A REPORT ON THE CAUSES AND EFFECTS OF MOISTURE IN OLD BUILDINGS IN DESERT REGIONS

INTRODUCTION.

The subject of this report is moisture in old buildings in desert regions. Therefore it is appropriate that I should define what type of desert Region is to be included herein, and define this region in terms of climatology rather than determine any geographic area in terms of physical limitations.

To begin with, I live in Santa Fe, New Mexico, a city situated at 7,000 feet above sea-level in a valley that is completely surrounded by mountains, but with climatic conditions similar to those that I'm about to describe, only somewhat more severe. However, within 50 miles of Santa Fe are to be found the true desert conditions that I will attempt to define in terms of climatology.

Moreover, I am an architect, not a scientist or research authority on the subject of moisture in buildings - but I have had considerable experience in the field of protecting, restoring and rebuilding ancient structures that have become damaged by moisture, both from within and from the outside. In fact, my firm is currently engaged in the repair and restoration of a large adobe building that through lack of proper maintenance has deteriorated extensively from the effects of moisturepenetration. So it is quite probable that my remarks will be largely related to, or concerned with, the type of buildings with which I am most familiar.

DESCRIPTION.

The south-western region of the U.S.A. is largely to be considered as a desert region, and that is the area that I will describe and define. However, upon a comparison of statistical data, it will be found that this area corresponds very closely to other desert regions, or dry land areas, in Africa, the Middle East and Australia; and these areas will include both arid and semi-arid regions at elevations from below sea level to as much as 5,000 feet above.

Also, since the climate in any given region is simply the pattern formed by the most generally prevailing combination of measurable components which go to make up our weather, an analysis of these components will show that it concerns such factors as temperature, precipitation (as rain or snow), moisture (expressed in terms of relative humidity and vapour pressure), wind and wind patterns, and the amount of sunshine that prevails.

When it comes to a consideration of moisture in old buildings, particularly in the desert regions, each of the factors that go to make up the prevailing weather must be considered in relation to each other factor and in combination. That is, we cannot consider relative humidity inside as being in still air when the winds outside have a velocity of 24 km per hour; and rainfall at high temperatures has a very different effect on walls from that of rains accompanied by low temperatures.

Another factor that must be considered is that of the location of any 'old building' that might lie within this region. It is only logical to assume that, since all life is dependent upon a source of water, only those buildings that might be classified as tombs, monuments or seldom-visited structures would be located in completely arid regions. Therefore, my statistical data will encompass only semi-arid or fringe areas of the typical desert region where conditions are suitable for man to live.

DEFINITIONS.

Temperature : The dry bulb, dry shade temperatures during the course of one average year will vary as much as 70° Centigrade - from a low of minus 22°C in mid winter, to as high as plus 48° C in June or July. However of much more significance for our consideration is the fact that within one 24-hour day the temperature may vary as much as 27.8°C in April or October and will consistently vary between 19.5 tot 22.5°C for a daily average. The mean average temperature for the year will be about 21.3° Centigrade.

Dew-Point temperatures for nine months of the year will fall between -6,6°C and +10°C - and for July, August and September will fall in the range from +4,4°C to +21°C. There will be times when the dew-point will fall below or rise above these levels, but the incidence of these extremes is of such short duration as to be negligible.

The relative humidity will vary much as the dry bulb temperature, seldom rising above 35% in the daylight hours and frequently dropping below 15% during the same period. Early morning percentages - the highest each day - seldom exceed 60%.

Vapour pressures will be relatively low in comparison with other regions. For about nine months of the year they will range from 3.5 mm, merc. to 8.2 mm merc., and in the rainiest

saison rarely go above 15.3 mm. merc. during periods of high R.H. %.

Remember that these are statistics for a semi-arid region and do not reflect the extremes of temperature and humidity that are found in the micro-climatology of truly arid desert areas where we have suggested that few old buildings would exist.

Precipitation : rain or snow will occur on less than 38 days during the year, and while some rain may fall in every month of the year, it is not at all unusual for four to five months in succession to be completely rain-free; in some years rain may fall only during the months of July, August and September.

Statistically, the rainfall will average less than 20 centimetres per year and the smallest recorded rainfall for any one year would be less than 7.5 cm. This corresponds with an average rainfall throughout the U.S.A. of slightly over one full metre, or about one/fifth of the rainfall normal to most areas - and recall that this small amount of rain usually occurs in the 3 summer months.

