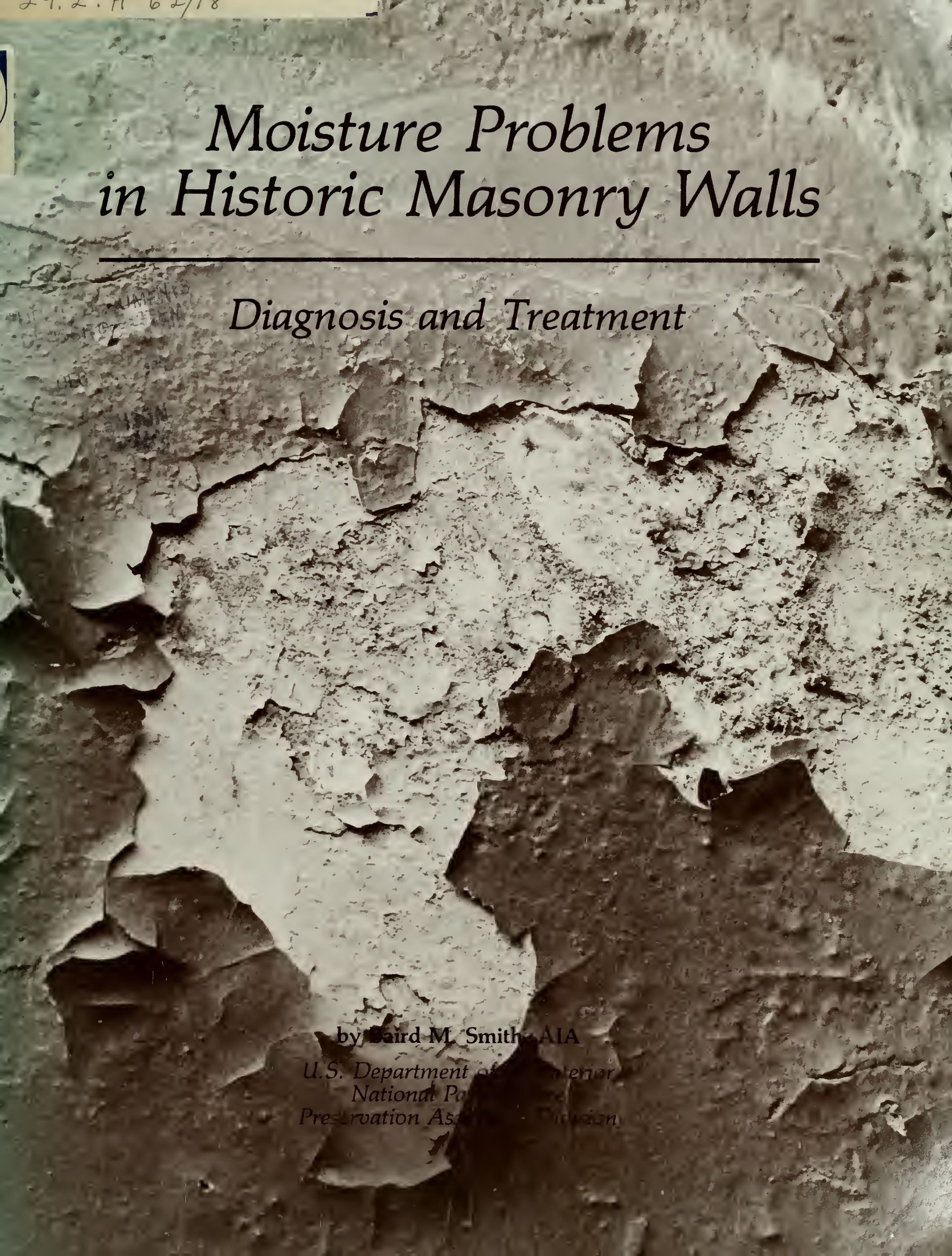
Moisture Problems in Historic Masonry Walls

Diagnosis and Treatment



by Baird M. Smith, AIA

U.S. Department of the Interior
National Park Service
Preservation Assistance Division

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Cover: Blistered paint and damaged plaster in the Pension Building, Washington, D.C., caused by a clogged rain leader. Photograph: Susan Dynes.

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Washington, D.C. 20402

Acknowledgements

The author wishes to acknowledge the kind assistance of the following individuals: Jukka Jokilehto, ICOMOS, Rome; John Ashurst, Department of the Environment (U.K.); R.W. Sharpe, Building Research Establishment (U.K.); Dr. Jeremy Taylor, Institute for Advanced Architectural Studies, York; Dr. James Clifton, U.S. National Bureau of Standards, and Dr. Erhard Winkler, Notre Dame University.

Additionally, professional staff at the National Park Service have contributed to the preparation of this report: Michael Auer, technical writer-editor; Sally Marusin Fackelman, copy-editor; and Chris Henry, delineator.

Contents

Foreword

Moisture is probably the greatest source of damage to historic buildings. Excessive moisture from rain, ground water, and condensation can inflict damage ranging from dampened wallpaper and plaster to severe deterioration of structural components. In extreme cases moisture can jeopardize brick and stone walls and can threaten building stability. As serious as moisture problems are to historic buildings, it is surprising that there is not more published information on the topic. This publication attempts to present sound technical information for architects, building owners, property managers and others responsible for the care and maintenance of historic buildings. This report is taken from a dissertation on moisture problems in English buildings prepared while the author attended the Institute for Advanced Architectural Studies, University of York, York, England in 1979. The current text addresses similar problems in the U.S., but because of the vast differences in climate and topography across this country, has focused on general, rather than localized, moisture problems here. It is hoped that this report will be the basis for future regional and local case studies to complement the material presented here.

Lee H. Nelson, AIA
Chief, Preservation Assistance Division

Introduction

Architects have attempted to control damage to buildings from excessive moisture since ancient times. Vitruvius (1st century B.C.) recommended the use of cavity walls to minimize rain penetration, and natural hydraulic cement stucco to reduce dampness at the base of exterior walls.[1] Renaissance architects likewise understood the value of cavity walls in reducing moisture, but, like the ancients, they showed apparently little recognition of the full range of causes of moisture damage.[2]

In the earliest extant buildings in the U.S. little was done to prevent moisture problems except to deal with certain aspects of site drainage and to provide a sound roof. The great majority of seventeenth and eighteenth century buildings had no protection against the moisture damage caused by ground water, although most urban buildings by the early nineteenth century were fitted with gutters and downspouts to control the rainwater that previously would have dampened walls and flooded basements.

Much of the progress made in controlling moisture damage to buildings in the nineteenth century is attributable to advances in the technology of site drainage systems. In the early and middle years of the century, major east coast cities such as New York, Boston, Philadelphia, and Savannah learned to control excess rainwater through drainage ditches or street gutters, and in some places, underground storm sewers. This technology was well developed by mid-century.[3]

Other advances were made in the nineteenth century. Water tables of granite or dense limestone were increasingly used, especially for public buildings, to prevent the upward rise of moisture within walls, and to direct rainwater away from the bases of buildings. The progress made in understanding and controlling moisture damage can be measured in *The Architecture of Country Houses*, published in 1850 by Andrew Jackson Downing. Downing was clearly aware of ground water problems when he wrote:

> . . . foundation walls . . . built of common lime mortar, will always be damp, from capillary attraction . . . common lime mortar offering no impediment to the absorption of the moisture from the soil, or to its gradual passage upwards into the main wall of the house. The remedy for this is to build the foundation walls of hydraulic lime mortar, which completely prevents any such foundation dampness.[4]

He also noted that "in damp soils, the dampness should be prevented from the soil into the unbuilt wall, by laying one course of slate, or of brick, laid in cement of hydraulic mortar, at the top of the foundation."[5] The detail he recommended is now known as a physical damp proof course (dpc). To prevent problems resulting from rain penetration through walls, Downing recommended cavity wall construction[6] (see figure 1).

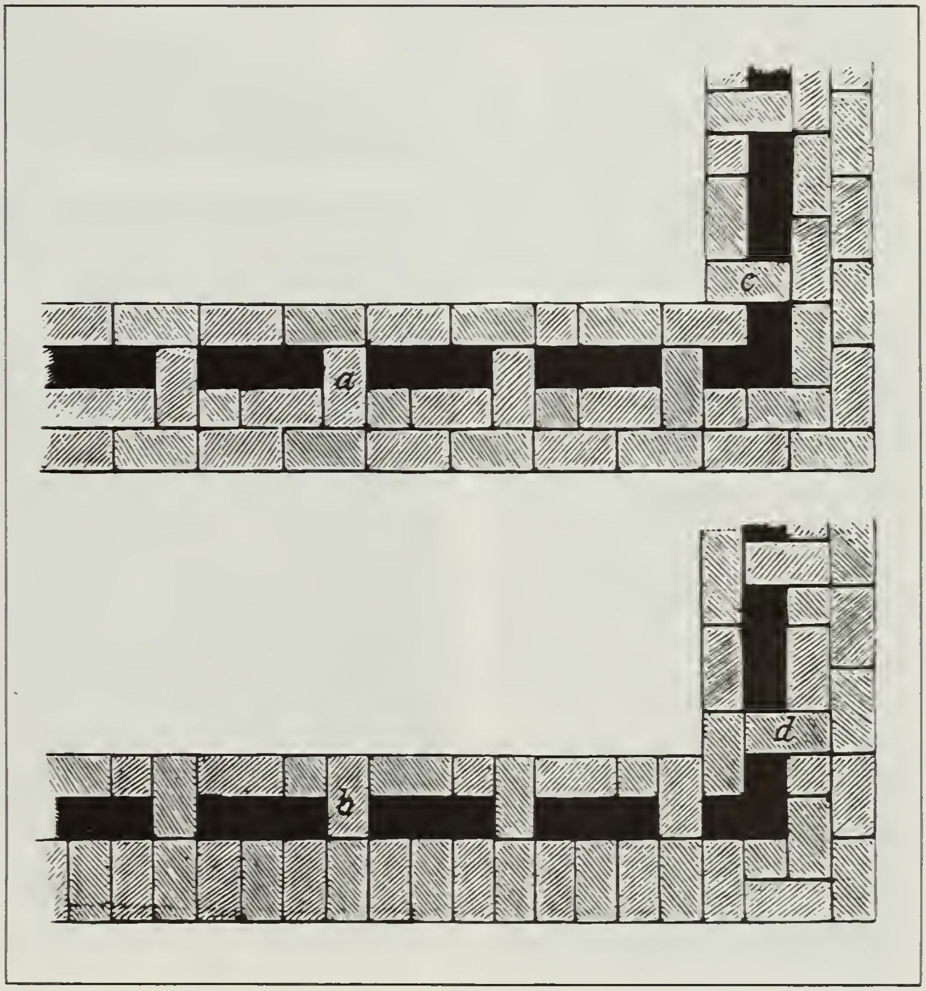

figure 1

Patented cavity wall systems recommended by A. J. Downing in The Architecture of Country Houses *(1850). Since the walls containing such cavities appear outwardly normal, they are difficult to identify without physical probing.*

Like Downing, the British writer Joseph Gwilt also understood that rising damp resulted from capillary action. Gwilt, however, attributed the problem to damp construction materials, as the following glossary definition from *An Encyclopedia of Architecture* (1842) demonstrates:

> Dampness. A moisture generally attendant on buildings finished hastilly, on account of materials, not being dry, carrying up the moisture by capillary attraction. A layer of powdered charcoal mixed with pitch or resin and powdered pitcoal laid over one of the courses of the wall near the foundations, will prevent the evil.[7]

While Gwilt failed to realize that porous building materials draw moisture from the earth whether they are dry or wet, he understood that a horizontal damp proof course would arrest the problem.

In the second half of the century a flurry of patented inventions followed, as architects and builders sought to capitalize on the newly discovered virtues of damp proof courses. Some patented courses were made of brick, fired at high temperatures, and often glazed, in order to render them impervious to moisture.[8] Other common damp courses included double courses of slates; a single sheet of lead or zinc set in cement; a layer of tar and sand; or a layer of bituminized building paper.[9] (Figure 2 shows two examples.)

At the same time, techniques for waterproofing exterior masonry were tested. Some builders impregnated bricks and stone with solutions of animal fat or insoluble silicates of lime.[10] (These techniques may have increased, rather than reduced problems.) Despite failures of these and other exotic treatments, substantial progress was made by the end of the century, including the incorporation into local building codes of some provisions for protection against ground water.[11] Another practice during this period was to install rain leaders or "hidden downspouts" within masonry walls. However, these were exceedingly difficult to keep clear. When they became clogged, extensive

a

b

figure 2

Typical physical damp courses. (a) partially dismantled brick wall with exposed slate damp course. This Washington, D.C. building dates from about 1890. (b) Cavity wall with the outer brick wythe removed exposing a tar damp course (note that the tar, when poured, overflowed slightly into the cavity). Photographs: Baird M. Smith.

interior and exterior damage resulted (see figure 3).

In the early decades of the twentieth century the building industry devised many new dampproofing treatments. Knapen tubes, shown in figure 4, were invented in 1911.[12] Inserted in a horizontal line within damp walls, they were intended to increase evaporation and thus drying. In these years also a rash of masonry waterproofing treatments and mortar additives were patented. Szerelmey's Stone Liquid, Symentrex, Antihydrine, Liquid Konkerit and Dehydratine are a few of these.[13] Between the wars, large-scale scientific study of moisture problems such as capillarity and efflorescence was undertaken for the first time, yielding a basic understanding of these phenomena.

With the end of World War II, the building industry moved into the era of synthetic materials and high technology. Silicones, initially used in construction to waterproof road surfaces, were used to waterproof masonry walls.[14] In the 1960's silicones and silicone latex mixtures were injected in a horizontal band into buildings in England and Germany to form a continuous dampproof layer (see figure 5). Other new sheet materials like polyethylene, bituminized lead, and asbestos sheets enlarged the choices of materials available as damp courses. Portable chain saws and carborundum blades made cutting mortar joints for the installation of such courses easier. In America chemicals and sometimes clay were injected into the soil adjacent to foundations in order to stop the horizontal migration of moisture through the soil and into the foundation walls. Electro-osmotic systems were another European contribution to the waterproofing field. To preclude the upward movement of water, these systems establish an electric field at the point at which a damp course is installed. Both "active" systems that supplied a direct current, and "passive" systems that used the natural electrical potential between the saline saturated wall and the earth were installed (see figure 6).

As was the case with many of the products and methods used during the nineteenth century, however, many of the

a   b

figure 3

(a) The stain shown here is caused by overflow from a clogged rain leader (a 4 inch diameter cast iron pipe set within the masonry wall). (b) Extensive damage to the interior wall plaster opposite the rain leader also resulted. Photographs: (a) Baird M. Smith. (b) Susan Dynes.

treatments developed in the twentieth century have proven ineffective or inconclusive in treating moisture problems. By the 1970's evidence was clear that Knapen tubes, which had been in fairly wide use since their invention, were not working.[15] Both active and passive electro-osmotic systems have been ineffective.[16] Silicone waterproof coatings have been found in some instances to do more harm than good, and soil injections have generally proven ineffectual.

Yet the record is far from totally negative: polyethylene sheeting and other "traditional" damp courses, used extensively in Europe, perform as absolute barriers to vertical moisture movement. And a new generation of water repellant coatings known as silane shows great promise. The lesson to be learned from previous attempts to prevent moisture damage is that practitioners should be wary of using methods that have not been extensively tested. This is especially true for historic buildings; they should not be viewed as testing ground for untried methods.

Before undertaking work to correct moisture problems in historic buildings, those involved in designing remedial measures must understand the fundamental types and causes of moisture damage. They must be able to make proper diagnoses and to select appropriate treatments, preferably conservative ones. This report attempts to provide such a framework for approaching moisture problems in historic buildings.

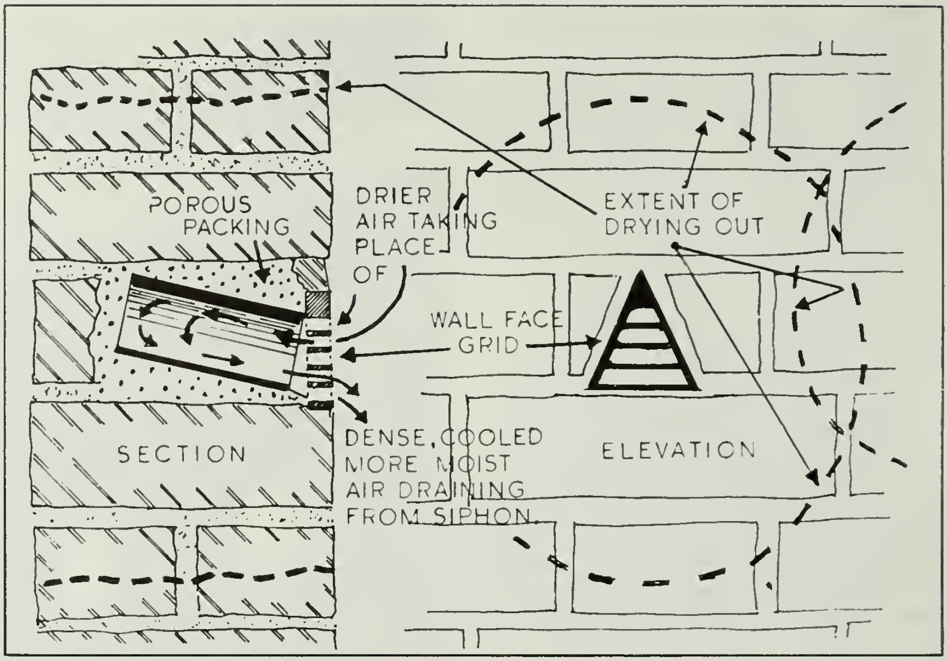

figure 4

Knapen tubes. They are installed every 18 inches in a horizontal line at the top of the foundation wall and are intended to increase evaporation inside the wall and hence, reduce moisture build-up. Their effectiveness in any but dry climates, however, is questionable. Drawing: R. T. Gratwick, Dampness in Buildings.

figure 5

Evidence of an injected chemical damp course. Each header brick has been drilled, injected, and subsequently patched. Note that the injected damp proof course is above an existing damp proof course of two courses of high fired brick. Photograph: Baird M. Smith.

figure 6

A passive electro-osmotic system. The thickened mortar joint holds the copper strand, which is grounded to the earth. In theory, an electrical potential difference is established that halts the migration of moisture above the copper strand. In practice, however, there is little proof that the passive systems work. Active systems do work, but are subject to rapid corrosion of system parts and hence are not considered appropriate for long-term moisture problems. Photograph: Baird M. Smith.

