THE ROLE OF ABSORBENT BUILDING MATERIALS IN MODERATING CHANGES OF RELATIVE HUMIDITY

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Ph.D. thesis

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Department of Structural Engineering and Materials

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Abstract

An experimental climate chamber controls the water vapour flux, instead of the relative humidity which is the parameter controlled by ordinary climate chambers. This chamber allows measurement of the influence of porous, absorbent materials on the indoor climate.

An assortment of common and unusual building materials has been tested for efficiency in buffering the indoor relative humidity: brick, cellular concrete, wood, earth, lime mortar, gypsum plaster and wool insulation. The best buffer performance among the materials tested is given by wood arranged with the longitudinal direction perpendicular to the exposed surface. The best inorganic material is a specially developed mixture of bentonite, a montmorillonite type clay, with perlite, an expanded volcanic glass.

Such materials, used as walls within buildings, will moderate the indoor relative humidity, over a period which depends on the air exchange rate. This humidity buffering effect is particularly useful in kitchens and bathrooms where intermittent production of steam is effectively absorbed, to be released later. Effective buffering of the daily variation of relative humidity can be achieved.

In buildings with a much lower air exchange rate, such as archives and stores, the buffering by absorbent walls is so effective that it evens out the annual cycle of relative humidity, without needing help from mechanical air conditioning.

In buildings which require both a moderate air exchange rate and a stable relative humidity a symbiotic design, combining mechanical air conditioning with buffering by building material, allows air conditioning of a museum store, for example, using only a small dehumidifier.

Outer walls of buildings which are porous on both sides should theoretically pass water vapour through according to the relative humidity difference across the wall. This means that such a building when warmed in winter will have a higher relative humidity than that calculated from the water content of the outside air, raised to the inside temperature. This is a controversial assertion, which is here supported by indirect evidence from measurements of church climate. This matter is presented as a conjecture that deserves further investigation.

PREFACE

The moderating influence of absorbent materials on the relative humidity in small enclosures has been known, and written about, for ages. The extension of the concept to moderating the relative humidity of large, leaky enclosures like houses has been unaccountably neglected. The influence of the material is diminished by ventilation but a useful contribution remains. In buildings such as museums, where total control of the indoor climate is considered necessary, absorbent materials can be combined with mechanical air conditioning to provide a simpler and more stable control system. Absorbent walls also have the ability, not yet fully explained, to pump water vapour to increase the indoor relative humidity in warmed buildings in winter.

Now we coat all surfaces with almost impermeable paints and even the porous materials we build with are not very water absorbent, or react very slowly. Architects and engineers have divided the task of making a habitable building, so it is not surprising that engineers have concentrated on designing walls as bearing structures and screens against the outdoor climate and have completely failed to see how a wall can contribute to the pleasantness of the indoor climate.

This evolution in building tradition has not only hidden the potential for humidity buffering that lies in common materials, but has also generated an array of condensation problems, not only within buildings but in the structure of walls and roofs.

I became aware of this by chance, when I was called in to investigate a particularly dramatic example of water apparently being spontaneously generated by a building. Later, as happens when one completes one job successfully, other examples of sick buildings came my way. Some of these studies have been published but they are reworked here to form a coherent study of the role of absorbent materials in the regulation of humidity in the indoor air as well as in the structure of walls and roofs.

This thesis is written to satisfy the engineer's demand for solid evidence and justifiable speculation but I hope that it will also be read and in large part understood by architects and by conservators, who mostly have an arts rather than a scientific education. I have tried to avoid jargon and unnecessary use of mathematical symbolism and manipulation.

I have been able to combine old experiences with new experiments through the generosity of the National Museum of Denmark, which gave me study leave for two years and contributed to the experimental expenses. The Danish Ministry of Culture paid my salary for one year. The Technical University of Denmark gave me three months Ph.D. grant. The Danish Ministry of Energy paid for some research which I have used in this thesis. The Copenhagen Conservation School paid for some research equipment.

