Victoria & Albert Museum, London
Medieval & Renaissance Galleries: A Passive Approach to Humidity Control

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ABSTRACT

The new Medieval & Renaissance Galleries employ a passive approach to environmental control. The design exploits the massive nature of the building and uses sophisticated control techniques to minimise variations in humidity in the galleries, but uses neither refrigeration nor humidification machinery to achieve its performance.

The challenge was to develop a low energy system that would provide the internal environment demanded by conservation requirements. The strategy developed involves controlling ventilation on moisture content so that it only operates when helping the internal conditions. The control system constantly compares internal and external air moisture content, introducing outside air through the ventilation system only when the effect will be to change internal relative humidity so that it moves closer to its set-point. To verify this control strategy, detailed analysis was carried out to assess the conditions that would occur in the galleries throughout the year. A 30% energy reduction is achieved, compared to similar galleries, through the omission of cooling and humidification.

The passive approach provides a level of control compatible with the conservation requirements of the project, it requires less capital investment in terms of mechanical equipment and leads to reductions in energy usage, running costs and carbon dioxide emissions of the galleries.

INTRODUCTION

During the design stage of the new Medieval & Renaissance Galleries (the project) the decision was taken to adopt a passive approach to environmental control. This paper describes the rationale, analysis and benefits of this approach. The passive approach developed specifically for these galleries has, as far as we are aware, not been tried before, and certainly not on this scale for such an important historical collection.

BACKGROUND

The project, constructed within the existing museum buildings, was much more than a simple refurbishment and involved the carving out and joining together of new spaces from pieces of the museum. Careful coordination of services and architecture was required to achieve the high quality finished product required for an English Heritage Grade One listed building. Services disappear in the final image having been woven through the existing fabric, where possible taking advantage of original chimneys and trenches. Addressing sustainability in the project required the balancing and optimisation of a range of issues that had the potential to create conflicts; artefact conservation and energy use, improving accessibility and conserving the existing listed building. Achieving galleries with stable conditions suitable for displaying artefacts that are sensitive to light and fluctuations in humidity and temperature was further complicated as the galleries are either south facing or have extensive roof glazing. The aim was to make a high quality finished product without sacrificing any aspect of design or performance.

ENVIRONMENTAL CONDITIONS

The environment for conservation of objects needs to consider many factors. This paper is primarily intended to describe the design measures developed for the control of humidity and temperature. Other factors such as lighting and dust filtration are not treated in detail in this article, though the use of daylight to improve the quality of spaces without causing damage to artefacts was also a key consideration.

During the design phase of the project it became clear that the release of an important revision of the V&A environmental guidelines, for conservation of objects in the museum, would open up the opportunity of moving away from the traditional approach for environmental control; reliance on mechanical systems of air conditioning to closely maintain the internal environment within a specified range of conditions. Such systems are energy intensive, require substantial space for machinery and considerable capital investment. Furthermore, in the case of the Medieval and Renaissance Galleries, the installation of such a system of air conditioning would have required expensive alterations to the fabric of the building.

Sensitive objects located within the exhibitions fall into four main categories (table 1).

Table 1. Exhibition categories

B	C	D	E
Collections Sensitive to high humidity (>55%)	Collections Sensitive to low humidity (< 35%)	Collections needing minimum fluctuation	Collections Sensitive to Fluctuations (>10% rh change in one day. Longer term (seasonal) drift is acceptable)
• Metals	• Organic material (shrinkage and cracking) • Photographs	• Reverse painted glass • Amber • Parchment • Salt-laden stone/terracotta/ceramic/plaster • waxes	• Leather • Books • Ivory • Lead • paper • Stretched canvases • Organic materials particularly where there is a large surface area to volume ration. • Jointed furniture. • Composite objects where expansion and contraction rates of each material differ. • Multi-layered decorative surfaces. • Collections conserved with organic materials

The challenge to the design team was to develop a low energy system for environmental control that would provide the internal environment demanded by conservation requirements. Such an approach was found and developed for the project and its strategy and performance are described here.

Figure 1, Target Conditions, illustrates the range of thermodynamic conditions permitted by the revised V&A environmental guidelines and compares them with a more traditional control range associated with mechanical air conditioning systems. The range of conditions permitted by the approach adopted for the project is far wider than that traditionally associated with gallery control.