Also, since we are considering the semi-arid area of desert regions, we must assume that in areas above 2,000 feet in altitude, we will get some snow, infrequently perhaps but a real cause of wall damage. Unlike the sudden rain showers of summer, which occur when the surface materials are warm and expanded and cracks are closed, snow occurs when the surface materials are cold, cracks are open and the melting snows penetrate through the surface coatings and into the base structure of walls. Should snows occur when freezing conditions exist - and this is fairly common - the existing cracks are further opened and frequently cause surface material spalling.

Another component part of our weather that must be taken into consideration is wind. The large diurnal temperature ranges of these semi-arid regions give rise to active convectional currents during the warmer hours of the daytime and winds 15 to 35 MPH are quite common occurences. However, nights are relatively calm and cool.

Diurnal cumulus clouds are often absent, due to the excessive dryness of the air, and are frequently replaced by clouds of blowing dust and sand. This blowing sand erodes and polishes not only the natural earth and rock formations in the region, but also has a similar effect on the materials that we build with, and the drying effect of these winds is such that following a rain shower the walls are soon dry again. The effects that this rapid drying and sand-blown erosion have on building materials I'll leave to your imagination rather than attempt to describe; but do consider this.

Sunshine : In the regions that we are considering, the sun will shine through an unclouded atmosphere for about 85% of the possible daylight, with an intensity that will produce an average of better than 200 BTU's :"British Thermal Unit", per h. striking a horizontal surface. Few statistics are available for the surface temperatures of materials exposed directly to the sun's rays; but citizens who dwell in these areas seem to take delight in frying eggs on cement walks to show how hot they are.

Naturally, if cement becomes hot enough to fry eggs on, then stone, stucco and other materials that will retain heat must become equally hot - and when a sudden cold rain hits these heated surfaces, spalling can and frequently does occur.

Summarizing this statistical data we find that :
Dry bulb temperatures show an annual range of from -22°C to +48°C, and a daily range of extremes from 19,5 to 22,5°C. m
Dew-point temperatures - Mean : +2,2°C for nine months, about +15,5°C for summer months.
Relative humidity - Daytime average below 30% - Highest pre-dawn average 63%.
Vapour pressure : During the three wet summer months will average 13.1 mm. merc.
for the other nine months of the year - average 5.4 mm merc.
Precipitation - Less than 20 cm rain per year - three to five months completely dry.
Snow - 3 to 4 storms a year possible - none of any depth.
Wind : Fairly consistent throughout daylight hours - seldom over 56 km/hr.
Frequently dust- and sand-laden.
Sunshine : 88% of possible daylight hours - Very intense through clear air.

These, then, are the statistical averages that we will consider to govern the climate within the area that we have described as a semi-arid to arid desert region.
We will not consider or discuss the micro-climatology for any specific areas within this region; but when we have an individual building to consider it is essential that we do examine the micro-climatology for the individual location with regard to its siting and orientation, prevailing winds and all other factors in detail.

STATEMENT.

We are here to discuss the causes and effects of moisture in old buildings, and I take this to mean a discussion of moisture not only within the confines of the building but also moisture within, or attacking the structural components of the buildings, particularly

the exposed walls and roof.

Also, since we are discussing old buildings, I take that to mean that we will not be discussing modern materials, such as insulation, vapour barriers, etc. except as these materials may be suggested to be used in connection with the correction of moisture conditions that may have developed within such buildings.

Within the area that I am familiar with, such an old building would have been constructed of either adobe (ie. sundried bricks) or stones set in adobe mortar and with bearing walls supporting a framework of round or squared timbers, upon which would be laid a flat roof with an earth fill for its insulation value.

Such a building would have some timber posts supporting beams that carried a wall above. The lintels would have been wood timbers; the window sash - except where a slab of selenite was set into the wall - would have been of wood, as would the doors. The walls of such a building would have been from 50 to 120 cms. thick and probably would have reinforcing buttresses at the corners, and possibly around door openings. Window openings would have been relatively small; room sizes would have been set by the length and diameter of the available timbers, and corbels or brackets may have been used to shorten the roof span. Also, it is most likely that such a building would have been a church with an attached rectory or convent.

INSIDE.

First let us consider the interior of the building. What are the normal conditions that should be maintained within the building? Personal comfort levels will vary, dependent upon the age and sex of the occupants, but certainly there are norms within which the majority of persons would feel comfortable when dressed alike.

