methods that might lead to moisture problems. Some grantees dealt directly with the moisture problem in the projects, and their experiences are reported in this publication.

To a large extent, using the experience gained through the DOE projects, this publication provides a systematic approach to understanding, recognizing, solving, and preventing moisture-related problems. Developed with the contractor, energy conservation specialist, or skilled homeowner in mind, the publication also will be of use for those who teach building technology.

Because excess moisture can cause a large number of problems—ranging from extreme discomfort in hot, humid weather to serious building damage—building specialists need a thorough understanding of the forces behind moisture's behavior in order to successfully correct or avoid many dilemmas.

To provide this understanding, this publication covers the following topics:

- why and where most moisture problems are likely to occur;
- symptoms, causes and the range of possible solutions to excess moisture;
- techniques used to remedy moisture problems, including vapor retarders, ventilation, drainage improvements and basement and foundation treatments;
- a generalized moisture audit methodology, including tests and tools needed for the job.

SECTION I

AT THE ROOT OF THE PROBLEM

Moisture problems can be tricky to solve, yet with an understanding of the basic controlling forces one can usually predict where, how, and when a moisture problem could occur. In this section, the roots of most moisture problems are explained, including climatic differences and the physical forces that can affect moisture. How weatherization affects moisture's behavior is emphasized, and the range of general solutions to moisture problems is covered, to allow the reader to relate basic principles described in this section to actual building practice.

Moisture Problems Can Vary by Region or Climate

Although moisture problems can surface almost anywhere in the United States if conditions are right, certain climate zones and regions are more prone to particular problems.

More than half the country is moderately or highly prone to wood decay due to outdoor humidity levels (see Figure 1). In many of these areas, mold, mildew, and rot are constant problems. High outdoor humidity can also lead to considerable summertime cooling and dehumidification expense, as well.

In locations where January temperatures average 35°F or below, wintertime condensation problems can occur (see Figure 2). Buildings in this region need special treatment to avoid condensation damage to building materials.

Although climate differences provide a framework for looking at the forces that control moisture, building design and construction and occupant behavior also play critical roles with moisture troubles.

WINTER CONDENSATION ZONE
(Adapted from USDA Forest Service Information Bulletin No. 373, USGPO)
AVE. JAN. TEMPERATURES OF 35°F OR BELOW
(AREAS WHERE VAPOR RETARDERS ARE RECOMMENDED)

FIGURE 2

DECAY PRONE AREAS
(Adapted from USDA Forest Service General Technical Report FPL-15, 1977)
HIGH
MODERATE
LOW

FIGURE 1

Moisture Transfer Methods

Moisture can be present in a home in three different forms: as a vapor (gas), liquid or solid. Thus, a number of physical factors influence moisture's behavior in a home. Water vapor travels in two principal ways—air movement and diffusion. Liquid water travels by capillary action (see Figure 3).

Air movement is the major water vapor transfer method, in that more moisture is moved by this means than by the others. Air movement is largely determined by several factors, including vapor pressure, wind, convection and temperature differences that set a "stack effect" in motion (see Figure 4).

In climates that require home heating in winter, *high water-vapor pressure* may be created indoors when moist air is heated. (Water-vapor pressure is the contribution made by water to the total atmospheric pressure.) Because high vapor pressure always seeks to move moisture toward areas of lower vapor pressure, this warm, moist air tends to be driven through cracks and holes in the building, where it can condense if temperatures are right, causing the potential for deterioration of building materials. In warm, humid climates that demand interior cooling, the high vapor pressure can come from the outdoors, pushing moist air toward the interior of the house.

As *wind* strikes a building, it creates additional air pressure effects. The upwind side of the building (the side hit by the wind) experiences higher pressure, with the wind pushing toward and into the building. Walls on the low-pressure or downwind side of the house may show more signs of moisture because the warm, moist air is being drawn to the outdoors through that section.

The *stack effect* illustrates the fact that warm air always rises. The higher the temperature of the air, the greater the upward thrust or buoyancy of that air. As warm air rises and escapes through the upper regions of the house, it creates a lower pressure situation in the lower areas. Cooler outdoor air is then pulled into the low pressure areas, and the cycle continues as this air is warmed and rises.

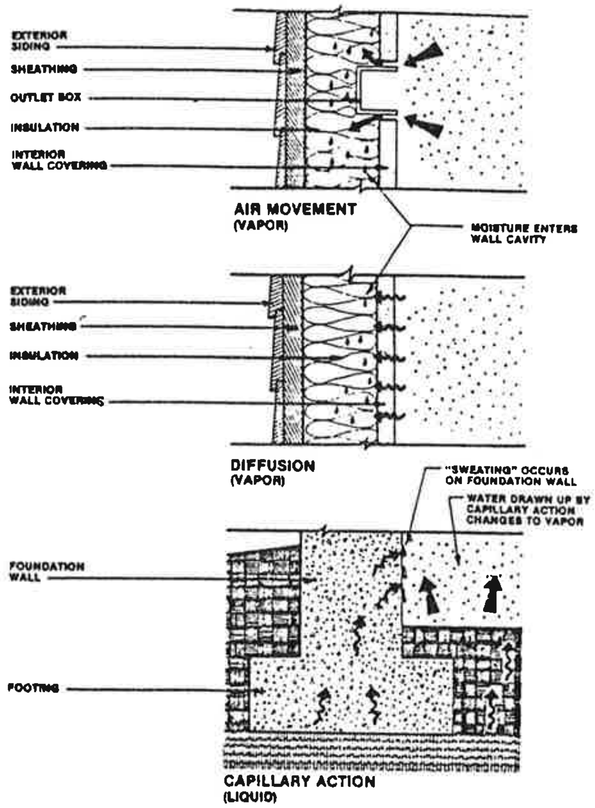


FIGURE 3: MOISTURE TRANSFER METHODS

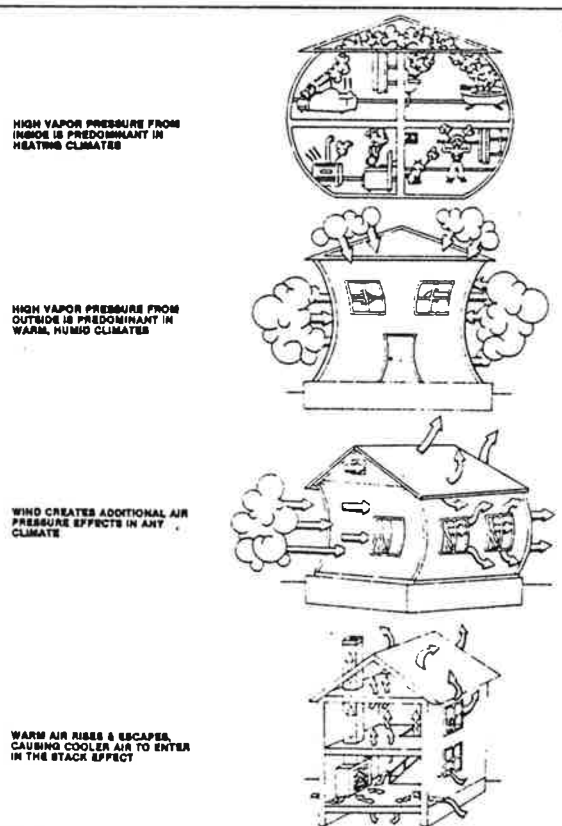


FIGURE 4

Convection describes the action of warm air moving upward until it is cooled or strikes cooler surfaces, such as windows. As the air is cooled, the amount of water vapor it can hold decreases, and condensation can take place. The cooled air then falls until it is reheated, and the process begins over again. Convection currents occur throughout the interior space of the home, powered by temperature differences. Air movement through convection can also happen in wall cavities and other enclosed areas of the building, which can reduce the thermal effectiveness of the insulation, as well as cause moisture problems (see Figure 5).

In cold climates, after a house has been weatherized by sealing, caulking and weatherstripping air leaks, air movement is reduced, and less heat and moisture escape. Tighter homes usually have greater comfort levels and lower fuel bills. However, if there are a significant number of moisture sources in a tight home, ventilation may not be great enough to remove moisture as fast as it is produced. And, in extremely tight houses, controlled ventilation through heat-recapturing devices, such as air-to-air heat exchangers, must be employed to remove normal moisture build-up and potential indoor air pollution.

After a house has been thoroughly sealed, moisture transfer through *diffusion* becomes more important. Because the amount of water vapor that escapes through air movement has been cut to a minimum, water vapor must find another avenue of exit. Water vapor always attempts to move from high vapor pressure areas to low vapor-pressure areas; thus, water vapor will pass directly or "diffuse" through building materials. Water vapor that penetrates a surface may be cooled to the point where it turns to liquid or ice, which creates the potential for damage.

Vapor retarders (also known as vapor "barriers") are allowed to slow diffusion through building materials. Good vapor retarders allow very little water to pass through them; they should always be located on the *warm side* of the wall, ceiling or floor surface. With some of the new cold-climate building technologies, vapor retarders are used to slow both air movement and water vapor diffusion. If used in this manner, the vapor retarder must be installed with great care; any air leakage points that remain will experience relatively greater vapor pressure, as water vapor works to escape through the easiest route.

(Adapted from USDA Forest Service Information Bulletin No. 373, USFPO)

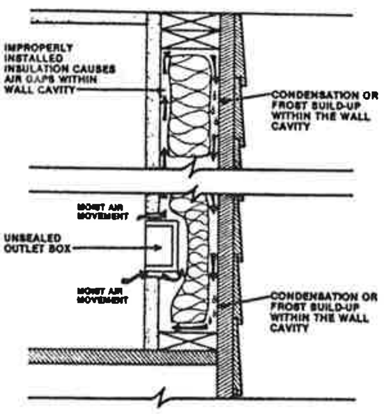
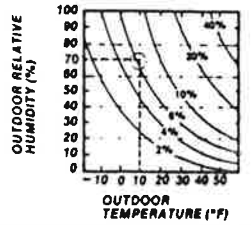
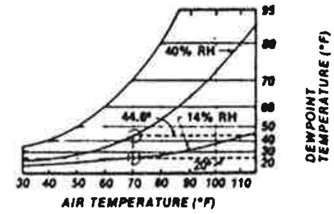


FIGURE 5: HOW CONVECTION CURRENTS BRING MOISTURE INTO WALLS AND REDUCE INSULATION EFFECTIVENESS.



APPROXIMATE RELATIONSHIP OF OUTDOOR TO INDOOR HUMIDITY AS A RESULT OF HEATING INFILTRATING AIR TO 70°F.



RELATIONSHIP OF DEWPOINT TEMPERATURE TO RELATIVE HUMIDITY (RH).

FIGURE 6

Vapor retarders also are used to reduce moisture transfer from *capillary action*, which involves liquid water being pulled from a source through a porous material, such as soil, that provides pathways for water transfer. In this use, vapor retarders don't actually stop the capillary action, but rather they prevent moisture from entering the air, which can then enter the house.

Relative Humidity and Dew Point

When designing an insulation job for new construction or retrofit for climates in the condensation zone (locations where January temperatures average 35°F or below), care must be taken to use vapor retarders effectively. This demands knowledge of the concepts of relative humidity and dew point temperatures.

Air temperature determines how much water vapor air can hold. Warmer air is capable of holding much more moisture than cooler air. The temperature at which air has been cooled to the point where water vapor condenses to liquid is called the "dew point."

One goal with vapor retarders is to keep the warm, moist air in the house from coming in contact with temperatures below the dew point. This is why vapor retarders are located on the warm side of the surface. The cold side of these surfaces must be backed with materials that can breathe, to allow any moisture that does not pass through to escape.

To determine the dew point temperature requires that one know the air temperature and relative humidity. Relative humidity describes the amount of moisture air holds relative to the maximum it could possibly hold at any given temperature. (Relative humidity should not be confused with *absolute humidity*, which simply describes the total amount of water vapor in the air.)

For example, assume that the outdoor air has a temperature of 10°F and 70 percent relative humidity. If this air enters a house where it is warmed to 70°F, the air's relative humidity would fall to 6 percent, because the warm air can hold so much more moisture than the cold 10°F air (see Figure 6). Cool, outdoor air will generally have higher relative humidity than warm, indoor air, yet the indoor air could have much higher absolute humidity.

The higher the relative humidity, the higher the dew point temperature. If a house has an air temperature of 70°F and the relative humidity is 40 percent, the surface temperature at which moisture will. condense is 44.6°F. If the relative humidity falls to 14 percent, the dew point temperature would fall to 20°F.

These examples illustrate that the higher the relative humidity in a house, the greater the chance that some surface will be cool enough (even in moderate or warm climates) to cause condensation. For this reason, keeping indoor relative humidity below about 45 percent, if possible, is a good way to avoid many moisture problems that may be related to constantly high indoor relative humidity.

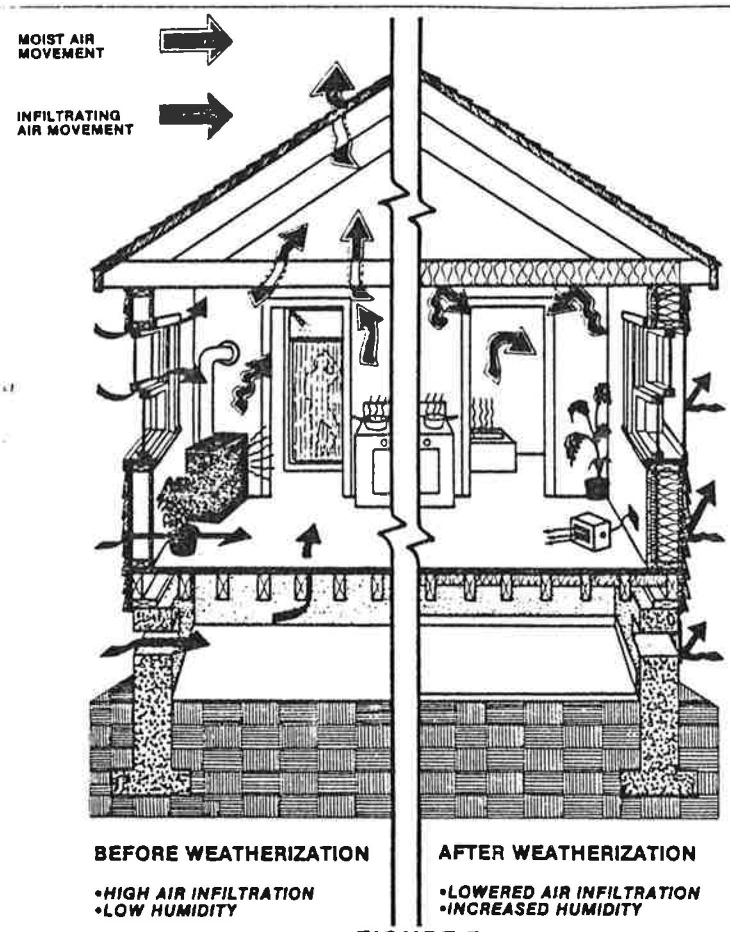


FIGURE 7

The relative humidity concept also explains why indoor air may become uncomfortably dry in cold climate homes during the winter. If the house has significant air infiltration, cool, outside air will be drawn into the house through cracks and leaks, where it will be warmed. Similarly, warm, indoor air will be pushed out of the house. The cool, outdoor air can absorb additional moisture as it is warmed, and it draws moisture from the air, surfaces, skin and other moisture sources. Thus, stopping air leaks in a house can save energy both from saved heat and the energy used to run humidifiers (see Figure 7).

On the other hand, this drying action can have a positive effect in humid climates. The process of drying air or wet surfaces involves four main actions: the intake of dry air, the warming of that air, the circulation of the air and the exhausting of the warm, moist air. The intake air must be drier than the air inside the house for drying to take place.

Effective drying involves good circulation and ventilation or exhaust. If air circulation is poor, moist air can become trapped and may not reach exhaust points in the house. Heat may not reach certain areas of the home, allowing some surfaces to cool to the point where moisture will condense and cause problems. Homes with good circulation can generally maintain somewhat higher indoor relative humidity without significant problems.

Obviously, a certain level of whole-house *ventilation* is needed to remove normal moisture and indoor air pollutant buildup from the usual activities of daily living. If the overall ventilation rate is too low, moisture problems may be the first sign that indoor air quality is less than adequate. However, localized ventilation in kitchens, baths and other high moisture areas can solve many moisture problems. If this spot ventilation is used regularly and a home still has significant moisture problems, the home probably has some major moisture sources that have been overlooked. Enclosed areas that are not heated or cooled, such as attics, crawlspaces, porches or basements need adequate ventilation and circulation to provide drying that helps avoid moisture build up and condensation damage.

The Moisture Balance

Four factors dictate whether a home's moisture balance will become uneven enough to cause problems. These four balancing factors are *source strength, temperature, moisture transfer rate,* and *circulation-ventilation rate.* In a home without moisture problems, these forces are typically in balance. These factors are critical to understanding and solving home moisture problems.

Source strength is often the most important factor, in that moisture problems can't exist without sources of moisture. Controlling the source of a moisture problem is usually the most productive and cost-effective approach to solving the dilemma. Examples of indoor source-reduction solutions include fixing plumbing leaks, reducing moisture from domestic activities and reducing humidifier use. Outdoors, source-reduction solutions include improving drainage, fixing leaks, and being aware of soaking and puddling from sprinkling. If sources can't be reasonably or affordably controlled, then it's time to try another route.

Temperature differences that promote unwanted condensation should be remedied. Temperature solutions include: bringing warm air to cold surfaces through improved heating patterns, insulating the surface against cold temperatures, installing vapor retarders, and simply being aware of temperature differences and not allowing warm, moist air to contact surfaces, such as walls in basements or crawlspaces.

The *moisture transfer rate* in a home can be altered in several ways. These moisture transfer solutions include sealing air leaks from inside the home, weatherizing before insulating, use of vapor retarders on the warm side of the wall or surface, use of ground-cover vapor retarders in crawlspaces, stopping all exterior leaks and puddling of water, and increasing the moisture resistance of exterior wood.

The *circulation-ventilation rate* of a home can be adjusted to help solve moisture problems. Venting moisture out of enclosed areas is a basic, common solution. Increased circulation and ventilation are also back-up options when internal moisture sources can't be reduced sufficiently. Circulation and ventilation solutions include installing properly sized vents located to promote circulation, using materials that can "breathe" on the cool side of moisture-resistant surfaces, using spot ventilation of high moisture areas such as baths and kitchens, using small, efficient fans to move internal air through a house, or use of air-to-air heat exchangers to exhaust moisture but reclaim heat or coolness.

SECTION II

SYMPTOMS, CAUSES AND BASIC SOLUTIONS TO EXCESS MOISTURE

Recognizing and diagnosing moisture problems is the first step in solving them. Once the symptoms and source of moisture have been positively identified, the problem usually can be approached in several ways. Some moisture problems can best be handled by a change in occupant habits or lifestyle, while other problems demand structural repair or other improvements that are best handled by a skilled person.