Introduction: Reference Notes

[1]Vitruvius advised that "...if a wall is in a state of dampness all over, construct a second thin wall a little way from it on the inside, at a distance suited to circumstances, and in the space between these two walls run a channel, at a lower level than the apartment, with vents to the open air. Similarly, when the wall is brought up to the top, leave air holes there. For if the moisture has no means of getting out by vents at the bottom and at the top, it will not fail to spread all over the new wall." Pollio Vitruvius, *The Ten Books of Architecture*, translated by M. H. Morgan (New York: Dover, 1960), p. 209. In another passage Vitruvius recommends the use of a natural hydraulic cement stucco at the base of an exterior wall where dampness had been found to be a problem (p. 208).

[2]"It is very commendable in great fabricks, to make some cavities in the thickness of the wall from the foundation to the roof, because they give vent to the winds and vapours, and cause them to do less damage to the building." Andrea Palladio, *The Four Books of Architecture* (London: Isaac Ware, 1738, reprinted New York: Dover Publications, Inc., 1965), p. 7.

[3]Marion M. Weaver, *History of Tile Drainage* (Waterloo, N.Y.: M. M. Weaver, 1964), p. 38.

[4]Andrew Jackson Downing, *The Architecture of Country Houses* (n.p.: D. Appleton & Co., 1850), reprinted, (New York: Da Capo Press, 1968), p. 68.

[5]*Ibid.*, p. 56.

[6]*Ibid.*, p. 62.

[7]Joseph Gwilt, *An Encyclopedia of Architecture* (London: Longman, et al, 1842), p. 513.

[8]John Taylor, "Sundry Sanitary Building Appliances," *Papers Read at the R.I.B.A. Session: 1962-3* (London: R.I.B.A., 1964), p. 77.

[9]Robert Scott Burn, ed., *Modern Building and Architecture* (London: A. Fullarton and Co., 1869), p. 26.

[10]*Notes on Building Construction, part III* (London: Rivingtons, 1879), p. 224.

[11]By 1897, Washington, D.C., had adopted several requirements to prevent dampness in buildings (primarily originating from ground water problems). Cellars and basements, for example, could not be inhabited unless they were dry. To accomplish this, the regulations required that: "A course of slate must be worked in all walls to the full width of the walls, two courses above the surface of the ground, and an additional course above footings in exterior walls where there is a cellar or basement." *Regulations Governing the Erection, Removal, Repair and Electric Wiring of Buildings...in the District of Columbia* (Washington: n.p., 1897), p. 37.

[12]W. Noble Twelvetrees, ed., *Rivington's Notes on Building Construction*, part 1 (London: Longmans, Green and Co., 1915).

[13] *Sweet's Indexed Catalogue of Building Construction* (New York: Architectural Record, 1906), pp. 142-150.

[14] B. L. Clarke and John Ashurst, *Stone Preservation Experiments; BRE 1972* (Garston, Watford, England: Building Research Establishment, 1972), p. 1.

[15] J. L. Heiman, et al., "The Treatment of Rising Damp," *Architectural Science Review,* December, 1973, p. 170.

[16] J. L. Heiman, "An Evaluation of Methods of Treating Rising Damp," *Rising Damp: Techniques and Treatment in Building Renovations* (Sydney: Graduate School of the Built Environment, University of New South Wales, 1978), p. 26.

Chapter 1:

Fundamentals of Moisture in Walls

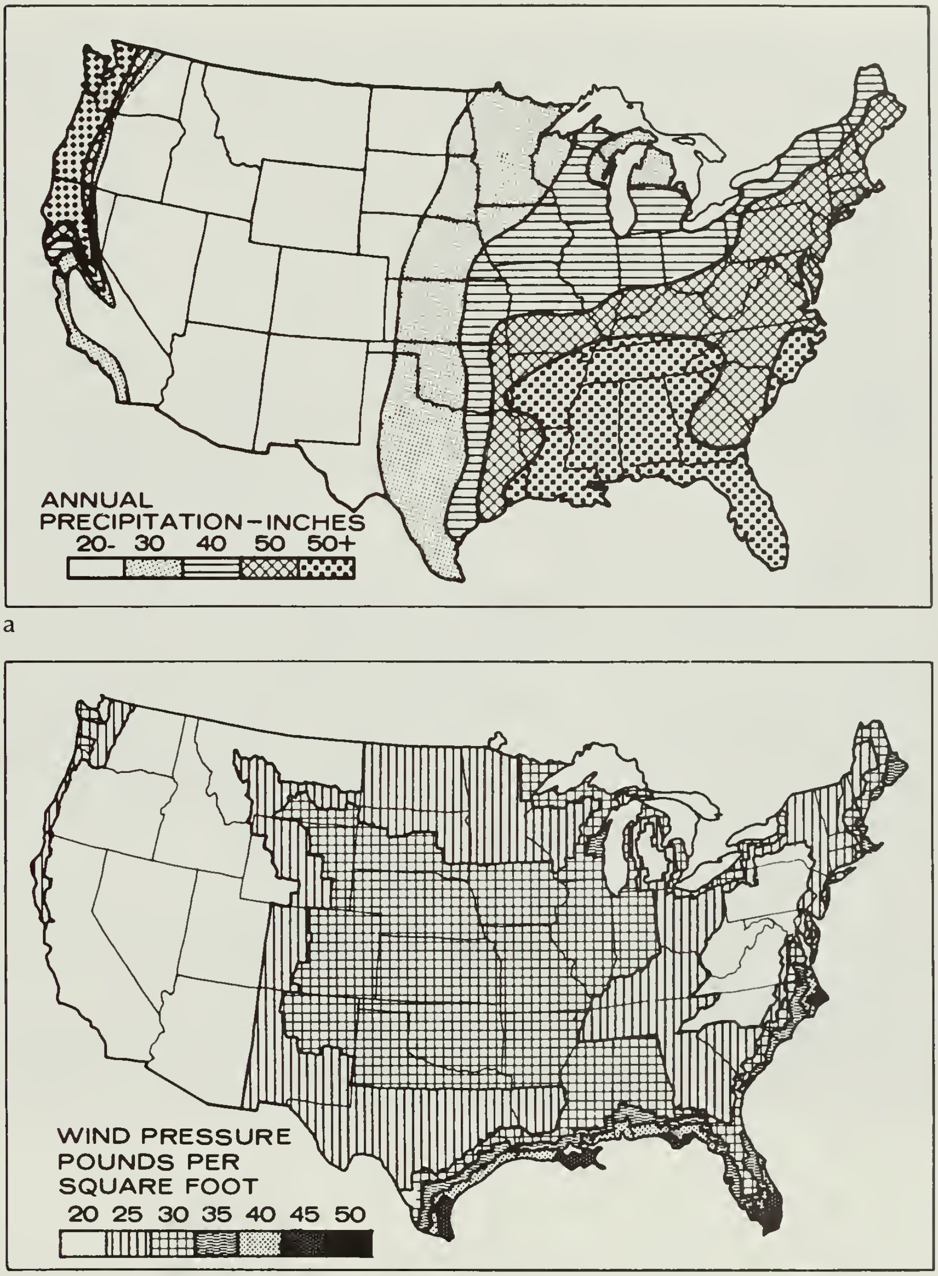

figure 7

Driving Rain Index for the U.S. The likelihood of rain penetration can be guaged by combining the values for (a) annual precipitation and (b) wind pressure as shown on these maps. The likelihood of rain penetration is severe *where annual precipitation is 30 in. or over and wind pressure is 30 psf or over;* moderate *where annual precipitation is 30 in. or over, and wind pressure is 20 to 25 psf, and* slight *where annual precipitation is less than 30 in. and wind pressure is 20 to 25 psf, or where annual precipitation is less than 20 in. Illustration: "Moisture Control in Brick and Tile Walls," Technical Notes on Brick Construction 7C. Brick Institute of America.*

Primary Sources of Moisture

Moisture is always present to some degree in building materials. It does not necessarily damage them. The point at which moisture becomes excessive moisture, and therefore, the point at which damage will occur, varies from one material to the next. Moisture in building materials becomes *excessive* moisture only when a condition of "dampness" exists. The Building Research Establishment in Great Britain reserves the term "dampness" for conditions under which "moisture is present in sufficient quantity either to become directly perceptible to the senses of sight and touch, or to cause deterioration in the decorations and eventually to the fabric of the building."[1] For a porous material to reach a moisture content level at which damage can occur, moisture must generally be introduced into the material from an outside source.

The common sources of excessive building moisture are *rain, ground water,* and *condensation. Building design defects* and *poor maintenance* will exacerbate problems. A familiarity with these sources is important for an accurate understanding of moisture problems and as an aid to proper diagnosis.

Rain

Light rains followed by periods of sun normally do not cause moisture problems in buildings. Both brick and stone

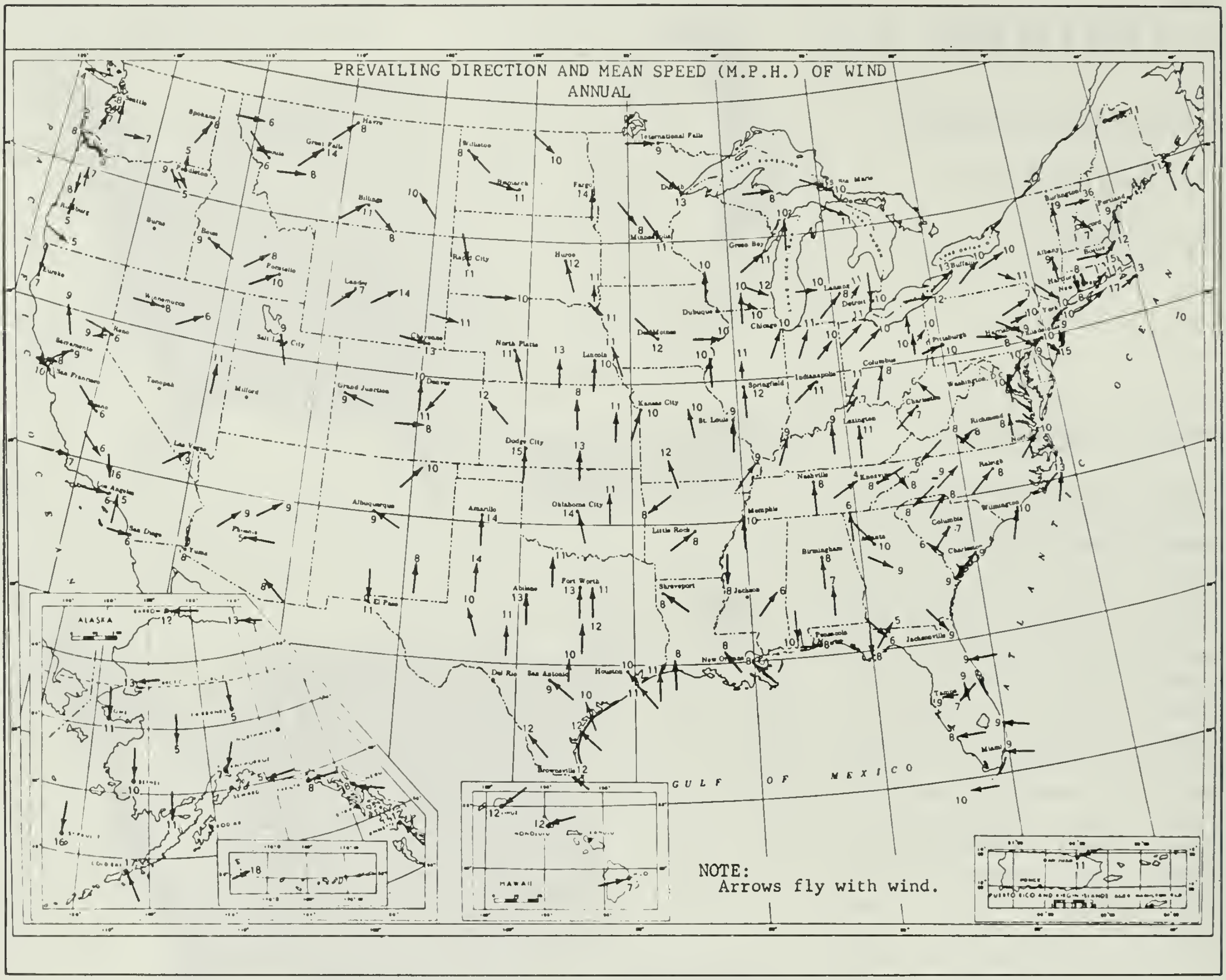

figure 8

Annual mean wind speed and direction. Illustration: Climatic Atlas of the U.S., *U.S. Department of Commerce.*

draw in some rain, which then evaporates during a period of dryness. Moisture penetration from light rains is deeper in some materials than in others, but this moisture also normally evaporates during a drying cycle. On the other hand, heavy or wind-driven rains force moisture deeper into materials and subsequent drying may not be complete. The most serious penetration occurs at the interface between brick and mortar where pointing has deteriorated. Minute cracks are quite efficient at drawing moisture deep into walls.[2] Thus, the penetration is through the joint, not through the masonry. The likelihood of serious problems from rain can be gauged by plotting the driving rain index, which combines wind pressure and annual precipitation (figure 7). It should be assumed that rain penetration is a possibility in buildings located in areas with heavy rainfall and winds.

In some locations prevailing weather patterns dictate that wind and rain tend to originate from the same direction. In these places rain is likely to affect only one facade. Figure 8, taken from *Climatic Atlas of The United States*, an invaluable aid, indicates prevailing annual wind direction and mean speed for many points across the U.S. (This information should be taken only as a guide, since it is an average of the yearly wind condition. Moreover,

figure 9

Typical interior staining from rain penetration. If rain penetration is occurring, staining should be uniform across the entire wall surface. If it is localized at a window or construction joint, then a construction fault would be the cause. Naturally, if rain is the source, the wetness will coincide with heavy rains, with drying occurring alternately. Photograph: Baird M. Smith.

for most localities, there is no prevailing weather pattern.)

However, in reality most historic masonry walls are of such thickness (generally 9 inches or more) that rain rarely penetrates entirely through the wall to the inner surface. Hence, rain penetration is not easy to detect. Patch-like staining on an interior wall is a sure sign of rain penetration (see figure 9). If there is no interior evidence, and if the mortar joint is in good condition, then it is very unlikely that rain penetration is a problem. On the other hand, if the mortar joint is weathered, then moisture is entering the wall and creating the conditions for damage to the masonry and mortar alike.

Rain also causes problems at the base of a building if allowed to splash back at the building or to form puddles against walls. Splash-up from sidewalks, roadways and other hard surfaces commonly adjacent to buildings can nearly saturate the walls, giving the appearance of ground water problems on both the exterior and the interior.

Ground Water

Ground water is another source of potentially damaging moisture. In

figure 10

Typical horizontal tide mark. The efflorescence gradually disappears above the tide mark. Photograph: Baird M. Smith

some locales, ground water levels (i.e., levels of complete water saturation) are only a few feet below the surface. These levels are marked by the subterranean water table, which rises and falls with seasonal changes of rainfall. During heavy rains, the ground from the surface down can become completely saturated; at these times the level of the water table can coincide with the ground surface.[3] When the rain ends, the upper portions of the ground lose this moisture and the point of full saturation is lowered to the level of the water table.

Suction of ground water into porous building materials is always a likelihood in structures built on ground that is damp from either a high water table or continually heavy rainfall. A broken water main, damaged storm pipe, or clogged drain can create similar conditions. This suction, or capillarity, occurs both vertically and horizontally; in fact, moisture travels twice as far horizontally as vertically.[4] The moisture will reach the maximum extent of its vertical and horizontal flow when it reaches equilibrium,[5] a precarious balance between the supply of moisture and its evaporation from exposed wall surfaces. Gravity is an added constraint on the vertical rise of moisture in the wall (see figure 10). The system is like a wick: the more moisture, the higher the rise; the more evaporation, the lower the rise. This mechanism is known as rising damp. It

EXAMPLES OF USE OF THIS CHART

1.

	Dry Bulb	Wet Bulb	RH	Dew Point
a.	75°F	75°F	100%	75°F
b.	75	73	90	72
c.	75	71	80	69
d.	75	63	50	55

2. Assume RH is designed for a specific room temperature. At intersection of 35% RH & 68°F Dry Bulb read horizontally to find Dew Point or cold surface temperature at which condensation will occur—40°F. At same intersection read 53°F Wet Bulb room temperature.

3. Know / Obtain

a. Wet & Dry Bulb Temperatures — RH, Dew Point & Vapor Pressure
b. RH & Wet Bulb Temperature — Dry Bulb Temp., Dew Point & Vapor Pressure
c. RH & Dry Bulb Temperature — Wet Bulb Temp., Dew Point & Vapor Pressure

4. Vapor Pressure Scale. Assume that a black roof had been installed at a temperature of 72°F with moisture vapor in or under the roofing exerting a pressure of .4 P.S.I.A. Temperature of a black roof in service can be as high as 160°F. The 88°F gain in temperature would induce a 4.3 P.S.I.A. or 619 P.S.F. gain in vapor pressure. This is the reason for rapid and easy growth of blisters in roofing once they have started.

NOTE: Outdoor air temperature will not ordinarily be the indoor surface temperature of doors and windows and their frames. Their indoor surface temperatures may be warmer by an amount sufficient to avoid condensation.