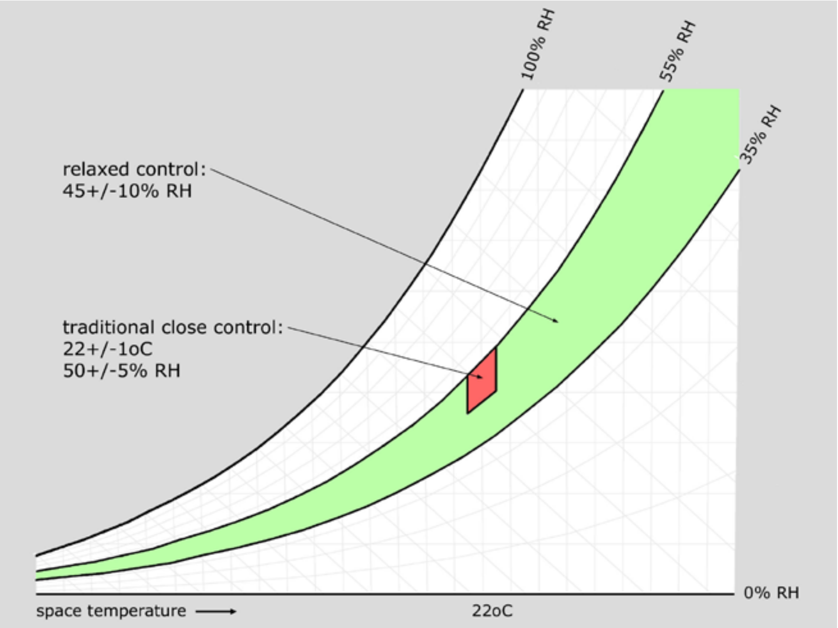

Figure 1. Target conditions

CONTROL STRATEGY

The internal environment of the galleries is subject to many constantly changing influences including, amongst others, internal loads generated by visitors, heat released by electric lighting, infiltration of outside air through the building fabric, and external temperature and humidity variations conducted and convected into the interior. The design strategy developed for stabilising the RH environment involves exploiting the external air condition together with the ventilation and heating of the interior. The galleries are served by a displacement ventilation and perimeter heating system. Examples are given below describing how the control system works in practice. Reference is made to Figure 2, which illustrates the environmental system behaviour depending on interior and exterior conditions.

