CIBSE National Conference 1997

PASSIVE CONTROL OF RELATIVE HUMIDITY TO ±5%

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Providing Quality for People has many aspects. Of these, one is providing buildings that give clients and users better value for their money. Another addresses the issues of preserving our heritage upon which our quality of life based. This paper describes how these can be achieved using the application of innovative design concepts supported by advanced analytical techniques.

For the majority of archive repositories, storing as they do paper type material, environmental conditions of 60±5% and 15.5±2.5°C are recommended by British Standard 5454. Convention tells us that controlling moisture to this close tolerance requires full air conditioning. However, building materials have the ability to absorb moisture during times of excess, retain it and then emit it at times of deficiency. To take full advantage of this effect needs advanced software based analytical tools, firstly to understand the extent of the moisture flywheel effect, secondly to allow the selection and design of appropriate combination of building form and materials, and finally to allow predictions of room conditions. This paper describes the development of such a tool by Ove Arup & Partners together with its first application on the design of the new Jersey Archive Centre. The result is a building that aims to achieve the recommended environmental conditions without air conditioning or mechanical ventilation.

INTRODUCTION

There is considerable largely anecdotal evidence to suggest archive material survived better prior to the advent of central heating and air conditioning. This may be arguable, but by observation of historical building types [1] [2] [3] and by comparing the actual performance of mechanical systems against the calculated predictions it is evident that the building itself can exert a significant moisture as well as a thermal inertia effect.

The building fabric, and its contents, have an ability to absorb moisture and heat during periods of excess and re-emits them during periods of deficiency. The result of this phenomena is the smoothing of both room temperature and humidity fluctuations. With the recent development of advanced computer based analytical techniques for predicting the thermal dynamic performance of passive building materials has come the potential to develop similar techniques for predicting moisture performance. However, to date there has been no generally available moisture analytical techniques suitable for use during the design process. It is when these techniques are available that the scale of moisture effect can be explored and from that its potential established. Only then can buildings to be designed to fully exploit this phenomena as an equal to the more mechanical equipment based room environmental control solutions.

This paper describes the Jersey Archive Centre building project, where the proposal to make maximum use of passive environmental control received active support from the client. The main proviso was that repository conditions should aim to achieve the recommendations of British Standard 5454:1989 [4] namely, 60±5% relative humidity and 15.5±2.5°C. To allow the combined passive environmental effects to be better understood and to establish how far they could provide total control, an integrated moisture and thermal dynamic building simulation computer tool was developed. Unlike previous examples of non-air conditioned archive repositories, this tool allowed quantitative analysis of building design options and hence a design tailored to maximise the passive effects.

As with most passive environmental control projects the real benefits are yielded where this approach allows a step change in the design solution. Simply reducing the size of the normally provided mechanical plant generally provides only marginal benefit particularly with regard to capital cost. So this project set out to establish the feasibility of eliminating total systems, with the prime targets being mechanical cooling and mechanical ventilation.