In this section, the common symptoms of excess moisture are identified, and the most common moisture sources, both inside the house and outside, also are listed. Following each moisture source, possible solutions to the problem are presented, to make the reader more familiar with the range of solutions that could be applied to each problem. Also, DOE project examples are given to illustrate how grantees discovered, dealt with or solved various moisture-related troubles.

Detailed information on tackling specific moisture problems is presented in the next section, *Fixing the Problems.*

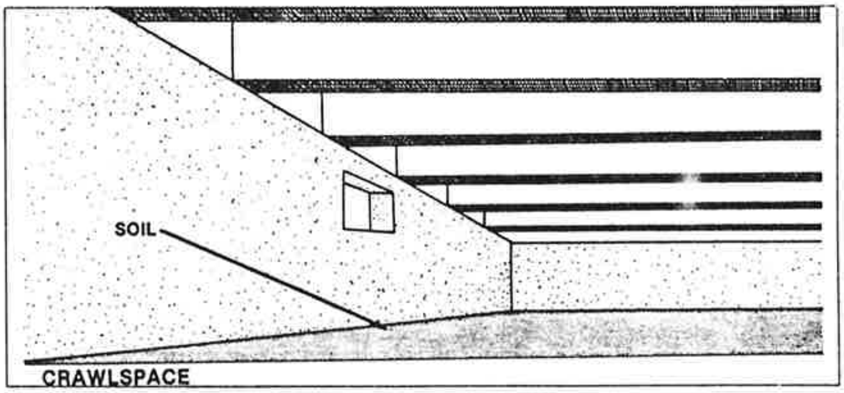
Defining the Problem: Symptoms of Excess Moisture

Symptoms of excessive moisture can usually be sensed in some way, though the process of detection can sometimes be difficult. Some symptoms are easily seen, while others demand the use of our senses of smell, touch or hearing. Successful detection is based on becoming aware, doing a thorough search and using all one's senses.

Many symptoms of excess moisture are readily apparent and not easily overlooked. Thus, focusing on the less-obvious symptoms is a good habit to adopt. Bear in mind that some moisture symptoms may be seasonal and may not be evident during the time of inspection. For example, the soil in a crawlspace may appear dry in mid-winter; however, the subsurface could have a high moisture source from summer irrigation, drainage, or ground water. One clue, in this situation, might be a damp feeling when entering this area.

One of the major challenges in solving excess moisture problems is that one symptom can have several causes. Conversely, one moisture source could be causing a large number of seemingly unrelated symptoms.

The following list describes the major symptoms commonly encountered in homes with moisture problems:



- **Odors**—Odors increase in intensity with high relative humidity. Musty odors may signal mold, mildew or rot. Also, odors from everyday household activities that seem to linger too long may be a signal of less-than-adequate ventilation.
- **Damp feeling**—The sensation of dampness is common in areas with high relative humidity.
- **Mold, mildew**—Growths of mold or mildew can often be seen in the form of a discoloration, ranging in color from white to orange, from green to brown to black. If they can't be seen, they may often be noticed as a musty odor. Mold and mildew are surface conditions that may indicate that conditions favoring decay are present.
- **Discoloration, staining and texture changes**—These are usually indicative of some degree of moisture damage, no matter what the material. These changes may appear as black or dark streaks or lines, which border a discoloration. The area in question may not be wet at the time of inspection, but it obviously has been subject to some moisture source.
- **Rot, decay**—Rot and wood decay indicate advanced moisture damage. Unlike surface mold and mildew, wood decay fungi penetrate the wood and make it soft and weak. Look for any type of rot or fruited bodies (mushroom-like growths). (Refer to the Pick Test in Appendix A for more information on detecting wood decay.) Decay fungi grow in a temperature range from just above freezing to 100F. Wood decay usually happens at a fast rate in the middle temperature ranges, 50°F to 75°F if wood is more than 30 percent saturated with moisture. Fungi growth is slow below 50°F and above 90°F. At below freezing, fungi go dormant, and at 150°F, most spores are killed.
- **Water-carrying fungus**—This fungus is special—it carries water across surfaces, sometimes to distant locations. It looks like a fan, with vine-like strands emanating from it. These growths are papery,

and usually have a dirty, white color with a tinge of yellow. This fungus fan can spread over moist or dry wood, and can be found under carpet, behind cupboards, on framing between subfloors or on damp concrete foundations.

- **Fogging windows**—Condensation on windows and other smooth surfaces can be a sign of excess moisture, or the need to insulate or warm the surface in question. Another possibility is a faulty heating plant, or some other flame-fired appliance, which is causing excess moisture and combustion gases to enter the living space. Physical symptoms include frequent headaches, drowsiness, or other unexplainable illnesses. This possibility should be checked at once.
- **Sweating pipes, water leaks and dripping**—Water vapor may be condensing on cold pipes, or the pipes may be leaking.
- **Frost and ice**—Roof ice dams occur both in roof valleys (where two roof lines meet) and along the eaves. They frequently occur when there is insufficient ceiling or attic insulation and poor ventilation in the roof, problems that are aggravated by the freeze-thaw cycle. Snow or ice melts as the sun strikes the roof and as the interior roof surface is warmed from within. This moisture freezes again when temperatures drop, forming dams that impede drainage. Ice can build up under shingles, which eventually can result in moisture penetrating into the attic when temperatures rise. Frost or ice on any surface is an indication of possible trouble.
- **Paint peeling, blistering or cracking**—Moisture may be working from outside or inside the home to damage paint. A major signal of moisture-caused paint damage is when the raw surface is exposed between cracks or under blisters.
- **Corrosion**—Corrosion, oxidation and rust on metal is a sure clue that moisture is at work.
- **Deformed wooden surfaces**—Wood swells when it becomes wet, and it warps, cups, and cracks when allowed to dry. Shrinking, warping wood can cause new air leaks in the home, making it less energy efficient.
- **Concrete and masonry efflorescence and chipping**—Concrete or masonry may show sign of "efflorescence"—a white, powdery substance or line—after moisture has moved through it. Freeze-thaw cycles speed the process of deterioration, causing chipping and crumbling.

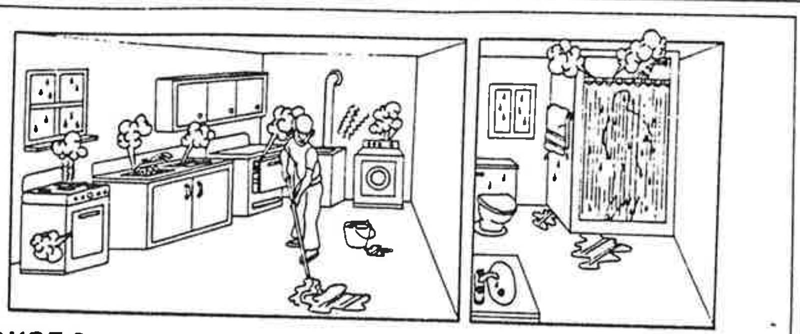


FIGURE 8: NUMEROUS DOMESTIC MOISTURE SOURCES CAN CAUSE EXCESS MOISTURE AND HIGH INDOOR RELATIVE HUMIDITY.

Common Causes and Basic Solutions to Moisture Problems

Sources of moisture can be found both inside and outside the home. Outdoor moisture sources usually stem from three main causes: poor drainage, blocked air circulation and high outdoor relative humidity. Indoors, the situation is more varied and complex; sources range from cooking habits to poor circulation. By focusing on the more common moisture sources and possible solutions to each problem, the reader can become familiar with the problems to be experienced in the home.

Indoor Causes

Continually High Relative Humidity Indoors—Many sources of excess moisture can lead to continually high indoor relative humidity levels. Prolonged high indoor relative humidity—above about 45 percent—can cause a wide variety of problems. Check each possible moisture source, and take corrective action. If in doubt, test for relative humidity, using the Relative Humidity Test described in Appendix A.

Too Many Occupants; Small Buildings—People, pets and domestic activities generate moisture; buildings under 800 square feet tend to be more prone to moisture problems. Check how many occupants (both people and pets) live in the building. If there is less than 250 square feet of living space per person or pet, there could be a problem. Also watch for seasonal changes in occupancy.

Possible Solutions: If occupancy exceeds the above guidelines, step up circulation and ventilation. Consider dehumidification. Alert occupants to try to reduce interior moisture sources in any reasonable manner. Look for moisture damage in attics, around windows and doors and other likely areas, and take action if needed.

Too Many Internal Sources from Domestic Activities—Unvented bathrooms and kitchens are a common problem; cooking without lids, open-flame heating and cooking appliances, bathing, and hanging wet clothing and towels inside to dry can produce excessive moisture (see Figure 8). Low-volume shower heads save energy, but generate greater amounts of water vapor. In addition, houseplants and aquariums without covers can produce a considerable amount of moisture. Don't vent clothes dryers to the indoors; air pollution may result from lint and laundry products, and excess moisture may become a problem. Drying firewood inside the home may produce excess moisture.

Possible Solutions: Use existing exhaust equipment in kitchens and bathrooms. Vent clothes dryers to the outdoors. Install exhaust fan vents in the kitchen and bath if they aren't present. If appropriate, ask occupants to become aware of moisture-generating activity and voluntarily reduce moisture production. Step up overall ventilation, if necessary, through windows, whole-house or local exhaust fans, or consider installing an air-to-air heat exchanger if appropriate.

Inadequate Circulation and Ventilation—Moisture becomes trapped when air circulation and ventilation are inadequate. Inside the home, poor circulation of heat can lead to condensation problems, and inadequate ventilation of high moisture areas such as kitchens and baths can lead to damage. If the house has inadequate ventilation overall, moisture problems may be the first clue. In attics, crawlspaces and other unconditioned structural spaces, poor circulation or ventilation can cause a variety of problems. For instance, roof ice dams as well as attic condensation problems may be caused by trapped air when ceiling insulation touches roof sheathing, without allowing for proper circulation.

Possible Solutions: Install externally venting fans in kitchens and baths if needed. For localized moisture problems in the home, especially unstoppable condensation, try aiming a small fan at the area to better circulate warm air. Provide circulation and ventilation inside the home by opening windows, considering cross-ventilation, and similar strategies. An air-to-air heat exchanger should be considered if the house has been built or retrofitted with an air-tight vapor retarder. If a significant amount of ventilation is needed, a central exhaust fan could also be considered. Install any needed vents in attics and crawlspaces or other structural spaces. Check insulation for any needed repair or re-installation.

Improper Temperature Differences, Lack of Insulation—When warm, moist air hits a cold surface, condensation can sometimes cause water or frost damage, or lead to the growth of mold or mildew. Rooms shut off from heating sources or used only intermittently (such as bedrooms or closets) are prime problem areas. Uninsulated walls and windows in heating-season climates, and wall, ceiling or floor areas where insulation is missing or has shifted are other key locations for this type of problem (see Figure 9).
Possible Solutions: In heating-season climates, seal the infiltration leaks first, then insulate, employing proper vapor retarder techniques. Check existing insulation. Insulate windows with additional glazing or treatments that seal around all edges. If insulation is impossible, continuous circulation of air with a fan in the problem area will help prevent condensation. For closets or other out-of-the-way places, better air and heat circulation can be achieved by leaving doors open or installing louvered doors.

Lack of or Improper Placement of Vapor Retarders—If you are in a climate where vapor retarders are called for, action may be needed. New, tightly built and well-insulated homes or homes that have been thoroughly weatherized have a greater need for a durable vapor retarder that has been carefully installed on the warm side of the surface to stop moisture transfer through building materials. If the vapor retarder is installed haphazardly, every point subject to air leakage will experience pressure, and condensation may be damaging. Improper placement of vapor retarders is not uncommon. For example, if

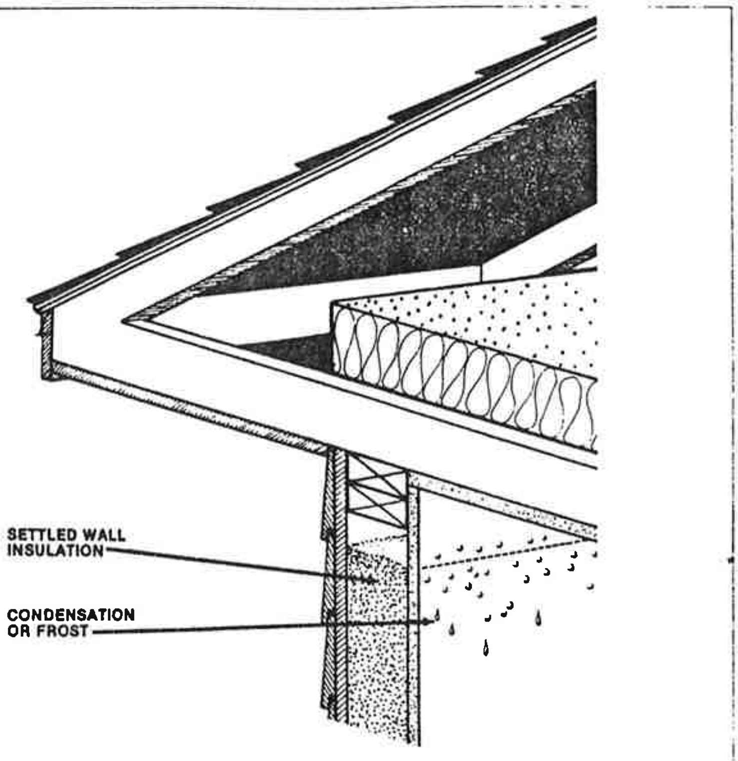


FIGURE 9: SETTLED WALL INSULATION CAN LEAD TO CONDENSATION OR FROST ON COLD SURFACES.

a building material that is, in fact, a vapor retarder has been installed on the cold side of the wall surface, moisture may be condensing in the walls. If a low-perm vapor retarder is used on two sides of a wall surface, moisture may build up without an avenue of escape. In areas of high ground water, the lack of a gound-cover vapor retarder in the crawlspace may allow water vapor to constantly enter the dwelling, leading to a variety of problems.
Possible Solutions: Inspect materials on the cold side of the home's envelope to determine whether a sheathing or siding may be acting as an unwanted vapor retarder. Search for places where the vapor retarder may not have been installed, such as the rim joists, between floors. Install vapor retarders where they are needed, in conjunction with insulation work. Always use materials that can breathe on the cool side of walls, ceilings or floors once vapor retarders are in place.
Examples: *A Nebraska Department of Energy Appropriate Technology grantee experimented with a double-wall, pole frame home construction system, to create a wall cavity that would hold from 8 to 10 inches of insulation. A polyethylene vapor retarder was employed on the inside, or warm, surface of the walls. However, joints and penetrations in the vapor retarder were not sealed. The result was that air infiltration caused a serious heat loss. If a vapor retarder is used to stop both moisture transfer and air leakage, the retarder must be installed with great care, making sure that all penetrations, joints and other breaks are sealed.*

A number of grantees reported installing vapor retarders on both sides of a wall surface. One grantee used this method when retrofitting a multi-unit row house. A 4-mil polyethylene vapor retarder was used as a sound insulator on both sides of a party wall, between units. The seal with the vapor retarder was not airtight, thus moisture could accumulate in the wall cavity. Double vapor retarders must be avoided, if moisture is to be controlled. This involves using vapor retarders on the warm side of the wall, ceiling or floor surface and a breather material on the cool side, to allow any moisture that passes through to escape. Generally, vapor retarders should not be used in party walls.

New Construction, Retrofit or Remodeling—New foundations, concrete floors, brick fireplaces, taping of sheetrock, painting, green lumber, wet wood or uncured masonry materials contain an enormous amount of moisture until the dwelling has dried. New, tightly constructed homes are more prone to this problem and may take longer to dry.

Possible Solutions: To facilitate the drying process, increase ventilation and circulation, both during the building process, if possible, and during the first year of occupancy. Avoid humidifier use.

Example: *A Vermont Appropriate Technology grantee, working with air-to-air heat exchanger, reported that construction drying can be speeded by installing and using the heat exchanger before construction is complete. In one test, an air-to-air heat exchanger was installed in one house on a multi-house construction site, and it was operated to reduce interior humidity from the newly installed gypsum board. The grantee reported that the walls of the house with the heat exchanger in use were dry and ready for paint in one-quarter to one-fifth the time required by the other houses (see Figure 10).*

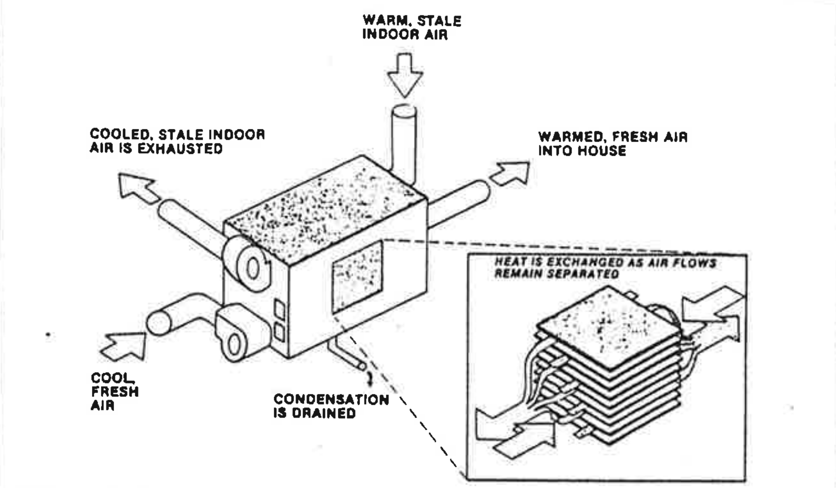


FIGURE 10: AIR-TO-AIR HEAT EXCHANGERS RECAPTURE HEAT FROM THE STALE EXHAUST AIR AND CAN REDUCE INDOOR HUMIDITY.

Faulty or Problem Flame-fired Heating Plants—Faulty flame-fired appliances used for heating, water heating or cooking can be sources of moisture problems. Without adequate combustion air, these appliances can spill water vapor and deadly, odorless carbon monoxide gas into the living area. Incomplete combustion is revealed by an excessively yellow or wavy flame, and can cause drowsiness, recurring headaches or even death. Windows that fog for no apparent reason are another clue. Other types of heating systems may also influence moisture's behavior in the home. Note that liquid propane gas produces more moisture during combustion than other systems. If wood heat is used, wood stored inside the home may be producing excess moisture. And, in tightly built all-electric homes that have no chimneys, normal internal moisture sources can occasionally present problems.

Possible Solutions: Check for blocked furnace vents, a chimney blockage, a chimney that is too short, insufficient combustion air or whether the system is vented at all (unvented gas and kerosene heaters). If you suspect the flame-fired heating plant is faulty in any way, call for help from the local utility or a contractor. Don't wait. If wood heat is used, store wood outside the home, when possible.