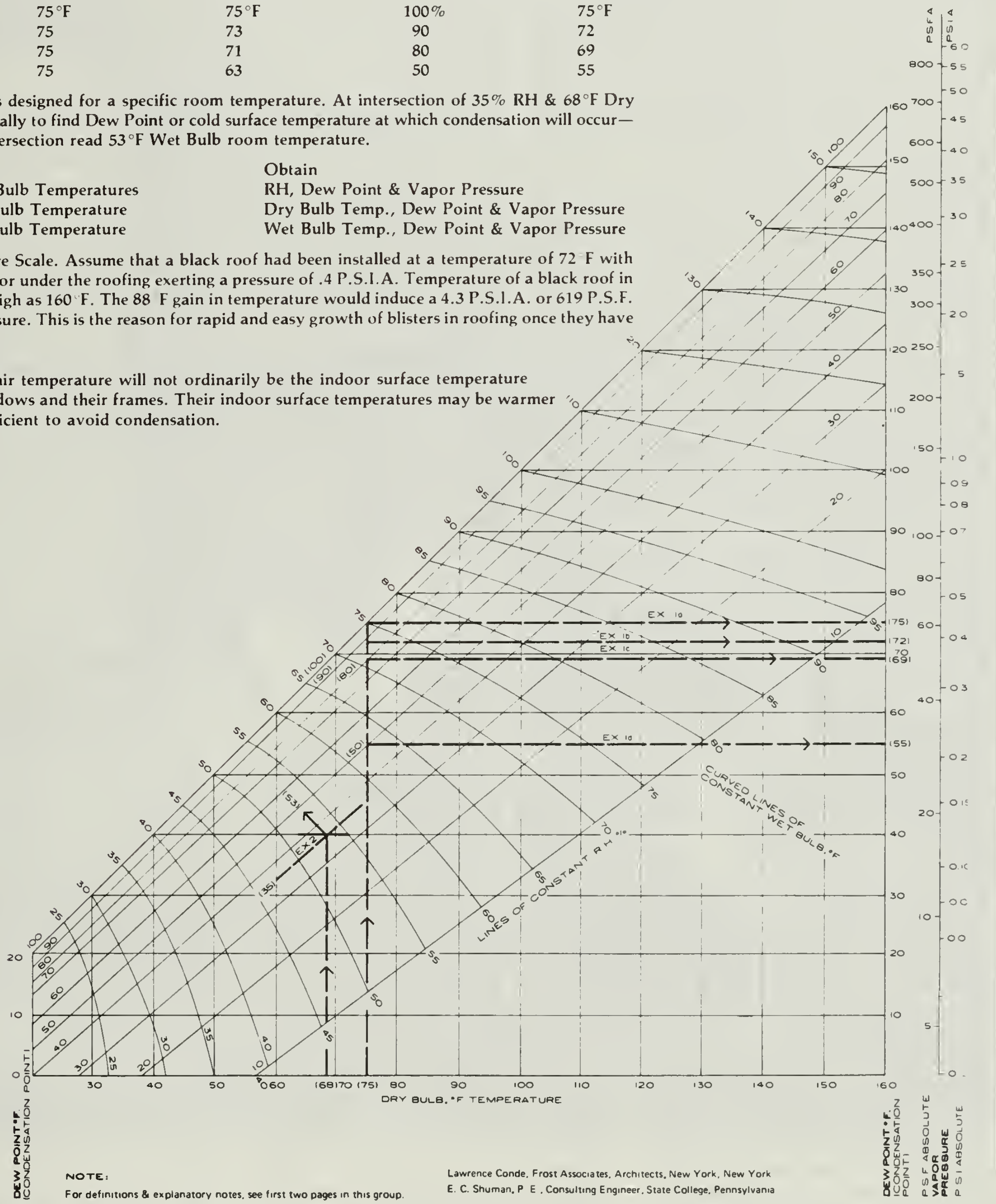

figure 11

Psychometric chart. Using this chart, the dew point can be determined if two of the following variables are known: wet bulb temperature, dry bulb temperature, relative humidity. Chart: Joseph N. Boaz, ed., Architectural Graphic Standards, *6th ed.*

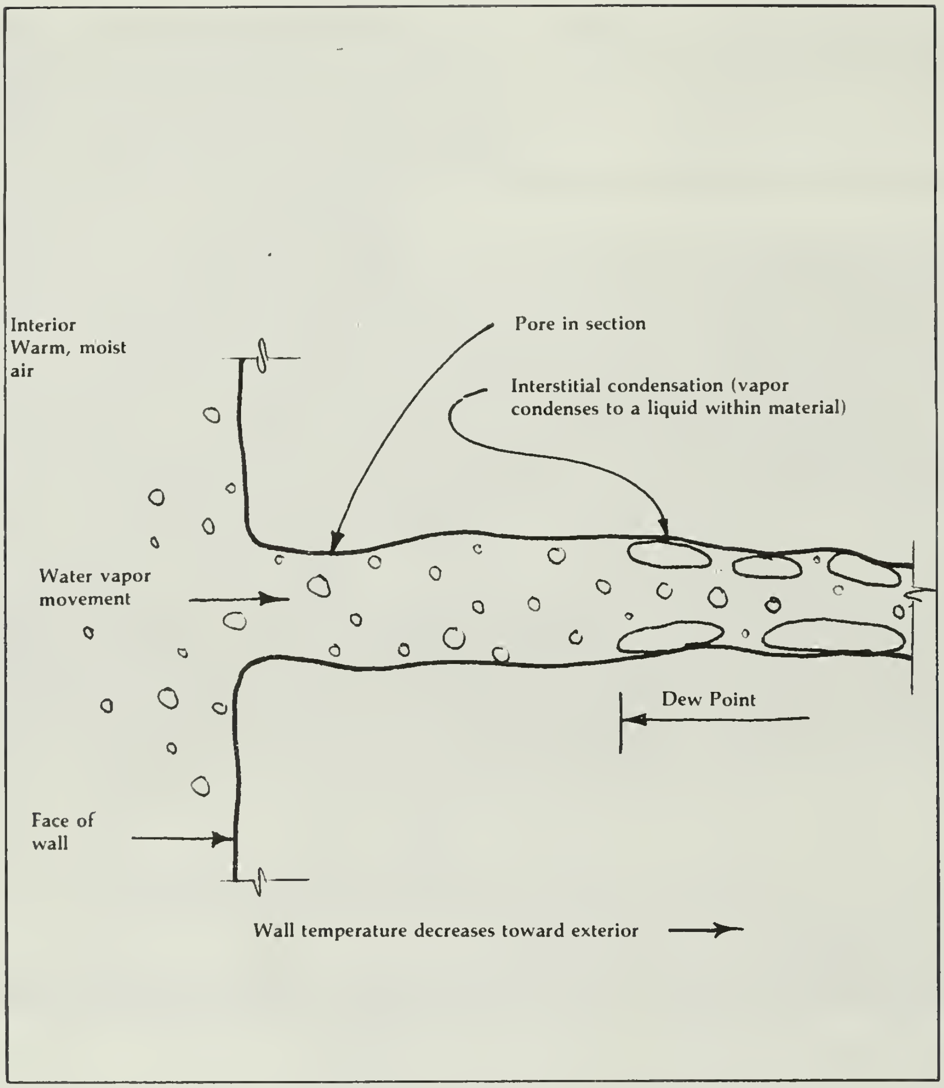

figure 12

Surface and Interstitial Condensation. Note that a dew point can be reached within the body of the wall. Drawing: Baird M. Smith.

is generally identifiable by a horizontal stain or "tide mark" on the wall. The tide mark is formed at the point where equilibrium has been reached between capillarity and evaporation, thus leaving large, visible accumulations of crystallized salts, called "efflorescence." Below the tide mark, moisture is rising through capillarity. This area often appears damp. Efflorescence is unusual below the tide mark because the high moisture content retains the salts in solution, although there is continual evaporation. Above the tide mark, the moisture content in the wall can vary as the equilibrium changes with the weather. In this transition area, the moisture content is sometimes high enough to support capillarity; at other times only water vapor is present. In the transition area, salts are brought to the surface, leaving a band of salt crystals above the tide mark.

Condensation

Condensation occurs when moist air reaches its dew point, that is, when moist air is cooled to the point at which the water vapor (a gas), changes state into water (a liquid). This can occur on the surface of materials, on glass or at the base of cool walls, for instance, or within porous materials. Using the psychometric chart (see figure 11) dew point temperatures can be predicted when air temperature and relative humidity (RH) are known. Thus, it is possible to avoid condensation by controlling air temperature or relative humidity.

On impervious materials such as glass or heavy-bodied wall coverings, condensation will occur on the surface, in very noticeable droplets. This water can collect on window sills or wooden baseboards, and over time (3-5 years) could damage paint coatings or cause the wood trim to rot. In porous materials, such as plaster or masonry, condensation will occur within the material where the temperature is low enough to create a dew point. This moisture content could build to levels sufficient to cause deterioration of the plaster or mortars or the ends of wooden joists or beams embedded in the wall. In extreme cases, at temperatures well below freezing, this condensed, frozen moisture could cause exterior brick or stone to spall. Figure 12 illustrates condensation within porous materials, known as interstitial condensation (differentiated from surface condensation).

In northern climates condensation occurs most often in the colder times of the year when the outside walls are cooler. Moisture generated through cooking, laundering, bathing and other activities condenses on the interior surface of walls. These activities can often raise interior relative humidity by 15 to 30%, creating the conditions for condensation to occur.[6] The problem is aggravated when windows and vents are closed, leaving little ventilation to reduce the moisture content of the air. It is even further aggravated if a building is only heated during part of the day so that the outside walls never warm up. They remain cold and receptive to condensed moisture. Energy conservation measures such as tightening windows, which reduces air movement, and reducing heat compound condensation problems.

In southern climates, the problem is reversed. Where a building is air-

figure 13

Typical evidence of maintenance-related moisture problems. When inspecting the outside of a building for moisture-related problems, all staining, patches of efflorescence, location of gutters and downspouts, special brick or stone details, and the general condition of the roofing and flashing should be noted. Photograph: Baird M. Smith.

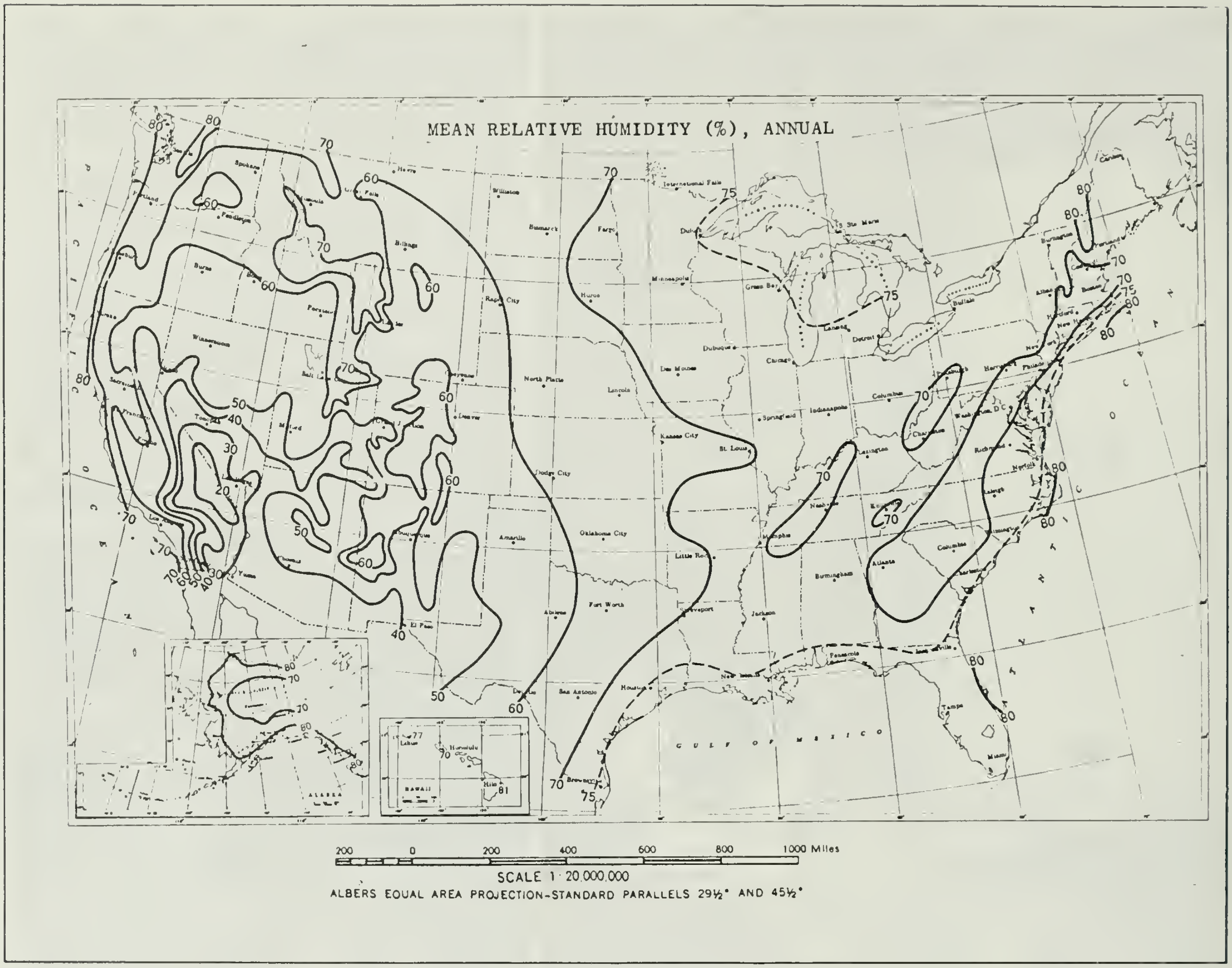

figure 14

Annual mean relative humidity. Detailed information on major cities is kept by the U.S. Weather Service. Illustration: Climatic Atlas of the U.S., *U.S. Department of Commerce.*

conditioned, the warm, moist outside air condenses on cooled exterior surfaces. Uninsulated wood frame walls and windows are the most susceptible. Exterior paint failure is often a result.

Identifying condensation requires continual monitoring of interior wall and window surfaces for water droplets. Also, measuring interior levels of relative humidity with a humidistat should serve as an early warning of potential condensation. Condensation can occur in every occupied building in cool northern climates except where there is adequate heating and extraction of warm, moist interior air to the outside.

Building Design Defects and Maintenance Problems

The most frequently encountered causes of excessive moisture accumulation are building design defects and lack of maintenance. Poorly designed roofs, for example, may not drain properly; parapets may lack proper cap flashing, or improperly installed basement concrete slabs may fail to preclude damp. Architects and builders occasionally try to cut costs, or save time, and sometimes use poor quality materials or use materials in ways in which they were not intended. These and other design and construction errors can be difficult to correct.

Moisture problems stemming from lack of maintenance can also be quite

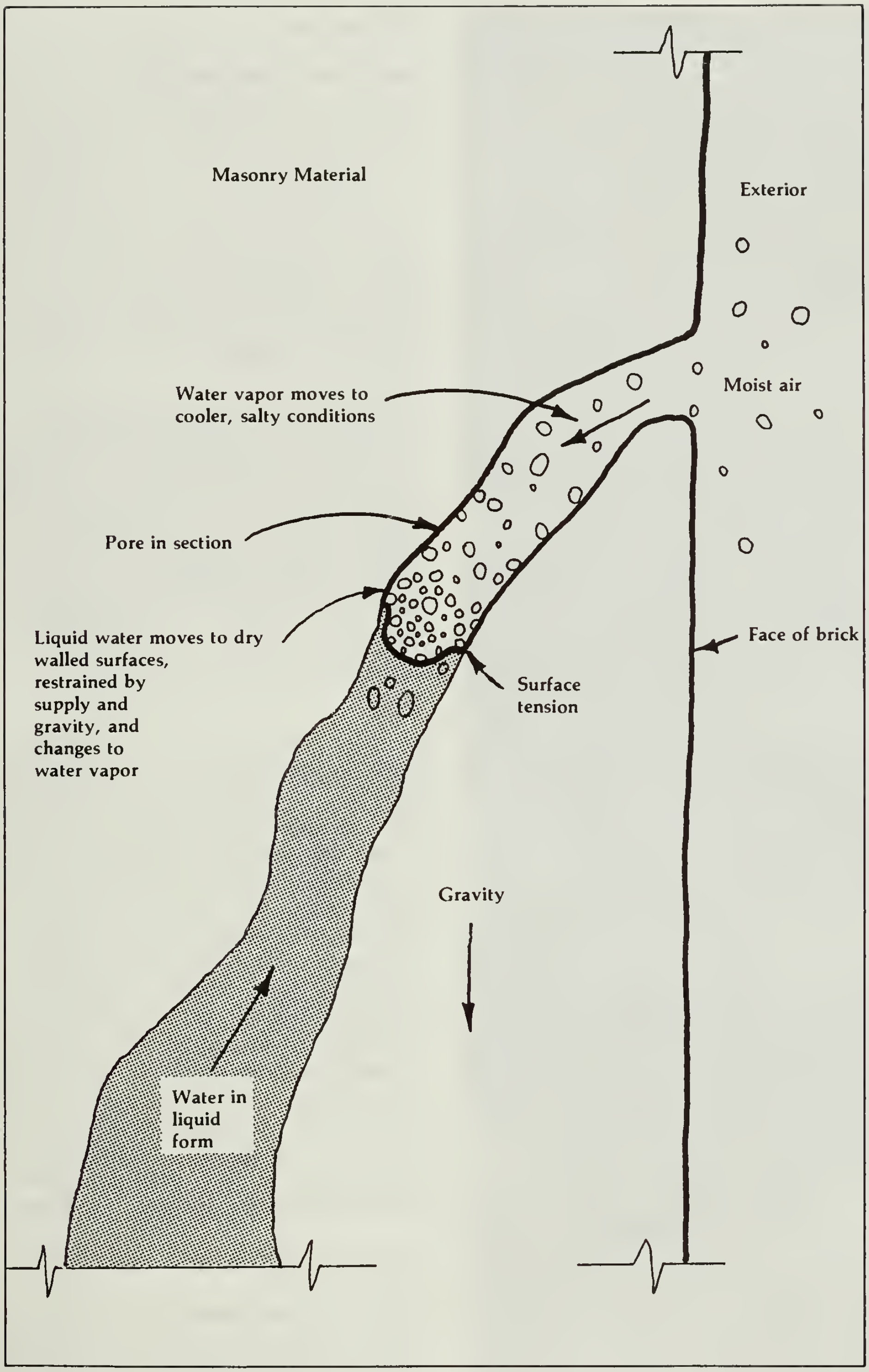

figure 15

Water and water vapor movement in a pore. In a greatly enlarged cross-section of porous masonry, water is drawn upwards by capillarity through the pores. Simultaneously, water vapor from moist outside air is drawn to cooler, salty areas within the masonry. Drawing: Baird M. Smith.

destructive. More common than building defects, these maintenance-related problems are normally easy to remedy. Clogged or broken rainwater pipes, leaky roofs, deteriorated flashings, or loosely fitting window frames result from *lack* of maintenance (see figure 13). In other cases *improper* maintenance practices cause problems. These practices include using excessive water to clean floors, and planting flowers and shrubs adjacent to walls and watering them too often. Additional related problems can be caused by earlier repairs or alterations. Pressure-grouting weak masonry walls can bridge existing damp courses and fill purpose-built wall cavities. Changes to site landscaping, roof alterations or extensions, and blocking in basement doors or windows with masonry can also cause serious moisture problems. Lastly, improperly used or malfunctioning heating, cooling and other mechanical equipment can cause or exacerbate moisture problems. Poorly controlled humidifiers, for example, can lead to excessive humidity levels and to serious condensation problems.