There are many people I wish to thank. Those who have contributed to what scientific merit there may be in this work are Poul Klenz Larsen, Jesper Stub Johnsen and Poul Jensen, from the Conservation Department of the National Museum, Bent Eshøj from the Copenhagen Conservation School, Conservator Annabel Robinson, David Erhardt of the Smithsonian Institution and my supervisors at The Technical University of Denmark: Anders Nielsen, Kurt Kielsgaard Hansen and Carsten Rode. For technical help in constructing the climate chambers I thank Bent Hansen, Steen Jørgensen, Klaus

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Tim Padfield

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1

INTRODUCTION

Human sensitivity to temperature and indifference to humidity

This thesis is about controlling the relative humidity inside buildings by using the water absorption properties of porous materials.

Figure 1.1 A cafe scene in Phoenix, Arizona. The air is cooled by evaporation of water sprayed from the edge of the canopy. The air becomes more humid but the customers are more concerned with keeping cool.

We put considerable energy, expense and ingenuity into holding a moderate temperature around us but are much less concerned with the humidity of our environment.

This does not mean that the ambient humidity is unimportant to our welfare. There are organisms that thrive at high humidity which provoke allergic reactions, moulds and dust mites for example (1). On the other hand people seem to be able to tolerate the very low relative humidity of warm houses in cold climates (2), so our ideal environment is on the dry side.

Many of the objects with which we share our space are more sensitive to humidity than we are and are affected by both high and low extremes. Pianos and organs go out of tune, wooden furniture warps and its joints loosen, metals corrode (3). The dimensional changes of materials as diverse as hair, paper, and cellulose butyrate are used in commercial humidity sensors. An example of extreme humidity sensitivity is the geranium seed shown in figure 1.2, which twists round on its curly stalk several times as the relative humidity moves from 30% to 90%.

Because of our relative indifference to humidity over a rather large range, houses

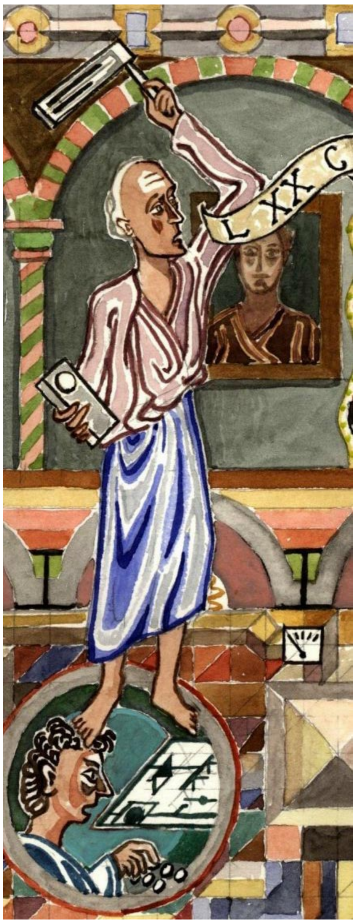
Figure 1.2 The seed head of a geranium. The tightly curled, feathered stalks unwind about five turns as the relative humidity changes from 30% to 90%. Photo: John Lee.

and offices do not generally have any humidity control at all. Only museums, art galleries and printers insist on equally close control of both temperature and relative humidity. The building industry is not therefore as experienced in humidity control as in temperature control, a priority that is also reflected in the research papers in building physics.

Alternative, "green", low energy strategies for controlling indoor humidity are much less developed than methods for collecting, storing and controlling heat in buildings, even though there is no difference in principle between using a massive wall to store heat and using a massive wall to store moisture. It just isn't thought to be necessary. The word 'humidity' in the building industry is almost synonymous with condensation and the acute damage that it causes. The architects who design museums do not ever design with a view to providing a natural stability of relative humidity. They design the building as they would for any other purpose and then leave the engineer to provide the necessary air conditioning by mechanical means. The design of one recent archive building hints at a change in attitude, at least for utilitarian buildings whose main role is storage (4).

In this thesis I discuss humidity control from the point of view of a museum conservator, but the arguments apply equally to ordinary houses and offices.