Example: *The family of one Ohio Appropriate Technology grantee began experiencing unusual colds and frequent headaches. The grantee's house was extremely tight, and he traced the problem to his gas hot water heater. After the grantee isolated the water heater with insulated walls and ducted in outdoor combustion air, the family's symptoms ended.*

Problem Cooling Systems and Humidifiers—Evaporative coolers (commonly known as "swamp coolers"), humidifiers and air conditioning units all can be sources of excess moisture or moisture problems. A swamp cooler operates by drawing outside air through louvers in the cabinet where it passes water soaked pads. The water in the pads absorbs the heat from the air. Water is automatically metered into the cooler to replace evaporation losses, thus a swamp cooler is a constant source of moisture. The process of evaporation cools the air, while increasing indoor relative humidity. These coolers are effective in dry climates, but they may cause major excess moisture problems in humid, warm locations. Used in a new or newly retrofitted house, humidifiers only add to construction moisture. Also, humidification after a house has been weatherized or tightened to reduce air leaks can cause trouble. With air conditioners, condensation is sometimes a problem on ductwork or in floors.

Possible Solutions: For swamp coolers, avoid use in high humidity climates. If internal moisture or relative humidity becomes too high, discontinue use. Use humidifiers only when needed. Otherwise, avoid them. An unnecessary central humidification system can be disconnected, saving energy. The main overall action for air conditioners is to keep the thermostat setting at 75°F or above, to help save cooling dollars and to keep surface temperatures above the dew point. Drain air conditioning condensation to the sewer system or the outdoors, not the crawlspace. Check for adequate crawlspace ventilation. Check for air conditioning ducts, and seal, insulate and add vapor retarders where needed.

Plumbing Leaks—The best way to check for plumbing leaks is to run each part of the system for 10-15 minutes and watch and listen for leaks. Check all accessible connections, and thoroughly inspect the house during the process. Leaking pipes may be buried in a concrete slab floor or hidden in the walls. Find and fix all leaking plumbing.

Attached Horticultural Greenhouses— Because of its many moisture sources, the attached greenhouse can cause moisture problems indoors. Plants prefer relative humidity levels under 70 percent; higher levels cause greater leaf production at the expense of the fruit or vegetables. Check relative humidity in the greenhouse over time. Attached greenhouses can cause moisture problems in the wall they are attached to, through condensation. In addition, drainage may be a problem.

Possible Solutions: Above all, provide adequate circulation and ventilation in the greenhouse. If greenhouse relative humidity is high, avoid venting into the home. Provide proper exterior drainage away from the house and the greenhouse. Avoid excess watering of plants. Use proper vapor retarder and insulation techniques.

Example: *A Vermont Appropriate Technology grantee, developed a simple concentric tube air-to-air heat exchanger for greenhouses that may have applicability for residential greenhouse use. This type of heat exchanger could be employed to deliver low-humidity warm air to the living space, thus avoiding moisture problems that stem from direct venting of greenhouse air into the home.*

Outdoor Causes

Poor drainage—This is the major exterior moisture dilemma. With bermed or earth-sheltered construction and for foundations in general, proper drainage is especially critical. If drainage problems cannot be properly corrected, try increasing resistance to moisture through the use of wood preservatives, dampproofing and waterproofing. General solutions to each problem are described below (see Figure 11).

Surface water: Poor drainage of water and moisture from rain and snow, and irrigation of nearby foliage and lawns is common, especially in locations with clay-type soils.
Possible Solutions: Check for blocked downspouts and gutters, or lack of rain gutters. Check for cracks in foundations, and install proper dampproofing. Check for proper soil slope away from the house. In new construction, use proper perimeter footing drain.
Example: *A Kansas Appropriate Technology grantee wanted to build a bermed house on a hillside. The grantee noted that homes in the vicinity suffered from flooding problems from surface water. Most homes employed sump pumps equipped with a battery powered back-up, in case of power outages. However, even with the sump pumps, some homes in the area still experience basement flooding.*

To avoid the flooding problems and reduce energy consumption, the grantee built a successful passive drainage system that involved installing drain pipe under and around the base of the foundation, sloping soil away from the house, installing proper gutters, down pipes and extender pipes. The below-grade drain pipe slopes down the hill to provide good gravity flow. (Similar construction details are illustrated in the next section.)

Ground Water—If excess ground water (high water table) is a suspect, try the following solutions. To determine if moisture is wicking up through the ground or coming from the interior space, use the Capillary Test found in Appendix A.
Possible Solutions: Add a ground water retarder in the crawlspace. Ventilate the crawlspace. Fix basement drainage through use of drain tiles, drain pipe or sump pump. Try fixing cracks in the foundation and use foundation waterproofing or dampproofing. In new construction, lay down a moisture barrier before pouring concrete slab floors.

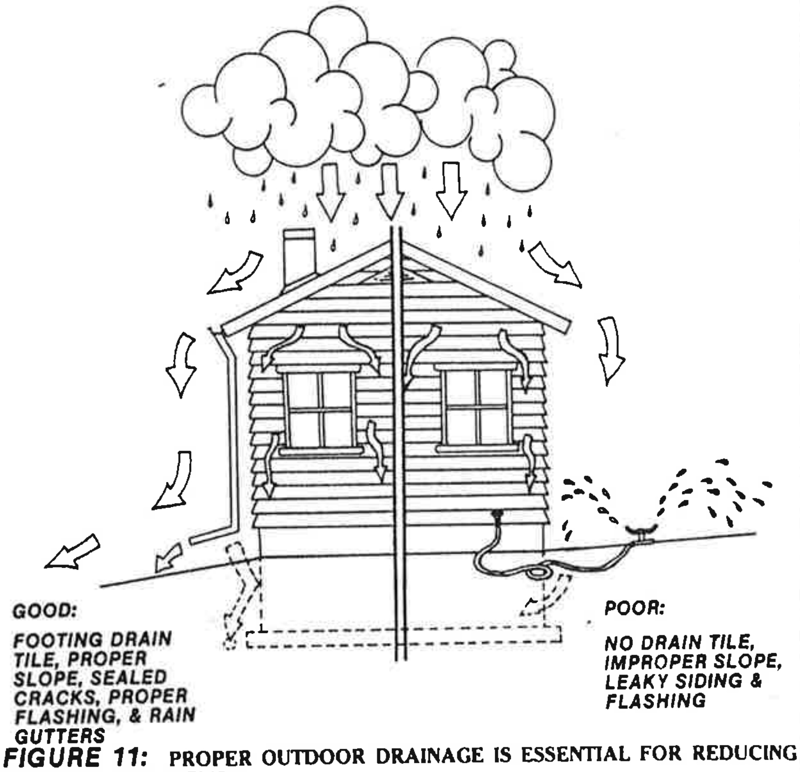


FIGURE 11: PROPER OUTDOOR DRAINAGE IS ESSENTIAL FOR REDUCING MOISTURE PROBLEMS.

Example: *An Ohio Appropriate Technology grantee found that many homes in the area had damp basements. When he built his new solar home, he used a variety of good drainage techniques to avoid the problem. These included exterior insulation and water barrier, proper soil slope, gutters and downspouts, drain tile around the foundation, and footings built on high-drainage gravel. The grantee also drilled weep holes in the base of the hollow concrete block wall that allowed moisture to drain properly to the gravel base. His concrete floor featured a gravel base, covered with a vapor-water barrier, over which rigid insulation was laid before concrete was poured. The grantee reported that his foundation walls have remained dry.*

Soil Problems—Clay-type soils that expand when wetted can cause cracks in the foundation.
Possible Solutions: Provide for drainage away from the foundation with the proper slope and through the use of gravelly soil backfill, thereby reducing pressure.

Poor Construction Details—Flat ledges, places for moisture to puddle, and inadequate drip edges and flashing all can cause troubles.
Possible Solutions: Repair poor construction details before insulating, to avoid moisture problems that could damage insulation or otherwise cause problems. Check all places where water drains for proper slope down and away from the house. Install flashing where needed or repair current flashing or drip edges. Or extend the protective overhang of the roof. Caulk and seal to save energy and stop leaking water.
Example: *A Connecticut Appropriate Technology grantee studied the feasibility of weatherization and solarization of a public building. One problem noted was that the building's flat roof and 11 skylights were a constant water problem, a problem that had been repaired unsuccessfully several times during the building's 16-year history. To ensure a positive result, the grantee proposed that the skylights be removed and the roof thoroughly repaired before energy conservation work is attempted.*

Note Seasonal Changes—Rain, irrigation and ground water table all can change seasonally, potentially creating a problem that shows only at certain times in the year. Other factors that can change seasonally include soil moisture content, foliage, rain, snow, surface water and relative humidity. If the moisture problem occurs only seasonally, it might not be of a magnitude that requires immediate remedial action. But, seasonal water problems can sometimes cause great damage. Check on the situation several times during the year. Watch for seasonal change periods: spring and fall.

High Outdoor Humidity—Consistently high outdoor humidity can cause a variety of problems, particularly higher cooling costs and constant mold, mildew and decay. Ventilating crawlspaces, attics and interior living spaces with this high humidity air can aggravate all existing moisture problems, or even cause new ones.
Possible Solutions: On the exterior of the home, take measures to increase resistance of wood to moisture, using pressure-treated wood or wood that has been treated with a fungicide preservative. Caulk and seal to stop moisture transfer and reduce heating or cooling costs. In cooling climates, tighten up the home with weatherization techniques, provide dehumidification, and avoid ventilating crawlspaces in times of high outdoor humidity and temperature.
Example: *An Iowa Appropriate Technology grantee wanted to use cool basement air to reduce his air conditioning costs during the summer. High outdoor relative humidity was a problem, however, causing discomfort, sweating of walls and pipes in the basement and mold and mildew.*

The grantee developed a system that circulates warm, humid air from the upstairs to the basement, where the air was mechanically dehumidified and then cooled by contact with the basement wall and floor surfaces. The cool air is then pumped back to the living space through the ductwork for the heating system. Before installing his system, the grantee reported reduced relative humidity in the 40 percent range. The grantee found his system to be a successful way to reduce cooling costs and increase comfort, through dehumidification. Note that this technique may not be advisable in areas where soil radon levels are high unless the basement is first monitored for radon.

Blocked Exterior Circulation—Foliage close to the dwelling or items stored next to the house (such as firewood), can block air circulation and lead to mold, mildew and other moisture damage.
Possible Solutions: Cut back foliage to allow for circulation. Move firewood or other stored items away from the house to avoid reducing circulation. High moisture areas can be treated with zinc oxide paint to avoid mold and mildew problems, but use of this type of paint should be kept to a minimum as it isn't as long-lasting as some other types of exterior paint.

SECTION III

FIXING THE PROBLEMS

Once moisture problems are correctly diagnosed, choices must be made on how best to remedy them. Some problems can be tackled with a low-cost change in living habits, such as using existing bath and kitchen exhaust fans to reduce indoor humidity levels. But, more complex problems demand careful evaluation and inspection to solve, and substantial action to fix.

This section illustrates a number of techniques to correct and prevent moisture problems in the home, including:

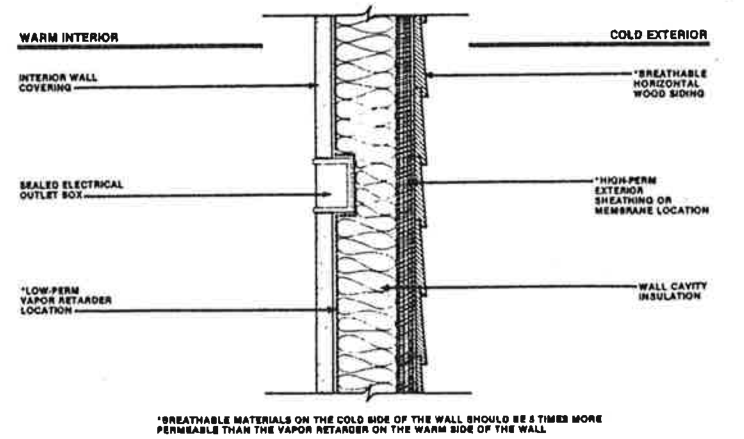
- *How to evaluate the use of vapor retarders and breathable materials, in attics, walls, floors and crawlspaces;*
- *How to determine ventilation requirements for attics and crawlspaces, as well as ventilation requirements for kitchens and baths and high moisture areas;*
- *When to avoid ventilation of crawlspaces and basements with outdoor air, including a discussion of dehumidification options;*
- *Evaluating drainage problems, including details for controlling surface and ground water, and insulation of basements and foundations;*
- *How to protect the home from the elements, including preserving exposed wood and avoiding and solving moisture-caused paint problems.*

Vapor Retarders

Vapor retarders have been used in conjunction with insulation in colder climates for the last several decades. The familiar term "vapor barrier" has recently been replaced with the term "vapor retarder" to avoid the misconception that vapor barriers stop all moisture transfer, when they actually only reduce the rate of moisture transfer.

In cold-climate locations, vapor retarders have traditionally been employed to avoid condensation by stopping water vapor from diffusing outward under pressure through building materials. But, new information shows that much more moisture is transferred by air movement than through diffusion. Thus, to truly block most moisture transfer, the vapor retarder must be carefully installed to stop air leakage, as well as diffusion. Vapor retarders that stop air leakage are a major feature of the new, energy-efficient construction and retrofit applications.

Vapor retarders should always be located on the warm, or high-vapor pressure, side of the wall surface. The cold side of the wall must be allowed to breathe, to allow any moisture that does not pass through to escape (see Figure 12).



*BREATHABLE MATERIALS ON THE COLD SIDE OF THE WALL SHOULD BE 5 TIMES MORE PERMEABLE THAN THE VAPOR RETARDER ON THE WARM SIDE OF THE WALL

FIGURE 12: **THE LOCATION OF VAPOR RETARDING AND HIGH PERMEABILITY MATERIALS IN COLD CLIMATE REGIONS IS AN IMPORTANT CONSIDERATION.**

Wall and ceiling vapor retarders are not recommended in areas outside the condensation zone (see Figure 2) because if both wintertime heating and considerable summer cooling are called for, the vapor retarder may be on the wrong side most of the time. In addition, in warm climates the temperature difference across the insulation tends to be less, thus less moisture will migrate through the surface, and it is less likely that condensation will occur because dew point temperatures will be higher.

Using Perm Ratings

Vapor retarder effectiveness is measured in "perms," which stands for the permeance of the material; one perm equals one grain (or drop) of water per square foot per hour per unit vapor pressure difference. The lower the perm rating of a material, the better the material is at slowing moisture transfer.

Knowing the perm rating of a material is critical when choosing materials for walls. To allow any moisture that does pass through the vapor retarder to escape, the outer skin of the wall should be at least *five times more permeable* than the vapor retarder. This 1:5 ratio should be applied when choosing a vapor retarder and also when choosing sheathing materials for the outer skin of the house (see table, Generic Permeance of Materials to Water Vapor).

In the past, materials with a perm value of 1 or less were considered to be vapor "barriers." However, the current state of the art is to use vapor retarders of 0.1 perm or less. For this reason, polyethylene films, which have extremely low perm ratings in the .02 to .08 range, are generally the material of choice.

Asphalt-coated laminated papers and kraftbacked aluminum foil were once commonly used, but installation problems, lack of airtightness, and the breakdown of some flame-retardant aluminum foils when exposed to high humidity tend to make them less effective and popular than polyethylene films.

Special Problems with Vapor Retarders

While vapor retarders are meant to avoid condensation problems, improper placement, installation errors and incomplete use of vapor retarders can cause moisture problems. Common errors include:

- *Vapor retarder installation on the wrong side of the wall surface.* If low-perm products are used on the outer skin of a wall and indoor humidity is high, moisture can become trapped inside the wall. Examples of low-perm exterior-use products include vinyl or metal sidings, insulating sheathings with foil coverings and low-perm plastics that are substituted for breathable building papers. Low-perm sidings are typically outfitted with small vents or perforations that allow moisture to escape, but sometimes these points can become blocked or are intentionally closed off. In colder climates, condensation problems are more likely when metal siding is used on an uninsulated home that has no vapor retarder. Low-perm, high R-value sheathing can experience condensation during times of very cold temperatures. Manufacturers' instructions for use of these types of sheathings should be followed exactly to avoid moisture problems. Finally, low-perm plastics should not be substituted for higher-perm sheathing papers.
- *Double vapor retarders, or vapor retarders on both sides of a wall.* Using a low-perm product on both sides of a wall or foundation can result in moisture buildup. The cold side of the wall or foundation must be able to breathe. Vapor retarders are not meant for use in party walls; both sides of the wall are conditioned, and water vapor can enter any leakage points and become trapped in the wall. Several DOE grantees inadvertently installed double vapor

GENERIC PERMEANCE OF MATERIALS TO WATER VAPOR

Perm ratings for a given generic product will vary, depending on manufacturing techniques used and other variables. Permeance is measured in two ways—wet cup and dry cup testing. Wet cup testing exposes the material to greater amounts of moisture. A material's perm rating will be lower in dry cup testing than wet cup, which means wet cup ratings are best when choosing a vapor retarder for an extremely wet location.

The following table gives the dry cup perm ratings for a representative sample of standard building components. The ratings shown in the table will permit comparisons and should be used only for general reference. For specific applications and materials, selection of vapor retarder materials should be based on values obtained from the manufacturer or from recognized laboratory test results.

Perm values in the table are given for the thickness of material shown. When a material is followed by the notation "perm-in," which means perm value per inch, the permeability for greater thicknesses can simply be estimated by dividing the perm-in by the number of inches. (For example, to determine the perm value of concrete 8 inches thick, divide the perm-in value of 3.2 by 8. This gives a perm value of 0.4 for 8 inches of concrete.)