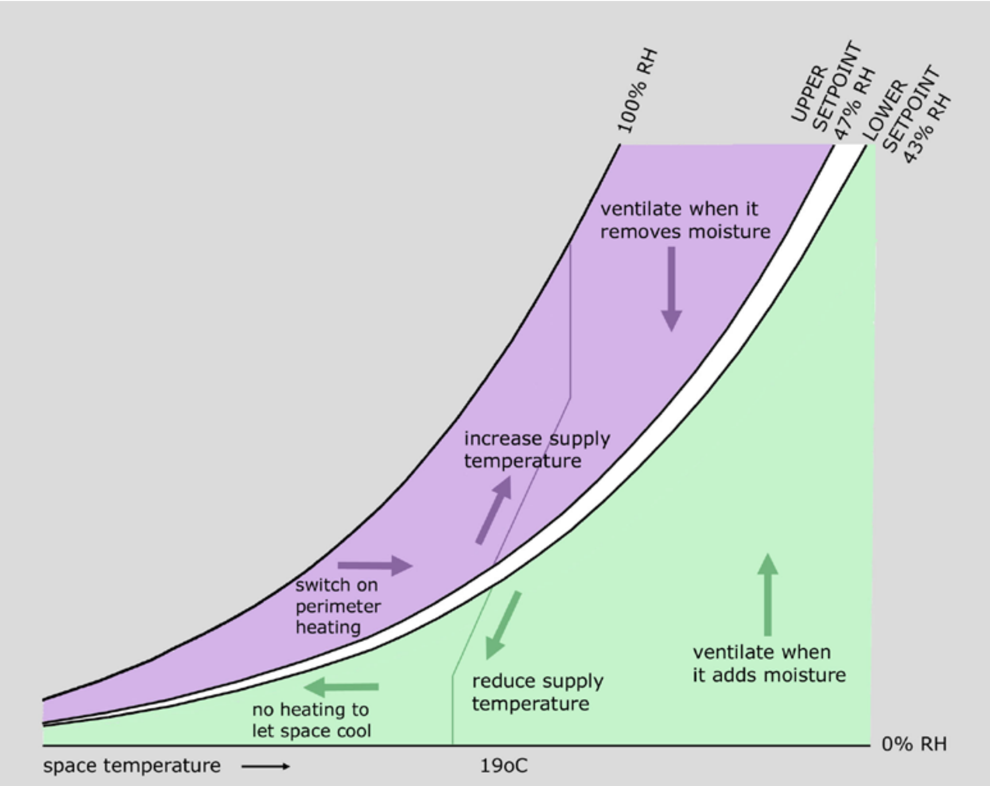

Figure 2. Control Strategy

“Set points” are included here that govern the system behaviour: the upper and lower set points are tight control targets for the environmental control system that allow it to react before the conservation limits are reached.

Case 1: Internal RH above the upper RH set point. When the internal RH is above the upper set point [47%] the system aims to increase the temperature and lower the moisture content in order to bring the RH back to within the set points. Perimeter heating may be switched on to increase temperature and so lower RH. Air is supplied at a set point of 19°C initially, with the set point increased as RH rises; note that, since there is no mechanical cooling of outside air, it will be supplied at whichever is the greater of the set point or the outside air temperature. To lower the moisture content the ventilation system is only switched on when the external moisture content is less than the internal moisture content.

Case 2: Internal RH below the lower RH set point. When the internal RH is below the lower set point [43%] the system operates in reverse and aims to reduce the temperature and increase the moisture content to bring the RH back to within the set points. Ventilation is only run when the external moisture content is higher than the internal moisture content. Perimeter heating is switched off and air is supplied at a set point of 19°C initially, with the set point reduced as the RH falls.

ANALYSIS

To verify this control strategy, detailed analysis was carried out to assess the conditions that would occur in the galleries throughout the year and assess the degree of control that would be achieved (Reference 1). IES Virtual Environment dynamic thermal analysis software was used and in particular the Apache Simulation module. The program performs a detailed analysis of heat transfer and humidity processes and includes the effects of heat storage within the thermal mass of the building. The analysis used the CIBSE Design Summer Year weather data set for London which gives typical hourly values for temperature, moisture content and other climate factors corresponding with a hot summer.

A base case control strategy was analysed for means of comparison, representing the way the galleries may be controlled if comfort rather than conservation was the driving factor. Night time ventilation and humidity control strategies were tested to investigate the improvements that could be made on internal conditions. The key assessment criteria were the occurrence of high and low internal temperatures, high and low internal relative humidity levels, and the rate of change of relative humidity.

<u>Summertime Overheating</u>

The base case showed a relatively small number of hours with extreme temperatures, taken as above 28°C, around 5% of hours or approximately 3 weeks. This compares with around 13% of hours above 28°C for similar existing galleries based on recorded data. Both lighting and occupancy were found to have a significant effect on maximum temperatures and the amount of time where temperatures are too high to be comfortable. Night cooling, achieved by ventilating the space utilising outside air which is at a lower temperature than the internal air, was shown to give a useful reduction in temperatures, with a reduction of 1.6°C off the peak (Figure 3). However it resulted in large temperature swings between day and night which would be undesirable for the conservation of artwork. The humidity control strategy gave increases in internal temperatures because the ventilation system operates less frequently.