Humidity levels *must* be controlled. Simple, inexpensive humidity gauges should always be a part of a humidification system. Whenever humidity rises above 35% in the winter, the humidifier should be turned off. Higher humidity levels will lead to serious condensation problems.

Movement of Moisture in Masonry

Once excessive moisture has been introduced from any of the sources discussed above, inherent properties of building materials promote the migration of this moisture. Porosity and permeability are key characteristics of this moisture movement.

Porosity

The porosity of a material is the ratio of pore space of a material to the total volume, normally expressed in percent. Thus, it is the percentage of the volume of the material that is not solid.[7] Light, soft brick, for example, has a relatively high porosity of 55%, and is therefore much more likely to absorb moisture than dense, hard granite, which has a porosity of about 1%.

figure 16

Typical freeze damage to brick. Since the damage has occurred at the base of the wall, rain splash-up would be suspected as the source of the moisture. Damage from freezing moisture in porous materials is very common. Photograph: Baird M. Smith.

Permeability

The extent to which the pores in a solid are interconnected determines the permeability of the material, or the extent to which liquids can pass through it.[8] In brick, most of the pores are interconnected. It is thus a highly permeable material. Limestone, although of low porosity (about 15%), can also be quite permeable because there are numerous tiny interconnected pores that allow paths for moisture migration.

Permeability is measured in perms. A perm is the rate of vapor transmission of 1 grain (0.002285 ounce) per square foot per hour per inch of mercury pressure difference. The higher the perm value, or permeability of a substance, the more likely it is to transmit moisture. The perm values for some common building materials and surface coatings are given below.[9]

Building Materials	Perm Value
Aluminum foil	0.0
Polyethelylene (4 mil.)	0.08
Brick (4 in.)	1.1
Wood (fir, 3/4 in.)	2.9
Plaster on metal lath (3/8 in.)	15.0
15-lb. tar felt building paper	18.2
Gypsum wall board (3/8 in.)	50.0

Applied Surface Coatings	Perm Value
Hot melt asphalt (2 oz./sq. ft.)	0.5
Paint—3 coats (exterior) Oil on wood	1.0
Paint—2 coats (interior) Enamel on plaster	1.5
Primer, flat oil on plaster	3.0
Polyvinyl acetate latex (4 oz./sq. ft.)	5.5

Moisture Content Levels

The concentration of moisture in building materials often determines the extent of migration and the degree of damage. Three stages of moisture content, ranging from higher to lowest, are: saturation, critical water content, and hygroscopic moisture content.

Saturation

A material has reached saturation when every pore, or more specifically every interconnected pore, is filled with water.[10] At this point water can literally flow through the material. Fairly porous brick is saturated when the moisture content reaches 30% by volume. While saturation of masonry walls would cause considerable damage to mortar and excessive exterior and interior staining, few walls above ground ever reach the saturation point. Burst water pipes or clogged downspouts are exceptions that can result in saturation.

Critical Water Content

If the moisture content of a saturated material is reduced to the point at which capillary movement is just possible, the point of critical water content (cwc) would be reached. Below this moisture content level, transport of water is not possible.[11] Vapor movement is possible, but not liquid movement. The cwc can range from 6% in low porosity brick to about 20% in high porosity brick. Therefore, in walls affected by rising damp (caused by moisture rising through capillarity), the moisture content must be at or above the cwc. Staining of decorations and damage to structural members occurs when the moisture content exceeds the cwc.

Hygroscopic Moisture Content

The point of hygroscopic moisture content is that point at which the only remaining traces of moisture are held by tension in the smaller interstices of the pores.[12] This level is dependent on the moisture content of the surrounding air (the relative humidity) and is considered to be the natural moisture content of the material (see figure 14). Thus, materials are rarely absolutely dry:

> . . .dampness is something that can never be entirely removed from a

figure 17

Freeze damage to granite. Granite is a very hard stone and generally very durable, but internal pressure from freezing water within the very tiny pore structure of the stone can cause fracturing. Photograph: Baird M. Smith.

house structure, nor is it desirable that it should be... The moisture content varies widely according to the type of material involved, the content varying from under 1% in the case of plaster to up to 20% in the case of timber. A certain level of natural moisture content is therefore necessary for the correct condition of the building.[13]

Materials do not deteriorate or show signs of damage at the hygroscopic moisture content level. Thus brick at a moisture content of about 1% and limestone at about 4% would be at their natural moisture content levels and stable.

The table below compares these aspects of moisture for some common building materials.[14] (Where values are missing, they are unavailable.)

The table indicates that the density and porosity of a material must be known before an appraisal of exact moisture content is meaningful. For example, at a RH of 65%, the hygroscopic moisture content of limestone is 10%. This high moisture content might wrongly be attributed to rising damp, for instance, when it was actually just the natural moisture content of the material at that humidity.

It is important to understand moisture content levels in materials to diagnose the source of moisture properly. Several hand-held moisture meters and laboratory techniques (described later) facilitate measurement of moisture content levels. To diagnose rising damp accurately, and to differentiate it from damage caused by condensation, the moisture content at the surface and within a masonry wall should be determined. Higher moisture content at the

figure 18

Damage to sandstone from freezing. Porous sandstones can withstand some internal pressure from freezing water, but those sandstones with a very tiny pore structure are quite susceptible to damage from freezing. Photograph: Baird M. Smith.

	Density lbs/ft³	Porosity % vol.	Saturation % vol.	Critical Water Content % vol.	Hygroscopic Moisture Content % vol. at RH of: 40%	65%	95%
Wood	48		12-20	10	15	26	
Brick, medium grade	108	33	10	6	0	0	1
Brick, soft	92	55	35	19			
Limestone	114	5-25	11	2	4	10	
Slate	162	0.1-0.5	Trace		Trace		

surface would point to condensation as the source of the problem, whereas higher levels within the wall would suggest rising damp. Also, if the moisture content is not at the cwc or above, then capillarity is not occurring, and, hence, rising damp is not present. Again, condensation is probably the source.

Lastly, it should be understood that the moisture content levels in materials do not change through these extremes with great regularity or rapidity. It can easily take several years for the moisture content of a masonry wall to drop to the level of hygroscopic moisture content after having been nearly saturated. Even after remedial treatments, therefore, such as the insertion of a damp proof course, it can take several years for the full beneficial results to be realized.

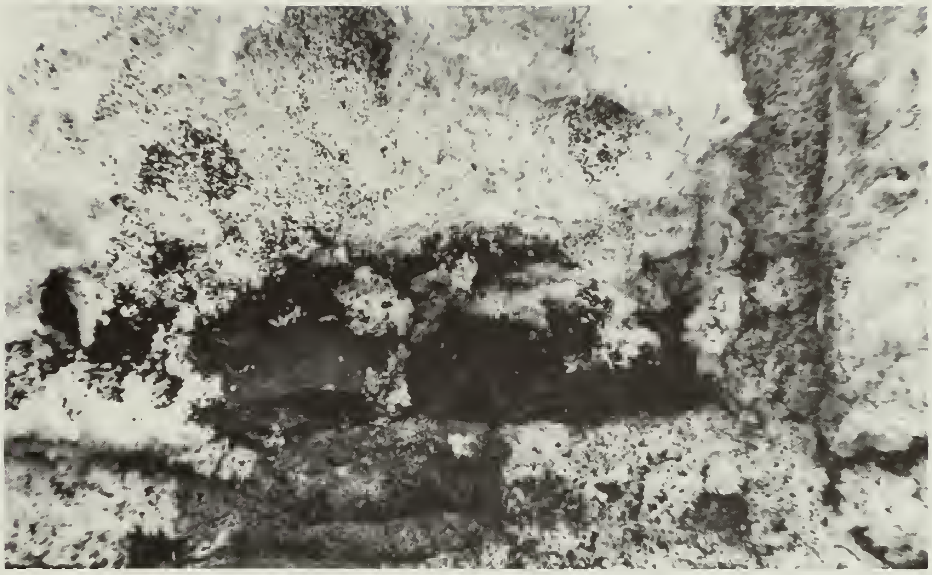

figure 19

Close-up view of efflorescence (scale: approximately full size). Identification of the types of salt in a patch of efflorescence by sight or taste is unreliable. Laboratory tests should be considered to identify the type of salt, and therefore, possibly the source of the moisture. Photograph: Baird M. Smith.

Moisture Movement and Salts

As a liquid (water) and a gas (water vapor), moisture is constantly in motion. As a liquid, it moves by capillary action through pores (farther in pores of small diameter than in pores of large diameter and from points of lower to higher salt concentration).[15] Water vapor moves from warm to cold spaces in a pore, from fresh to salty conditions, and from smaller pores to larger ones.[16] Figure 15 illustrates moisture movement in a representative pore. As a liquid, the moisture moves up the pore by capillarity until restrained by gravity, while water vapor moves down the pore from a warmer point to a cooler one.

These movements occur with relatively small temperature differences. However, when the differences in the temperature and relative humidity are great between the interior and exterior (as is usually the case in northern climates), the moisture is driven from the inside out, through porous wall materials because of the differences in vapor pressures. Thus, interior moisture will be drawn into and through porous wall materials.

When water freezes in a pore, it expands. The pressure exerted by the expanding ice increases greatly with each degree the temperature drops below freezing.[17] These forces can become great enough to overcome and fracture even apparently strong materials (see figure 16). This process is known as spalling. Damaging from freezing is quite common in parts of the U.S. where heavy daytime rains can be followed by nighttime freezing. The masonry, partly saturated from the rain, has no time to dry before the freeze occurs. Serious spalling is the inevitable result (see figures 17 and 18). Exposed parapets or garden walls, and other walls that receive no heat from a building interior are susceptible to this form of moisture damage, which can be severe.

Moisture present in building materials always carries soluble and insoluble salts. These salts include numerous chlorides, sulfates, and carbonates. The most common salts are sodium chloride, calcium sulfate, calcium carbonate, and magnesium sulfate.[18] They come from the materials themselves (especially from mortars and most limestones), from air and rainwater, from salt-charged ground water, and from sodium and calcium chloride used to melt ice on sidewalks and stairs. When the water in a saline solution evaporates, salt crystals are formed. This process is known as efflorescence (see figure 19). As the salts crystallize, they expand. This increase in size does not normally create a problem when the efflorescence is on the surface of the material. But it also occurs within the porous material (in which case it is known as subflorescence), where expansive forces can overcome the internal strength of the material and cause spalling.[19] Figure 20 illustrates the formation of efflorescence and subflorescence.

Since water and water vapor move toward areas of evaporation and higher salt concentration, freshly salt-charged ground water will continuously move by capillary action toward wall surfaces, and will deposit fresh salt crystals on those surfaces through evaporation. Thus, the salts are continuously left at the points of evaporation, causing increased efflorescence and subflorescence through the passage of time. Figure 21 shows the measure-

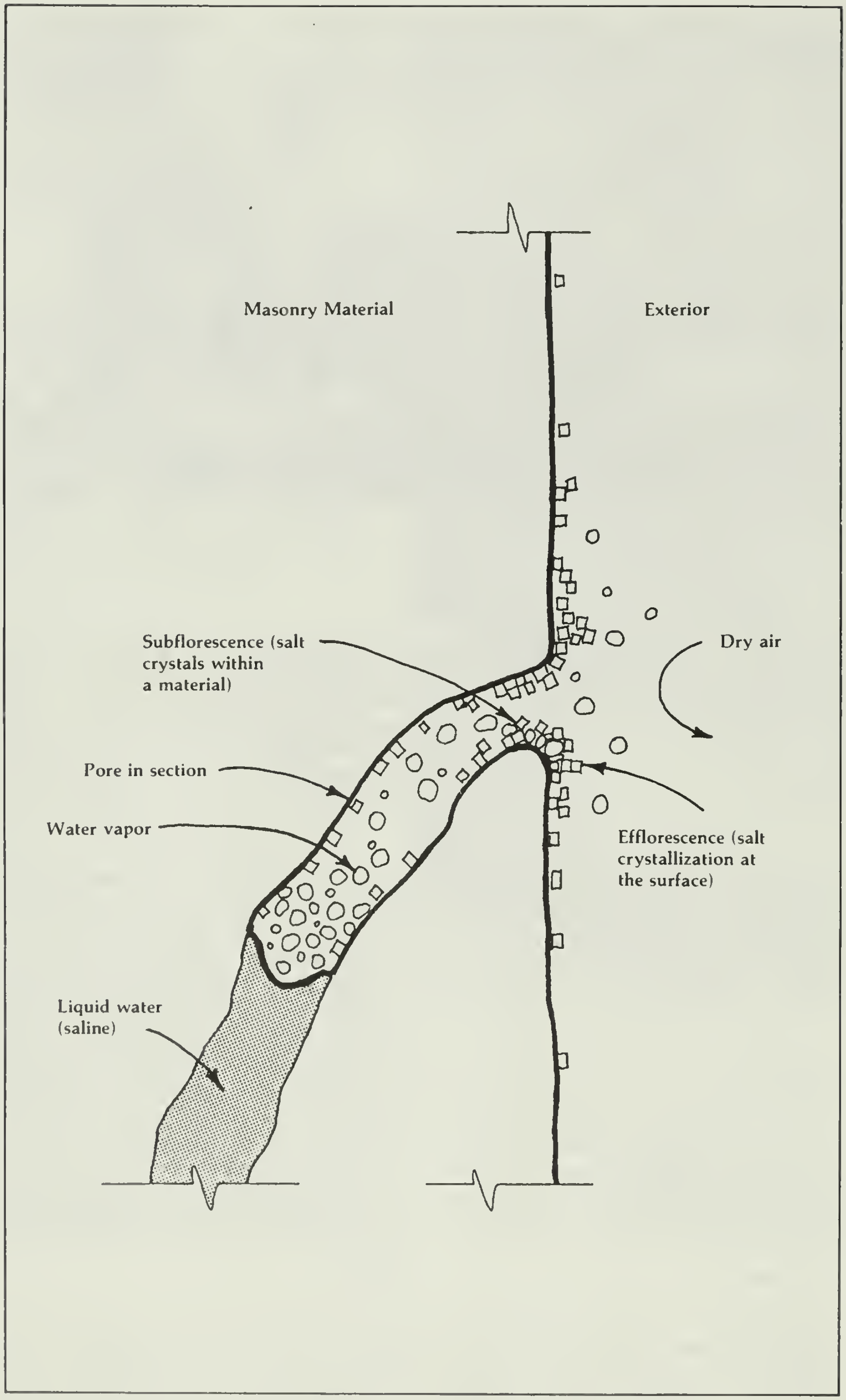

figure 20

Efflorescence and subflorescence in a pore. As water evaporates, salt crystals form on both the exterior and the interior of the brick. Drawing: Baird M. Smith.

ment of salts at various points in a wall which has been suffering from rising damp for well over half a century. The concentrations of chlorides and nitrates are very high at the wall surface (the wallpaper) and nearly nonexistent in the center of the wall. Efflorescence is a problem only in a zone at the surfaces of materials, rarely deeper than half an inch. The cores of materials are largely unaffected by salts.

Some evidence suggests that the movement of water toward higher salt concentrations causes moisture to rise higher in a wall over time by drawing more moisture from the ground. This phenomenon is called an "osmotic head."[20] It helps explain why rising damp reaches higher in buildings where the dampness has remained untreated for many years.

An additional characteristic of some of these salts, notably sodium chloride, is that they are hygroscopic. That is, in their crystalline state they absorb moisture, or more precisely, draw moisture, becoming re-hydrated. Thus, in highly salt-charged plaster or wallpaper, it is not uncommon during periods of high humidity for the walls to absorb more moisture, becoming very damp, sometimes nearly to the saturation point. With a drop in the relative humidity, the salts give up the moisture and the wall surface dries.

The hygroscopic characteristic of salts in walls also adds greatly to the amount of moisture held in the wall in its own natural or hygroscopic moisture state. Figure 22 charts the theoretical increases in moisture content of a wall with different sodium chloride (NaCl) concentrations at varying levels of relative humidity.

As the chart demonstrates, the moisture content of a wall with sodium chloride salts can easily be doubled or trebled during periods of high humidity. The periodic increase in moisture content in walls with high salt concentrations can lead to inaccurate diagnoses of moisture problems. Readings of the moisture content, therefore, should be made on several occasions throughout the year to rationalize the differences in relative humidity and hygroscopic moisture content.