Basic Materials Used In Construction	**Permeance (Perm)**
Concrete (1:2:4 mix)	3.2 (Perm-in)
Brick masonry (4" thick)	0.8
Concrete block (8" cored, limestone aggregate)	2.4
Tile masonry, glazed (4" thick)	0.12
Plaster on metal lath (3/4")	15.0
Plaster on wood lath	11.0
Gypsum wall board (3/8" plain)	50.0
Hardboard (1/8" standard)	11.0
Hardboard 1/8" tempered)	5.0
Plywood (douglas-fir, exterior glue, ¼" thick)	0.7
Plywood (douglas-fir, interior glue, ¼" thick)	1.9
Thermal Insulations	
Air (still) (1")	120.0
Cellular glass	0.0
Corkboard (1")	2.1-2.6 (Perm-in)
Expanded Polystyrene - extruded	1.2 (Perm-in)
Expanded Polystyrene - bead	2.0-5.8 (Perm-in)
Expanded Polyurethane (R-11 blown, board stock)	0.4-1.6 (Perm-in)
Plastic and Metal Foils and Films	
Aluminum foil (1 mil)	0.0
Aluminum foil (0.35 mil)	0.05
Polyethylene (4 mil)	0.8
Polyethylene (6 mil)	0.06
Polyethylene (8 mil)	0.04
Polyethylene (10 mil)	0.03
*Polyethylene cross laminated high density (4 mil)	0.02
Building Paper, Felts, Roofing Papers	
Duplex sheet, asphalt laminated, aluminum foil one side	0.002
Saturated and coated rolled roofing	0.05
Kraft paper and asphalt laminated, reinforced 30-120-30	0.3
Blanket thermal insulation back up paper, asphalt coated	0.4
Asphalt saturated and coated vapor barrier paper	0.2-0.3
15 lb asphalt felt	1.0
15 lb tar felt	4.0
Single kraft, double	31.0
*Olefin, spunbond, high-density polyethylene fiber	94.0
Liquid Applied Coating Materials	
Commercial Latex Paints:	
Vapor retarder paint	0.45
Primer - sealer paint	6.28
Vinyl-acetate/acrylic primer	7.42
Vinyl-acrylic primer	8.62
Semi-gloss vinyl-acrylic enamel	6.61
Exterior acrylic house & trim	5.47
Paint - 2 coats	
Aluminum varnish on wood	0.3-0.5
Enamels on smooth plaster	0.5-1.5
Various primers plus 1 coat flat oil paint on plaster	1.6-3.0
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

(SOURCE: Adapted from ASHRAE Handbook, 1981 Fundamentals)
*NOTE: Perm ratings for this product were supplied by the manufacturer.

retarders in walls, party walls and foundations, a practice that they later discovered could lead to problems.

- *Incomplete installation of vapor retarders.* If some areas of the house are missed or avoided during vapor retarder installation, these areas can become escape routes for water vapor. If the home has constantly high indoor humidity, these areas can suffer deterioration over time. A typical example is when the vapor retarder is installed over walls and ceilings, but not rim joists (see Figure 13).
- *Haphazard installation of vapor retarders.* Vapor retarders are not effective if they are not tightly installed. If used to stop air infiltration as well as moisture transfer, the installation must be extremely conscientious. With polyethylene sheeting, this means sealing seams completely with non-hardening sealant (acoustical sealant is recommended) and taking care to carefully seal all breaks caused by electrical and plumbing runs.

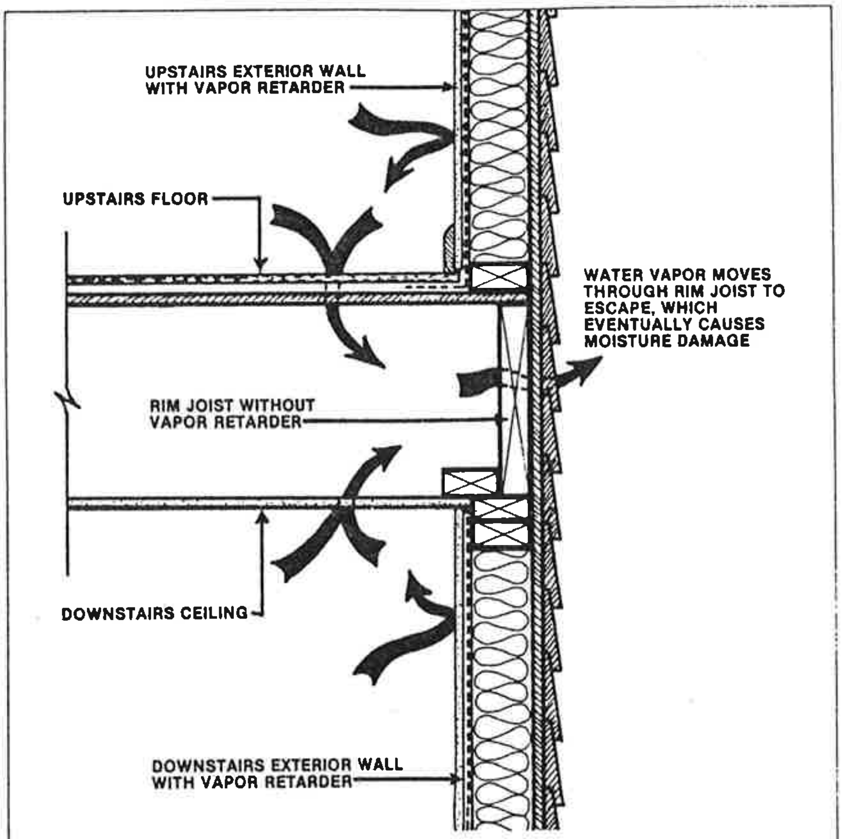


FIGURE 13: WATER VAPOR CAN MOVE THROUGH THE RIM JOIST WHEN A VAPOR RETARDER IS NOT INSTALLED.

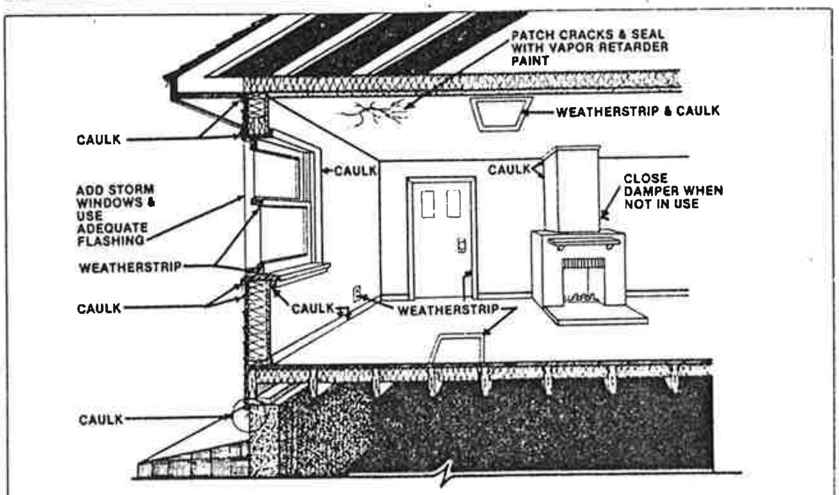


FIGURE 14: FIRST SEAL THE INSIDE, THEN SEAL THE OUTSIDE TO REDUCE AIR MOVEMENT AND MOISTURE TRANSFER.

Conventional Insulation Retrofits

Walls

Millions of houses have had wall cavities retrofitted with insulation in the last decade, usually with the insulation being blown in and no vapor retarder added. The question of the need for vapor retarders was raised by utilities and other agencies who were sponsoring insulation work. A number of studies have found that while condensation does occur, usually next to the cold inner surface of the exterior sheathing, wood rot and decay problems seem to be dependent on local climatic conditions and are not prevalent.

Researchers note that if moisture buildup within an insulated wall isn't extreme, it tends to correct itself. As the insulation gets wet, the insulating power decreases, and heat losses increase. The temperature inside the wall then increases, and this slows further condensation and steps up evaporation.

Wet insulation can pose problems in severe cases. First, insulating power can decrease dramatically if moisture content is high. In addition, wet insulation touching electrical fixtures may cause a fire hazard, and some researchers are finding evidence that moisture may rob cellulose insulation of its flame retardancy as the moisture evaporates away.

Remember that water vapor moves into wall cavities both by air movement and diffusion, but air movement is the more powerful force. For this reason, air leakage points should be sealed from the *inside* of the house as a first step in a conventional wall insulation job. This means sealing penetrations around windows, doors, where the wall meets the ceiling and floor, and any cracks or holes in wall surfaces. Once air leakage points are closed off, then vapor retarder paint can be applied to give wall surfaces some resistance to water vapor diffusion (see Figure 14).

Attic and Ceilings

Attic ventilation is the main strategy to avoid moisture problems in attics, and until recently, it has been common not to use tightly installed vapor retarders with attic insulation, except in the coldest climates. The reason for this was that if a good vapor retarder was used in the walls, too much moisture might accumulate in the house if the ceiling also had a vapor retarder. Any water vapor that passes through the ceiling insulation would then be vented away through attic vents.

However, with the move toward using vapor retarders to stop both air and moisture transfer, tightly installed ceiling vapor retarders are becoming more common in all condensation-zone locations for new construction and sometimes in comprehensive retrofits. And, a carefully installed vapor retarder is the only way to avoid moisture damage if attic ventilation is likely to be inadequate, particularly with flat roofs or cathedral ceilings.

With conventional attic insulation retrofits, batt insulation with attached vapor retarders can be carefully and tightly stapled to the rafters. For loose fill attic insulation, polyethylene can be cut into strips and tightly fitted between the joists (see Figure 15). Existing vents at the eaves must not be blocked during the insulation retrofit.

With greater thickness of attic insulation, care must be taken to provide additional ventilation at the eaves. Rigid vent troughs can be installed on the underside of the roof sheathing to provide this ventilation and prevent thicker levels of insulation from blocking air flow (see Figure 16).

If a vapor retarder isn't used in the attic or ceiling, attic ventilation must be greater than when a vapor retarder is used.

Crawlspaces and Floors

In all climate regions, ground cover vapor retarders are needed to stop moisture migrating up from the soil in the crawlspaces. A tough, puncture-resistant material (often 6-mil polyethylene) is simply laid over the soil, and held in place with weights or bricks. For additional protection from damage from foot traffic, a layer of sand can be put over the vapor retarder. As with attic ventilation, crawlspace venting can be less if a good, soil cover vapor retarder is used.

Floor vapor retarders can be used in conjunction with insulation in both cold and hot climates to stop condensation. These vapor retarders should not be substituted for ground cover vapor retarders, but rather used in addition to them. In cold climates, the vapor retarder is, as usual, on the warm side of the floor. In warm climates where long periods of air conditioning occur, the warm side is the bottom of the floor (see Figure 17).

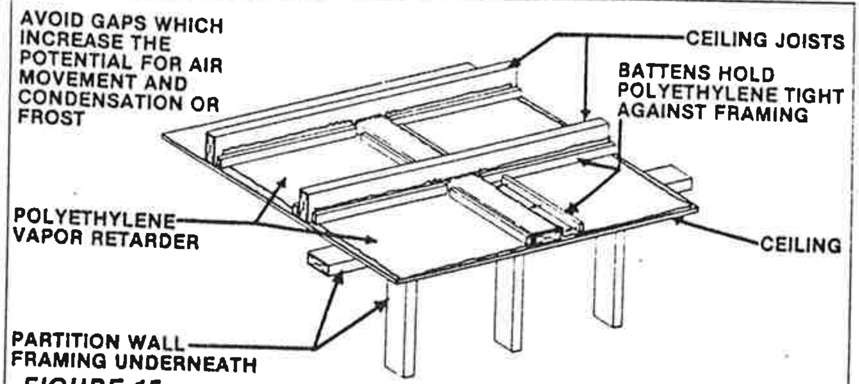


FIGURE 15: POLYETHYLENE STRIPS CAN BE INSTALLED PRIOR TO LOOSE-FILL OR BLOWN-IN ATTIC INSULATION.

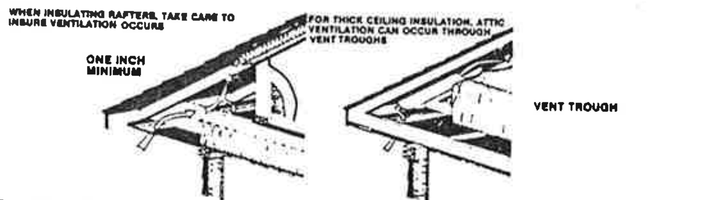


FIGURE 16: INSULATION WORK SHOULD NOT BLOCK ATTIC VENTILATION AT THE EAVES.

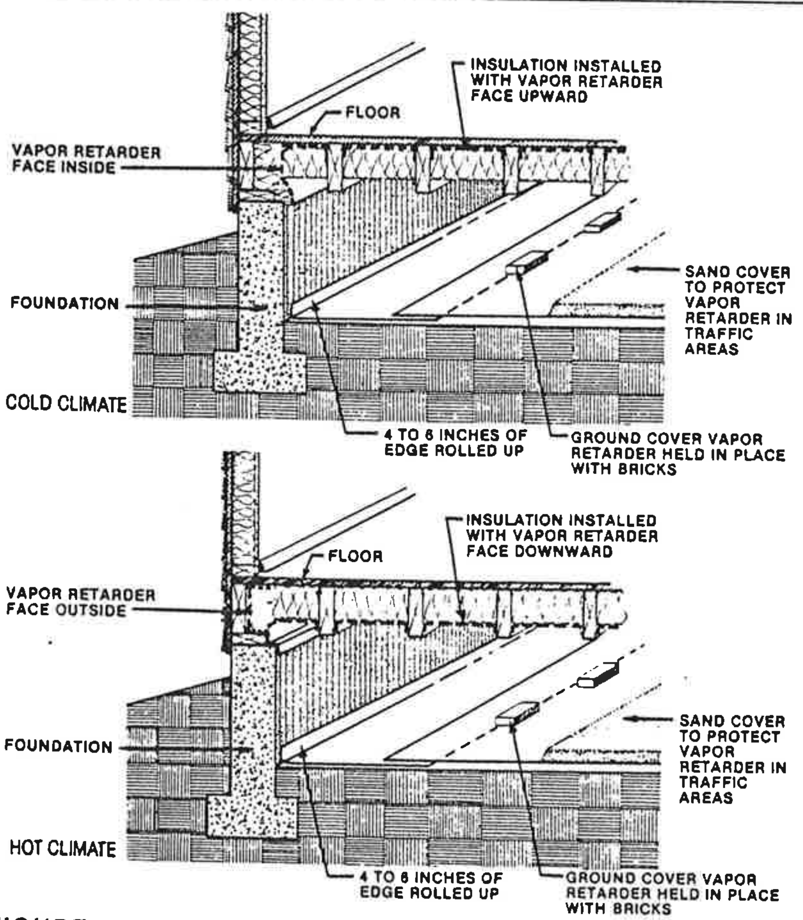


FIGURE 17: VAPOR RETARDER LOCATIONS FOR CRAWLSPACES AND FLOORS DIFFER DEPENDING ON CLIMATE.

Windows

The same concept of putting a tightly installed vapor retarder on the warm side of the surface applies to storm windows, which act as both air and vapor retarders as well as additional insulation. Condensation can result when the outer sash is tighter than the inside window.

A good rule of thumb with older windows is to always tighten the existing window first with weatherstripping and caulk. If an outer storm window is being added, a product with small weep holes at the bottom is recommended to allow moisture to escape. With interior-side storm windows, make sure that the seal is tight around all edges.

If storm windows are properly installed and fogging and icing still happens, indoor humidity levels may be too high, or the window may need still another glazing layer. In the coldest climates, triple-glazing is recommended. Newer window insulation products that have a built-in vapor retarder must provide for a tight seal around all edges to avoid condensation problems. Similarly, traditional drapery and blinds can aggravate window condensation because the window surface gets colder, heat circulation is impeded and the window covering doesn't provide for a tight seal.

Vapor Retarders for New Construction and High-R Retrofits

In new construction or substantial retrofit in colder climates, great care should be taken when installing a continuous vapor retarder that is intended to stop air infiltration as well as moisture transfer. Care must be taken to provide an unbroken vapor retarder between floors, ceilings and interior walls (see Figure 18). If these locations are left open to moisture, degradation can occur because these are the only open paths for moisture's transfer.

An excellent insulation and vapor retarder installation will result when a polyethylene vapor retarder is used over insulation that is friction-fit between the framing. Like any vapor retarder, polyethylene film's perm value will increase dramatically if holes caused during installation are left unrepaired. Thus conscientious installation is essential to avoid damage.

Seams in the vapor retarder must be overlapped and carefully sealed with acoustical sealant, making sure that seams fall over a solid surface to facilitate a good, strong bond. Special attention must be given to sealing all breaks caused by electrical and plumbing runs. Inadvertent tears in the vapor retarder can be patched with acoustical sealant and polyethylene. One popular way to seal gaps around windows, doors and plumbing is to foam the area with polyurethane.

A number of new products have been developed to help achieve a tightly sealed vapor retarder. These include special plastic pans for use with electrical and plumbing fixtures, and new, tougher polyethylene blend plastics for vapor retarder use. In addition, new products known as "air barriers" are being employed in place of felt paper under the siding to reduce air movement in the insulation, thus maintaining the insulation's effectiveness. These air barriers, made of olefin (a high-density spunbound polyethylene fiber), have extremely high perm ratings, thus moisture easily passes through while air movement is curtailed. Consult references listed in Appendix B for additional information about these new vapor retarder installation techniques and products.

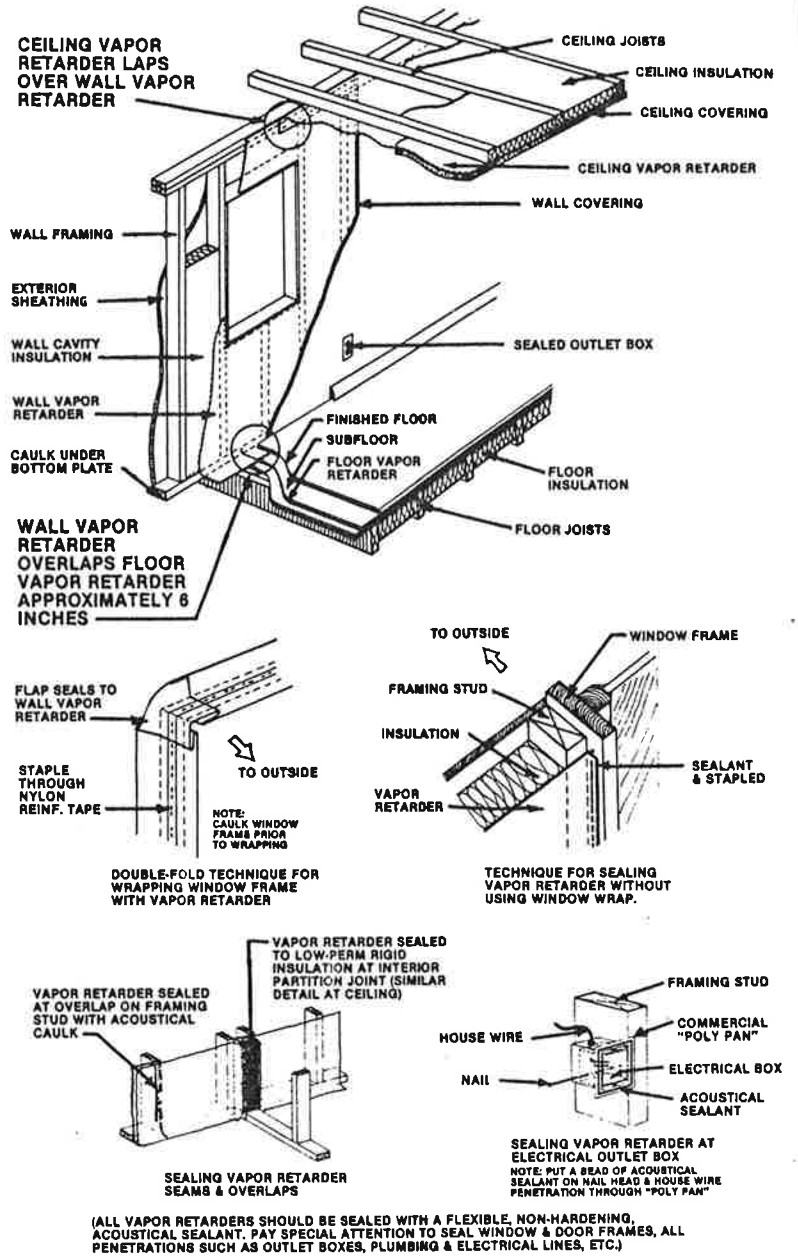


FIGURE 18: INSTALLATION OF A CONTINUOUS VAPOR RETARDER INVOLVES ATTENTION TO DETAIL.