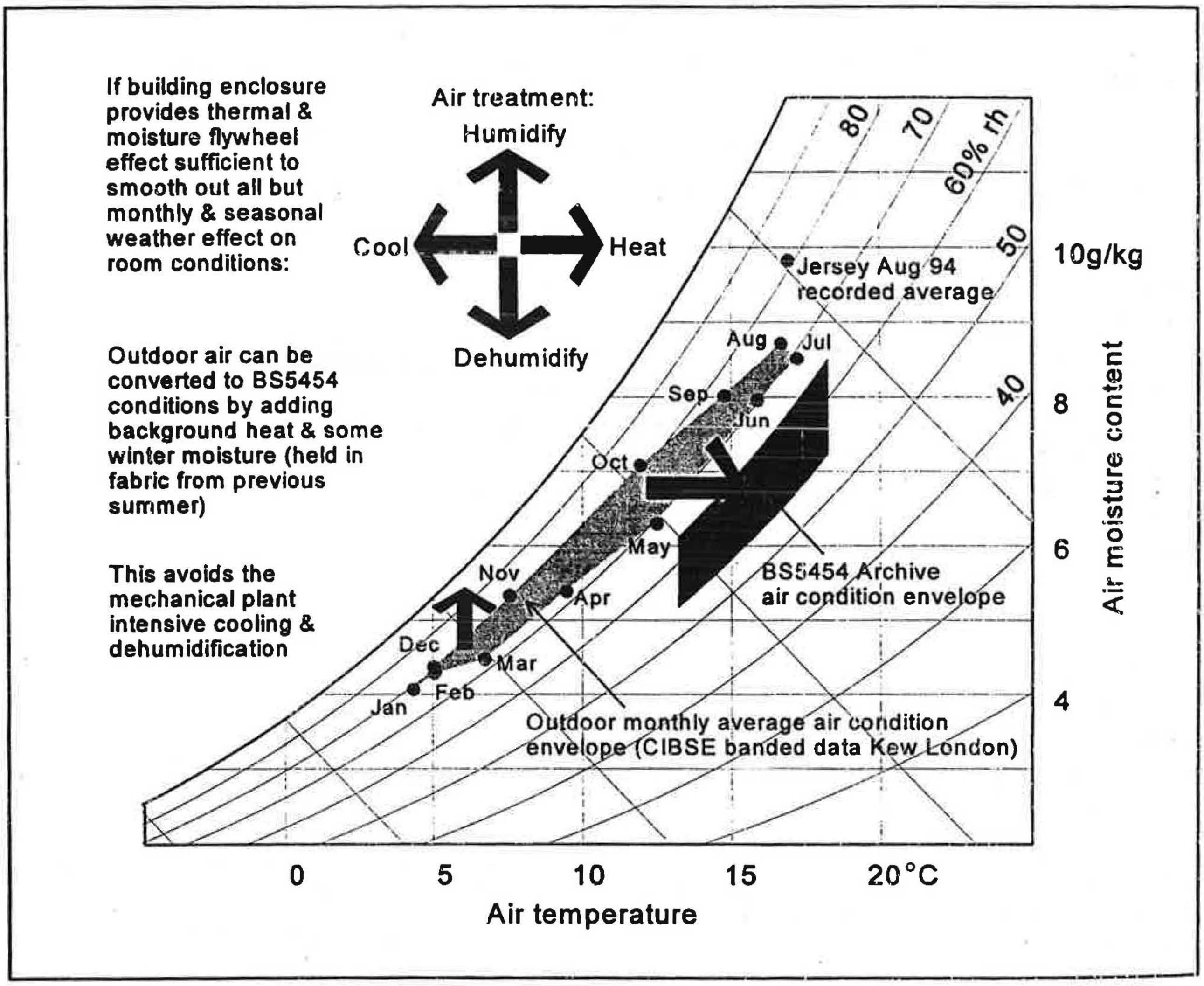


Figure 1 Concept stage psychrometric diagram

Figure 1 is based on one of the initial concept sketches used to illustrate that with standard UK weather data[5] a building with sufficient moisture and thermal inertia to respond only to monthly average weather conditions could stay within the critical top limit of BS5454. If this could be achieved it offered the client considerable benefits, including:

- significant reduction in building services capital costs
- reduction in plant room space and hence further reduced building cost
- reduced site infrastructure costs (eg in this case the avoidance of an electrical substation)
- less systems complexity

- reduced risk of plant failure jeopardising archive conditions
- low energy consumption
- low long term operating and maintenance commitments
- reduced pollution emissions and environmental impact.

REVIEW OF PUBLISHED MOISTURE RESEARCH

Approaches to modelling moisture movement through porous fabric over the last thirty years can be classified into two categories. Either they apply the physical characteristic to representative nodes (lumped parameter models)[6][7] or they consider the variation of moisture flux within the thickness of the fabric. Where the movement of moisture within the fabric is to be considered the latter more rigorous method is required.

Luikov's work [10] [11] is theoretically rigorous, being based on the fundamental laws of irreversible thermodynamics, but in spite of the comparative ease of numerical solution the lack of available material property data considerably restricts its usefulness.

Most of the more applicable methods use evaporation and condensation theory such as in the equations of Huang [9]. Berger and Pei [12] modelled liquid and vapour movement due to the mechanisms of capillary transport and diffusion respectively. They also considered the maximum sorptional liquid content of the porous media, above which vapour density was calculated from the Clausius-Clayperon equation and not via the sorption isotherm, as is normally the case. Berger and Pei considered vapour diffusivities constant, whilst Hamarthy [15] and Kerestioglu & Gu [16] attempted to model what is considered to be a strong relationship between diffusivity and moisture content.

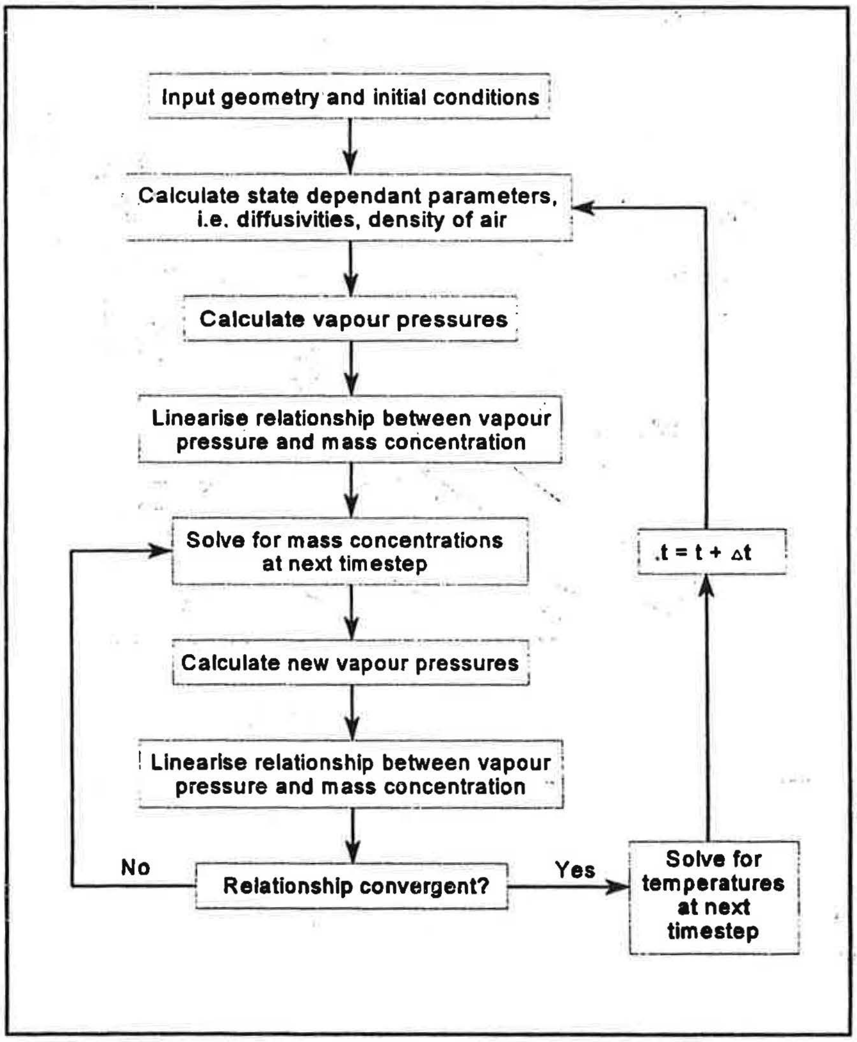


Figure 2 Moisture algorithm flow diagram

Yik [8] in his later research concluded that modelled vapour diffusion only was sufficient, and that vapour filtration (which he showed to constitute only 2 % of the moisture flow) and all liquid state movement could be ignored.