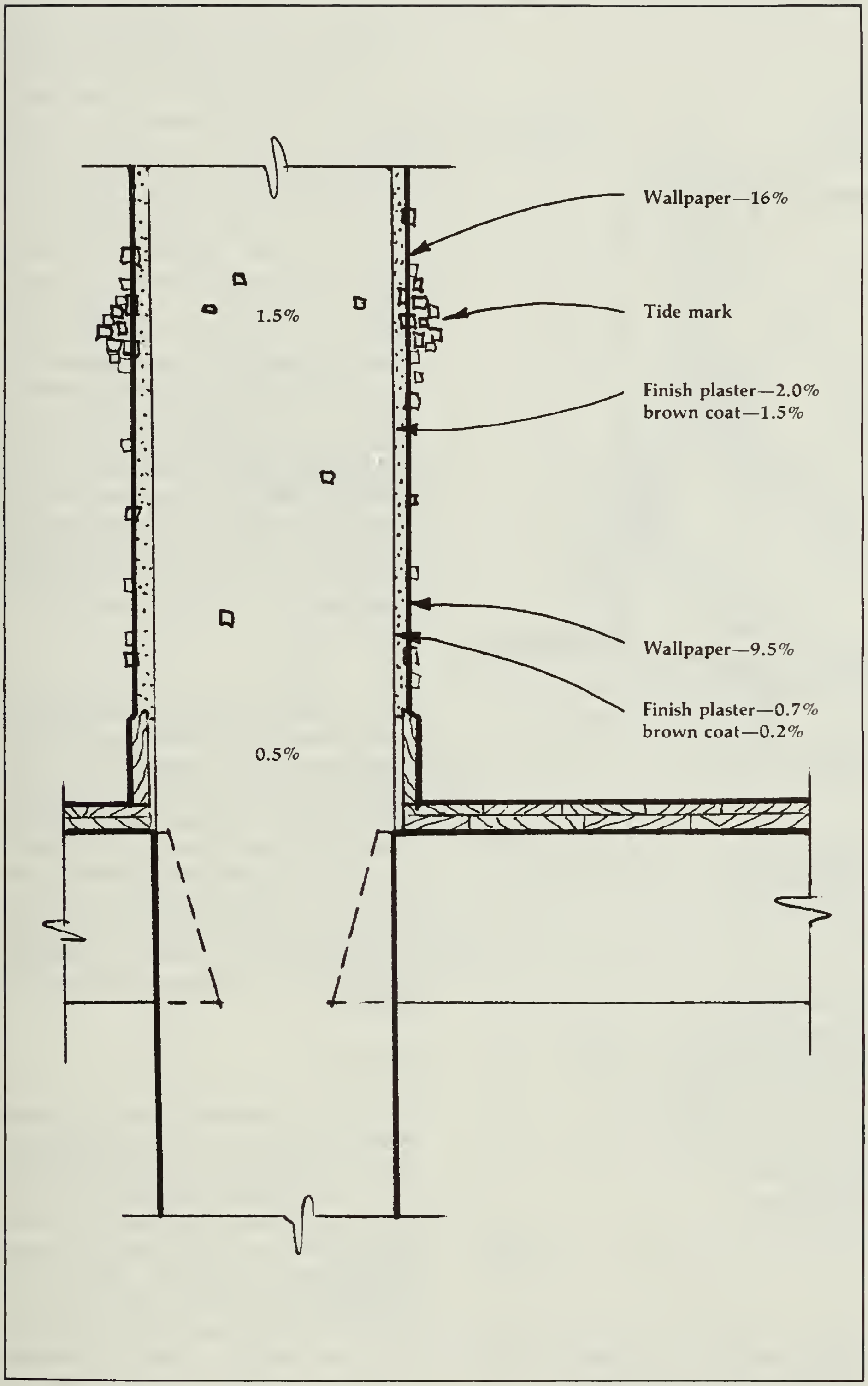

figure 21

Salt concentration in a wall. This illustration shows the percentage of chloride and nitrate salts in a brick wall with 80-year old rising damp. (Drawing: Baird M. Smith after that in Building Research Station, "Rising Damp in Walls; BRE Digest No. 27," p. 1.)

Moisture Conditions: Conjectural Models

In order to summarize the previous information about moisture movement in materials and as an aid to proper diagnosis of moisture problems, the following discussion presents four conjectural models that simulate typical moisture conditions. They are generalized illustrations of common situations rather than precise descriptions of actual occurrences. (Detailed investigations at one historic site in the southwest do support these findings, however).[21] The four models illustrate unrelated cases. The wall remains the same throughout: three wythes of soft porous bricks, laid with lime mortar. Only the ground floor portion of the wall is considered.

Model I

In the first model, excess moisture from the ground, from rain penetration and from interior condensation results in severe dampness, with pronounced efflorescence, staining and damage to interior wall decoration. Figure 23 illustrates this case after a heavy rainstorm and after some drying. Damp rises to a point where equilibrium is reached. Below this point in the wall, indicated by the tide mark, the moisture content is at or above the critical water content, 6% to perhaps 20%. The moisture content immediately above the tide mark or point of capillarity is at a transitional level; this level decreases until it reaches the hygroscopic moisture content. This transitional level is continuous throughout the center of the wall. Both rain and interstitial condensation contribute to the transitional moisture content there. Efflorescence forms in large quantity at the top of the capillary rise and to a lesser degree at other points along the inside and outside of the wall. Subflorescence results internally in areas of transitional or hygroscopic moisture content. Evidence of damage from freezing is apparent just above ground level, since the brick is saturated with moisture from ground water.

Model II

Model II shows the effect of adding interior heat or a dehumidifier to the moisture problem shown in Model I,

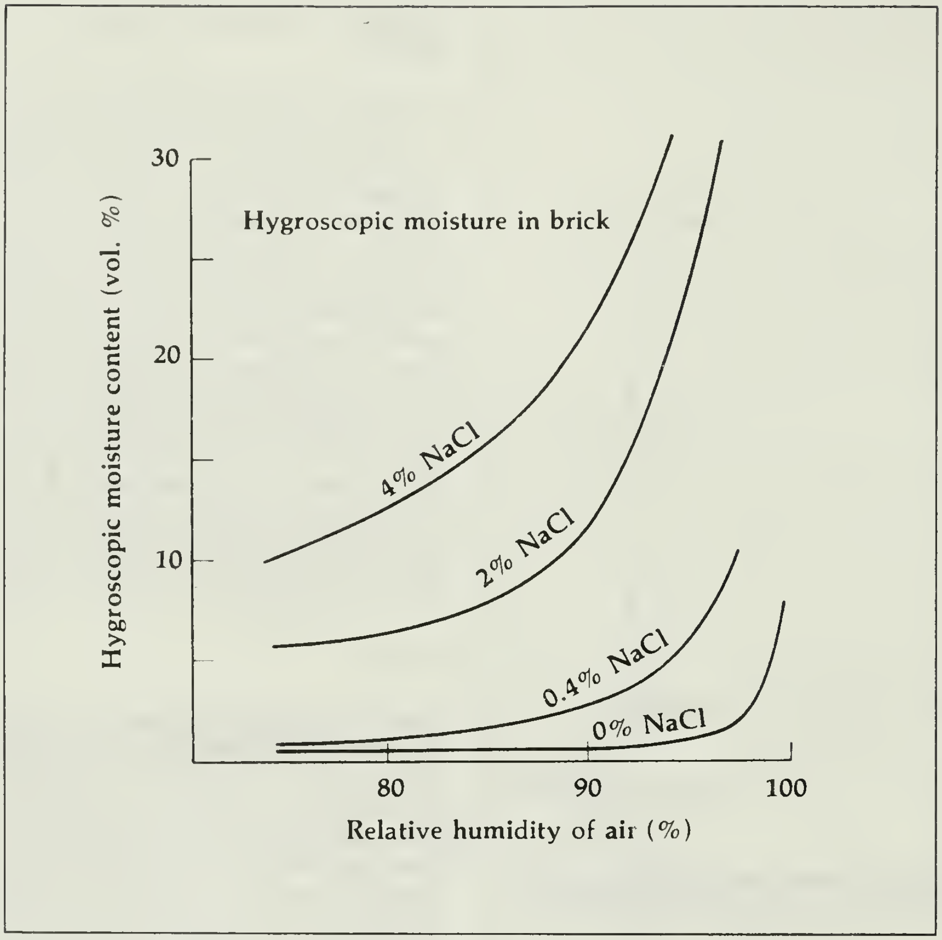

figure 22

Hygroscopic moisture content of brick at varying concentrations of NaCl and different levels of relative humidity. Because NaCl is hygroscopic, it draws more moisture into the brick. The higher the salt content, the greater the capacity to hold moisture. Illustration: B. H. Vos and E. Tammes, "Moisture and Moisture Transfer in Porous Materials," Rept. Nr. B 1-69-96, Institute for Building Materials and Building Structures TNO.

with no other remedial efforts undertaken (see figure 24). The supply of moisture from the ground, from rain, and from interior condensation remains unchanged. Increasing interior heat or dehumidification increases evaporation on the interior surface, and thereby reduces the height of the rising damp. The increased evaporation, however, would draw additional salts from the inner portions of the wall, thus causing extreme efflorescence and subflorescence on the interior surface of the wall. In the summer, the same result would be expected from the addition of air-conditioning, since it effectively dries interior air.

Model III

In Model III, an attempt is made to solve the existing problems present in Model I. Moisture from the ground, rain and interior condensation has left efflorescence and staining along the outside ground floor wall. In an effort to improve the appearance of the building, and in an attempt to reduce the rain penetration, the owner applies an impervious coating of cement stucco to the exterior ground floor wall. Figure 25 illustrates the results. With evaporation of the existing wall moisture precluded on the exterior, evaporation is increased on the interior; efflorescence and subflorescence result, and the tide mark occurs at a higher point. Therefore, all damage is now shifted to interior wall coverings. Simultaneously, moisture migration in the winter caused by vapor pressure difference is inhibited by the exterior stucco, and subflorescence can occur at the interface between the brick and the coating. The subflorescence will, in time, cause the coating to become dislodged. The base of the wall remains susceptible to freezing, creating the potential for further deterioration of the coating.

If in a different case the impervious layer (perhaps paint or dense plaster) were placed on the interior rather than the exterior, the reverse would occur; the evaporation would take place on the exterior, driving the tidemark higher. In cases where a dense waterproof coating has been applied to the inside of a damp basement wall, the result is often to drive the moisture up to the first floor where it damages wooden joists, flooring and decorative finishes.

Model IV

Model IV illustrates what happens when land drains are placed adjacent to the footings of the wall (see figure 26). The drains are effective in extracting water, which percolates down through the soil from each rainstorm or is present in ground water, thus removing significant quantities of water normally available for suction into the wall. A new equilibrium would be reached in the wall and the tide mark of efflorescence would drop. However, the extent of the drop would be hard to predict.[22]

The simulations provided in the four models shown here indicate the need for careful diagnoses of moisture problems. The models also demonstrate the need for accurate decisions regarding treatments. In some cases, as in Model

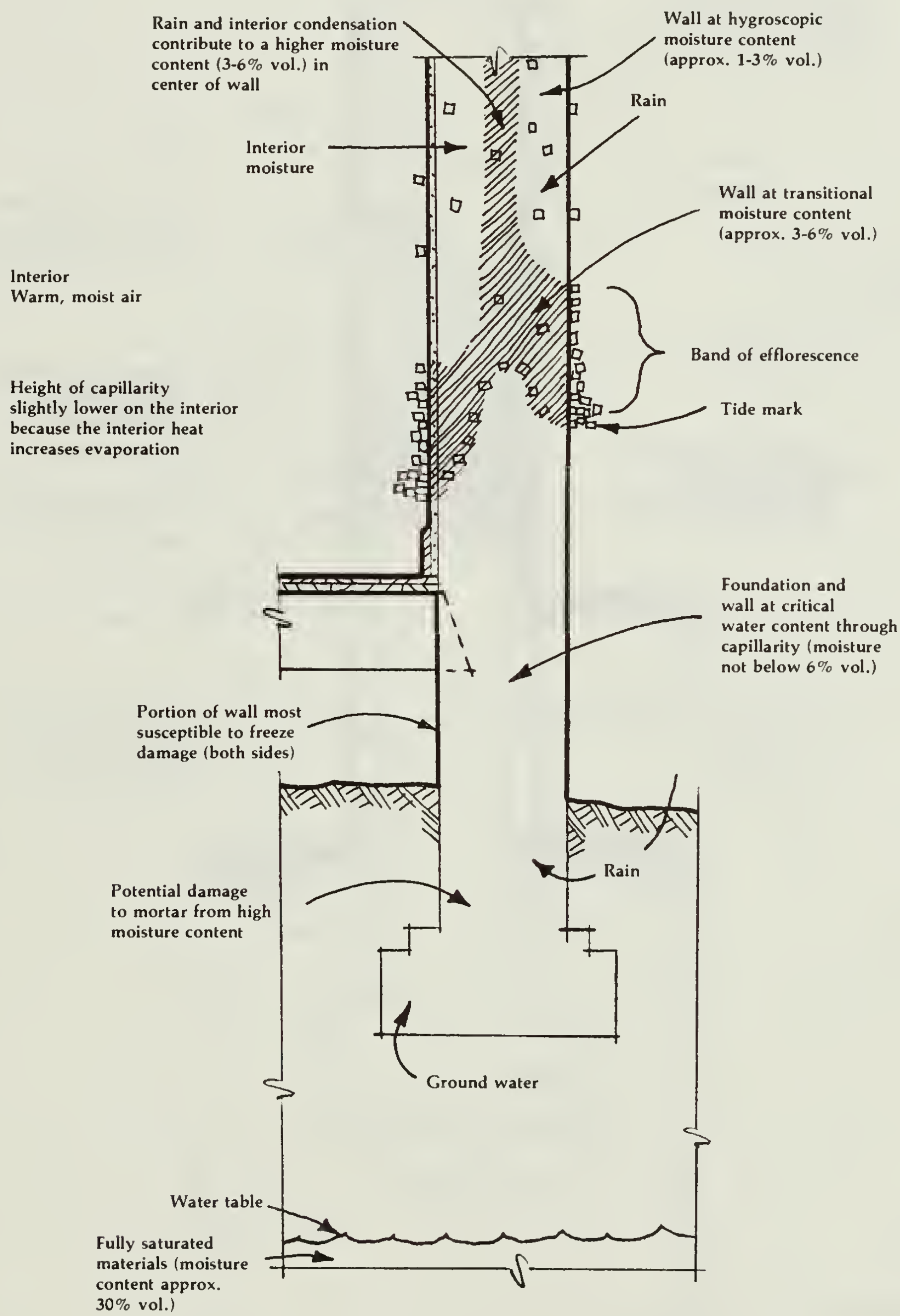

figure 23

Model I: A case of complex dampness problems resulting from unwanted moisture from the ground, rain and condensation. An equilibrium is reached between the supply of moisture and its evaporation. Severe damage would be likely. Drawing: Baird M. Smith.

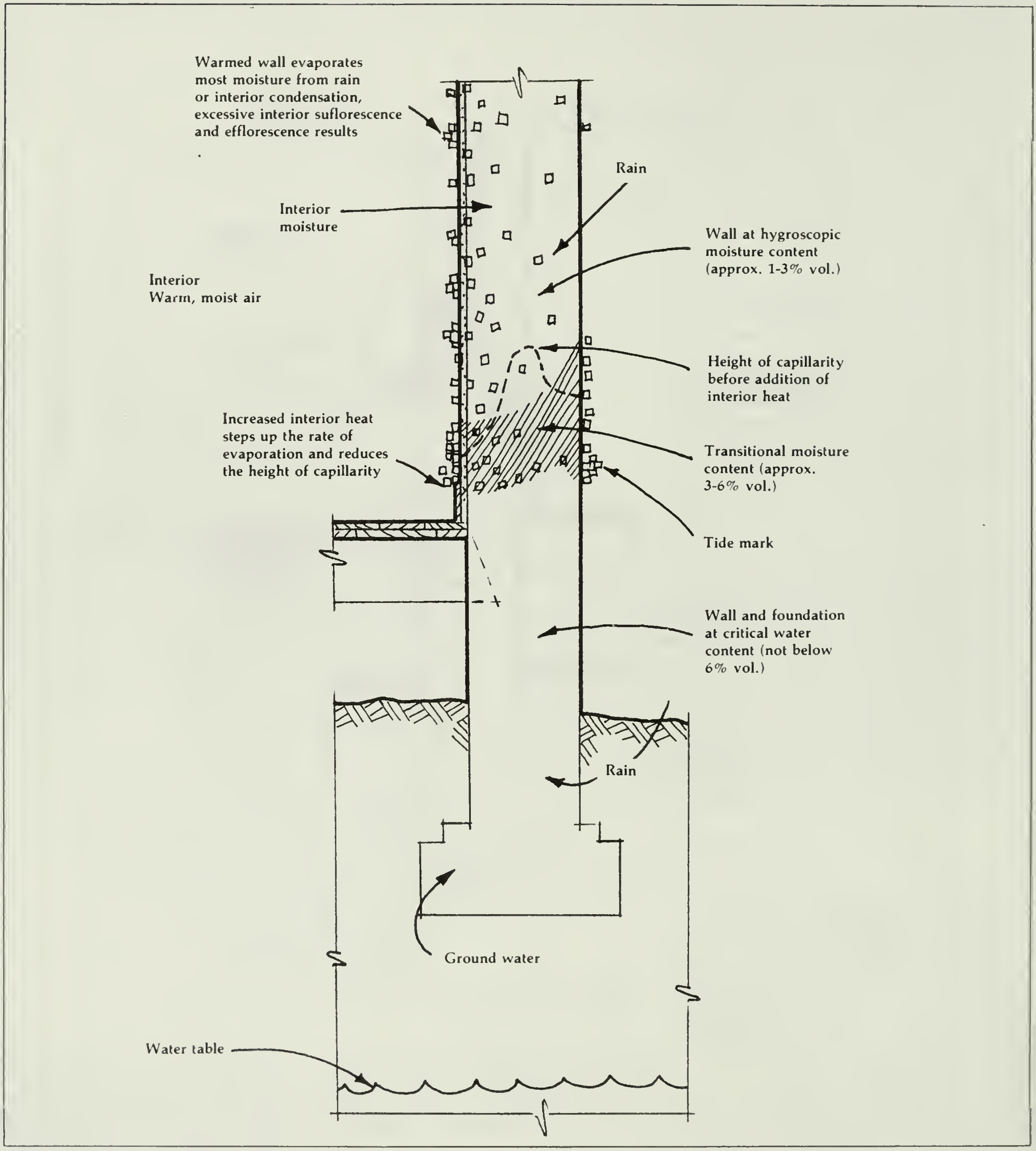

figure 24

Model II: The results of the addition of extra heat to the interior of the damp building shown in Model I. Excessive efflorescence and subflorescence would result on the interior. Drawing: Baird M. Smith.