Ventilation

Ventilation and circulation with outdoor air is a major moisture control strategy, and this section deals with a variety of ventilation options and requirements. Passive ventilation is important for crawlspaces and attics and other unconditioned spaces, and mechanical localized ventilation is needed in kitchens, baths and sometimes other areas of the home. In extremely tight homes, mechanical whole-house ventilation with an air-to-air heat exchanger is advised.

During warm, humid weather, ventilation with outdoor air can cause condensation in basements and crawlspaces. And, sometimes dehumidification is necessary, either mechanically or with chemicals.

Controlling Moisture in Attics and Crawlspaces with Ventilation

The basic rule-of-thumb is that an unconditioned space shouldn't be underventilated: when in doubt, go to the next largest vent size. These spaces should be ventilated with passive vents that are located to promote good air circulation. (Using a fan for attic ventilation is not cost effective and can draw moisture from the dwelling into the attic.) The following recommendations reflect *minimum* vent requirements, given current practice.

Sizing Attic and Crawlspace Vents

Vent sizing depends on four factors: area to be vented, type of vent obstructions (screens or louvers), where the vents are placed and whether a vapor retarder is used.

If a vapor retarder isn't used, more vent area is needed. The rule of thumb is to multiply square footage to be vented by .0067 (or 1/150). Then, note what type of obstruction (screens, louvers and the like) is used on the vent, and multiply the answer you just obtained by the number shown in the chart below.

If a vapor retarder is used, multiply the total area to be vented by .0034 (or 1/300). Then, multiply the answer by the number shown in the chart.

Steps to Determine Attic Ventilation Needs

1. Measure area to be vented.
2. Multiply this number by either .0067 (no vapor retarder) or by .0034 (vapor retarder in place).
3. Note what type of obstruction is covering the vents, and multiply by the appropriate number to obtain total gross vent area needed.
4. Determine where vents should be located (see Figure 19).

Steps to Determine Crawlspace Ventilation Needs

1. Measure square footage to be ventilated.
2. *If ground cover vapor retarder is not used,* multiply the square footage by .0067 (or 1/150) to determine needed vent space. Then, consult the obstructions chart, and multiply venting by the number given for the type of material used.

If ground cover vapor retarder is used, multiply squre footage by .0067 (or 1/150), then multiply needed venting by number shown on the obstructions chart.

3. Determine location of needed vents (see Figure 20).

For example, say you have a 595 square foot attic to be ventilated. No vapor retarder is used. Multiply 595 times .0067 = 3.99 square feet of vent needed. If a ⅛-inch mesh screen is used to cover the vent, multiply 3.99 by 1.25 = 4.98. Rounded up to the nearest foot, 5 square feet of vent area would be the minimum needed in this case. Then, the vent area would be divided (depending on the design of the house and attic) between several vents located to promote good cross-ventilation and circulation.

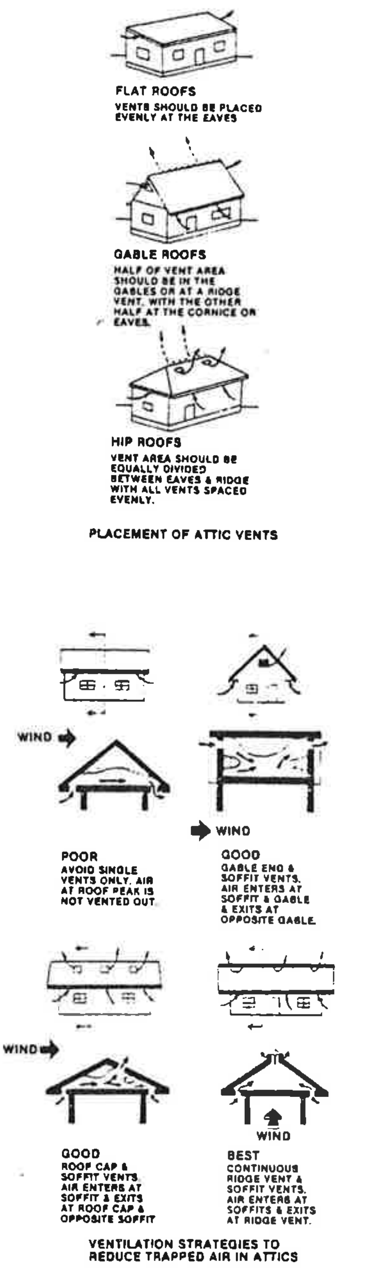


FIGURE 19: ATTIC VENTILATION IS CRITICAL TO AVOIDING MOISTURE PROBLEMS.

SIZING VENTS WITH OBSTRUCTIONS

OBSTRUCTIONS IN VENTILATORS, LOUVERS AND SCREENS[1]	TO DETERMINE TOTAL GROSS AREA OF VENT, MULTIPLY AREA IN SQUARE FT. BY:
¼ inch mesh hardware cloth	1
⅛ inch mesh screen (8 mesh screen)	1¼
No. 16 mesh insect screen (with or without plain metal louvers)	2
Wood louvers and ¼ inch mesh hardware cloth[2]	2
Wood louvers and ⅛ inch mesh screen	2¼
Wood louvers and No. 16 mesh insect screen	3

[1] In crawlspace ventilators, screen openings should not be larger than ¼ inch; in attic spaces no larger than ⅛ inch.
[2] If metal louvers have drip edges that reduce the opening, use same ratio as shown for wood louvers.

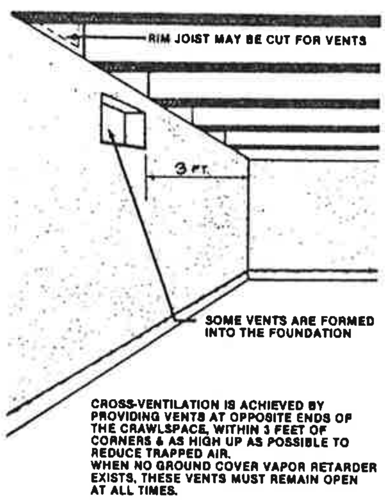


FIGURE 20: **CRAWLSPACE VENTILATION IS ESPECIALLY IMPORTANT WHEN A GROUND COVER VAPOR RETARDER ISN'T EMPLOYED.**

USING OUTDOOR TEMPERATURE AND RELATIVE HUMIDITY TO REDUCE MASONRY SWEATING

Outside Air Temperature (°F)	Outside Percent Relative Humidity less than	Dew Point Temperatures (°F) (Basement/crawlspace surfaces must be above these temperatures to not have condensation)
90	80	83
	60	75
	40	63
80	80	74
	60	63
	40	54
70	80	64
	60	56
	40	45
60	80	54
	60	47
	40	36
50	80	45
	60	37
	40	28
40		35
	60	28
	40	20

Crawlspace Venting and Sweating of Masonry Walls

Ventilation of crawlspaces and basements may cause sweating of concrete or masonry walls below grade because these surfaces stay at a constant, cooler temperature and outdoor air may hold enough moisture to cause condensation. Beyond the routine action of installing a ground cover vapor retarder in the crawlspace, other actions may be needed to avoid causing this problem.

Condensation can be avoided by closing off vents when outdoor temperatures and humidity become too high. The goal is to keep warm, moist air from contacting surfaces (masonry walls) below the dew point temperature. The chart below shows the relationships between outdoor temperature, relative humidity and dew point temperatures.

For example, assume the basement/crawlspace temperature is 50°F on the masonry surfaces. Below-grade ventilation would be recommended when outside temperature is 60°F or less and outdoor relative humidity is below 60. The dew point for the wall would be 47°F in this instance, and condensation will be avoided because the surface temperature of the masonry is 50°F.

For more detail on determining dew point temperatures, consult the psychrometric chart in Appendix A.

Ventilation for Kitchens, Bathrooms, and High Moisture Areas

The major preventative and corrective action with kitchens and baths is to install and use direct fan venting systems that pull moisture out quickly. The 1981 standard of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommends providing the capacity for ventilation of 50 cubic feet per minute (cfm) in baths and 100 cfm in kitchens. The higher rate for kitchens reflects the possibility of gas cooking appliances, which need greater ventilation rates if indoor air pollution and moisture buildup are to be avoided.

Ductless kitchen and bath recirculating units that simply filter air, not remove it, are not suitable for removing moisture. Where moisture and indoor air pollution aren't major problems, these devices can work well enough. Another popular tactic for reducing condensation in bathrooms is to install an overhead infrared heat lamp. These lamps are sometimes combined with a blower to help circulate the warm air. Obviously, these heat lamps do not remove moisture, but they reduce visible signs of condensation. An exhaust fan is a better solution to remove moisture.

Clothes dryers should always be vented to the outdoors to avoid excess moisture and possible indoor air quality problems from laundry additives. If the home's relative humidity is consistently high, wet towels from bathing and hand washing should be hung outdoors or dried in a dryer.

If it is impossible to install the required vents in kitchen and bath, another option is to install an exhaust fan in a central location as close as possible to the humidity source and duct it to the outdoors. For automatic control of unwanted moisture, any of these vent fans can be successfully connected to a dehumidistat that operates the fan automatically.

Air-to-air Heat Exchangers

Another mechanical method of ventilation and dehumidification is the use of an air-to-air heat exchanger. In today's tightly built cold-climate homes, the air-to-air heat exchanger serves as a heat-recovery ventilation system—a system that recovers heat in outgoing stale air and uses it to warm the fresh, cold air coming into the house. Heat exchangers also need defrosting in very cold climates, and some exchangers on the market have an automatic defrost cycle. Small wall- or ceiling-mounted heat exchangers are available for use in place of bathroom exhaust fans.

Some heat exchangers will do little or nothing to solve moisture problems, because they allow moisture to pass into the fresh air stream. These exchangers, called "enthalpy" models, should be avoided if excess moisture is a problem. Another problem with heat exchangers that pass moisture is that some indoor air pollutants readily dissolve in water, and these contaminants would then be passed into the fresh air stream.

Air-to-air heat exchangers are necessary in any home that is tightly sealed with a continuous air-vapor retarder. The best heat exchanger systems are ducted to all areas of the home. Tightly constructed, well-insulated homes that employ centrally ducted heat exchangers can tolerate somewhat higher humidity levels, because circulation and ventilation are constant and uniform.

Dehumidification

When high relative humidity is a constant problem, one option is to dehumidify the air. This can be accomplished by mechanical or chemical methods.

Mechanical dehumidifiers are typically the refrigerator type that remove moisture by cooling the air. Moist air is drawn into the device where it is pulled past refrigerator coils, which are cooler than the dew point. The dry air is then exhausted back into the house. Water vapor condenses on the cooling coil, then drips into a collection pan.

At cooler room temperatures of 65°F or below, frost or ice will form on the cooling coils, and dehumidification stops until the unit is defrosted. Some units have an automatic defrost cycle, while others must be manually defrosted by shutting the unit down until the ice melts.

For good circulation, place the dehumidifier in the center of the room. For maximum effectiveness, close off the area to be dehumidified. Clean and empty the drainage pan regularly.

Chemical Dehumidifiers

Chemical dehumidifying agents, known as "desiccants," absorb moisture out of the air. Desiccants are a good option for small, confined places like closets, but they can be used in larger rooms, as well. Some desiccants are very corrosive and must be handled with extreme care. Others are reusable and non-toxic, but hands should be washed thoroughly even after handling the non-toxic variety. Below is a chart that details characteristics of the two major types of desiccants.

Evaluating Drainage Problems

Drainage problems often obstruct insulation and weatherization work, especially with basements and foundations, which are major heat losers in heating season climates. Common sources of drainage problems include excess surface and ground water and clay-type soils. When combined with poor construction details, drainage problems can quickly cause moisture damage, from roof to basement.

In the construction of bermed or earth-sheltered housing, special attention to proper drainage details is critical. See references on drainage in Appendix B for references on this topic. And, in all new construction, foundations need proper design and protection if a long-lasting dwelling is to result.

Some drainage improvements are fairly simple, such as adding downspouts and replacing flashing. Others are extremely costly for retrofit applications, such as excavating around the basement walls to get at the source of a severe ground-water problem. Because of the expense, some basement and foundation moisture problems, simply cannot be remedied and insulation must be foregone. Many factors must be taken into account when evaluating basement and foundation water problems, and thought should be given to choosing the lowest-cost option that best meets the homeowner's needs.

Surface Water

Basement and foundation water problems can sometimes be simply solved by improving drainage of surface water from precipitation and irrigation. Adding soil around the foundation to achieve a good slope is a basic solution. A 6-inch slope over a 10-foot run is recommended. Where cost and lack of room prohibit meeting the recommended slope, try to channel moisture away, as well as sloping the soil as much as possible. Another option is to install drain gutters on the roof eaves with long extension spouts to channel water away from the dwelling, as well as inspecting and repairing flashing details all around the house (see Figure 21).

However, in some locations where surface water typically causes basement flooding due to terrain and seasonal run-off, more radical action may be needed, including actions that are traditionally used to control excess ground water (high water table). These actions include adding sump pumps and dry wells, installing additional or new floor drains, laying a new basement floor over a waterproofing layer, and installing a drain tile. In new construction and comprehensive retrofit, another basic preventative measure is to install a sloped drain pipe along the footings with use of gravelly soil next to the foundation.

In the optimal situation, the best course of action is always to tackle the water problem from the outside of the wall surface. In new construction, this is easily possible by employing good construction techniques suited to the location. In most retrofit applications, however, excavation of the exterior of the basement or foundation wall is too costly for consideration. In these cases, interior retrofit action is usually the only available route, but it may not pro-

DESICCANTS FOR DEHUMIDIFICATION

Desiccant	Characteristics	Application Guide
Silica gel or activated alumina	• Not harmful to fabrics • Can be placed in paper containers (i.e. paper bag) • Uses: Hung with clothes, placed in containers or shelves, floor basement • Reuseable • Suitable for above-freezing application	• Place in suitable container that is porous or open at top • Close off areas to be dehumidified for maximum effectiveness • Dry silica gel is a blue color and pink when wet • Reuse by drying in oven at 300°F for a couple of hours
Calcium Chloride	• Corrosive to clothes, metal, burns skin, etc. • Keep away from vegetation • Wash surfaces after contact (i.e. metal, skin, clothes) • Uses: Basements, crawlspaces • Turns to a liquid as it absorbs water • Suitable for above-freezing application	• Place calcium chloride salt in non-corrosive container (i.e. glass, some plastics • Close off area to be dehumidified for maximum effectiveness • Larger areas (i.e. basements or crawlspaces) use several 25 lb. containers • Dispose of the corrosive liquid and replace with new calcium chloride daily or as needed

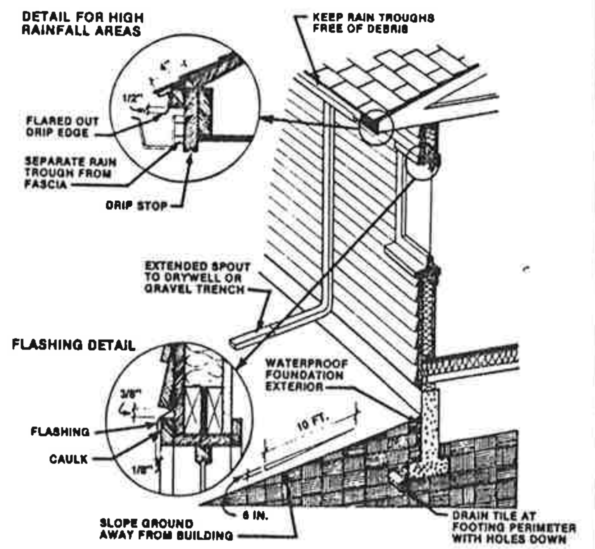


FIGURE 21: PROVIDE PROPER DRAINAGE AND PREVENT SEEPAGE INTO STRUCTURE TO AVOID DAMAGE.

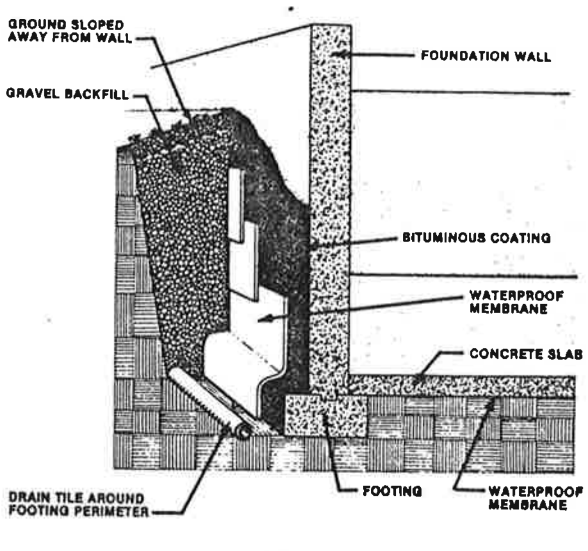


FIGURE 22: EXTERIOR WATERPROOFING IS OFTEN REQUIRED FOR "SEVERE" GROUND WATER MOISTURE PROBLEMS.

only available route, but it may not produce satisfactory results in severe situations. The main problem with interior retrofit action to stop water is that the wall may become fully saturated with water, causing a variety of problems.

Assessing the Problem

To choose the proper solution, one must first know the extent of the moisture problem. Remember that concrete can be an adequate vapor retarder, but when subject to standing water or ground water pressure, capillary flow can occur. Waterproof coatings should be used with concrete in high ground water situations, or special additives can be mixed with concrete when it is poured to retard leaking. The wetter the concrete is poured, the higher its permeability.

If the problem is *severe, waterproofing* the basement or foundation walls and slab floors is recommended. This is an exterior operation usually limited to new construction, but it can be adapted for a radical retrofit, if necessary. Waterproofing stops the direct flow of water, and it often consists of built-up membranes layered several times. A variety of waterproofing products are currently in use, and contractors dealing with earth-sheltered construction differ over which method and products are the best.