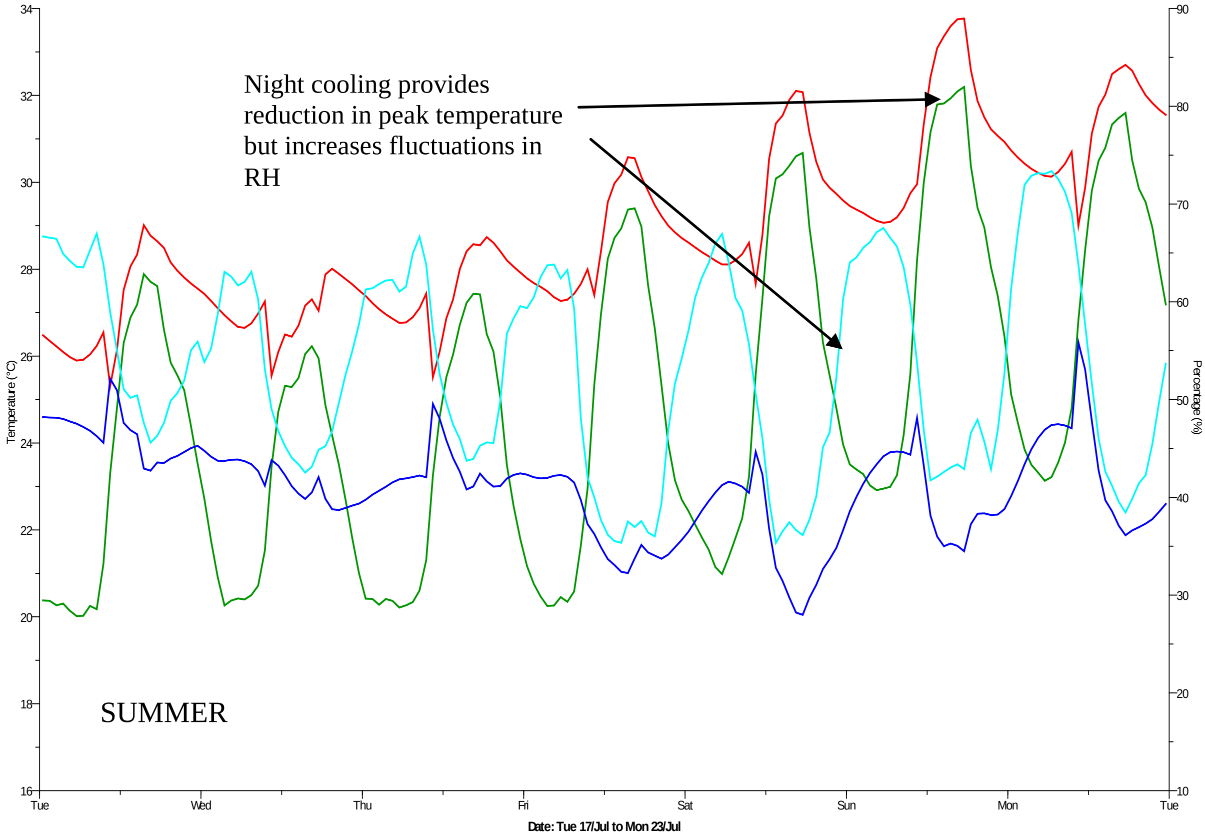

Figure 3. Summer overheating

The graph compares base case (Internal air temperature and relative humidity) with night time ventilation control when internal temp above 20 (Internal air temperature and relative humidity)

High Humidity Control

In the base case high relative humidity levels, greater than 55%, occurred over a small but significant proportion of the year, around 12% of hours; utilising a humidity control strategy helped to reduce the amount of time with high humidity to around 7%. The control strategy is particularly effective in colder weather when heating can be used to reduce relative humidity by increasing the space temperature (Figure 4). High relative humidity levels in summer are difficult to deal with because when internal latent gains and high external moisture content occur at the same time there is no way of reducing the relative humidity, other than raising the space temperature which will make comfort conditions worse and waste energy (Figure 5). Each figure compares base case (Internal air temperature and relative humidity) with humidity control between 45% and 55% (Internal air temperature and relative humidity)