In my studies I came across a standard psychrometric chart, published by John Hopkins University, that shows "Reported tolerances for lightly and normally clothed men" in interior environments, and this chart indicates that :-

Within the limits of dry bulb temperature 21.3°C - Wet bulb 10°C with a relative humidity of 20% and a vapour pressure of 10 mm Hg - to a dry bulb temperature of 27.7°C, Wet bulb 20°C and a relative humidity of 85% and vapour pressure of 18 mm Hg and with both extremes subject to an air movement of 3 metres per minute, at least 50% of those tested felt pleasantly comfortable within these ranges, with a metabolic rate not exceeding 120.

And if we consider material contents of a building - well, my firm has recently had the opportunity to design two museum buildings, and the most reliable figures that we could obtain for the climatic environment which would be required to protect these exhibit materials from deterioration was a climate with a dry-bulb temperature of between 19°C and 22°C, and a relative humidity range that should not fall below 45% and not exceed 60%, with a vapour pressure of approximately 15 mm maximum.

In this connection, and possibly to point out some inconsistencies in this reasoning, it might be well to note that the exhibits and materials of one of these collections had been in storage, under far from ideal conditions, for about forty years, and had consistently been exposed to relative humidities ranging from well below 30% to well above 65% - and with dry bulb temperatures often below 10°C in the winter and frequently above 30°C in the summer; but, in so far as we could make a physical determination, no deterioration has resulted due to these exposures.

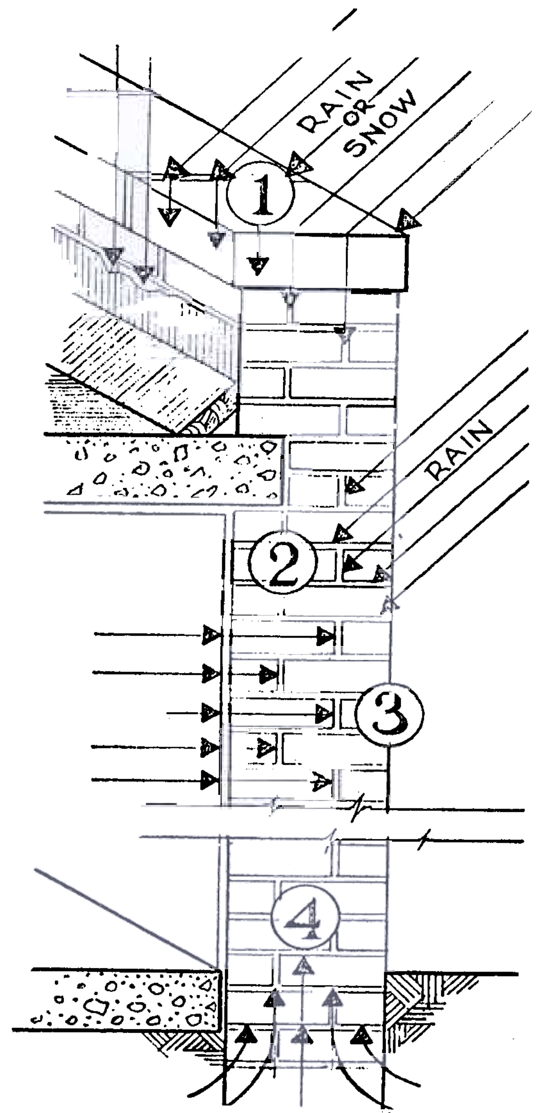
The materials in this collection included bird and animal skins, hides, parchment, papers of all qualities, books, pamphlets and some painted canvases. What deterioration we could detect appeared to be the result of careless handling by the museum personnel.

Therefore, gentlemen, it would seem to me that a dry-bulb temperature range within the limits of 20°C, to 30°C, a wet-bulb temperature not exceeding 30°C with a pressure within the limits of 8 to 20 mm of merc., and a relative humidity range of from 25% to 65%, could be considered the ideal comfort zone for building interiors.

Assuming such conditions, in the desert areas, any building with a reasonably sound roof, an adequate wall structure, and a dry floor can be maintained within these limits by a relatively simple form of adiabatic (evaporative) cooling during the hot months of the year, and with an equally simple circulating warm-air heating system during the winter months, possibly with some simple humidifier attached, but probably requiring some form of artifical air circulation within the building to combat the heat radiated from the walls during the early evening hours. However, should excessive moisture be present in any one of the three normal parts of the building structure - floors, roofs, or walls - then we have a situation where it would be difficult to maintain either the relative humidity or the vapour pressure within the limits that have been described. This would be one effect of moisture in old buildings and I'll now try to deal with some of the causes of moisture in buildings.