Severe moisture problems are typically found in locations near swamps, rivers and lakes, which are prone to ground water pressure. In these cases, water pressure won't be relieved by standard drainage methods such as footing tiles, which drain to storm sewers. A variety of preventative measures should be used in these locations, including impermeable exterior waterproofing. Minimum property standard codes call for waterproofing (at least the equivalent protection of 2-ply hot-mopped felts, 6-mil polyvinyl chloride or 55-pound rolled roofing) that is carefully applied and sealed at all seams. Waterproofing should extend from the edge of footings to the finished soil line, as well as under basement and ground slabs (see Figure 22).

If the problem is moderate, *dampproofing* may suffice. Dampproofing products interrupt the capillary action of the moisture, but are not intended to totally stop water penetration. (See chart below for examples of common dampproofing products.) Dampproofing is a common solution for basement or foundation retrofits, but it cannot be expected to handle severe water pressure problems. If the problem is moderate, dampproofing in conjunction with other actions can do an adequate job.

DAMPPROOFERS FOR INTERIOR FOUNDATION SURFACES

A. Ready-mix Paints	• Hydrocarbon solvent base (mineral spirits) pigments, portland cement (to increase solids content) and a form of synthetic rubber as a binder. • Convenient to use, good choice, competitively priced and can be quite effective. May require more than one coat.
B. Ready-mix "Latex" Paints	• Water base, pigments and synthetic rubber binder • Easy to clean up, no flammable solvents, safer and easy to use and give off less odors. May not be as effective as other types. May require more than one coat.
C. Ready-mix Solvent Based Paints	• Contains portland cement, pigments, resins and linseed oil. • Cleans with solvents. May require more than one coat.
D. Two-Part Epoxy Paints Solvent or Water-Base	• Require careful mixing, are more costly than most other products, may require more than one coat, but are usually more effective.
E. Portland Cement Based Powders	• Mix with water. • Require the most work to mix and apply, dries quickly, making application difficult, requires constant rewetting during application. Least costly, may require more than one coat. Some staining may result. Reasonably effective.

NOTE: BE PARTICULAR REGARDING CORRECT SURFACE PREPARATION AND APPLICATION. FOLLOWING THE MANUFACTURERS' DIRECTIONS AND SUGGESTIONS CAN MAKE THE DIFFERENCE BETWEEN SUCCESS WITH A POORER PRODUCT OR THE FAILURE WITH A SUPERIOR PRODUCT. EXPERIMENTING WITH DIFFERENT TYPES PRIOR TO A TOTAL COMMITMENT SHOULD BE CONSIDERED.

Unlike severe moisture problems, *moderate* moisture problems define situations where water pressure can be relieved by drain tiles at the footings. However, heavy rains may cause seasonal back-up of storm sewers, and if soil is heavy, it may retain water for long periods of time even though high ground water isn't a normal problem.

In general, if the soil type is sandy and gravelly, and ground water is below the foundation level, drain tiles at the footings are unnecessary because the soil's natural drainage will be adequate. However, seasonal changes and terrain may dictate that previously discussed preventative actions should be considered. Remember that when exterior waterproofing is required, a backfill of crushed gravel should be considered, especially for areas where soil is the clay type and expands when wetted.

Excessive moisture pressure, which can cause buckling of walls and slabs, should be relieved. In the floor, consider the addition of a dry well and a sump pump to reduce pressure from ground water (see Figure 23). In addition, commercially available mixtures can be applied to the interior masonry wall to make it less permeable. These mixtures must fill the surface pores to be most effective.

Exterior Insulation Options

Foundation and basement walls can be insulated on the outside to reduce condensation and save energy, and insulation should be a part of cold-climate retrofit or new construction waterproofing or dampproofing. Insulating on the outside is the superior method, because it protects the wall or foundation from the freeze-thaw cycle.

When insulating on the exterior, use rigid insulation that does not deteriorate in below-grade applications (typically high-grade extruded polystyrene) and cover the insulation to protect it from ultra-violet rays and damage. In new construction, the rigid insulation should extend from the top of the foundation to the footings. In retrofit applications, the rigid insulation should extend from the top of the foundation to at least two feet below grade (see Figure 24).

Interior Insulation Options

Remember that most interior water-stopping action deals with the symptoms of the problem more than the cause. Generally, when it isn't possible to tackle severe mois-

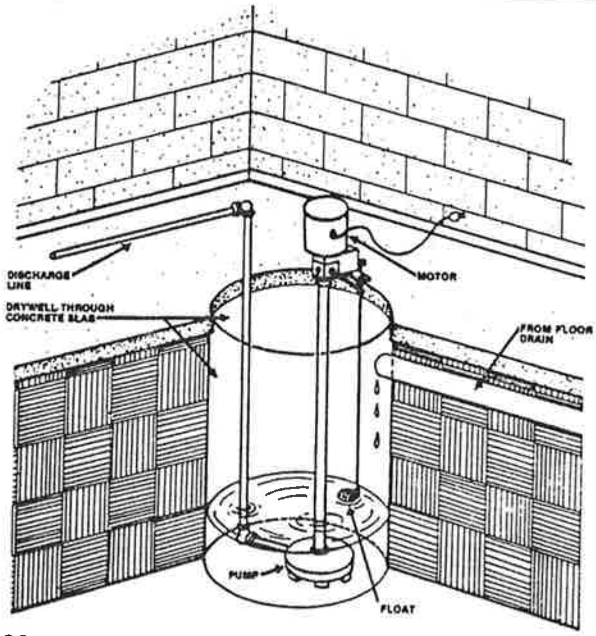


FIGURE 23: A DRYWELL AND SUMP PUMP ARE OFTEN NECESSARY IN AREAS OF HIGH GROUND WATER OR PROBLEMATIC SURFACE WATER.

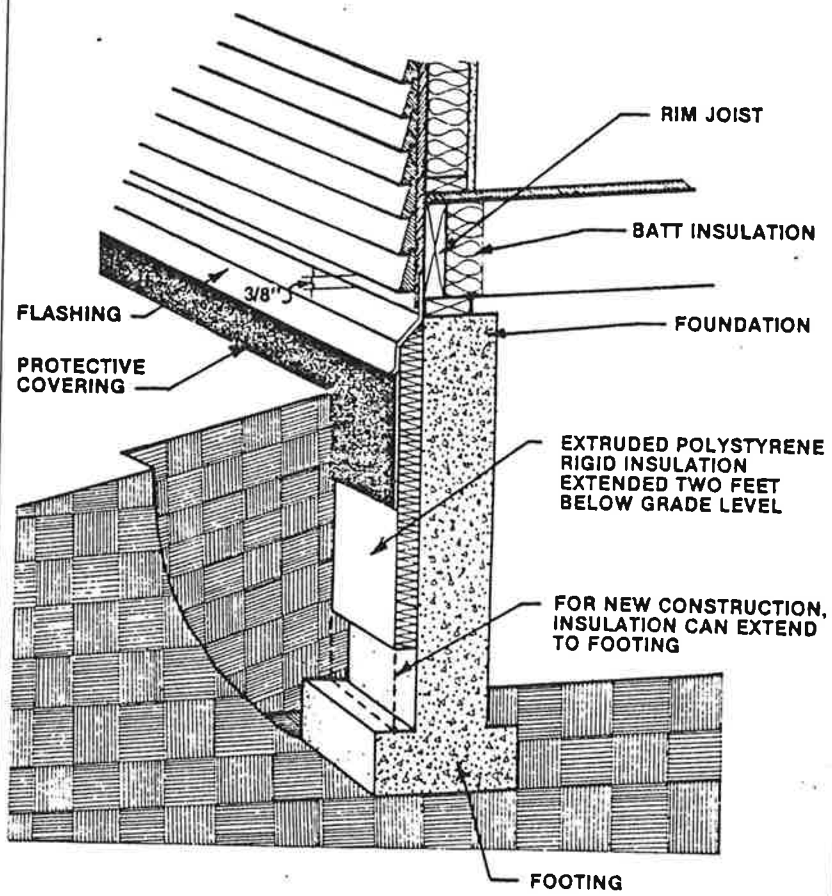


FIGURE 24: AN EXTERIOR RETROFIT INSULATION JOB CAN HELP REDUCE HEAT LOSS THROUGH EXPOSED CONCRETE WALLS.

ture problems from the exterior, basement walls should not be insulated. Attempts can be made at controlling the moisture problem with the use of dampproofing, drainage and sump pumps, as previously illustrated. If moisture cannot be controlled, add a vapor retarder and insulation to the ceiling instead of the walls, in order to stop moisture migrating to the living space above.

With moderate moisture problems, wall dampness can be reduced with the application of a cement-base dampproofing or an epoxy or latex paint. Before insulation is added, the moist or wet wall must be thoroughly dried. The drying process for a wet basement wall, whether from new construction, an outside source or from interior condensation, may take weeks or even months. For new construction, it's often common to wait through one heating season to allow the foundation to dry.

To insulate on the inside involves either building a new frame wall and adding batts and a vapor retarder, or using the simpler method of installing rigid insulation directly to the dry concrete walls with construction adhesive. Note that with the rigid insulation option, electrical installations are limited to the ceiling or surface mounting on the walls. The rigid insulation should be covered with an airtight vapor retarder and fire-rated board to reduce fire hazards associated with foam board insulations (see Figure 25).

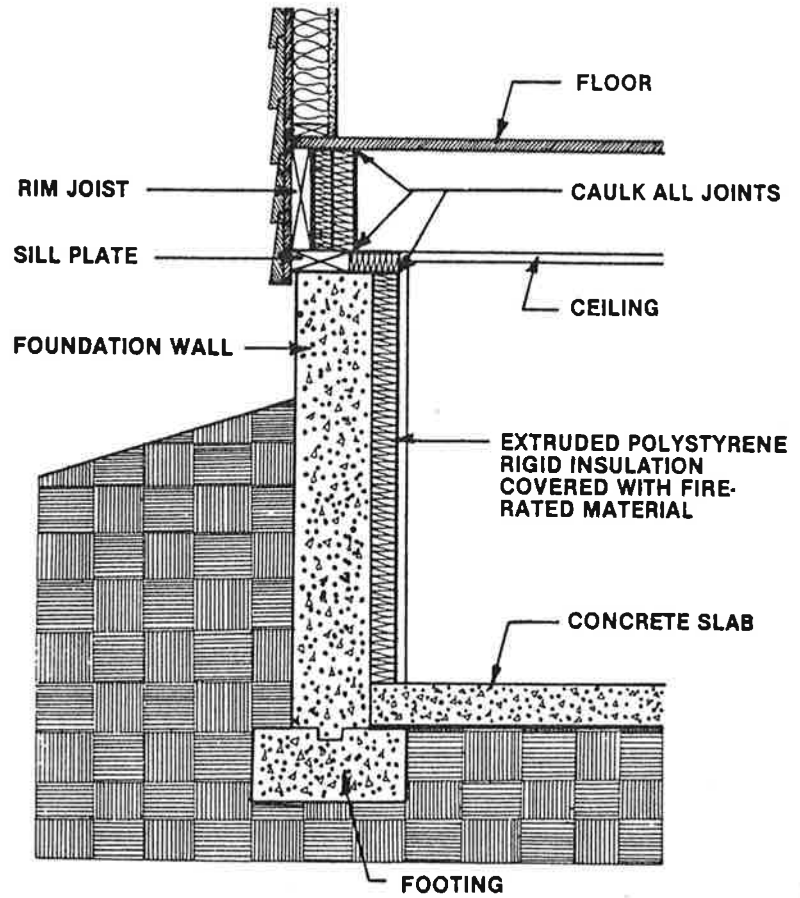


FIGURE 25: **AN INTERIOR RETROFIT INSULATION JOB MAY BE A SUITABLE OPTION IF SOIL MOISTURE PROBLEMS ARE NOT SEVERE.**

Increasing Resistance to Moisture

When moisture sources cannot be sufficiently reduced or in areas of high outdoor humidity, high rainfall, or constant wetness, increasing wood's resistance to moisture is the major prevention and correction option. In this section, wood preservatives and water repellents are discussed, and moisture-caused paint problems are examined.

When Wood Needs Protection

In general, wood should be protected if:
* it is in contact with soil;
* it is in or around masonry or concrete within 18 inches of the ground;
* it is an exposed, structural member subject to wetting, such as porches, decks and steps or;
* it is a joint end grain or water-trapping area that is unprotected from moisture.

Water Repellants and Preservatives

Pressure-treated wood is a good option where wood will be exposed to extreme moisture conditions. Chemicals are impregnated through the wood under pressure to protect it from decay and insects. Some preservatives can't be painted over. For more information on wood preservatives and related federal standards, see references in Appendix B.

A water repellent penetrates the wood and seals it from absorbing moisture. A preservative contains an additional toxic fungicide that resists decay and insects. Repellents are good choices for above-ground applications, while preservatives are recommended for below-ground locations and areas subject to constant wetting.

Penta (Pentachlorophenol) is the most common fungicide preservative in use. Copper napthanate is another, less toxic choice, but it does have an undesirable odor. A coating of spar varnish will reduce odor problems. Dipped, brushed or sprayed repellents do not have the strength of pressure-treated wood, but they do provide substantial protection. Preservative solutions made with mineral spirits or turpentine can usually be painted when the solution dries. Refer to the manufacturers' instructions for application details.

Paint Isn't a Preservative or a Repellent

Paint isn't an effective preservative or repellent because it only coats the surface. A true repellent or preservative soaks into the wood and seals the interior of the wood cells. A cracked, painted surface will readily take in moisture, while slowing the evaporation process. Thus, a cracked, painted surface is a perfect climate for decay.

Water repellents or preservatives should be liberally applied before painting or finishing a surface. And, if the surface is exposed to constant wetting, a better protection method than paint should be considered.

Decayed wood won't benefit from preservatives. Decayed wood should be replaced, along with wood up to two feet on either side of the decayed area to make sure all the infection has been removed.

Paint Problems

Peeling, blistering, or cracking paint can point to a moisture problem, especially if the raw surface or wood is visible under paint blisters or cracks. Moisture inside or outside the dwelling can attack paint. Paint problems are usually most visible after the heating season, but before spring rains (see Figure 26).

Moisture-caused paint problems are most common on the coldest side of the building or areas subject to heavy wetting through rain or sprinkling. Often, paint problems are severe on outside walls of rooms with high humidity. Unfortunately, some paint problems are not recognized as moisture-related, and sometimes the problem is simply covered up with new vinyl or metal siding. Of course, some paint problems are strictly linked to poor application of the paint, or use of a paint that wasn't meant to do a particular job.

Like other exterior-use products, paint should shed water, but should still be breathable to allow moisture to escape. For this reason, latex paints with vinyl or acrylic polymers are often the best choices because they breathe, yet protect. High-luster oil-based paints are the least porous. When choosing paint, ask the dealer for advice on the right paint for the job, and follow the manufacturers' instructions to the letter.

Gable ends of heated buildings often have paint problems if the attic is uninsulated, poorly vented, without a vapor retarder or if the dwelling has excess moisture. Treat these problems, and the paint problem should be alleviated.

Fascia board may be the site of difficulties if poor drainage is being caused by undersized, plugged or leaking gutters, or design or construction errors with eaves, shingles or soffits. Also, ice dams will contribute to paint deterioration. Inadequate ventilation at the eaves is another possible culprit.

Solutions to fascia paint problems are numerous. Clear debris from the roof area, such as leaves, pine needles and other damming items. Unplug rain gutters, and repair them to stop leaks. Sometimes, increasing the size or number of downspouts is the answer. For eave/rake or flashing/drip edge dilemmas, consider increasing the length of the shingle drip edge or install a new metal drip edge under the shingles, leaving a gap between the drip edge and the fascia for drying purposes. The drip edge should extend at least one-half inch below a butting wood member.

Soffits suffer problems similar to fascia board and gable ends. Generally, all the above-mentioned remedial actions should be considered.

Paint can deteriorate below windows on both the exterior and the interior. Watch for poor seals around exterior window trim that allows water to get behind siding. Cracked or deteriorated window sills will also cause difficulties. Note all places around windows where water or water vapor can

Making Your Own Wood Preservatives

Wood preservatives are available commercially, or they can be made from common household supplies. The key in application is to concentrate on the end grain, or any holes or cuts in the wood. (Note that the end grain absorbs moisture much more readily than the side grain.) These areas require multiple treatment if the wood will be used in an area where it will be exposed to constant wetting.

The following repellent recipe is not as toxic as most preservatives, and it can be painted after drying. It is lower in cost than most preservatives and is a good choice for above-ground exposed wood, such as furniture, decks, railings and playground equipment.

Water Repellent Recipe—Makes One Gallon
1½ cups boiled linseed oil
(or 3 cups exterior grade varnish)
1 ounce paraffin wax
Solvent (turpentine, mineral spirits or paint thinner) to make one gallon

Mixing: Mix the solution in a well-ventilated area, and wear rubber gloves and goggles or mask. Melt the paraffin in a double boiler. Have the solvent at room temperature (60-80°F). Stir the solvent vigorously while slowly pouring in the melted wax. Add linseed oil (or the varnish) and blend well.

Use: A 3-15 minute dip is the superior method of use. The repellent also can be sprayed or brushed liberally, especially at the board ends and joints. Allow two warm days drying time after brushing or spraying it on, and allow a week for drying dipped pieces. The repellent will keep, but ingredients may separate at cooler temperatures. Warm to room temperature and stir before re-use.

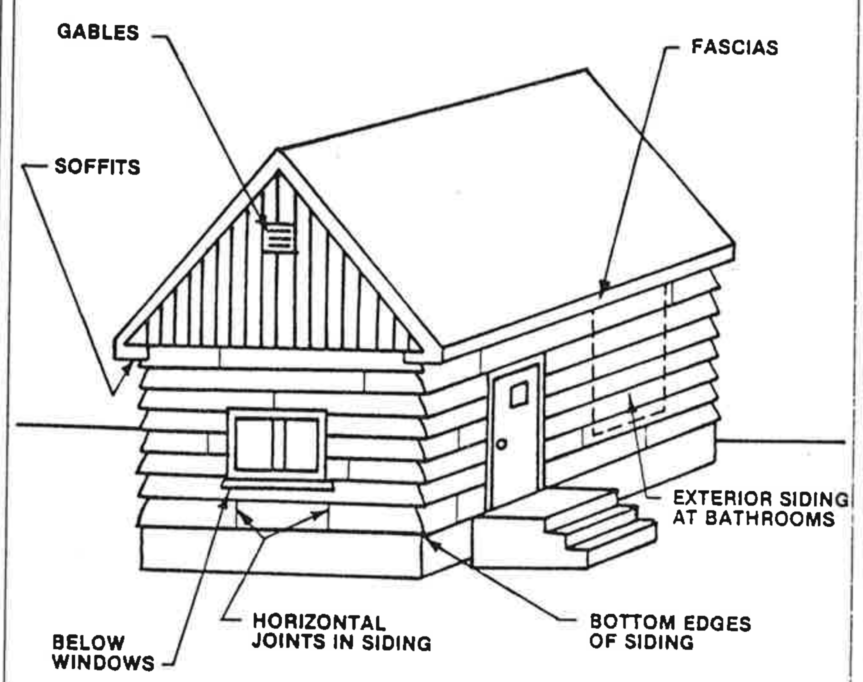


FIGURE 26: EXTERIOR PAINT DETERIORATION CAN OCCUR IN MANY LOCATIONS AND IS OFTEN A SIGN OF MOISTURE PROBLEMS.

enter. Another good move is to replace or seal the flashing above the window.