Humidity control in museums



Museum conservators are concerned with relative humidity because all the organic materials of museum objects change size with changing relative humidity, much more than they change size through thermal expansion over the normal temperature range on earth. Laminated materials, such as oil paintings and veneered furniture will therefore distort and suffer shearing stresses with changing relative humidity. At low relative humidity organic materials also become stiff and therefore less tolerant of the shearing stresses between layers. High relative humidity accelerates the very numerous degradation reactions which involve hydrolysis: the addition of water or the hydroxyl group to materials. Corrosion of metals usually accelerates with increasing humidity and finally high humidity encourages living organisms, which are seldom beneficial to museum collections.

The present standards for humidity control in museums derive from an influential book by Garry Thomson (5), though he was by no means the first to emphasise the importance of humidity control.

Figure 1.3 Garry Thomson's book "The Museum Environment" became the bible for conservators specifying climatic conditions for museums and art galleries.

Garry Thomson (pictured in figure 1.3, reciting the standard numbers: 50 % RH, 20°C and 100 Lux, while the obedient air conditioning engineer struggles to adjust the machinery) is much more moderate in his views than many conservators, who demand impossibly precise, or at least very expensive climate control, thus shifting responsibility to the air conditioning engineer.

This strict standard for permissible fluctuation in RH has discouraged experiments in passive methods of humidity stabilisation in galleries, because such methods cannot achieve absolute constancy. It is no exaggeration to say that the tight environmental standards have had a pervasive, not necessarily beneficial, influence on museum design.

Humidity control by simple passive methods has been suggested from a very early stage in the development of environmental conservation in museums. In 1934 McIntyre (6) attempted to improve the climate in the orangery at Hampton Court Palace in England by putting lengths of old linen water hose in the ventilation ducts. This was a remarkably ingenious solution at that time, because the response of organic materials to moisture was first accurately measured in the twenties and thirties. He also commented on the usefulness of absorbent buffers in showcases and picture frames.

Since then, development of passive means for stabilising the humidity around art objects has concentrated on refining the performance of the immediate enclosure, the showcase, in museums that are too old, or too poor to enjoy the benefits of modern air conditioning (7). Another popular subject for research has been humidity stabilisation during transport of works of art (8).

Humidity control in showcases and packing cases is rather simple, even trivial, because the air exchanges only slowly with the environment. Almost any absorbent organic material, in rather small quantity, will stabilise the climate in a confined space for a short time. The only difference between a showcase and a packing case is that the temperature is likely to vary more during transport. The effect of temperature change on humidity control in a confined space is described in reference (9).

Humidity control in ventilated spaces

Humidity control in storerooms is a little more complicated than in showcases or packages because the ventilation rate is enough to stress the ability of absorbent materials to absorb and release water vapour fast enough to compensate for the air change. The ventilation rate in store rooms can be low, because there are no people permanently resident in the room, but it is desirable to maintain a slight over-pressure within the room to stop dust and pollutants from entering. The possibilities for low energy control are summarised in chapter 6.

Figure 1.4 Humans, from the point of view of building physics, are merely sources of water.

Humidity stabilisation in a well ventilated space such as a museum gallery, or the living room of a house, is much more difficult. Moisture exchange through ventilation competes with the moisture released or absorbed by the stabiliser. An important complication is the presence of people, who, from the point of view of building physics, mainly function as sources of water.

The factors that must be considered when attempting to increase the scope of humidity stabilisation from the small container to the inhabited area are therefore the rate of transfer of water vapour through the surfaces of the room, the water capacity of the material, the generation of water vapour by people and the loss (usually) of water vapour through ventilation.

The porous wall

Stabilising the humidity in a ventilated space cannot be done by discretely distributing canisters of silica gel. The walls and ceiling of the room must be brought into action as stabilisers.

The original practical work reported in this thesis is mainly directed towards evaluating the performance of porous, water-absorbent walls as moisture buffers for rooms that have the typical ventilation rate for inhabited spaces: about half an air change per hour.