CAUSES OF MOISTURE PENETRATION

Simply illustrated, there are really only four ways that



moisture can penetrate through the surface of a wall and into the interior structure. Even in the best-designed buildings, water and moisture can enter through cracks in the building materials, through copings and window sills, as condensation of vapour from the interior and by capillary action through contact with wet subsoil structure.

Sometimes this penetration of moisture into a wall will show some sign on the surface - but frequently it is not until the wall becomes saturated that we have any indication of its moisture-content.

1) Penetration through joints or cracks in parapet copings - and penetration through leaks in roof flashings.

2) Penetration through openings as cracks or pores in the masonry. (Driving rains or snows)

3) Penetration through condensation of moisture from the interior.

4) Penetration by capilliary action through contact with wet surfaces.

Some of the consequences of moisture-penetration are as follows :

A. Efflorescence : Penetrating rain water concentrates the water-soluble salts (In desert regions usually alkaline salts) and carries these salts to the exterior face of the masonry. Here, as the water evaporates, they recrystallize, causing the excrescent disfigurement commonly referred to as efflorescence. This condition often causes a breakdown between the stucco surfacing and the masonry backing resulting in cracks or spalling.

B. Chemical Breakdown : Soluble salts carried in the water frequently react chemically to break down the mortar joints in masonry, and also in the surfacing material to cause serious damage to the materials of the wall construction, and this condition may or may not be apparent.

C. Frost or Freezing : The presence of excessive moisture in a wall whenever the outside air temperature is below freezing makes for the formation of ice crystals or expansion by frost action, and this uncontrollable swelling causes cracks and spalling within the walls.

D. Moisture-Content : Unfortunately there is no accepted standard or measurement or device to determine the amount of water that is safe or tolerable within a wall, and until we do have such a standard of measurement all our comparative assumptions are just guesswork.

Let us first consider moisture penetration from or through the floors. In the desert regions, the soil condition in the earth that surrounds any building would seldom, if ever, be in a moist condition for a protracted period of time, and never for so long a period of time as to be detrimental to the condition of the floor. Given proper drainage around the building, there would never be any serious problem with moisture in the soil under a floor; except that sometimes, when a change in maintenance management occurs, the new management will cause or encourage the planting of shrubs, lawns and flower-beds adjacent to the building walls, and, due to the excessive amounts of irrigation water required to cause these plants to grow in the desert soil, the amount of moisture in the soil can reach levels that will be detrimental.

So it is most important that proper drainage be established around the perimeter of a building, and that, once established, this drainage pattern be maintained. Given proper drainage, we can eliminate the problem of moisture penetration through the floor, whether the floor be of wooden or of concrete construction.

Next, let's consider the roofs and the penetration of moisture through this structural element. Unquestionably we must assume that an older building in this desert area would have a flat roof - most likely supported on either round-section or rectangular beams, spaced approximately three feet on centres, over which would be a layer of much smaller logs (or savinos), covered with a matting of reeds or rough-sawn boards, and topped with less than a foot of screened earth or soil, with a trowelled finish.

Such a roof would have been contained within a perimeter of an extension of the side walls as parapet walls, and would have to be considered as not very adequate for protection against moisture penetration. As you might well imagine, such a roof is easy to make watertight by the installation of a built-up or composition roof composed of asphalt felts and asphalt, with a gravel surface to provide protection from the heat of the sun, and against hail damage, and with proper wall-flashings.

So it would seem that our most important consideration appears to be that of preventing moisture-penetration into the composition of the vertical walls.

CONSTRUCTION.

The most commonly-used material for wall construction in the south-western U.S.A., and possibly in most other desert regions, is sun dried earth in the form of adobe building units, although rammed earth of pise de terra, and puddled earth, are not to be completely overlooked. Another commonly used form of wall construction was rather thin slabs of sandstone laid up in adobe mortar, or poor lime mortar.

Cut stone, kiln-burned brick or veneer surfacings of marble were so seldom used that they may be considered as applied ornamentation and not structural components.

Naturally a certain amount of wood was used in these adobe walls. Normally the wooden structural members would have had no applied treatment or protective coating of any nature, and usually dry rot would destroy them in places where they were buried within the walls, or wet rotting from moisture penetration would destroy them where they were in exposed locations. To correct this condition of rotted wood, it is usually necessary to replace the member, and to avoid any repetition of this rotting process, it becomes necessary to protect the wood members.