The Double-hung Window Dilemma

A special and hard-to-spot problem can occur with double-hung windows. Warm, moist air can enter the cavities, through the holes where the pulley-sash cord is located or from the sides of the interior window trim, and condense on the cold weights inside the cavities. Frost and ice can build up on these weights, and when it melts, it can leak into the wall cavity.

Two solutions: either caulk around the interior window trim where it meets the wall and seal the pulley holes, using one of the new sealing devices that allow the cords to still operate; or remove the weights, seal the cavities, and seal the pulley openings. To keep the window operable with the second option, install low-cost spring clips. (Note that these clips may not work on extra large windows.) With the remove-the-weights option, a good weatherstripping job is possible because the sash cords are out of the way (see Figure 27).

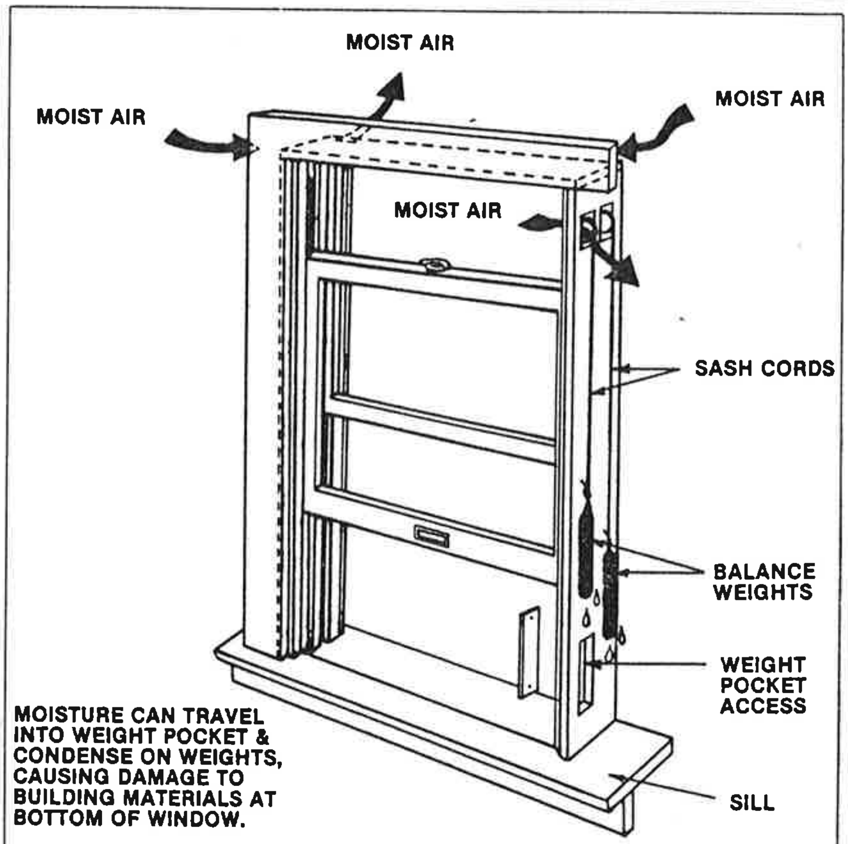


FIGURE 27: DOUBLE-HUNG WINDOW BALANCE WEIGHTS MAY CONTRIBUTE TO MOISTURE DAMAGE.

SECTION IV

A MOISTURE AUDIT PROCESS

The process described in this section is a generalized method for conducting a moisture audit on a home. It is not all-encompassing; a process is presented rather than a comprehensive "cook book." Simple forms are included to provide a systematic framework and to give the reader a handy place to keep notes. The reader should be familiar with the material in the preceding sections before using this audit.

The audit process follows five main steps: I. Identify the Symptoms, II. Get the History, III. Start Searching, IV. Define the Solutions, and V. Select Corrective Measures.

The following tools will be useful as you conduct this audit.

- ☑ Coveralls, hat or hardhat, cotton gloves
- ☑ Magnetic compass
- ☑ Pocket knife or awl
- ☑ Tape measure
- ☑ Flashlight and spare bulb/batteries
- ☑ Step ladder
- ☑ Sling psychrometer and charts
- ☑ Thermometer (electronic is fast and best choice)
- ☑ Duct tape
- ☑ Polyethylene film 6-1½' x 1½'
- ☑ Camera, flash, film (optional)
- ☑ Clipboard, paper, pencil(s) and eraser
- ☑ Binoculars for multi-story buildings (optional)
- ☑ Calculator (optional)
- ☑ Hair blow dryer

I. IDENTIFY THE SYMPTOMS

The first step in the moisture audit process involves noting symptoms of excess moisture and identifying their locations considering the entire house, both inside and out. The following checklist can help identify locations where moisture problems may exist. Try to be as specific as possible when describing the location.

Typical Symptoms	Locations
☑ Strong or musty odors	______
☑ Damp sensation	______
☑ Mold and mildew	______
☑ Discoloration, staining or texture changes on wood or masonry surfaces	______
☑ Rot or decay	______
☑ Water-carrying fungus	______
☑ Fogging windows	______
☑ Condensation or sweating	______
☑ Frost or ice build-up	______
☑ Paint peeling, blistering or cracking	______
☑ Corrosion or rust on metal surfaces	______
☑ Leaks or dripping noise	______
☑ Deformed wooden surfaces	______
☑ Concrete or masonry chipping	______
☑ Drainage problems (interior and exterior)	______

II. GET THE HISTORY

After the obvious symptoms of moisture problems have been identified, the next step is to obtain as much information as possible about the structure and its use patterns, both from inspection and from the building occupants. Except in rare cases, moisture problems don't appear overnight, and this historical information will help to interpret the symptoms and diagnose the causes of moisture problems.

A. Building Components and Operation

The mechanical and structural components of a home all help to define its moisture balance. These questions will aid in identifying important factors in this moisture balance.

1. What type of heating system is used? (Circle all appropriate answers)
System Type:
Central Forced Air
Central Hot Water
Central Steam
Fireplace
Wood Stove
Portable Space Heater
Fuel Type:
Electricity
Natural Gas
Propane (LPG)
Fuel Oil
Coal
Wood
Kerosene
(Electric homes without chimneys may have higher indoor relative humidity levels.)

2. Are any rooms in the home closed off with only intermittent heat? YES NO
Comments: ______

3. What is the normal thermostat setting?
Day ______ Night ______
(When warm moist air contacts cold surfaces, condensation can take place.)

4. Does the heating system have poor distribution?
Are there any cold spots? YES NO
Comments: ______

5. If you use wood for fuel do you store it inside or directly against the side of your home outdoors? YES NO
(Wet wood contains a lot of moisture and can contribute to home moisture problems if not stored properly outdoors away from the side of your house.)

6. Is a dehumidifying device ever used? YES NO
Type: Central______
Portable______
Season(s) used: ______
hours/day______
Location of use: ______
Percent relative humidity setting______

7. Is an air conditioner ever used? YES NO
Type: Central______
Portable______
Seasons(s) used: ______
hours/day______
Temperature setting ______°F
Location of use and comments: ______

8. Is a humidifier ever used? YES NO
Type: Central______
Portable______
Season(s) used: ______
hours/day______
Percent relative humidity setting ______
Location of use and comments: ______

9. Is an evaporative cooler (swamp cooler) ever used? YES NO
Type: Central ______
Portable ______
Season(s) used: ______
hours/day ______
Machine setting—High ______ Med. ______ Low ______
Location of use and comments: ______
(Humidifiers and evaporative coolers can contribute large amounts of moisture to the home.)

10. Is propane or natural gas used for cooking: YES NO
If yes, is a vented range hood provided? YES NO
(Cooking with propane and natural gas discharges water vapor to the living space.)

11. Do any windows have single glazing? YES NO
Comments: ______
(Single glazed windows may be a simple remedy.)

12. Do windows fog up even though they have two or more layers of glazing? YES NO
(Generally, this is a reasonable indication that indoor relative humidity is too high.)

13. Is circulation or ventilation of indoor air curtailed in any way? YES NO
Comments: ______

14. Does the attic and/or crawlspace have inadequate ventilation? YES NO
Note total vent area: attic______
crawlspace______

15. Does the attic or ceiling insulation touch the roof sheathing, leaving no gap for circulation? YES NO
(Note: Further information on how to determine whether attic and crawlspace ventilation is adequate is provided in the text in Section III.)

16. Are vapor retarders present in the home? YES NO
Where are they located?______
Are they properly installed? YES NO
Comments: ______

17. Are vapor retarders located on both sides of the same wall in any locations? (This is an invitation to moisture problems.) YES NO
Comments: ______

18. Is a ground cover vapor retarder used over the soil in the crawlspace? YES NO
(Further information on vapor retarders is found in the text in Section III.)

B. Modifications to the Building Structure

Modifications to a home can sometimes lead to changes in ventilation and air circulation, which can affect moisture transfer patterns. Have any building changes been made in the last year or two? Yes answers to the following questions should be noted for further analysis.

19. Have any of the following energy conservation/weatherization activities been recently conducted?

- Caulking/weatherstripping YES NO
- Insulation YES NO
- Vapor retarder installation YES NO
- Storm Windows YES NO

20. Has any remodeling recently been done? YES NO

Comments: ____________________

21. Has an attached solar greenhouse been added? YES NO

Comments: ____________________

22. Have any modifications to the heating/cooling system been made? (For instance, has a new humidifier, air conditioner or furnace been installed?) YES NO

Comments: ____________________

C. Occupant Behavior

The lifestyle of the building occupants can also have a significant impact on the moisture balance. Yes answers to these questions indicate that moisture is being contributed to the home from sources that can easily be controlled through behavior changes if a home's moisture balance is out of adjustment. See Section II for further information.

23. Is there now or was there in the past more than one occupant for every 250 sq. ft. of floor area in the home? YES NO

(Home water use is generally proportional to the number of building occupants.)

24. Does bathing take place without the use of an exterior vented exhaust fan? YES NO

25. Are wet towels hung in a confined area indoors to dry? YES NO

26. Does cooking take place without an exterior vented exhaust fan? YES NO

27. Does cooking take place without lids on pots? YES NO

28. Are clothes dried on a line indoors or with a clothes dryer vented into the living space. YES NO

29. Are floors frequently mopped? YES NO

30. Are large open terrariums or aquariums present? YES NO

31. Are there large numbers of house plants present? YES NO

III. START SEARCHING

Now that background information has been obtained and the obvious symptoms of moisture problems in the home have been identified, it's time to initiate a thorough search and begin diagnosing problems. You will need to draw heavily on the principles which have previously been described in the text. You must also be careful and thorough because a single symptom of excess moisture may have multiple causes, and multiple symptoms may result from a single cause.

A. The most important tool for the analysis of moisture problems is the moisture balance principle discussed in detail in Section I.

- *Sources* of moisture must be identified—where they come from, when and how they appear and whether they need to be reduced or eliminated.
- *Temperature* plays a major role in the moisture balance. As was previously noted, the amount of moisture that air can hold depends on its temperature. Are temperature and/or temperature differences causing moisture problems?
- *Moisture transfer* must be analyzed. Should it be increased or decreased?
- *Ventilation and circulation* play a part in the moisture balance. Is moisture in a home being properly swept away by ventilation, or is moist air stagnating and causing problems?

B. Begin searching for the causes of the symptoms of moisture problems you have already identified. The search must be thorough and systematic. Make sure you have obtained the answers to all the questions in Section II of the audit. Start looking for causes at the location of the symptom, and move systematically away from it. For example, work in a clockwise direction, or start upward and move downward, or move from the exterior to interior. Do the same for every symptom of moisture problems you have identified. Make sure you have covered the entire house from attic to basement or crawlspace inside and out before you have finished. You may find other previously unidentified symptoms of moisture problems along the way. Sometimes it is better to focus on a single problem until it is diagnosed before addressing another, because the process can become complex.

C. As you search, use the "water hose method." *Pretend* you are washing the surface you are looking at with a hose in a systematic manner. Leaky locations are obvious sources of liquid moisture and water vapor. But, this method will also call attention to less obvious symptoms and their solutions.

D. *Use all your senses* to help diagnose the causes of moisture problems. *Walk* the perimeter of each room as well as the exterior perimeter of the dwelling. Usually, unevenness, slope, warpage and so forth, can be detected simply by walking over a surface. Use the *Tap Test* (Appendix A) to identify signs of decay. Sound wood will normally present a clear ringing sound. *Look* for signs of discoloration or changes in texture on all surfaces. Check behind furniture, drapes, shades, and foliage. Note any strong or musty *odors*. Be particularly sensitive to any *damp sensation* in the air.

E. The moisture tests (relative humidity, dew point, capillary, and wood deterioration) in Appendix A will aid you in your search for symptoms and causes. Don't be afraid to investigate and experiment. Moisture problems are often complex to solve. Often bits of information from several different sources will be required to come up with a solution.

F. Special or unusual problems will demand even more careful searching. If a moisture source is eluding you, look for the following:

- Look for hidden passages to upper or lower levels of the dwelling. Open wall cavities, on the exterior or interior, may extend from the basement or crawlspace to the upper levels. Balloon framing, partition walls, vents, shafts and ducts can all be sources of moisture transfer between floors.
- Certain moisture problems are seasonal in nature. Some complex roof designs (roofs with valleys) are conducive to ice dams, which are present only in the winter. Also, roof drainage problems may not be readily visible if it is not raining. Be aware of the season while doing your audit.
- With mobile homes, unusual water stains may appear along the outside corner where the wall meets the ceiling. This is caused by moist interior air condensing on the sheet metal roof. The moisture then follows the roof curve down to where the ceiling and roof join. The problem can be solved with an airtight ceiling vapor retarder, more attic ventilation and more ceiling insulation. The principles for controlling moisture in mobile homes are generally similar to those of site-built homes, although the techniques for resolving problems are sometimes different.
- Occasionally, mistakes can create serious moisture sources. Dripping water from recessed electrical fixtures after a ceiling insulation job calls for fast action. Never insulate over these fixtures or old knob and tube wiring, as dangerous levels of heat can build up. The solution is to replace recessed fixtures or old wiring before insulating with surface-mounted light fixtures, then install a vapor retarder and ceiling insulation.

IV. DEFINE SOLUTIONS

Once the sources of home moisture problems have been identified, the next step is to define solutions to the problems. Again, the solutions relate to adjusting the home's moisture balance. The following list of corrective and preventive options for moisture problems will be useful in defining solutions.

A. Reduce the sources: Stop water and plumbing leaks; repair or increase drainage; change home occupant behavioral habits; try dehumidification, passive or mechanical drying techniques.

B. Watch temperature differences: Warm up cold surfaces with circulation or ventilation; try insulating cold surfaces, such as walls, windows, ceilings, basements, and crawlspaces. Use local heating with space heaters to help warm surfaces. Make sure temperatures are above the dew point to avoid condensation of moisture.

C. Check moisture transfer rate: Seal inside surface air leaks. Stop capillary action with ground moisture vapor retarders. Consider using tightly installed vapor retarders where needed (heating climates) in attic or crawlspace or when adding insulation. Protect and seal exterior surface cracks and leaks and provide moisture proofing. Increase moisture resistance with wood preservatives and proper finishes.

D. Increase air circulation and ventilation: Eliminate or reduce trapped moisture or damp air. Increase circulation first, using natural or mechanical means, to accelerate drying and curtail the environment for deterioration. Allow enough room when placing home furnishings for proper air movement. Allow the cool side of insulated walls, ceilings, floors and basements to breathe with the use of proper materials and venting. In heating climates, in homes with reduced ventilation, consider the use of air-to-air heat exchangers. Another option is to connect a dehumidistat to an exhaust fan so that moist air is automatically exhausted.

V. SELECT CORRECTIVE MEASURES

Fill in the attached chart as you proceed through the audit. After you have completed the audit and filled in the chart, you need to prioritize the tasks necessary to solve the moisture problems you identified. Remember the following considerations:

A. Start with the easiest, lowest-cost remedies that address the most pressing problems.

B. Lifestyle modifications are often cheap and easy to make. They are sometimes ideal ways to reduce moisture sources.

C. If lifestyle changes do not solve the problem, make any necessary mechanical adjustments or repairs to reduce moisture sources and improve the moisture balance.

D. As a last resort, make any structural changes that are necessary to halt moisture problems (retrofitting vapor retarders, dampproofing foundation walls, and the like).

MOISTURE AUDIT FORM

PROBLEM/ SYMPTON	LOCATION	SOURCE/ CAUSE	REMEDY	COST ESTIMATE

NAME: ____________________
ADDRESS: ____________________
TELEPHONE NUMBER: ____________________
DATE: ____________________
ENVIRONMENTAL CONDITIONS: ____________________

Appendix A

MOISTURE TESTS AND TOOLS

The following is a group of tests that can help pinpoint moisture problems. The tests include: Relative Humidity and Dew Point Tests (for determining when high RH is a problem and discovering dew point temperatures to avoid condensation), the Capillary Test (for determining where moisture is coming from) and Wood Deterioration Tests. In addition, information is provided to help you clean and calibrate a humidistat.

RELATIVE HUMIDITY AND DEW POINT TESTS

The best method for determining relative humidity (RH) is to use a sling psychrometer made for that purpose (see Figure 28). If a sling psychrometer is not readily available, the RH can still be determined to within 5 percent by using a standard bulb thermometer.

Relative Humidity and Dew Point Determination with a Standard Bulb Thermometer

1. Set the thermometer with a small fan blowing across it until temperature stabilizes and record as dry bulb air temperature.
2. Wrap bulb with small piece of thin cotton gauze wetted with water, preferably distilled water.
3. Again turn on the fan and record the wet bulb air temperature when it stabilizes. Note: With two thermometers the test is completed more quickly and is probably more accurate, but the two thermometers must read the same before the test.
4. Use the dry bulb and wet bulb temperatures and the psychrometric chart to determine RH.
5. Next, use the RH and dry bulb temperature to determine dew point temperature from the psychrometric chart.