Porous, absorbent walls are almost extinct as a building element in the western world, but they have a history stretching back through millenia. Such walls are generally simple in structure and made of readily available and cheap materials such as earth, wood and plant fibres. One of their valuable assets is an ability to moderate the indoor relative humidity during periods when large quantities of water are released by cooking and bathing.

Walls with a porous surface towards the room are now limited to basements, stables and churches, where the tradition for limewashing survives. Everywhere else a smooth, washable surface is considered more desirable and plastic emulsion paint is the nearly universal interior finish in the western world.

I describe in chapter 6 an example of good humidity buffering in a church with porous walls, and a contrasting example from a nearby church with non-porous interior finishes.

Porous outer walls are particularly distrusted by modern architects and engineers. Their argument is that air from inside the house, where the water vapour concentration is nearly always greater than that outdoors, will move into the wall. In a cold climate the water vapour in the wall will sometimes condense. The liquid water can then cause damage by supporting rot, by freezing and by dissolving and transporting salts which corrode metal parts and crumble the wall through crystallisation. Architects therefore specify an impermeable barrier in the form of paint or a plastic foil close to the interior surface to prevent the inside air from penetrating the wall faster than it can evaporate to the outside.

Condensation damage is, however, not unknown in modern buildings with vapour barriers and more or less non-absorbent materials in the walls (10). The reason for this is that any hole in the barrier will allow air to flow into parts of the wall which have no ability to delay condensation by absorbing water vapour. After condensation has

Figure 1.5 In modern buildings an impermeable barrier is often placed just behind the interior finish.

occured, the nearly impermeable wall hinders the evaporation of water out of the wall. Absorbent walls, on the other hand, can be expected to survive a degree of leakage, because the materials will absorb water vapour for a considerable time. The absorbed water will later be released when the outside weather is warmer, or it will be released by diffusion into the relatively dry air outside.

Condensation in nearly impermeable structures is a particular threat to museums. Museums are humidified in winter to about 50% RH. Water is liable to condense at any point in the wall that is below about 9°C, which is the dewpoint of air at 50% RH and

20°C. Nevertheless, museums in old buildings, typically of massive brick construction, seem to survive whereas some purpose built museums with complicated precautions against condensation in the walls drip copiously from the facade in cold weather.

Figure 1.6 The National Museum of American History, in Washington D.C. On a bright spring morning the marble facade is stained by meltwater from ice that has condensed from the inside air.

There is another good reason for evaluating the absorbent wall as particularly suitable for museums. Museums have people in them for about eight hours a day. An absorbent structure will moderate the indoor relative humidity during the relatively brief opening hours. A rather small air conditioning system can then re-establish the correct climate during the long period when there is nobody in the building, and therefore no need for ventilation to the outside. The saving in energy and noise are two advantages, another is the smaller space occupied by the distribution ducts.

Indoor air quality

In the home and in the office, porous, absorbent walls are equally beneficial. The "Sick Building Syndrome" has become a cliché, used to berate designers for all manner of defects which cause psychological or physiological harm to the occupants. The extraordinary number of synthetic chemicals which outgas from modern interiors cannot be blamed on impermeability, but the mould growth that adds natural irritants such as spores to the air can certainly be reduced by permeable walls. Impermeable walls are much more prone to transient episodes of condensation caused by cooking and washing, or simply by the breathing of a large gathering. Insects also thrive where liquid water is available (11).

Dust mites, whose excrement is a potent allergen, thrive only above about 50% relative humidity. A bedroom with windows closed against the night cold will rise considerably in RH during the night, from moisture from the breath and bodies of the sleepers. A porous wall will absorb this moisture and release it when the room is aired during the day, giving a lower average RH. This will reduce the operating time of a dehumidifier, or make it unnecessary.

This brief description of the need for humidity buffering and the unused buffering potential, and other advantages, of porous walls has introduced the main themes of this thesis. The next sections of this chapter introduce those aspects of the physics of water vapour in air that underlie the arguments, and the experimental methods, that will be treated in detail in later chapters.