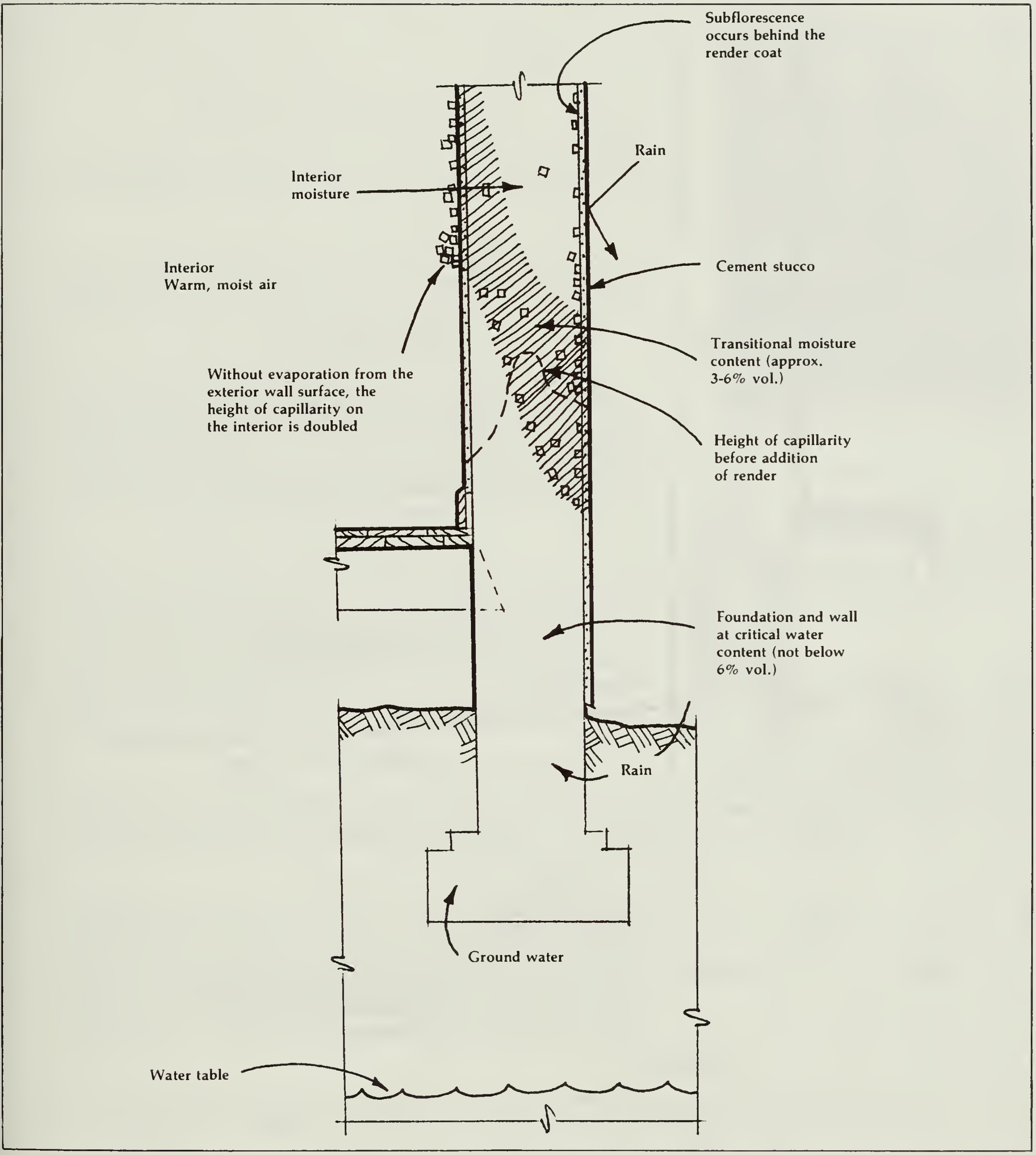

figure 25

Model III: Cement stucco has been applied to the building's exterior. This treatment will exacerbate the problems it is intended to remedy, especially on the interior. Drawing: Baird M. Smith.

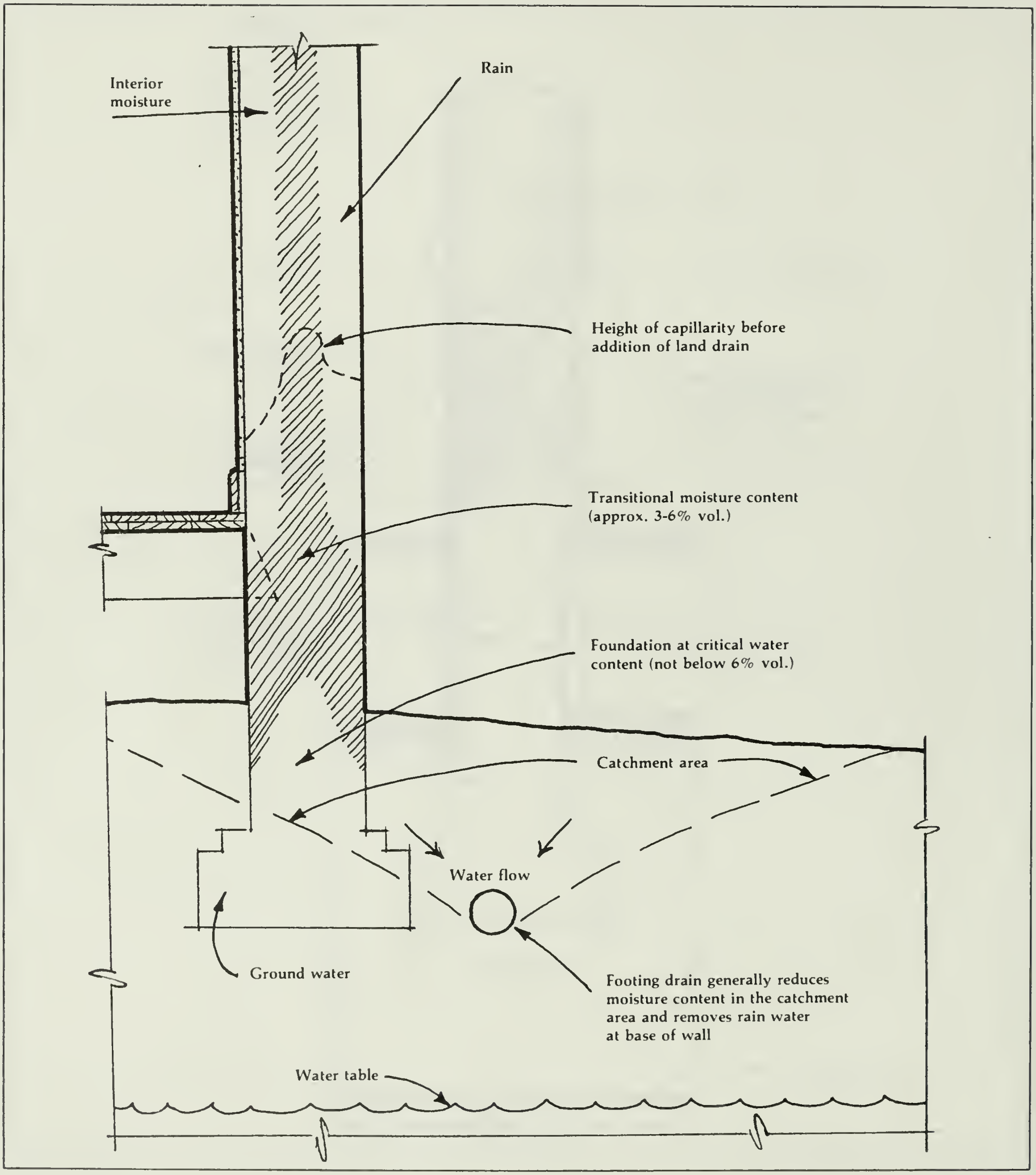

figure 26

Model IV: This case illustrates that the addition of footing drains will reduce, but not eliminate ground water problems. Drawing: Baird M. Smith.

Typical Damage to Materials from Excessive Moisture

Common building materials differ markedly in their ability to resist damage from moisture. A moisture level that might cause slight staining or other tolerable minor damage in one material may produce severe staining, decay or spalling in another.

Wood

When the moisture content of wood exceeds 20%, mold growth and decay set in. Timbers anchored in a damp wall could be seriously weakened, and decorative skirting boards, chairrails, and cornices could become so damaged that replacement would be necessary.

Brick

Moisture does not necessarily damage brick. In fact, most brick could remain submerged for decades and not be affected. Damage does occur, however, when the expansive forces of subflorescence and freezing exceed the strength of the brick, resulting in spalling or cracking. Efflorescence, or surface salt crystallization, *does not* adversely affect brick. But, wherever there is efflorescence, there will also be subflorescence, so its presence indicates potential for damage. Damage from subflorescence, however, takes many years, and often decades to result. Freeze damage, on the other hand, can occur overnight if the conditions are right.

Sandstone, Limestone, Mortar, Stucco, and Plaster

Like brick, these materials can adversely be affected by the expansive forces of subflorescence and freezing. (Like brick also, these materials are not damaged by efflorescence beyond the resultant visual blemish). Since these materials (with the exception of some varieties of sandstone) contain calcium, they are susceptible to damage from continued contact with water. Both calcium carbonate and calcium sulfate will precipitate out of the material, leaving a weakened physical structure and often an intractable encrustation.[23] Weaker materials, e.g., plaster and lime mortars, can be seriously damaged from this action because they dissolve and begin to crumble. Durable stones, on the other hand, require hundreds of years of continued moisture saturation before their strength is seriously weakened.

Iron, Steel, Tin, and Zinc:

These materials are quite susceptible to deterioration from any contact with moisture and they must be properly painted or protected to preclude moisture contact. Rusting or corrosion are the undesirable results of prolonged moisture contact.

Wall Coverings

Paint, whitewash, wallpaper and other surface coverings can become stained from dampness or efflorescence. This can be a nuisance and can require unplanned repainting or repairs. But the resultant damage is primarily visual, not physical. Subflorescence, however, is more troublesome. Permeable paints and other coatings are normally not affected by subflorescence to any greater extent than the base material. Impervious coatings, however, will often become separated from their base because of subflorescence (see figure 27).[24] The expansive forces of freezing could affect either permeable or impermeable surface coatings if the base materials were saturated and a hard freeze occurred.

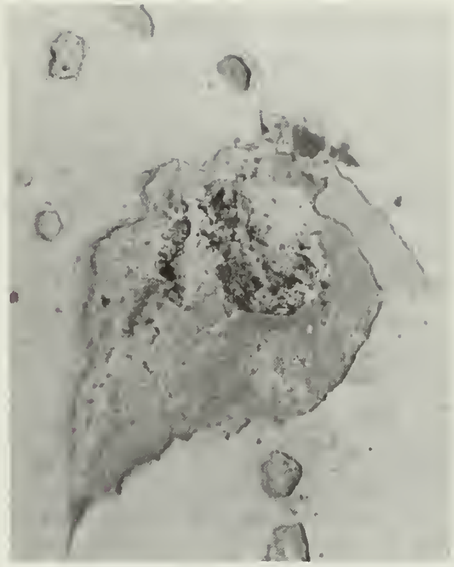

figure 27

Damage to paint from salt subflorescence. As the crystallizing salts expand, the paint blisters and separates from the wall. Photograph: Baird M. Smith.

II, efforts undertaken to improve climate controls in buildings, such as the addition of dehumidifiers, compound moisture problems. In others, insensitive remedial work worsens the situation, as in Model III, where stucco coatings hastened deterioration from excessive dampness.

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[17]Winkler, *Stone*, p. 176.

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[19]Winkler, *Stone*, pp. 109-119.

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Chapter 2:

Diagnosis: A Procedure

Diagnosis involves two processes: first, the *identification* of a problem, including its nature and extent (e.g., identification of a typical problem might be: "Severe break-up of plaster in ceiling of attic bedroom, next to the west dormer; about 10 square feet involved"); second, diagnosis provides an assessment of the *cause* of the problem (e.g., identification of the source of the above-noted attic plaster problem might read: "Examination of base flashing at dormer revealed severe rusting; obvious point of water entry"). Diagnosis thus identifies both the *cause* and the *effect* of each problem, and it usually starts with identification of the effect because this is the most noticeable aspect of the problem.

After careful diagnosis of each moisture problem, specific treatments are chosen. While the choice of appropriate treatment will be influenced or even determined by practical considerations such as cost and technical feasibility, it is essential to have an accurate diagnosis before informed decisions on treatments can be made. Inaccurate diagnosis can lead to the selection of ineffectual or even harmful treatments.

In undertaking a diagnosis of moisture problems, it is important that the investigator not be biased in favor of possible solutions. The diagnosis should be conducted by an independent professional rather than a damp proofing firm, especially where an important historic resource is involved. If there is a bias present, it should be for the protection of the historic building, rather than for the use of a product. The following methodology for the diagnosis of moisture problems is an outline only. It is assumed that individuals will modify this system to suit the exigencies of particular moisture problems.

A basic premise of the methodology is that the investigation and the gathering of data become increasingly detailed as the moisture problems become more complicated. Thus, straightforward moisture problems, such as common maintenance-related problems, can be identified early in the process. However, severe or complex moisture problems require more detailed examination, often including measurements of the moisture contents in the materials, as well as of temperature and humidity.

Diagnosis of moisture problems in historic buildings begins normally at one of two points. Either the building owner has noticed evidence of dampness and has called in someone to treat a problem, or an architect seeks to verify the presence of moisture problems as part of a larger preservation effort.

If the latter is the case, the diagnosis procedure should begin early in the process so that the urgencies of the building rehabilitation do not shorten the time necessary for a careful diagnosis. Generally several weeks are required to diagnose moisture problems in small projects. Steps one, two, and three listed below should suffice in these cases. However, if the building is very large, or if the moisture problems are complex, accurate diagnosis may require all six steps listed below, which may take up to a year to complete.

Step 1: Background Information

Before remedial efforts of any kind are begun, it is essential to identify building elements and materials important in defining the character of the historic building. Repairs contemplated or undertaken must not impair these features. Additionally, it is important to understand the record of past efforts in treating dampness problems at the site. This should include reroofing, painting or site improvements. Also, patterns of recent building use should be known, especially the degree of heating, cooling or humidification. Lastly, characteristics of the local climate should be noted or researched, including winter and summer design temperatures; average winter and summer relative humidity; patterns of prevailing wind and weather; and driving rain index. Often, this information can be obtained through interviews with the owners or research into original drawings, past account books, or other records.

Step 2: Building Inspection

Inspect the building, noting all evidence of dampness, and the extent and nature of each problem. To accomplish this, the following tasks should be undertaken:[1]

a. Beginning on the *inside* of the building, identify and record evidence of dampness (normally by means of a room-by-room inspection). Bathrooms, kitchens, laundries, and other potential sources of unwanted moisture should be noted.

b. Interior temperatures and relative humidity should be identified and recorded. Many hand-held temperature and humidity gauges are available, including even wristwatches that make instant readings of air and surface temperatures.

c. Evidence of dampness on the *exterior* should be identified and recorded. Verification of the proper functioning of the roofing, gutters and downspouts, and related roof items is a must (see figure 28).

d. The presence or absence of a damp proof course at relevant points around the building should be noted. (Physical probing may be necessary.) The height of the ground floor relative to the earth outside at relevant points around the building should also be recorded, along with a determination of site drainage patterns.

e. The exterior air temperature and relative humidity should be recorded. (The daily weather report will provide the exterior data.)[2]

This report has assumed throughout that excess moisture affecting materials leaves some visible evidence such as staining, salts, or corrosion. However, this is not always the case. The moisture content of a material may be high, but not yet high enough to result in visible damage. Thus, an aid to completing the visual inspection is to measure invisible moisture using a hand-held moisture meter, also known as a "resistance" type meter.[3] Such a device measures the electrical resistance between two points in a material. The more moisture, the greater the resistance. The meter has two stainless steel probes, about 3/4 in. in length, separated by 1/2 in. By pressing the two probes *into* a material, in the case of wood, or *against* the material, in the case of brick or plaster, the surface moisture content at that point can be determined. Measuring at several points along a wall or in a wooden joist, for instance, can help establish areas of high moisture content, which would not otherwise be visible. These readings should be taken for both exterior and interior materials as an aid to identification and diagnosis.

Properly recorded data will always repay the extra time involved. Sketch floor plans and supplementary note sheets are normally used to record the location, extent, and nature of the evidence discovered during the inspection.[4]

Step 3: Preliminary Diagnosis

At this point the experienced investigator would have enough information to make an accurate diagnosis of straightforward problems like those resulting from a lack of maintenance. Comparing interior dampness with exterior evidence, for example, might point to clogged downspouts or earth piled against the building as the source of the harmful moisture. Once the sources of these problems have been determined, remedial treatments can be selected confidently.

For the problems where the source of moisture is not readily apparent, further work is necessary before a diagnosis can be made. For example, a horizontal tide mark may be very apparent but the source of the problem (rising damp, rain splash-up or condensation) cannot be identified without further detailed examination.

figure 28

Typical evidence of moisture problems. Investigation would record location, extent, and nature of moisture staining and condition of all metal gutters, downspouts, and flashings. This would in turn be correlated with evidence collected during interior inspections to determine if water is gaining access. Photograph: Baird M. Smith.