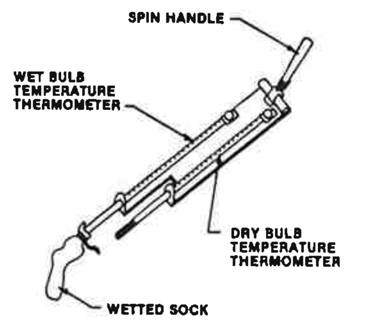
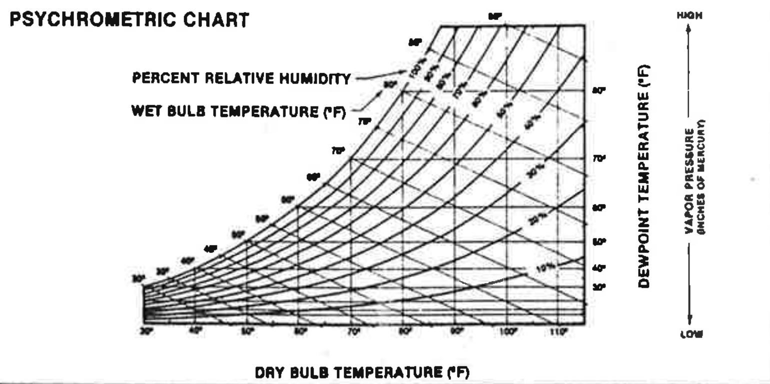


FIGURE 28: **A SLING PSYCHROMETER IS A HANDY TOOL IN DETERMINING INDOOR RELATIVE HUMIDITY.**



A Low-Cost RH Indicator

A simple low-cost tool is available for determining indoor relative humidity (see Appendix B). It consists of a cardboard gauge that is color sensitive to humidity. By simply mounting this indicator to the wall, humidity can be monitored.

CAPILLARY TEST

Capillary rise of soil moisture is upward movement of water through the soil. To determine whether this moisture is coming through the foundation walls or floor to the inside or whether moisture is coming from inside the dwelling itself, do the following:
1. Identify the damp interior surface. Note that testing of multiple locations on the floor or walls may be necessary to locate external sources of moisture.
2. Dry a portion of the damp area approximately 18 inches square. (A hair blow-dryer can quickly dry this surface.) Note that lower areas below grade may be more prone to high moisture content.
3. Cover the dried area with a vapor retarder, preferably polyethylene, firmly attached and sealed with tape around the edges (see Figure 29).
4. Check the underside of the vapor retarder after a couple of days. If there are beads of moisture under the vapor retarder, there is water seeping or wicking through the surface into the dwelling. However, if the vapor retarder is wet on the room side and dry underneath, the dampness is due from another source of moisture, such as plumbing leaks or poor ventilation. The condensation is forming due to warm moist air cooled to its dew point by the cold masonry surface. It is possible for both sides to be damp indicating both external seepage and internal condensation problems.

NOTE: This test is sometimes difficult to interpret. Seasonal variations in surface water flow patterns and the ground water table can cause confusion. You may need to seek further professional advice.

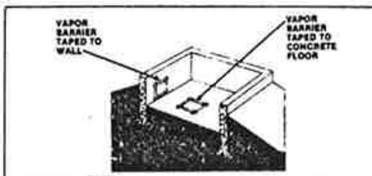


FIGURE 29: **THE CAPILLARY TEST IS AN INEXPENSIVE WAY TO DETERMINE THE SOURCE OF MOISTURE IN BASEMENTS.**

WOOD DETERIORATION TESTS

Decayed wood is more permeable to moisture and, therefore, more subject to further damage and decay. Recognizing wood decay is a skill that comes with practice, but several symptoms do stand out.

White rot is probably the worst form of wood decay, and often it is the most difficult to recognize. Wood infected with white rot appears somewhat whiter than normal, sometimes with dark lines bordering the light discoloration. Because the wood doesn't visibly shrink or collapse, people sometimes miss the fact that wood with white rot is seriously weakened and possibly ready to collapse. In advanced stages, some cracking across the grain occurs with white rot.

In contrast, brown rot readily shows as a brown color or brown streaks on the face or end grains. In advanced stages, the wood appears very damaged, with surface shrinking and collapse, as well as cracks across the grain. Both white and brown rot are serious forms of wood decay that deserve treatment and/or wood replacement.

Soft rot and blue stain are less damaging forms of wood decay that tend to be more active on the surface. Soft rot is recognizable because the wood surface appears soft and profusely cracked, resembling driftwood in color. The soft rot decay is slower acting than white or brown rot. Blue stain indicates somewhat weakened wood, with a blue, brownish black, or steel-gray colored staining. The discoloration actually penetrates the wood cells and is not a surface stain.

The following tests can help you determine if the wood decay process has started.

PICK TEST

This test is a simple means for detecting the toughness of wood fibers and testing for hardness. One of the first indications of wood decay is reduced toughness. It is most reliable on thoroughly wetted wood.

A sharp pointed instrument of tough steel (ice pick, small chisel, sharpened screwdriver) is jabbed into the wood across the grain and pried up (see Figure 30).

The resistance to prying and the characteristics of the sliver when it breaks are indicators of the wood's toughness. Wetted wood in good condition lifts with a long sliver or breaks by slivering. Decayed wood breaks out with less resistance and lifts/breaks as two relatively short lengths breaking abruptly across the grain without splintering. Wood surfaces that have reduced toughness may also appear rough or fibrous.

SAW TEST

Cutting a piece of wood (board or timber) will produce a rougher finish cut on wood even in the early stages of decay than noninfected wood. This is a good test for purchase of lumber, logs for construction, and so forth.

JAB TEST

Wood decay can also be detected by jabbing or scraping the surface with a sharp pointed instrument. Start at ground level or below, and work up. Note areas that appear soft for other symptoms of decay, such as wood color and texture changes.

TAP TEST

Tap the surface of wood to detect sound differences. A sharp, clear, almost ringing sound is typical of good, dry wood. A dull, dead, soft sound is characteristic of wet or decaying wood.

CALIBRATING HUMIDISTATS AND DEHUMIDISTATS

Humidistats and dehumidistats measure the moisture content of the air through sensing devices. They are designed to control the relative humidity in confined spaces. The element that controls the device is a material that expands as it absorbs moisture and contracts when drying, thus opening and closing the electrical circuit of the humidifier or dehumidifier mechanism. When the elements become dirty, lengthened or shortened, these devices may no longer be accurate (See Figure 31).

Cleaning the contact points is easily accomplished by drawing a piece of clean paper between the points to remove oxidation.

The element can be cleaned gently with a very soft bristle brush and distilled water. Allow the element to dry out before trying to calibrate the device.

To adjust the device, first determine the relative humidity of the air where the control device is located using the previously described techniques.

While watching the point contacts, turn the humidity control knob to the relative humidity that was just determined. If the points do not close or prematurely close at the setting, turn the adjusting screw until points are adjusted properly.

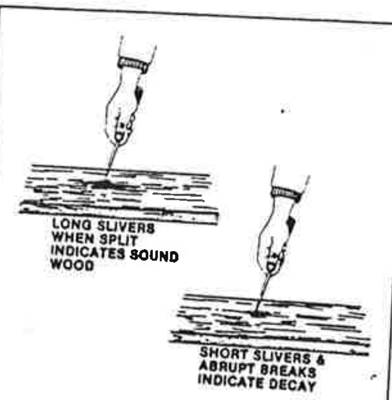


FIGURE 30: THE PICK TEST IS A SIMPLE WAY TO DETECT WOOD DECAY.

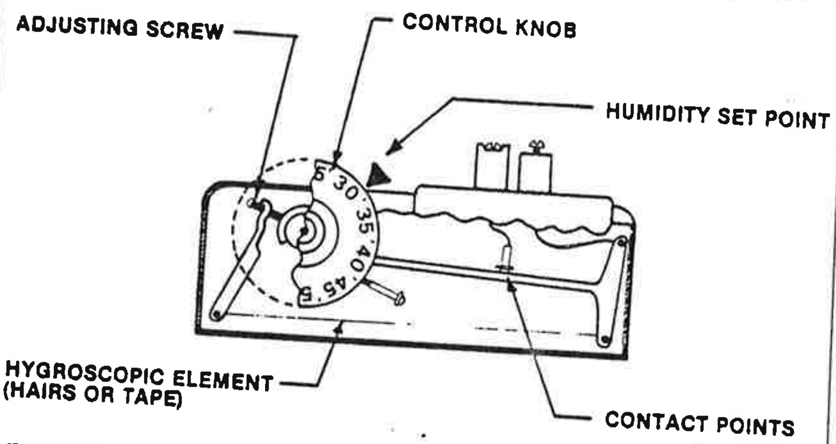


FIGURE 31: LEARNING ABOUT THE COMPONENTS OF A TYPICAL HUMIDISTAT CAN HELP WHEN CALIBRATING THESE DEVICES.

Appendix B

SUGGESTED READINGS, NEW PRODUCTS AND FURTHER REFERENCES

VAPOR RETARDERS

Eyre, D. and Jennings, D., *Air Vapor Barriers*, 1981. Available from Canadian Oil Substitution Branch, Room 1120, Killeany Bldg., 460 O'Connor St., Ottawa, Ontario K1S 5H3. 613/995-1118.

Marshall, Brian and Argue, Robert. *The Superinsulated Retrofit Book*, Renewable Energy in Canada Publishers, Toronto, Ontario, 1981.

VENTILATION

H.C. Products Co., *Fundamentals of Residential Attic Ventilation*, Princeville, IL, 1974.

Shurcliff, William A., *Air-to-Air Heat Exchangers*, Brick House Publishing Co., Cambridge, MA, 1980.

DRAINAGE AND WATERPROOFING METHODS FOR FOUNDATIONS

Jones, R.A., Kapple, W.H., and Leadrum, J.T., *Basements*, Small Homes Council, University of Illinois, Champaign, IL, 1953.

Underground Space Center, *Earth Sheltered Housing Design—Guidelines, Examples and References*, University of Minnesota, Minneapolis, MN.

"Basement Waterproofers," *New Shelter*, pp. 39-48, April 1981.

Sarah Fitz-Hugh, "The War Against Water," *New Shelter*, pp. 30-32, January 1982.

WOOD FINISHING AND DECAY

U.S. Department of Agriculture, *Wood Finishing: Water Repellants and Water Repellant Preservatives*, Forest Service Research Note FPL-0124, Madison, WI, 1978.

U.S. Department of Agriculture, *Wood Handbook: Wood as an Engineering Material*, USDA Handbook No. 72, Madison, WI, 1974.

U.S. Department of Agriculture, *Principles for Protecting Wood Buildings From Decay*, Forest Service Research Note FPL-190, Madison, WI, 1973.

Drisko, R.W., *Paint Failures—Causes and Remedies*, Techdata Sheet 82-08, Naval Civil Engineering Laboratory, Port Hueneme, CA, 1982.

Specific information on wood preservative treatment can be obtained from: American Wood Preservers' Association, 1625 Eye St. NW, Washington, D.C. 20006. 202/931-8180; and American Wood Preservers' Institute, 1651 Old Meadow Rd., McLean, VA 22101. 703/893-4005.

SPECIALTY PRODUCTS

The following product list is provided to help the reader locate new, unusual or hard-to-find products that relate to moisture control or measurement. Reference to a company or product name does not imply approval or recommendation to the exclusion of others that may be suitable.

VAPOR RETARDER AND BREATHER MATERIALS

A new type of tough polyethylene has been developed especially for use as an air-vapor retarder. Known as TU-TUFF, it is available from:

Sto-Cote Products, Inc.
P.O. Box 310
Richmond, IL 60071
800/435-2621

Acoustical sealant is a special sealant used to stop sound transfer. However, it has also become the major sealant for polyethylene vapor retarders because testing revealed that it stays flexible and does not make the plastic disintegrate. This type of acoustical sealant is available from:

Tremco
10701 Shaker Blvd.
Cleveland, OH 44104
216/229-3000

Special plastic pans (also called "polypans") to protect the integrity of the vapor retarder around electrical and plumbing runs are available from:

Solatech
7726 Morgan Ave. S.
Minneapolis, MN 55423
612/866-7672

High-perm exterior paper that breathes, yet stops air movement is being used to enhance insulation effectiveness in high-R new construction and retrofit. This product is available from:

PARSEC
P.O. Box 38534
Dallas, TX 75238
800/527-3454

Product name: TYVEK
E.I. DuPont, Fibers Dept.
Centre Road
Wilmington, DE 19898
800/441-7515

A variety of products are available for fixing moisture problems related to weights in double-hung windows. These products and their distributors include:

(Sash-cord pulley seal)
Anderson Pulley Seals, Inc.
920 West 53rd Street
Minneapolis, MN 55419
612/827-1117

(Double-hung window position control—spring clips)
Grovco Sales Company, Inc.
537 Easton Road
Horsham, PA 19044

Wright Products Co.
2515 Wabash Street
St. Paul, MN 55114

(Position control with window jamb channels)
Quaker City Manufacturing Co.
701 Chester Pike
Sharon Hills, PA 19079
215/586-4770

Specialty instruments for measuring humidity are available from:

Humidial Corp.
P.O. Box 464
Colton, CA 92324
714/825-1793

Brooklyn Thermometer Company, Inc.
90 Verdi Street
Farmingdale, NY 11735
516/694-7610

Preservation Resource Group, Inc.
5619 Southampton Drive
Springfield, VA 22151
804/323-1407

FURTHER REFERENCES

These publications were also instrumental in the production of this document.

Anderson, L.O. and Sherwood, G.E., *Condensation Problems in Your House: Prevention & Solution* USDA Forest Services Bulletin No. 373, U.S. Government Printing Office, Washington, D.C.

Brown, E.J., Kapple, W.H. and Percival, D.H., Technical Note #9, *Construction for Attic Ventilation*, Small Homes Council, Building Research Council, University of Illinois.

Jones, R.A., *Crawlspace Houses*, F. 4.4 Council Notes, Vol. 4, No. 2, Small Homes Council—Building Research Council, University of Illinois at Urbana, Champaign, IL, 1980.

U.S. Department of Energy, Office of Assistant Secretary for Conservation and Solar/Office of Building and Community Systems, *Residential Conservation Service (RCS) Auditor Training Manual*, Chapter 7, Moisture Control, Washington, D.C., 1980.

"Condensation in Attics: Are Vapor Barriers Really the Answer?" G.S. Dutt, May 15, 1979, *Energy and Buildings*, Vol. 2, #4, 1979, p. 251-258. (Study from Center for Energy and Environmental Studies, Princeton University, Princeton, NJ.)

American Society of Heating, Refrigeration and Air Conditioning Engineers, *ASHRAE Handbook 1981 Fundamentals*, New York, 1981.

Control of Condensation in the Walls and Ceilings of Retrofitted Houses, report by Special Ad Hoc Task Group under contract to National Bureau of Standards for Division of Building and Community Systems, Department of Energy, Dec. 29, 1978.

Duff, John E., *Moisture Conditions of a Joist Floor over an Insulated and Sealed Crawlspace*, Forest Service Research Paper SE-206, Southeast Forest Experiment Station, Asheville, NC, 1980.

Tsongas, George A., and Sieton, John and Odell, Inc., *Field Study of Moisture Damage in Walls Insulated Without a Vapor Barrier*, Prepared for the Oregon Department of Energy ORNL/SUB-78/97726/I, Dist. Category UC-95d, Contract No. W-74-5-Eng-26, Oak Ridge National Lab, Oak Ridge, TN, 1980.

Selvagg, John A., *Residential Humidification Versus Energy Consumption*, Research Products Corp., Madison, WI.

Rowley, R.B., Algren, A.B., Lund, C.E., "Condensation of Moisture and Its Relation to Building Construction and Operation," Bulletin No. 18, *Bulletin of the University of Minnesota Engineering Extension Station*, Vol. 18, No. 56, Sept. 10, 1941.

H.R. Trechasel Associates, *Problem Definition Study of Requirements for Vapor Barriers in the Building Envelope*, CR 83.D06, Germantown, MD, 1982.

Sherwood, Gerald E. and Tenwolde, Anton, *Moisture Movement and Control in Light-Frame Structures*, Forest Products Lab, Madison, WI, 1982.

Appendix C

INFORMATIVE DOE A.T. GRANTS RELATED TO MOISTURE

The National Center for Appropriate Technology has drawn upon the experiences of numerous DOE Appropriate Technology grantees to develop this publication.

Listed below are selected final reports which proved to be particularly informative in addressing specific moisture-related problems. This data is current through May 1983. Final reports and additional information about these grants can be obtained from NCAT upon request.

KANSAS

A 1,600 square-foot passive solar house with an attached greenhouse was constructed. The design also incorporated the use of a trombe wall. A 6-mil vapor retarder prevented moist, interior air from penetrating the 15½ inches of fiberglass insulation in the roof. Rigid insulation was used on the exterior of this earth-bermed, high-mass building. A woodstove was the source of back-up heat. The purpose of this project was to demonstrate how various building technologies could be integrated into a single dwelling to conserve energy.

Grantee:
Ross and Carolyn Duffy
224 Circle St.
Topeka, KS 66606
DOE Contract #:
DE-FG47-79R701014
ATMIS ID:
KS-79-005

NORTH CAROLINA

A demonstration house that employed both solar and energy-conserving building technologies was constructed on the campus of the North Carolina State University in Raleigh. The design included a sunspace that could easily be isolated from the living space, thereby reducing both the heating and cooling load. The results of 1½ years of monitoring indicated a yearly heating and cooling bill of under $40. A polyethylene vapor retarder was attached to the interior wall underneath the sheetrock to halt the migration of moisture from the house into the insulation.

Grantee:
Herbert Eckerlin
Department of Mechanical and Aerospace Engineering
North Carolina State U.
Box 5246
Raleigh, NC 27650
DOE Contract #:
DE-FG44-80R410141
ATMIS ID:
NC-79-008

OHIO

The grantee constructed a passive solar house, which integrated massive thermal storage and a wood back-up system into a forced-air heating system. Large amounts of insulation and infiltration-reduction techniques were also incorporated into the design. The grantee used an effective foundation drainage system that helped avoid typical basement moisture problems experienced by others in the vicinity.

Grantee:
Timothy Kimpel
2051 Chandler S. Ville Rd.
Roseville, OH 43777
DOE Contract #:
DE-FG02-79R510146
ATMIS ID:
OH-79-005

VERMONT

A prototype, residential-scale heat exchanger was designed, built and tested. This innovative system includes a defrost cycle which has been successfully tested in northern climates. The heat exchanger can effectively remove moisture from energy-efficient, airtight houses. The product of this research has since been commercialized.

Grantee:
The Memphremegog Group
Box 456
Newport, VT 05855
DOE Contract #:
DE-FG41-80R110348
ATMIS ID:
VT-80-004