In the event that the rotting process has not progressed to a penetration of more than one-third of the depth or diameter of a beam or post bottom, it is possible to remove the rotted wood and to replace it or rebuild to shape using an acryliclatex cement colouring the cement to match the wood colouring. This is a process that is frequently used in restoring the bases of wooden columns damaged by moisture.

Various methods of preservation for wood in protected areas or in contact with earth are available. Creosote treatments

are effective where wood is completely buried in earth or within walls, but it has many disadvantages, both in use and in application, so we have gone almost entirely to the use of a pentachlorolphenol- type preservative.
However, this is only a wood-preservative and offers almost no surface protection against checking or water penetration, so it is essential to provide the surface with a water-repellent coating - a silicone, varnish or colourless resinous treatment. These applications will offer good protection for a few years, but to retain their effectiveness would have to be renewed or re-applied every three to five years.

Painting of wooden members, where this is aesthetically permissible, becomes a matter of making sure that the wood is thoroughly dry (moisture from within the wood is probably one of the major causes of paint failure), and, secondly, conditioning the wood by means of the application of a preservative treatment.

There has been too much written, and too many studies have been made on the subject of paint failures and the multifarious types of paint materials for me to dwell on this point; but I do wish to emphasize that with all the information available there is little excuse for any responsible person to select anything but the paint material that is best suited to provide the required protection under the prevailing climatic conditions. And in desert regions, climatic conditions are the first consideration.

It would be possible for me to cite numerous examples of wooden members and iron articles that have survived for hundreds of years with no coatings or coverings of any nature - but always these members are to be found in protected locations.

Therefore, it seems to me that the key word in this matter of the consideration of moisture in old buildings is PROTECTION. Every building was erected to PROTECT its occupants and contents from exposure to the elements of weather. Walls were coated with stucco to PROTECT the more vulnerable masonry and adobe wall-joints from erosion, and the stucco was coated with some form of paint as PROTECTION of that surface. In fact, we have a saying in my country : "PROTECT the surface and you protect everything" - and this is not far from the truth.

We are concerned here, today, with the problem of protecting a building from the penetration of moisture. We have noted that problems of condensation and permeability of moisture through floors are negligible and can be controlled by normal methods that are readily available; so our problem becomes one of moisture in the walls.

An adobe wall, not protected by a coating of plaster or stucco, is very vulnerable to erosion from rain, particularly wind-driven rain, snow and hail. The vertical faces of such a wall will erode very slowly under normal desert climate conditions, but the erosion of the horizontal top surface of an adobe wall will be very rapid and the whole wall will appear to melt, much as Neapolitan ice-cream on a hot day,
becoming thin at the top and building up to greater thickness at the bottom.
Stone walls, similarly unprotected, will not erode as rapidly as adobe, but here the great weakness will lie in the joints, particularly the joints near the base of the wall; and walls of this construction are more susceptible to collapse by reason of undercutting than an adobe wall would be.

The most usual form of protection for stone or adobe walls was to coat them with a covering of plaster or stucco - either composed of mud, lime-plaster or cement. This need for protection of the bare wall was recognized by our earliest builders, and until recent years it was the custom in my desert region for the occupants of a town or village to turn out, usually just before the annual Saint's day, and to re-stucco with adobe mud the exterior surfaces of all building walls in town.

This is still the case in many small communities, but for larger buildings, and where the labour must be hired to do this work, this annual procedure is far too costly for most budgets to substain; so most of our adobe-walled churches and other public or semi-public buildings have been covered with cement stucco and so have created a new and different set of problems.

Under desert conditions of extreme dryness, low relative humidities and a high diurnal range of temperature fluctuation, cement stucco becomes a very brittle material and subject to fracture. Cracks and fissures can and do open up in walls and parapets.

Rain or snow penetrates these fissured openings, frost action enlarges them, and before long they will freely admit moisture to the absorbant adobe beneath.
Also, since the exterior stucco and the interior plaster are less absorbent and more easily surface-dried by the warm atmosphere, moisture can penetrate thoroughly into the adobe sub-structure with no visible sign of moisture on the exposed surface. Usually this moisture-penetration follows a verticle pattern downard from wherever the moisture enters until it reaches the bottom of the wall or some other obstruction. However, we have encountered conditions where the moisture-penetration spread out in a horizontal direction, why, I'm not sure; but in one instance we found that, from where the moisture entered three closelyspaced cracks, the mois-

ture in the adobes beneath extended for about 5 m. in each direction horizontally, then seeped down through the wall in the shape of an inverted cone to a width of 6 m. at the base.