Step 4: Detailed Examination

To identify the cause or causes of complex moisture problems, it may be necessary to undertake selected physical examinations, tests, or long-term monitoring. The goal is to differentiate between condensation, ground water or rain penetration as sources.

Condensation (interior or exterior) could be dismissed as a likely source of unwanted moisture if it can be ascertained that conditions of temperature and humidity do not normally reach the dew point. Using the psychometric chart, this can easily be determined. Rising damp from ground water could be eliminated if ground water levels are well below the foundations.[5] Consultation with a city engineer or soils testing could establish known ground water levels. If tests have not been made, then soil borings could be undertaken. If foundations are only a few feet below grade (presumably the case of most one-to three-story buildings), it is also possible to dig small test pits or 6 in. diameter post holes to at least the depth of the base of the footings. If ground water is encountered, or if water seepage fills the hole, then rising damp could be occurring. If no ground water is encountered, then the source of the moisture problem is probably limited to rainfall and attendant problems such as poor site drainage, puddling at foundation walls, or splash-up. Rain penetration in masonry walls can be dismissed as a cause of moisture problems if there is a cavity in the walls, or if the walls are over 13 in. thick. (It is unlikely that rain penetration can occur in walls over 3 wythes thick.)

Other tests can be conducted to narrow further the possible sources of moisture. If it is unclear whether condensation is occurring, then a hygro-thermograph can monitor temperature and humidity levels over an extended period of time, preferably through a winter and a summer.[6]

Additional physical probings should be done to verify, for example, exact wall configuration, presence of a damp proof course, foundation wall conditions, basement slab details, and condition of mortars, stucco, or plasters. Detailed paint layer examination can help determine if coatings are acting as vapor retardants or breathable layers. Lastly, laboratory identification of efflorescent salts can both identify sources of moisture or chemical reactions causing the salts and verify their hygroscopic nature.

Step 5: Follow-up Examination

For problems that remain unresolved a follow-up examination may be necessary. If so, the detailed examination described in Step 4 should be repeated in six months and perhaps again in 12. This will rationalize the contribution of moisture that occurs during periods of high humidity or unseasonably heavy rainfall. Further examination also permits monitoring of the effects of treatments undertaken after steps three and four.

Step 6: Final Diagnosis

The information gathered in previous steps should permit the investigator: 1) to understand the precise *sources* of the moisture problems; 2) to identify the *extent* or severity of the problem; 3) to determine the relevant *construction features* of the building and its relationship to site conditions; and 4) to identify moisture problems that might remain unresolved and require *further investigation*. Diagnosis is complete when the exact nature and extent of the moisture problems have been identified. Appropriate treatments for each problem can then be selected.

Reference Notes: Chapter 2

[1]This methodology is based on that presented by Ian A. Melville and Ian A. Gordon in *The Repair and Maintenance of Houses* (London: The Estates Gazette Ltd., 1973), p. 563.

[2]One may wish to measure humidity and temperature with hand-held devices. Various devices for measuring RH are explained in *ASHRAE Handbook: 1977 Fundamentals* (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, 1978), p. 13.24. See also, Ralph H. Lewis, *Manual for Museums* (Washington, D.C.: U.S. Department of the Interior, National Park Service, 1976), pp. 83-87. Thermometers are available in many types. One with relatively fast readings and capability of measuring surface temperatures would prove useful.

[3]Techniques for taking moisture samples are described in A. J. Newman, "Improvement of the Drilling Method for the Determination of Moisture Content in Building Materials; BRE CP 22/75" (Garston, Watford, England: BRE, 1975). Apparently the only carbide meter available is called the "Speedie" and is sold by Soiltest, Inc., 2205 Lee St., Evanston, IL 60202 (Model #MC-320). There are several sources for resistance type moisture meters; one is Delmhorst Instrument Co., 607 Cedar St., Boonton, NJ 07005 (Model #30-7); another is Preservation Resource Group, Inc., 5619 Southampton Dr., Springfield, VA 22151.

[4]One may wish to measure the height and width of dampness evident in the first inspection so that subsequent inspections would reveal if a problem were increasing (or decreasing) in severity. A methodology for taking moisture samples is described in W. Brown Morton, "Moisture in Historic Monuments," *Bulletin* of the Association for Preservation Technology, vol. VIII, no. 2, 1976, pp. 2-19.

[5]See Building Research Advisory Service, "Diagnosis of Rising Damp: TIL 29" (Garston, Watford, England, 1977). Also, diagnostic case studies are described in Giovanni Massari, *Humidity in Monuments*. (Rome: University of Rome, 1971).

[6]Martin Weaver, "A Masonry Deterioration Case Study: Holy Trinity Anglican Church, Hawkesbury, Ontario," *Bulletin* of the Association for Preservation Technology, vol. X, no.1, 1979, p. 11.

Chapter 3:

Treatments For Common Problems

Basic Considerations in Treating Moisture Problems

Cautious Intervention

It is best to be cautious in treating moisture problems in historic buildings. Such structures have become adapted to the physical environment. While obvious maintenance-related problems, such as damaged downspouts, clogged drains, and damaged roof flashings should receive immediate attention, reckless intervention in other situations can upset the sensitive balance between environmental forces and building responses. The addition of excessive heat, extensive structural modifications, extreme humidification, or rapid drying have been found to damage historic buildings.

Proper diagnoses can take up to a year (through a full season of weather). It is often good practice, furthermore, to address each problem systematically, and to monitor its full effects before treating another problem. This also takes time. Finally, it also takes time for treatments to work properly. A very damp wall can take several years after remedial treatments have been introduced to dry to the point at which damage would no longer occur. There are even cases of buildings in Venice that took twelve years to dry out from rising damp after the installation of a proper damp course.[1] Patience is therefore of prime importance in the diagnosis and treatment of moisture problems.

Proven Materials and Techniques

Historic buildings should not be the testing ground for untried materials or techniques. History has shown that many materials that were the most modern and the most promising, like sheet zinc, concrete, Knapen tubes, and active and passive electro-osmotic systems, have all failed to some degree to cure moisture problems. Up to thirty years of use have been necessary to demonstrate that some materials were not performing as intended.

Primary Consideration to Preservation of Materials

The goal of preserving historic buildings is to protect and preserve these examples of the nation's heritage well into the future. First priority must therefore be given to conserving building fabric and contents. In many situations there is no clash between building conservation and human comfort, but this is not always the case. Adding heat to a previously unheated building, for example, could cause increased efflorescence to the masonry and possibly unwanted wood shrinkage and checking. In the event of such a conflict, conserving historic building materials should come before increasing the comfort of building occupants to an unnecessary degree.

Practical Considerations

With the information supplied by following the diagnostic procedure outlined in Chapter 2, appropriate treatment or treatments can be selected. If multiple treatments must be undertaken because the moisture problems are complex, then treatments for rain and condensation problems should be undertaken before addressing damage from ground water. Measures taken against rain and condensation may sufficiently change the moisture equilibrium in a wall to produce a corresponding reduction in absorption of ground water.

Before a treatment program is devised, however, it should be kept in mind that successful treatment may not be possible for *all* moisture problems. Treatment of some problems in some historic buildings may be too expensive, or impractical. In a building with very thick or irregular stone walls, severe rising damp may not be fully treatable. In some cases walls may be constructed of materials poorly suited to the exposure they receive. Because they are historic, however, drastic measures such as rebuilding walls or foundations or wholesale demolition are not recommended. In these instances, the excessive moisture can be reduced and some of the damage repaired, but arresting the problem may be beyond the capabilities of present technology. The proper "treatment" for intractable moisture problems may be to select a new use for the historic building, a use that is compatible with a higher moisture content. A building with a moisture content level that is intolerable for a museum collection or art gallery, for example, may function very well as office space.

At the other end of the severity scale, very minor damage may have to be tolerated. It may be better to live with the odd stain, the patch of efflorescence, or other slight blemishes to the building's appearance and to address the problem with periodic cleaning or repainting, than to go to the trouble and expense of major repairs. The costs of fully arresting the problem may be too high when compared with minor inconvenience or slight impairment of the building's appearance. Performance, durability, cost and practicality must enter into the treatment selection process.[2]

Common Treatments: Ground Water/Rising Damp

The following presents a general assessment, rather than a definitive appraisal of the common treatments for moisture problems in American buildings. It provides the practitioner with a beginning point in choosing appropriate treatments. For information about installation techniques or more detailed information about the treatments, readers should consult the literature cited in the reference notes.

Footing Drains (French Drains)

For residential or other small-scale buildings, perforated 4 in. (100 mm) plastic, ceramic, or concrete pipe is normally used around the periphery (see figure 29). It is laid in a trench, at the level of the footings if possible, with 12 in. (300 mm) of sand above to filter particles of clay or organic matter.[3] Newly developed synthetic nettings can be used in lieu of the sand as filters. The drains will collect rain water falling within the catchment area or lower the ground water level, thus reducing the quantity of water affec-

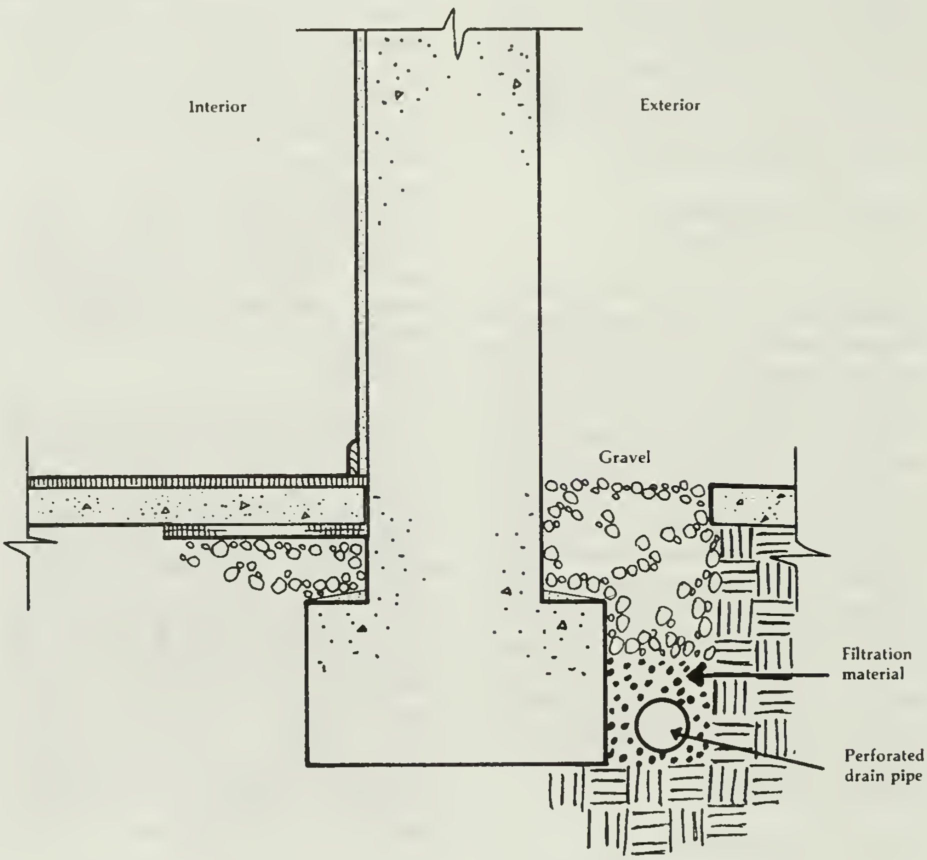

figure 29

Footing drains (French drains). Perforated pipe is placed opposite the footing to drain both ground water and excess water from periodic rain storms. Such drains will reduce, but not necessarily eliminate rising damp in a wall. Drawing: Baird M. Smith.

ting the wall. The collected water must then either drain or be pumped to nearby storm sewers.

When properly installed and sized, footing drains perform well. They will positively drain water from the catchment area, reducing, but not eliminating moisture problems resulting from ground water or site drainage. Drains can last indefinitely, but periodic inspection and clean-outs are required to ensure that silt does not build up and that tree roots or animals have not damaged the piping.[4]

Footing drains are most practical for rural sites or others where the entire periphery of the building is readily accessible and positive drainage is possible (i. e., pumping is not required). Urban sites can pose several complications: the inaccessibility of the building periphery to trenching; the inability to estimate the quantity of ground water; difficulties in establishing property boundaries and limiting liability for damage to adjacent properties; and inability to establish positive drainage of collected water (pumps are often required).[5]

For both rural and urban sites, two notes of caution must be struck. First, buildings on pilings or wooden footings can be severely jeopardized with an alteration of ground water conditions. For all but the simplest of such buildings, therefore, hydraulic or civil engineers should be consulted before drains are installed. Second, within the context of historic buildings, any disturbance of the ground should be undertaken in such a way as to protect and identify archeological resources.

The use of a footing drain system must be carefully weighed against alternatives and against the physical conditions of the site. However, since the cost of these systems can be low, they may be a first choice, especially if site drainage is an additional problem. There is no guarantee that the drains will arrest rising damp, but the slightest change in the moisture equilibrium could reduce a rising damp problem substantially. After installation, the effect should be monitored by taking moisture content readings.

Physical Damp Courses

Many damp course materials available in Europe have yet to be introduced here. Those that are available are listed as "flashings" or "waterproofing materials" in product listings such as *Sweet's Catalogue.*[6]

Roofing slates are a readily available damp course material. They can be installed in an existing wall by removing two courses of brick (or one course of stone) and inserting a double layer (lapping one over the other) through the entire thickness of the wall.[7] Generally slates are installed in work widths of about three linear feet, while supporting the masonry above, and working in alternative work areas along the length of the wall. Some building settlement can result, but modern nonshrinking mortars almost eliminate the problem.

Another type of physical damp course involves the use of damp proof ("flashing") materials inserted into a cut-out mortar joint. The flashings generally come in three-foot wide rolls (which are then cut down to the width of the wall) and consist of semi-rigid sheets of bituminized felt, impregnated

figure 30

Masonry saw with dust extractor. This saw is used to cut a narrow slot in a continuous masonry joint to allow the insertion of a physical damp course. When it is accessible from both sides, a wall up to 13 in. thick can be cut with this equipment. Photograph: MDC Services, Inc.

fiberglass cloth, or copper, lead or aluminum sheets coated with tar or rubber. The metallic sheets should be used on multi-story buildings where the compressive loads on the wall are great.

A technique developed in Europe, but yet to be introduced here, is to cut out existing mortar joints using a high speed carborundum mason's saw or an adapted chain saw. Hand saws are used at points where the power tools cannot reach, such as at corners or chimney masses. The masonry must be regularly coursed so that there is a continuous horizontal plane and the walls must be basically stable. As with the insertion of slates, work is normally accomplished in alternate work widths (in this case up to six feet), and the joint packed with nonshrinking mortar.

Limitations of power saws restrict the use of this insertion method. In Europe, chain saws can cut a wall up to 26 in. thick when both sides of the wall are accessible. The resulting slot is about 3/8″ thick. The carborundum masonry blade has a cutting depth of 5½″ (or 10″ if cut from two sides). The resulting slot is only 3/16″ thick, making the carborundum blade the most suitable for narrow jointed brickwork. Hand sawing, or the method of removing brick courses, does not have these limitations, but as the walls get thicker, these systems involve more time and expense and require precautionary measures. All systems create some dust and inconvenience, but modern dust extraction devices (for the power saws) greatly reduce the inconvenience factor (see figure 30). These systems can generally be installed by skilled builders or masons, but it is almost inevitable that some damage will occur to the masonry units as a result of the saw blades. Installation for residential-scale jobs can be completed in a few days.

When properly installed, physical damp courses form impervious barriers to moisture passage. They will absolutely block the vertical rise of moisture in a wall, and hence, can be expected to perform very satisfactorily.

figure 31

Chemical injection process. Solutions are injected under pressure into pre-drilled holes. The process is complete when the brick surfaces appear wet. The chemicals then cure into a waterproof horizontal zone. Photograph: SPI Chemical Injection, Inc.

The wall area below the damp course will continue to suffer subflorescence or freeze/thaw problems, but with periodic maintenance on ten-to-twenty-year intervals, mortar and possible brick repair can be addressed.

Damp course materials are generally chemically inert and have little potential for decay. Some have been in service for over one hundred years and new ones can be expected to last the life of a building. To assure the greatest durability, the type of damp course material should be selected to fit building conditions, especially the load bearing requirements.

Physical damp courses should be strongly considered, as they will arrest rising damp for most ordinary building types with walls up to 26" thick. Where installation is practical, or possible, they have the best all-around performance and durability and the extra cost should be acceptable when the long-term conservation benefits are considered.

Chemical and Electro-Osmotic Systems

Several treatments for ground water are readily available in Britain or Europe but have not yet been introduced here. One type, the Massari system, named after its Italian inventor, creates a physical damp course by using polyester resins to form an impervious layer. The system requires drilling a horizontal row of 1 1/2 in. diameter holes (overlapping each other slightly) through the width of the wall.[8] The holes are then injected with the resin, which solidifies on curing into a hard, continuous layer. The system works best on very thick walls of irregular stonework. It is, however, quite expensive. The visual impact of the large drilled holes upon the character of the historic building may or may not be acceptable, depending upon the design and materials of the building.

Chemically injected damp courses, common throughout Britain and Europe, provide effective and low-cost protection against ground water and their introduction into the U.S.cannot be far off. In Europe, these damp courses are normally installed by franchised specialists, using materials supplied by national manufacturers. Products fall generally into two categories: aqueous solutions of siliconate, and spirit solvent solutions with silicone or aluminum sterate. To inject, holes are drilled two to a brick (approx. 5 in., 125 mm, spacings) where the brick (or other wall material) is reasonably porous. If the wall material is fairly non-porous, or of low permeability, then the mortar joint is drilled. Injection is either by low pressure or by gravity feed (the latter is known as the transfusion method).[9] Injection (or transfusion) is considered complete when the operator observes that the injected fluids have saturated the brick in a continuous band and have begun to exude from the surface. Successful injection, and thus, successful establishment of a damp proof barrier, is normally dependent on the skill of the operator to recognize full saturation (figure 31).