Although it is generally accepted [13][14] that hysteresis is a significant phenomenon affecting moisture transport in porous bodies, it is just as widely accepted that it is far too complex and insufficiently researched to be modelled. All papers found ignore the effect of hysteresis.

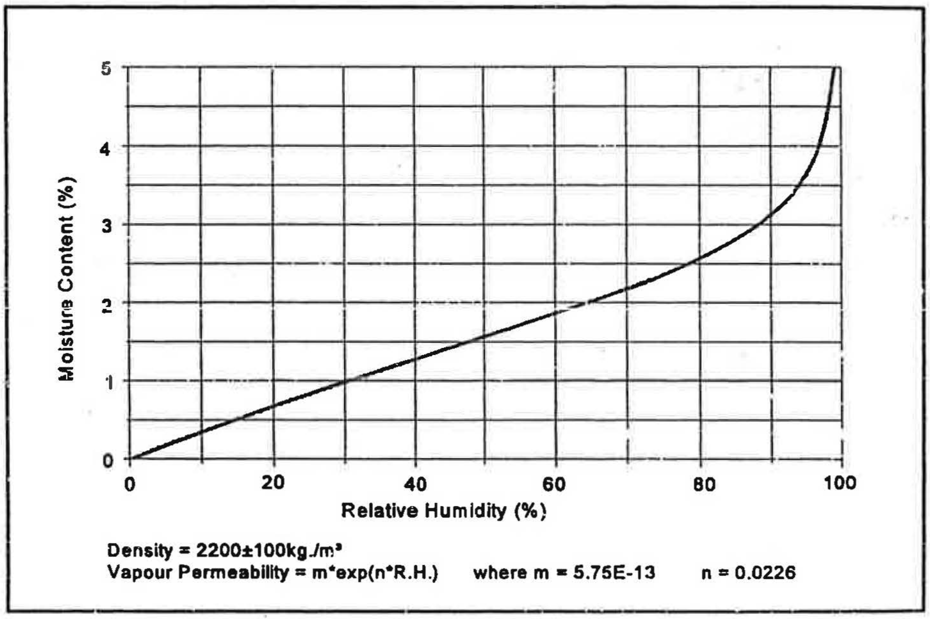
Cunningham[17] developed a three dimensional model which considers vapour transport through buildings driven by vapour pressure gradient. He regarded diffusivities as variable with moisture content and considered latent heats as well. Significantly he has also published subsequent work concerning validation of his algorithm with an analytical solution and experimental results.

IDENTIFYING AND DEVELOPING THE MOST SUITABLE METHOD

Three approaches were considered, namely those due to Yik, Kerestioglu and Gu, and Cunningham. Each approached the problem in a different way, though each is based, fundamentally, on the same theory.

Yik's work seemed appropriate to the problem at hand and appeared to be thoroughly documented, but when an attempt was made to apply his differential permeability model to a simple three node example, sufficient explanation of one of the terms of his equations could not be found.

The work of Kerestioglu and Gu is rigorous though complex, and it was thought that this complexity would make validation of results difficult and possibly obscure the underlying physics of the problem.



Density = 2200±100kg./m^3
Vapour Permeability = m*exp(n*R.H.) where m = 5.75E-13 n = 0.0226

Figure 3 Concrete sorption isotherm

The Cunningham method offered the best basis for an accurate model because of its 1, 2 and 3 dimensional versatile, it is well documented and is the only one of the above three which has undergone any sort of experimental validation. Subject to some adjustments to improve its numerical accuracy the Cunningham moisture method was used. Figure 2 describes the principles of the moisture algorithm written from for this method. The main modelling assumptions are:

- All moisture movement takes place in the vapour phase and is due to gradients in vapour pressure or air-borne convection. Thus all moisture must first be evaporated from the liquid phase with the latent heat considered in the thermal modelling.
- The fabric is divided into finite elements, the size of which depends on the extent to which moisture is expected to vary at a particular point.
- The vapour resistance of air / fabric interfaces is regarded as small in comparison with the vapour resistance of fabric.
- All fabrics are considered to be rigid, homogeneous and isotropic.
- Detailed hydrodynamics are not considered and the air nodes are considered to be well mixed.
- Thermal transmission values are not temperature dependant and thermodynamic equilibrium exists in all places at all times.
- Hysteresis of the sorption isotherm and any temperature dependance of the sorption isotherm are ignored.