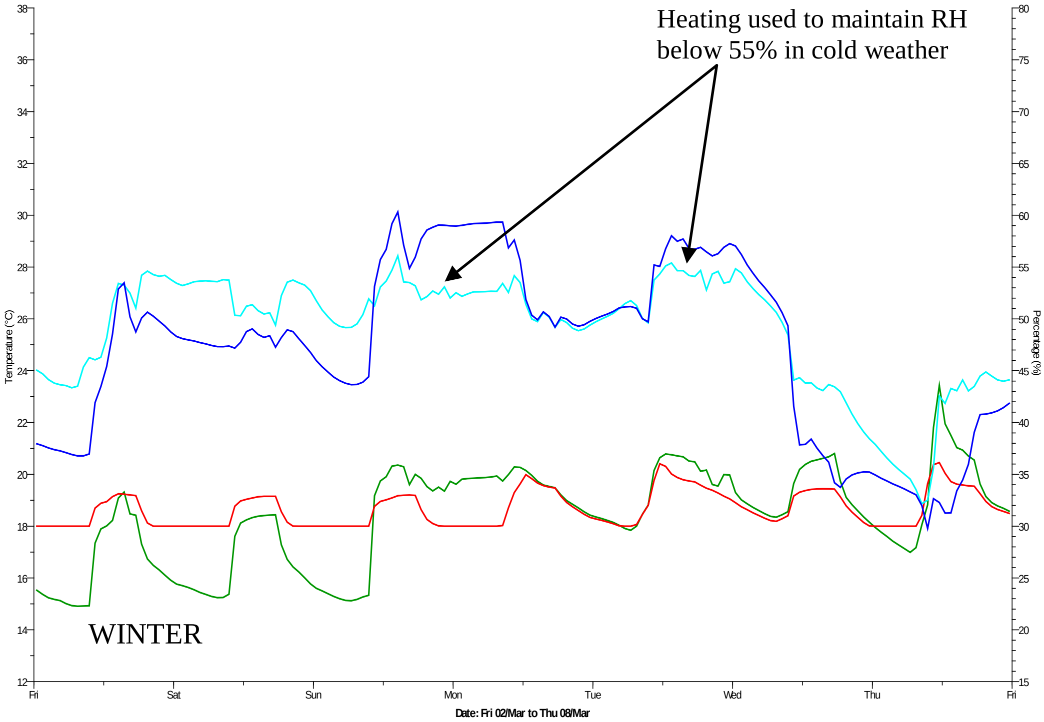

Figure 4. Winter high humidity

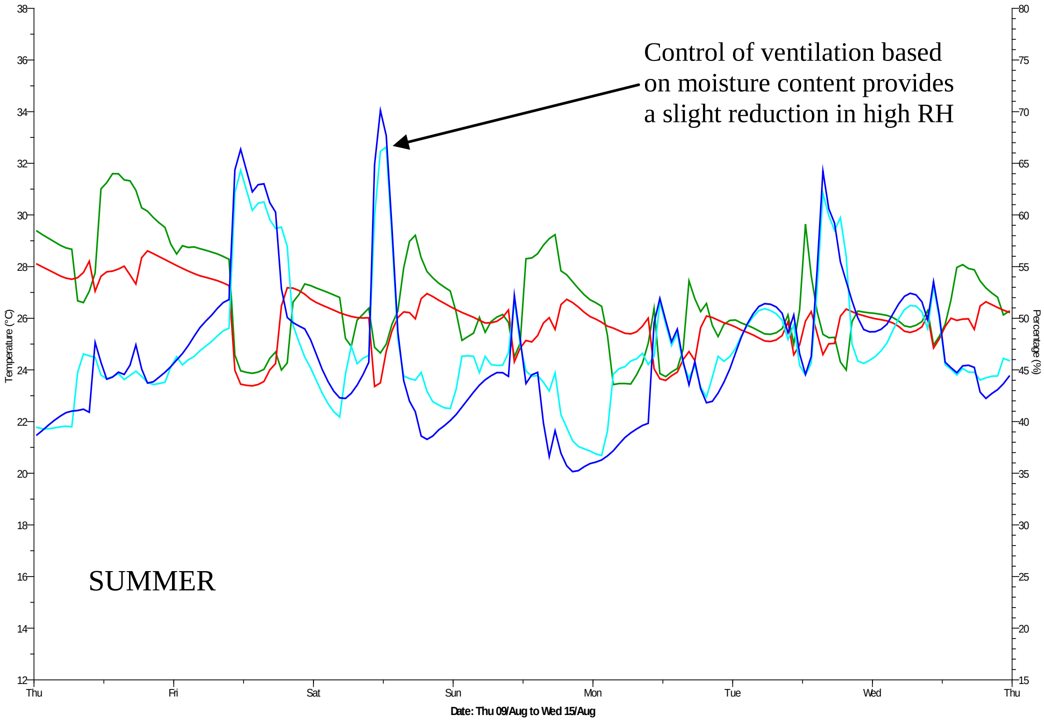

Figure 5. Summer high humidity

Low humidity Control

Low relative humidity levels typically occur in winter when the external moisture content is low and internal temperatures are higher than external temperatures. The analysis showed that low relative humidity can also occur in summer and mid-season due to high space temperatures and moderate moisture content. The base case showed a small but significant proportion, around 14%, of hours below a relative humidity level of 35%. Utilising a humidity control strategy reduced this to around 4.5%. This reduction was achieved by allowing space temperatures to drop in order to maintain higher relative humidity (Figure 6). Space temperatures dropped as low as 13°C but the temperatures during occupied hours are only below 18°C for a relatively small proportion of the time, around 7% of the occupied hours or 3 and a half weeks. This is because solar gain, occupancy load and the lighting load act to heat the space up in the morning. Eliminating low humidity levels entirely is difficult due to the effects of infiltration, whereby dry external air enters the space and reduces the moisture content. The lowest relative humidity typically occurs in the morning when there is a rise in temperature due to solar gain and the space moisture content has dropped overnight due to infiltration.

In Summer ventilation control based on moisture content is the only means of tackling low relative humidity (Figure 7).