Another manner in which moisture can penetrate into the adobe substructure is through horizontal cracks in the wall. Usually these cracks are occasioned by moisture penetrating near the top of the wall, moistening only slightly the adobe units at that point, and causing the outer surface of the adobe to slough off, falling between the adobe units and the stucco coating and causing bulging in the stucco, until it finally cracks and allows moisture to enter along progressively longer and wider cracks, permitting serious wall deterioration.

Protection or correction of cracks is a serious matter, and unless properly done the crack will soon re-open. Certainly the materials of the repair must be the same as the materials in the adjoining wall surfaces, and to protect the repair it is necessary to provide a glass-fibred membrane to bridge againt reopening.

Actually, with the exception of settlement cracks, all cracks in the surface coatings of buildings are caused by climatic conditions and are visible defects and can be detected and corrected; but it is astonishing how frequently these cracks are allowed to go uncorrected until excessive deterioration has occured.

Aside from cracks, but including crack repairs, wall surfaces can be protected against moisture penetration, and in fact can be rendered moisture-repellent by coating the wall with a number of various treatment coatings.

Any analysis or evaluation of available paints or coatings is beyond my technical capability, but there are many excellent products on the market that offer satisfactory protection for most of the surface materials in common use. But almost none of these products are suitable for use over adobe plaster and adobe is the material in most common usage in many desert regions.

Solvent-thinned polyrethane, a synthetic resin marketed as a viscid petrochemical, under the trade name of "Pencapsula", is the first, and so far the only, product that has been developed that will offer protection for an adobe surface. It has been extensively used in experiments by the U.S. National Park Service to restore or preserve the many adobe structures, or stone structures in adobe mortar, that come under their jurisdiction, and the results have been excellent. The product has been in use for only about 5 years, but the applications made five years ago appear to have stopped all deterioration in the structure and from all tests are as effective today as when first applied.

It is not my purpose to extol the merits of any named product, however, in this instance, and since this is the only product of its nature that has received any publicity or come to my attention I must state that this Pencapsula certainly seems to offer to those concerned with the preservation of adobe structures the first ray of hope for the protection and preservation of these old buildings.

SUMMARY.

In summary, to list the causes of moisture in old buildings in desert regions, it would seem evident that the climatic conditions of the region are not to be taken collectively as one of the causes of moisture in buildings but actually make it possible for the types of buildings we have been discussing to exist.

Now, since rain falls in any appreciable quantity on less than twenty days during the year and snow falls only about two or three times a year, it would seem that this condition should not contribute greatly to the presence of moisture in the building, or within the structure of the building. Indeed, as we've noted before, the problem of condensation of moisture within the building, and the presence of a troublesome vapour pressure, can be overcome or corrected by the simplest means.

Moisture in the walls or structure of the building is another matter. The cumulative effect of moisture-penetration - the deteriorating effect it has on the walls, and on all surface materials - coupled with the rapid surfacedrying that hides this condition from view, make this moisture problem one of serious proportions.

In old buildings certain outward manifestations of adverse conditions caused by moisture or penetration problems are readily visible, and when noted they should be corrected at once to avoid compounding the problem. But they seldom are.

Open cracks in the stucco surface, flashing leaks in the roof, wet spots in the plaster after a rain, peeling, blistering or scaling of paint, discoloration in wooden members indicating rotting of the members and spalling of the masonry, are all visible signs of trouble brewing, and, when noted, should be corrected.

Less conspicuous but more insidious problems that are usually unnoticed until the problem has become serious are :
Rotting of organic structural members, specially wood beams and posts.
Corrosion of metal structural members, often at the bearing end of the rods.
Creation of an atmosphere conducive to harbouring vermin (Occurs

... moist walls).
Sp...ling of stone masonry, usually due to freezing conditions.
Moisture trapped within an adobe or masonry wall, and hidden by surface-coatings.
These are the effects of moisture in or on old buildings, and these are the conditions that must be studied to correct or eliminate them from old monuments and structures.

Now, Gentlemen, half my life has been spent in or near the desert region of the USA and much of that time I've been concerned with old Indian or Spanish buildings, both dwellings and church buildings, and some ancient ruins. I've also built many new churches, dwellings, and other structures, using adobe walls. During this time I've encountered nearly every conceivable problem that could exist in this type of construction, and I'd be happy to discuss these situations with any of you who may wish to do so. But this is not the time, so I thank you for your reception of my remarks and hope that I may have contributed something of this conference.

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