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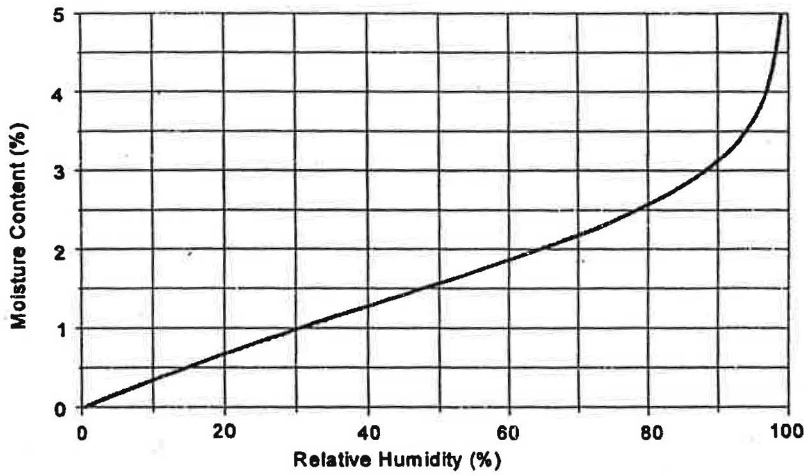

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APPLICATION OF MOISTURE ALGORITHM

Having developed the moisture algorithm it was added to the Oasys Ltd. ROOM [18] dynamic thermal software to allow simultaneous room temperature and humidity modelling. This thermal software was used in preference to the thermal side of Cunningham's method because it is considerably more advanced

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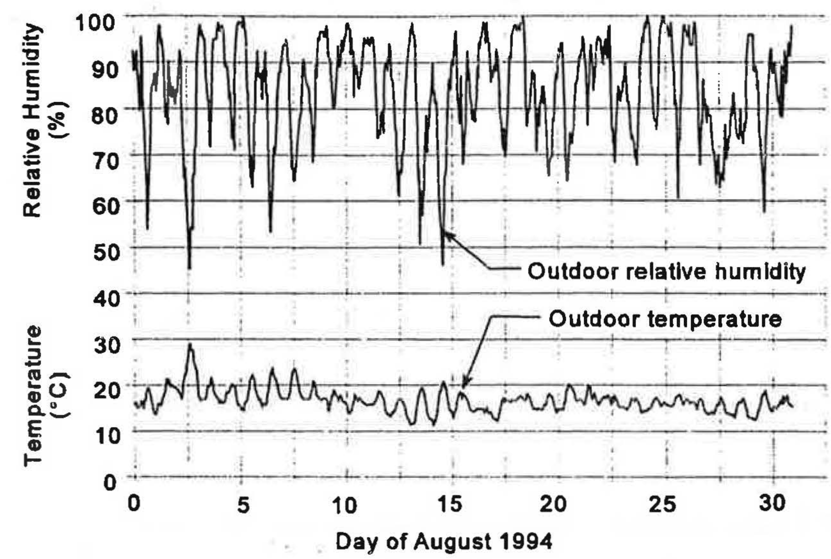


Figure 4 Jersey recorded weather data. See Figure 1 for comparison with UK standard data.

A computer model of a repository room was assembled and building component combinations tested to establish their relative thermal and moisture performance. Sorption isotherms of the form shown in Figure 3 provided the additional moisture data needed for each material. Based on the actual performance feedback from passive cooled buildings, the modelling used real weather sequences instead of simple cyclic data, to provide a more realistic peak design sequence. Recorded Jersey weather data provided importance information on the coincidence of temperature and moisture, particularly given Jersey's higher humidity levels than mainland UK (Figure 4).

The modelling indicated that room environmental conditions could be maintained within the 60±5% relative humidity and 15.5±2.5°C limits for the summer peak design day (Figure 5). An appropriate choice of materials and building form, the outside air infiltration rate, influence of the archive material itself and a level of material moisture content preconditioning were key parameters.

The following sections describes the main results of the computer modelling and the building design parameters provided.

Moisture Migration into Materials

The speed and progress moisture makes as it is absorbed by a typical building material is shown in Figure 6. The moisture movement is considerably slower than that to be

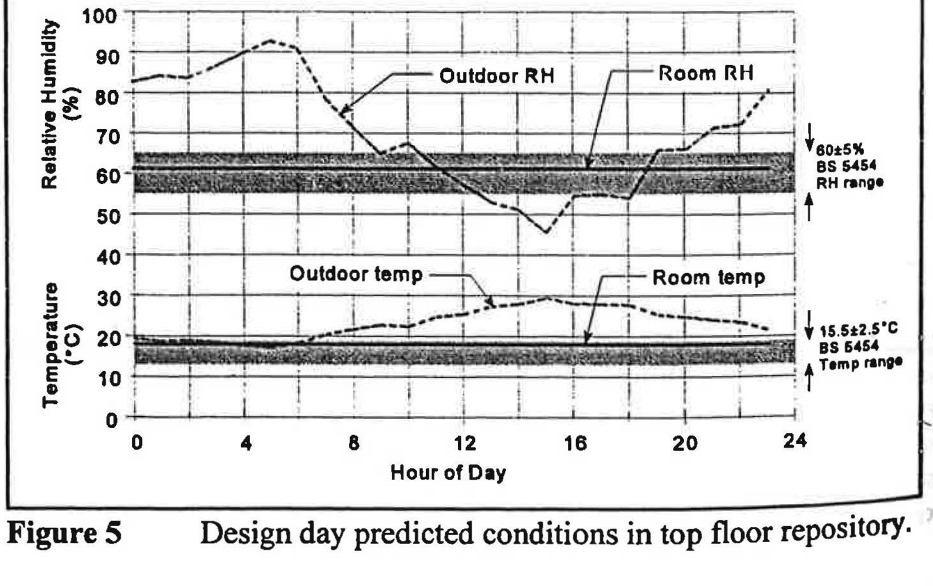


Figure 5 Design day predicted conditions in top floor repository.

expected of absorbed heat. In principle the first 100 mm responds over a timescale measured in the order of many weeks with the subsequent 100 mm responding over many months. On this basis one can see how in heavy weight construction buildings a proportion of summer room air moisture excesses can be absorbed for subsequent emission during winter room air deficiencies, effectively creating an annual flywheel effect. The selected building fabric has the potential to hold summer moisture sufficient to bring the winter air infiltration up into the BS5454 moisture range. In reality this is likely to be supplemented by the moisture held in the archive material itself.