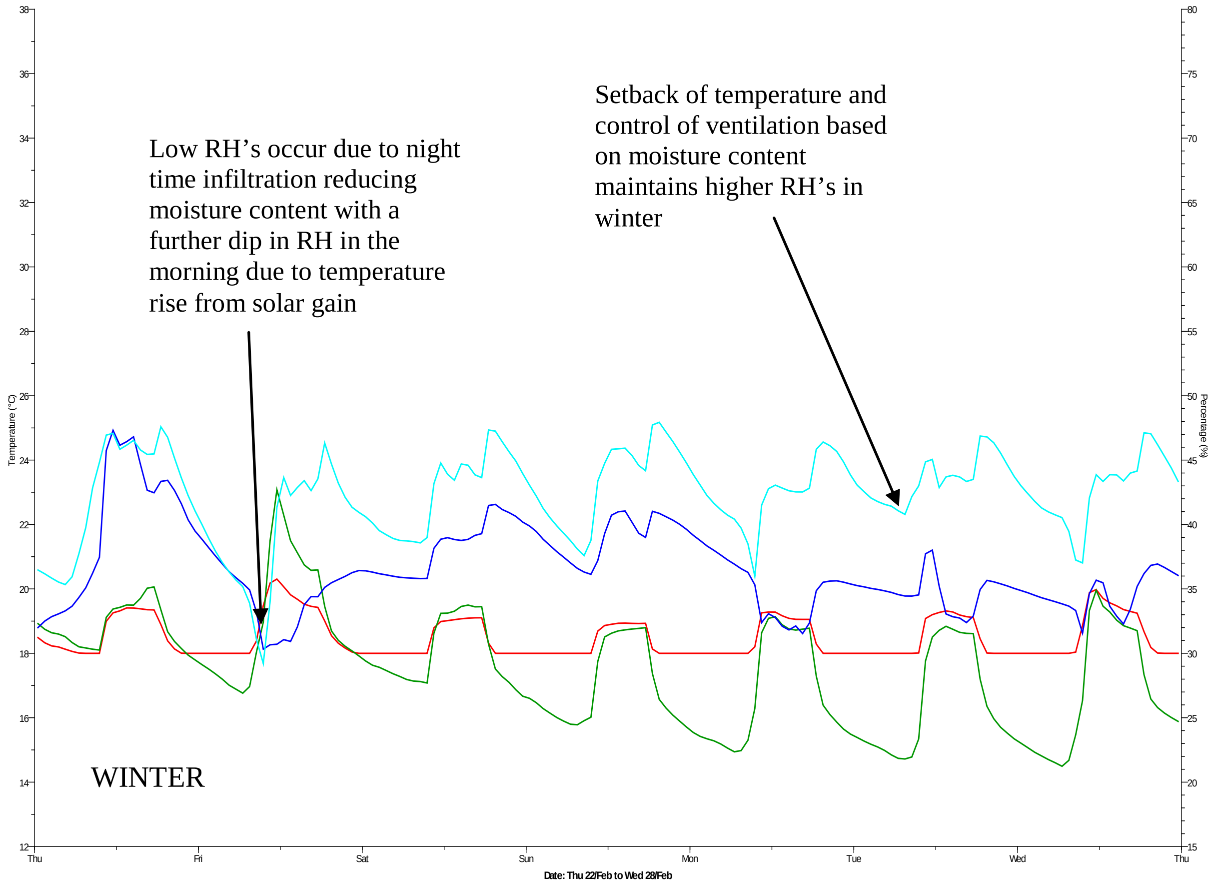

Figure 6. Winter low humidity

The graph compares base case (Internal air temperature and relative humidity) with humidity control between 45% and 55% (Internal air temperature and relative humidity)

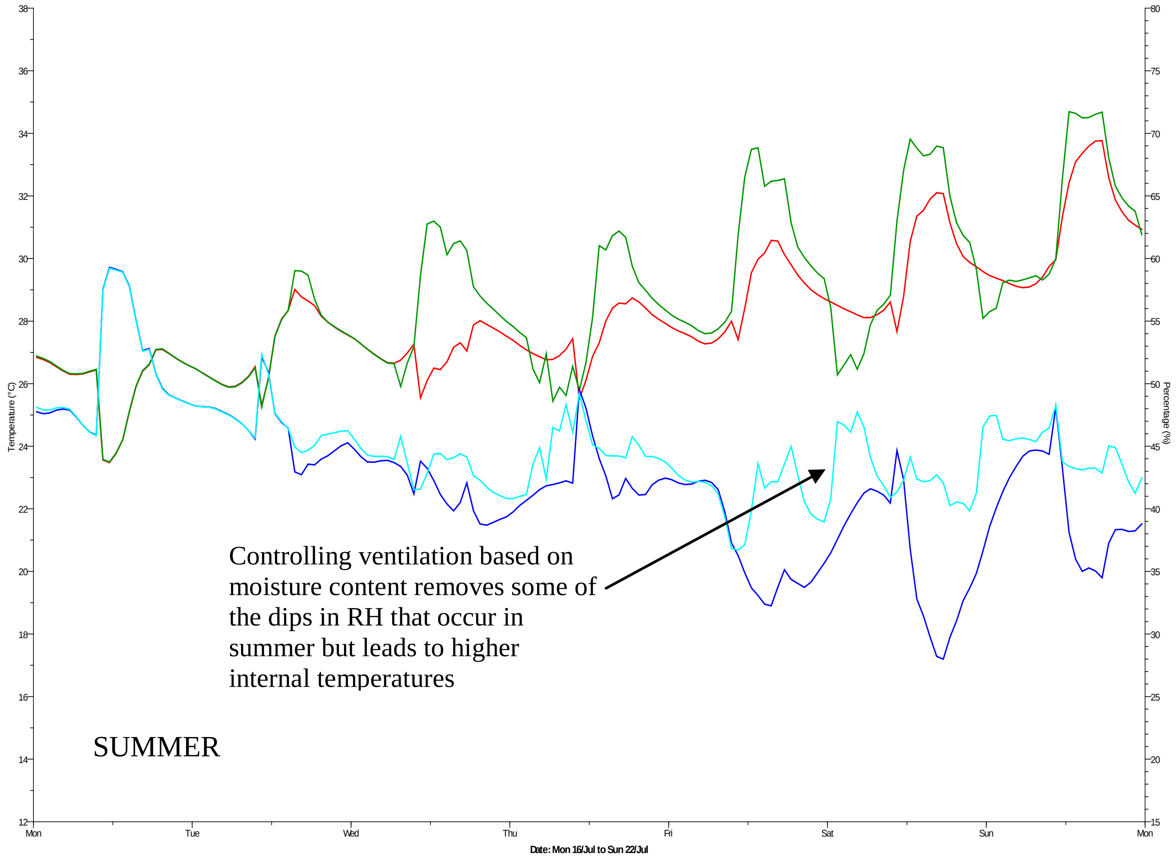

Figure 7 Summer low humidity

The graph compares base case (Internal air temperature and relative humidity) with humidity control between 45% and 55% (Internal air temperature and relative humidity)

Stability of relative humidity

The maximum change in relative humidity occurring in any 24hour period was assessed and for the base case the change in 24hours was found to be greater than 10% for around 56% of the time. The humidity control strategy reduced this to around 50% of the time. The rate of change is largely a function of variations in the external moisture content together with daily internal changes in temperature and moisture content due to heat gains that occur during the day but not at night.