Other systems utilize the principles of chemical injection through proprietary installation procedures. In one, the silicone is frozen and installed as a stick into pre-drilled holes. In another, silicone is mixed with mortar and then is injected into holes.

In Britain, where the technology is highly developed, successful chemical injections can be accomplished in almost any wall, regardless of thickness, materials, coursing or construction details. However, there are some exceptions:[10]

1. Very damp walls (that is, with a moisture content around 20% or above) present problems to successful injection. The invading chemical fluids do not seem to be able to displace the moisture and diffuse through the material. Therefore, for very damp walls, chemical injections may not be successful.[11]

2. Wall materials must have a basic minimum porosity or permeability. Materials such as flint, granite, many limestones, and some hard-fired brick may not be successfully injected.

3. Thick walls with unknown voids or fissures present problems, not necessarily insurmountable, but complex enough occasionally to make injection systems unacceptably costly and time-consuming. Before injection, the voids need to be grouted, which can prove to be a cumbersome procedure.

In these cases, additional injections at selected points can produce a continuous damp course if the initial treatment has proven only partially successful. However, in the following cases, successful chemical injection may not be possible:

1. Walls that are subjected to hydrostatic water pressure, such as basement walls, cannot be injected, because even a successful injection would not arrest the horizontal flow of the water.

2. Some mortars are so alkaline that the injected chemicals will not cure properly. Similarly, if the ground water is detergent-filled, curing will be incomplete. These cases are rare, however.

These materials have been used in Britain for about twelve years; while they should last well into the future, their long-term durability remains unproven.[12]

By contrast, passive electro-osmotic systems have generally proven ineffective (see Introduction for more information); they cannot be recommended for historic buildings.[13]

Common Treatments: Rain Penetration

Rain penetration is *not* normally a problem in older masonry buildings. In walls over 3 brick wythes in thickness or with cavities, penetration is very unlikely. There must be evidence of interior staining before penetration can be suspected. In the rare cases of severe penetration, few treatments have been found to be successful without undesirable side effects. As a general rule, when rain penetration occurs in masonry, it penetrates the mortar joint, not the masonry unit. With that in mind, treatments must focus on the joints.

Repointing Mortar Joints

When rain penetration occurs, it can be attributed to defective or weathered pointing and treatment requires the rather sizeable job of repointing. Care should be exercised in matching the strength of the pointing mix to that of the existing mortar and the masonry.[14] After a passage of time, if the repointing has not been effective in stopping the rain penetration, then more drastic measures could be taken, but only in cases where the rain penetration is so severe that staining or damage still occurs. Three courses of action are possible. None is wholly satisfactory, as will be apparent, but one or the other could work in certain special cases.

Water Repellent Coatings

The first possible course of action involves applying some form of water repellent coating to the exterior of the masonry or stone. Currently, clear solutions including either silicone or silane have shown limited success, primarily because they allow some moisture migration.[15] Either material should be tested in place. They have an expected service life of under ten years; hence, reapplication at a later time would be necessary. In some cases, however, these coatings *trap moisture and salts within the wall,* creating conditions for damage from freezing. Hence, they should be thoroughly evaluated before use.

Waterproof Coatings

A second treatment is to apply an exterior waterproof coating such as asphaltic or aluminized paint. Generally, because these are impermeable to moisture passage, they soon fail because of internal pressures from freezing water or from salt crystallization (subflorescence). Furthermore, they may not be compatible with the character of the historic building. As with water repellant coatings, waterproof coatings have major shortcomings. They can damage the substrate, and probably have a service life of only 5-7 years. However, in some special situations of extreme rain penetration they might be considered, but only after serious evaluation.

Stucco, Slates and Wall Coutings

There is historic precedent for the application of roofing slates, tiles, or cement stucco to an exterior wall that has suffered extreme weathering and rain penetration. These materials can be considered, but they should be mounted free from the wall on battens. This creates an inner cavity to reduce moisture penetration and reduces the potential for damage to the new coatings from freezing water or subflorescence. This approach is extreme and should only be considered in rare cases where the addition of such materials will not drastically change the appearance of the building.

Excessive rain penetration is usually treated through repointing and repair of exterior flashing (at windows and doors or other construction joints). Exterior coatings have only limited application and should be considered only in rare cases.

Common Treatments: Rain Splash-up

Rain splash-up and puddling can be a problem, especially with urban buildings or wherever there are hard pavements or materials adjacent to the base of walls. Good building practice assures that roof run-off be controlled with proper gutters and downspouts, and that the use of hard surface material at the base of a wall be avoided. It is best to assure that the paving material does not contact the building. This is done by creating at least a 2 in. (50 mm) gap so that surface water will not puddle. If space or conditions allow, a gravel strip 20 in. (500 mm) wide can be created next to the building (see figure 32). The gravel reduces splash-up and helps to drain water away. Rain splash-up or puddling at the base of a wall should be avoided in all situations.

Common Treatments: Interior Condensation

Condensation occurs when moist air contacts cool materials like windows and walls and results in staining or mold growth.[16] To eliminate the mold, the moisture content of the interior air should be reduced by installing extract fans (at the sources of the greatest moisture, e.g., the kitchen, the laundry and the bath) or by using a dehumidifier. Improving air circulation by natural or mechanical means also helps to equalize the humidity and air temperature, thereby avoiding isolated trouble spots in a building. Assuring that the building is properly heated is another preventive measure. These steps can increase the cost of yearly building operation, but the reduction in damage to the building should provide a counterbalancing benefit.

To reduce condensation damage further, attention should be paid to surface finishes. Hard and impervious surface finishes (enamel or waterproof paints, for instance) aggravate condensation problems.[17] Absorbent finish plaster and emulsion-type paints, on the other hand, allow moist air to be drawn into the walls, avoiding stains and disruption to the decoration finishes.

Common Treatments: Salt Encrustations

Efflorescence and subflorescence seem to occur with every moisture related problem. Treatment of such problems usually entails masonry cleaning, or, on interior walls, redecorating or replastering.

After successful treatment of a primary moisture problem, such as rising damp or rain penetration, walls begin to dry and efflorescence is the unavoidable result. Since problems from salts are always the by-products of treatments for dampness problems, the key to treating salt problems is to assure that the efflorescence occurs in a controlled way, without causing further damage. The following treatments are discussed in order, from most acceptable to least. Each discussion assumes that the interior wall surface is covered with plaster, and damaged from salts.

Dry Brushing

The first technique is quite effective for typical salt-charged walls. It minimizes potential damage from salts and is not very expensive, but can cause considerable inconvenience to building occupants. First, remove interior salt-damaged plaster to a point at which sound plaster is reached. For instance, for a wall suffering from rising damp, damaged plaster should be removed to bare brick in a horizontal band to a point about 12 in. above evidence of former salt damage. For walls (both interior and exterior) suffering from severe condensation or rain penetration, the majority of interior plaster may have to be removed. The walls are then left exposed until dry. (A rough rule of thumb is one month of drying for each inch of wall thickness.) During this period, often a year, efflorescence will appear on the interior and the exterior as the wall dries. This should be brushed off or vacuumed thoroughly, rather than washed, to removed all salts. The use of water in this instance will cause the salts to go back into the wall, and then to effloresce as drying occurs. At the end of the drying period, the interior walls should be cleaned completely with a soft brush and then replastered where appropriate. Salt problems should have been all but eliminated.

Absorbent Plaster Coats and Poultices

A second approach is more expensive than the first, but involves much less inconvenience to building occupants. In this scheme, salt-damaged interior plaster is removed. After an initial period of surface drying (about one month) obvious efflorescence should be removed. A layer of absorbent, weak plaster is then applied, solely as a sacrificial layer. This plaster, when dry, could be painted with one coat of emulsion-type paint and left during the rest of the wall's drying period. The plaster becomes salt-charged after a couple of years. Damaged portions are subsequently removed and replaced. A permanent wall finish can then be applied. This treatment may be preferable in cases where the inconvenience

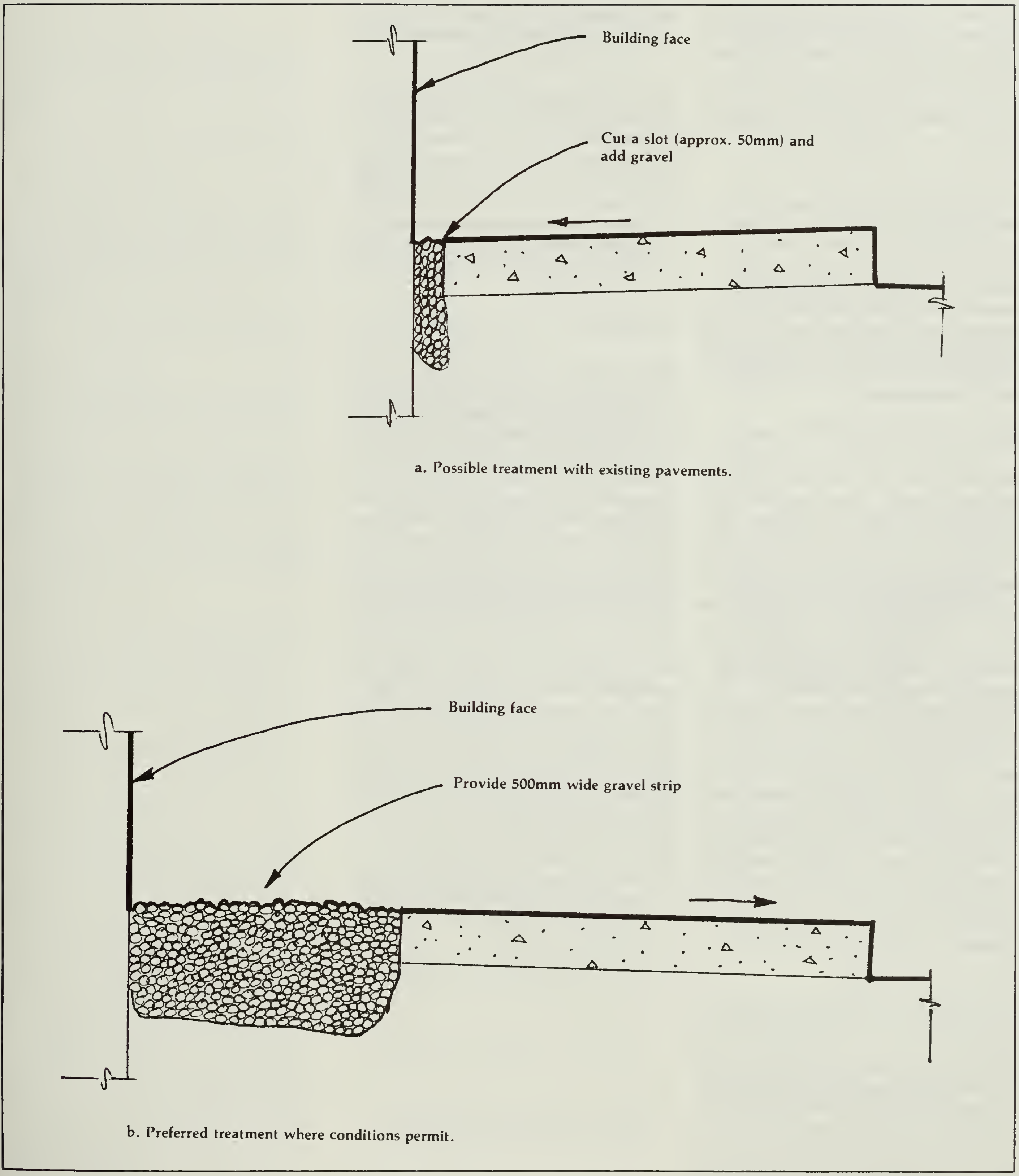

figure 32

Treatments for rain splash-up and puddling. Drawing: Baird M. Smith.

of bare brick or stone could not be tolerated, as in certain living spaces or public spaces like museums or art galleries. This treatment is more expensive and troublesome than the treatment discussed above, but it is equally effective in reducing potential salt damage.

A more direct system of salt removal, desalination, may have to be undertaken in severely salt-encrusted walls.[18] A common approach is to apply a damp clay poultice to the bare brick or stone. Upon drying, the poultice draws moisture and salts from the wall. The poulticing is repeated as necessary until salt content is sufficiently reduced to permit redecorating.

Non-absorbent Plaster or Stucco Coats

Applying hard, non-absorptive plaster or stucco coats over heavily salt-charged walls is not a treatment that should be undertaken. Such coatings trap salts within walls where they can damage the masonry materials and dislodge the plaster through the expansive forces of subflorescence. Other treatments to avoid include plaster additives and aerated plasters that supposedly reduce salt problems.[19] One such additive is advertised in Britain as a salt "neutralizer." There is, however, no effective way to neutralize salts except by adding an acid in solution, which would adversely affect both plaster and masonry. Aerated plasters, on the other hand, allow water vapor to pass through the plaster, and thus allow the walls to dry, but trap larger molecules such as salts.[20] The trapped salts can damage the masonry and the plaster.

Interior Wall Lining

Some products, such as impregnated paneling or wall coverings, merely cover up moisture problems or salt encrustations. They do nothing to treat the source of the problem, and can increase the damage in several ways. The wall linings reduce evaporation from the covered wall and increase it on the opposite side. In addition, the cover-up layer is a slight thermal barrier and tends to block the interior heat from reaching the wall. With cooler wall temperatures, the wall is more susceptible to condensation on the interior and frost damage on the exterior. For these reasons, wall linings are inappropriate for use in historic buildings.

Proper consideration for treatment of salt-charged walls is an absolute necessity in dealing with moisture problems. Efflorescence must be controlled and treated, not sealed into the wall. This only disguises a problem that is bound to re-occur. When dealing with historic buildings, treating salt-charged walls is as important as treating the original moisture problem.

Conclusion

Most moisture problems can be diagnosed and treated. While some situations may require examination by highly trained experts, most situations can be treated by architects and other building professionals by applying the diagnostic and treatment techniques discussed here. In the past, treatment decisions concerning moisture problems in historic buildings were often dictated by product salesman or by those undertaking the treatment work. Greater familiarity with the subject will help put such professionals in a better position to address dampness problems, thereby reducing the likelihood of inaccurate diagnosis and incorrect treatment. The need for architects, builders, and owners to become better informed on moisture problems in historic buildings will almost certainly become greater as more and more old buildings are rehabilitated to serve new uses, are made tighter against the weather to save energy or are improved to meet rising standards of comfort. This study has attempted to meet that need.

Reference Notes: Chapter 3

[1]Giovanni Massari, "Introductory Report," *Conference on the Problems of Moisture in Historic Monuments* (Rome: ICOMOS, 1967), p. 36.

[2]A performance test is described in Giovanni Massari, *Humidity in Monuments* (Rome: University of Rome, 1971), p. 21.

[3]G. P. Williams, "Drainage Around Buildings; Canadian Building Digest No. 156" (Ottawa: National Research Council, 1973), p. 3. See also *Architectural Graphic Standards* (New York: John Wiley & Sons, 1970), 6th ed., pp. 302-303.

[4]R. T. Gratwick, *Dampness in Buildings*, vol. 1 (London: Crosby Lockwood and Sons, Ltd., 1966), pp. 60-2.

[5]Ian A. Melville and Ian A. Gordon, *The Repair and Maintenance of Houses* (London: The Estates Gazette, Ltd., 1973), p. 646.

[6]Check Section 7.9 "Waterproofing Materials" and Section 7.10 "Flashings" in *Sweet's Catalogue* (New York: McGraw-Hill, 1979). See also *Architectural Graphic Standards*, p. 304.

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[8]Massari, *Humidity in Monuments*, p. 23.

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[10]"Installation of Chemical Damp-Proof Courses," pp. 2, 3, and 7.

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[12]An example is "Rentokil Silicone Injection Damp Course System; Certificate No. 77/512" (Garston, Watford, England: The Agre'ment Board, 1977), p. 3 passim.

[13]K. Alsop and L. H. Everette, "BRE Reservations on E-O," *Architects' Journal*, 9 April 75, p. 751; and David Gunn, "Treatment of Rising Damp; The Current State-of-the-Art," *Chartered Surveyor, Building and Quantity Surveying Quarterly*, Autumn, 1975, p. 5; and J. L. Heiman, "An Evaluation of Methods of Treating Rising Damp," *Rising Damp: Techniques and Treatment in Building Renovations* (Sydney: Graduate School of the Built Environment, University of New South Wales, 1978), p. 26; and also, J. L. Heiman, E. H. Waters and R. C. McTaggart, "The Treatment of Rising Damp," *Architectural Science Review*, December, 1973, p. 177.

[14]Robert C. Mack, *et al*, "Preservation Briefs 2: Repointing Mortar Joints in Historic Brick Buildings" (Washington, D.C.: Heritage Conservation and Recreation Service, revised 1980), passim.

[15]Building Research Station, "Decay and Conservation of Stone Masonry; BRE Digest No. 177" (Garston, Watford, England: BRE, 1975), p. 4. See also "Dampproofing and Waterproofing Masonry Walls," Technical Notes on Brick Construction 7 (McLean, VA: Brick Institute of America, 1968), pp. 1-3, and James R. Clifton, *Stone Consolidating Materials—A Status Report*, NBS Technical Note 1118 (Washington, D.C.: U.S. Department of Commerce, National Bureau of Standards, 1980), p. 21.

[16]*ASHRAE Handbook: 1977 Fundamentals* (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, 1978), p. 20.10.

[17]Building Research Station, "Condensation; BRE Digest No. 110" (Garston, Watford, England: BRE, 1972), p. 3.

[18]M. J. Bowley, "Desalination of Stone: A Case Study: BRE CP 46/76" (Garston, Watford, England: BRE, 1975), passim, and see Building Research Station, "Decay and Conservation of Stone Masonry; BRE Digest No. 177," p. 3.

[19]Department of the Environment, "Efflorescence and Stains on Brickwork; Advisory Leaflet No. 75" (London: HMSO, 1972), p. 3.

[20]Building Research Station, "Choosing Specifications for Plastering; BRE Digest No. 213" (Garston, Watford, England: BRE, 1978), p. 6.

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