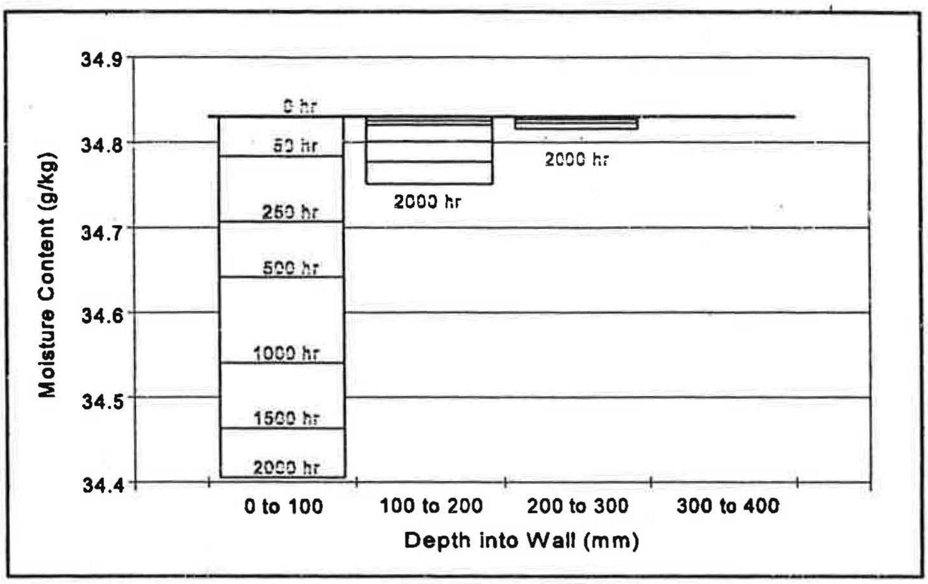


Figure 6 Change in concrete moisture content following a 70% to 60% change in room relative humidity.

Effect of Outside Air Infiltration

Having established the need for a certain amount of moisture absorbing material the next most important factor is the rate of outside air infiltration. The normal infiltration rates to be expected in UK buildings would quickly overwhelm the speed with which the building could absorb or emit moisture (Figure 7). Likewise the outside air change rates to be expected from conventional mechanical ventilation systems would also greatly reduce its effectiveness. After consideration of the airtightness likely to be practical in rooms of the repository form, an average outside infiltration rate of 0.05 air changes per hour (approximately one air change per day) was selected as an optimum. This is comparable to the Swedish building regulations air tightness standard. It involves particular care during construction but maximises the benefit to be gained from the building fabric moisture absorbing ability.

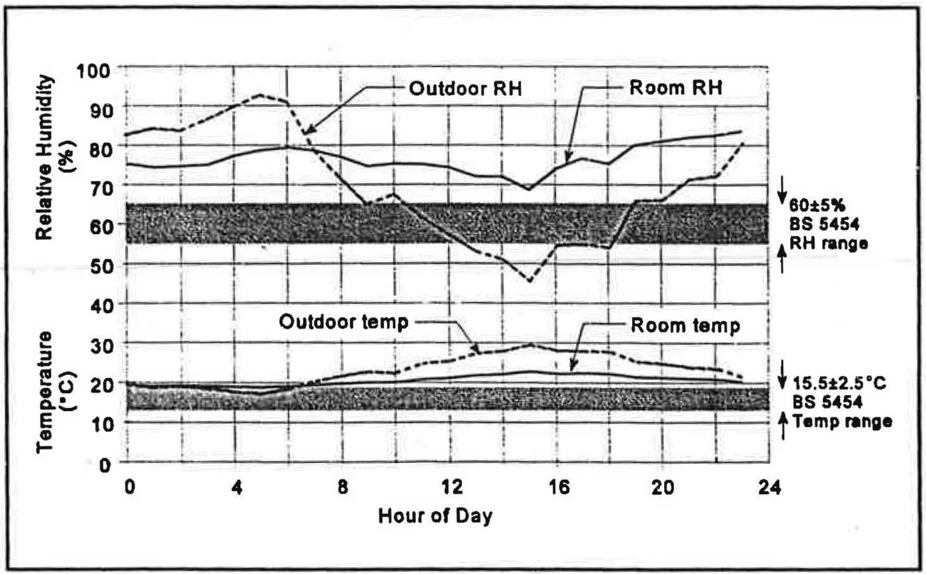


Figure 7 Influence of outside air infiltration (2 air changes per hour).

Ventilation

The moisture and thermal flywheel effect of the building fabric can be used in association with controlled natural ventilation. When the outdoor absolute moisture content is less than inside, introducing ventilation can remove room excess moisture. Likewise the converse can also be used. Similarly the temperature differences between inside and out can be useful, although for this application the moisture needs have priority. With the use of motorized vents (Figure 12) and a software driven Building Management System (BMS), repository and outdoor air temperature and moisture contents are monitored, and automatic ventilation permitted when beneficial. Figure 10 shows the control strategy.

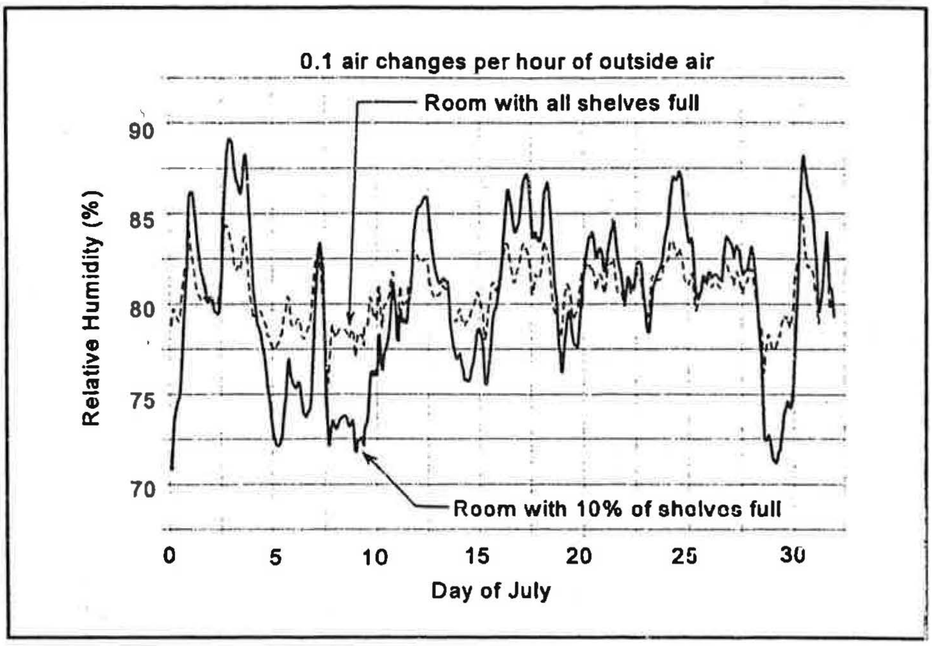


Figure 8 Influence of paper type archive material on room relative humidity

Archive Material Influence

Including a representation of the stored archive material in the computer simulation demonstrates the significant influence the surface area of a paper type material has. The effect on room conditions is considerable (Figure 8). On the daily time scale it appears that the archive material provided the bulk of the moisture stability effect. This is probably largely to do with its large surface area exposed to room air as well as its higher absorption rate. Compared with this, the moisture storage effect of thick building fabric components is likely to be of more influence across the seasons of the year.

Building Design Details

With the perimeter walls 200mm thickness nearest the room being the main flywheel zone

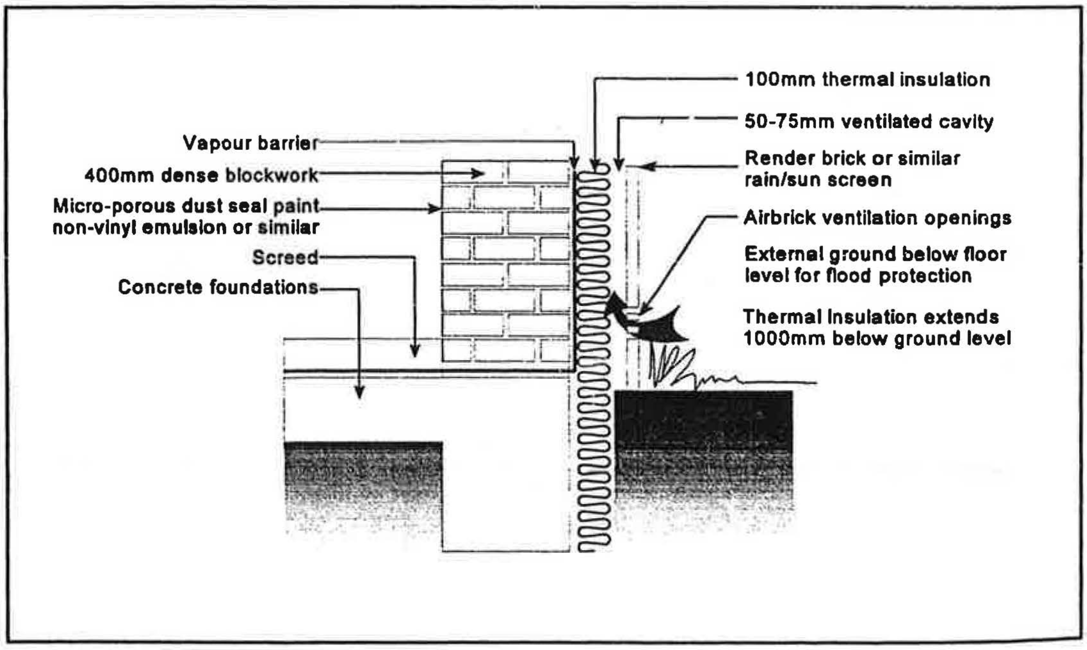
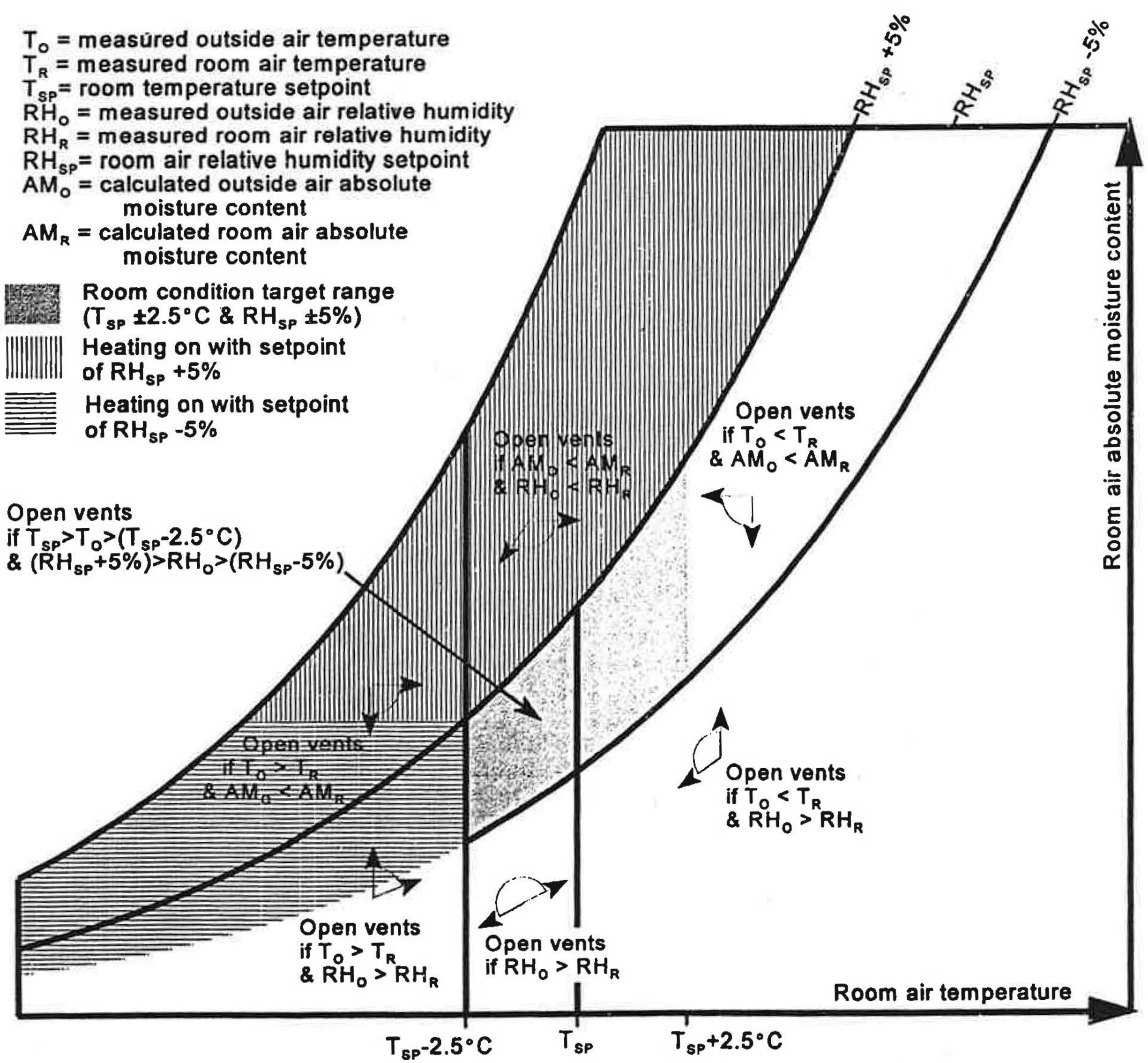


Figure 9 Repository wall detail.



General principles

Moisture control has priority over temperature

Open natural vents when:
- outside rh & temp within room target range
- room moisture high & outside is low (passive dehum)
- room moisture low & outside is high (passive hum)
- room temp high & outside cooler (passive clg)
- room temp low & outside warmer (passive htg)

Close natural vents when:
- room moisture high & outside is higher (room moisture inertia)
- room moisture low & outside is lower (room moisture inertia)
- room temp high & outside is higher (room thermal inertia)
- room temp low & outside is lower (room thermal inertia)

Vent actuators commissioned as open/shut control, but to have modulating ability for future flexibility.

Heating to operate when:
- room temp low & room rh ok
- room rh too high

Summer pre-cooling of room to be provided by controlling to lower temperature half of target room conditions.

10 minute periods between control adjustments

Figure 10 Repository control logic

To gain most from the thermal inertia it was found necessary the protect against south and west facing sun exposure by adding a layer of thermal insulation protected by an outer sun shade wall leaf. This also doubled as rain screen to reduce rain penetration (Figure 10).

The dense concrete blockwork (c1900 kg/m³) produced locally in Jersey provides significant benefits over more conventional blockwork because of its high density enhances both moisture and heat holding ability. It also allows floor slabs to bear directly onto the blockwork so reducing construction drying out shrinkage cracks identified on other archive repositories as a cause of excess outside air infiltration.

The roof thermal performance is enhanced compared to the walls because of its greater exposure to summer sun and cold night sky radiation. 200mm of insulation is provided in lieu of 100mm, together with a fully ventilated roof cavity. To further reduce the longwave radiant heat transfer, an aluminium foil type low emissivity finish is provided to both faces of the cavity (Figure 11).

Window summer heat gain and winter heat loss is significant and is best avoided by not providing windows in the repositories themselves. This also helps to reduces the infiltration so often associated with jointing window frames into walls.

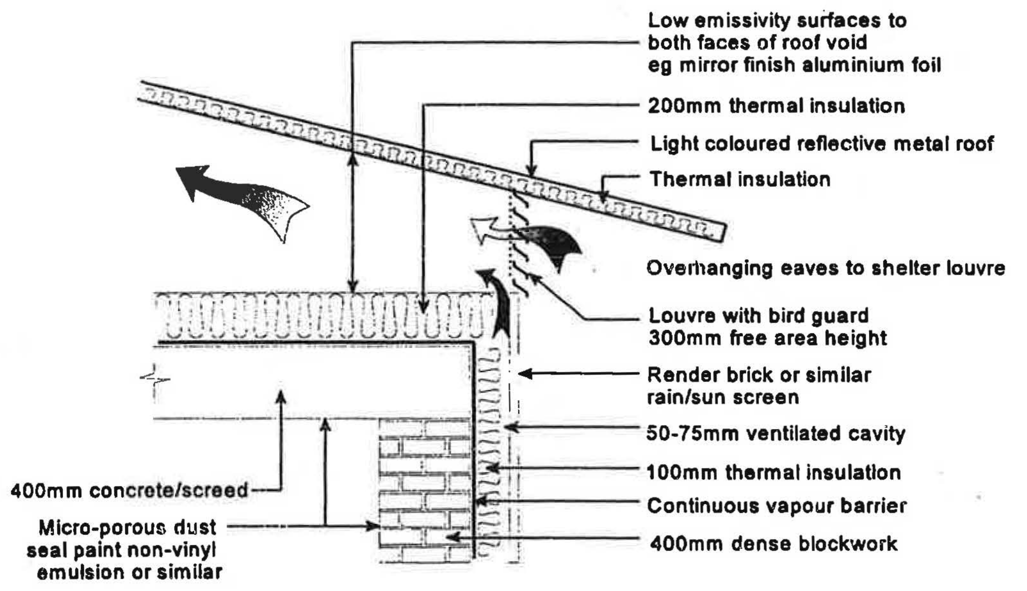


Figure 11 Repository caves detail.

Compared with the annual amount of flywheel moisture movement, the initial construction moisture exceeds it many times over. This must be evaporated and ventilated out from the building materials before the building is sealed. This requires careful construction programming to allow the inner wall leaf and floor slabs to dry out over perhaps a complete summer before installing the vapour barrier, outer wall leaf and doors. This process was followed for the construction of the Ipswich Record Office[19].

A low temperature (approx 40°C) water pipe heat emitter is provided against the repository perimeter walls to give low grade winter background heating effect. Of all the heating options available this minimised the local high temperature, and hence low humidity, effect that most smaller emitters and electric heaters give.

Although the predictions indicate it should not be needed, this background heating can also provides a backup facility for lowering relative humidities during peak summer conditions.

Site construction work on the Jersey Archive Centre is programmed to start November 1997 with completion due in 1999.

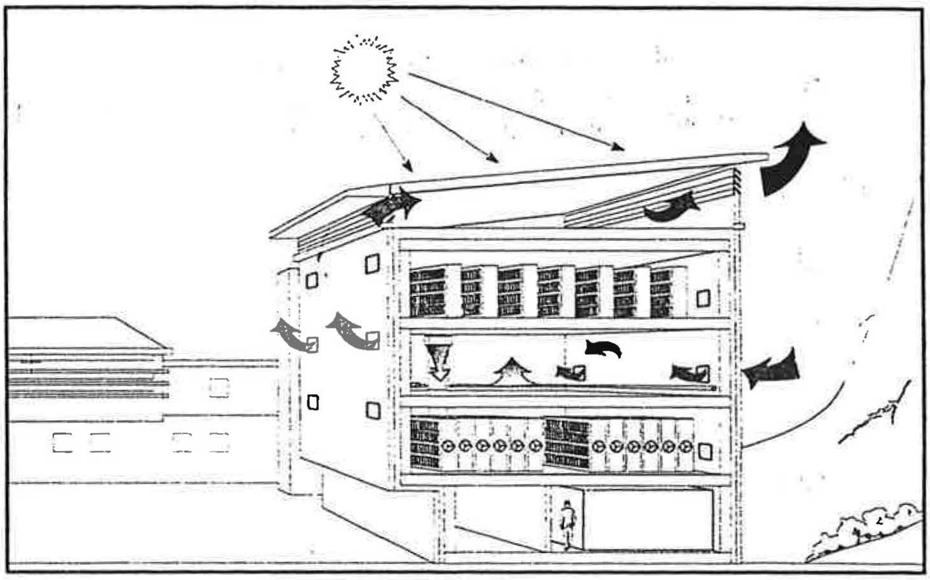


Figure 12 Section through main repository block. Second floor shows actuator driven wall vents, perimeter heating pipe and over-door air curtain (to reduce infiltration).

BS5454 Revision

It is worth noting that BS5454 is currently being reviewed. It is likely its relative humidity recommendations may be lowered by 5% and the temperature limits lifted slightly.

Although these new proposals did not form part of the scope of the study described in this paper, it appears likely that for most of the year they could be easily achieved, particularly after further construction moisture is evaporated out over the first few years. Consequently the BMS control strategy (Figure 10) Has been configured so the revised room set points can be used.

CONCLUSION

The development of a software based analytical tool able to simultaneously model both moisture and thermal dynamic performance, has permitted full use to be made of the building fabric abilities to moderate room temperature and moisture conditions. Not only has this allowed the elimination of the air conditioning normally needed to achieve the ±5% relative humidity limits, but it also significantly reduces the building's capital and running costs, and resource needs.

This design and analytical approach has significance beyond the archive repository building type. It expands the range of buildings for which passive environmental control may be suitable. It also has the potentially to reduce the peak load capacity needed for mechanical environmental solutions, as well as reducing the operating hours these systems need to run.

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ACKNOWLEDGEMENTS

The author acknowledges the active support and assistance provided by Denise Williams, Head of the Jersey Archive Service, David Prichard of architects MacCormac Jamieson Prichard and Paul Harding of architects BDK Design Associates of Jersey.

The Ove Arup & Partners team for the Jersey Archive Centre environmental study was Chris Twinn, Michael Holmes, Sasha Mackler, Peter Young, and Andy Hedges. A particular acknowledgement is given to Peter Young of Arup Research & Development for his work in identifying and reviewing suitable moisture simulation methods and writing the software algorithms.