Impact on exhibits

Collections sensitive to high humidity will be exposed to a significant number of hours, around 650, at relative humidity levels above 55% and peak levels could reach up to around 70%.

Collections sensitive to low humidity will be exposed to a significant, but reduced, number of hours, around 400, at relative humidity levels below 35%. There is the possibility of minimal exposure, a few hours a year, to relative humidity levels below 25%.

Collections sensitive to fluctuations in humidity are likely to be exposed to a significant number of humidity fluctuations above the target 10% in 24 hours. Fluctuations are less than this for approximately 70% of the time. Changes of up to 30% in 24 hours may occur infrequently.

Where being exposed to these conditions would be damaging for the objects mitigation measures have been implemented. This includes methods such as casing the objects to provide a more stable environment.

The majority of galleries at the V&A, and all of those with sensitive exhibits, have full air-conditioning systems. In these galleries the number of hours that conditions fall outside of humidity set-points is negligible. In adopting this passive approach to environmental control the V&A are taking a realistic approach to conditions required for artefact conservation.

Summary of analysis

The RH control was found to be very effective with the gallery spaces within the target band for more than 94% of the year, as shown in Figure 8. This performance is comparable with what would typically be achieved by a traditional close control mechanical air conditioning system and, in terms of time spent outside of the desired control band, represents a very good level of control. Extremely low and high RH levels are almost completely avoided with only around 0.7% of the time below 30% RH and no periods above 65%.

In terms of occupant comfort the control strategy does lead to hot and cold periods which could be considered uncomfortable in a conventional space. However for around 68% of the time conditions are maintained at what would generally be considered comfortable temperature levels.

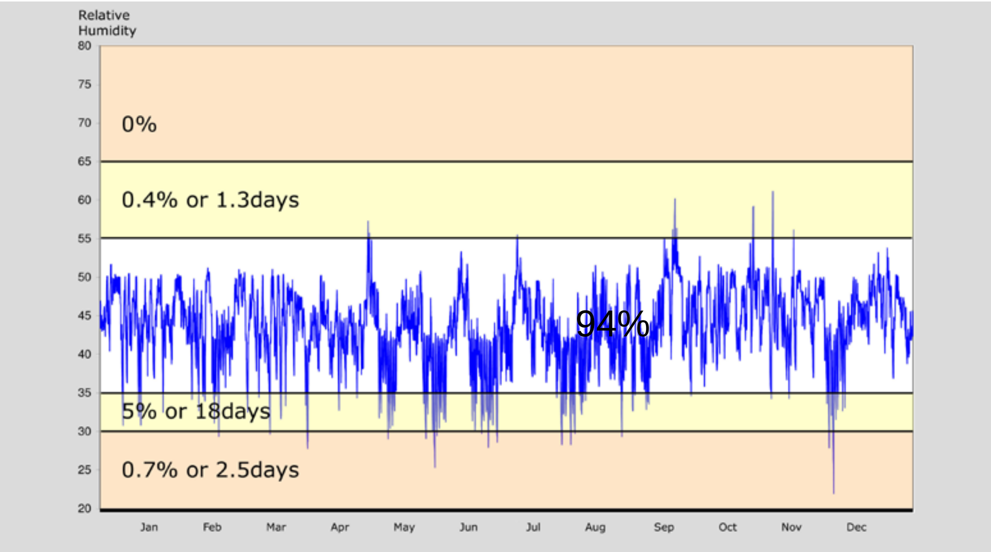

Figure 8. Relative Humidity Level Results

Tests carried out with an alternative weather file, the CIBSE Test Reference Year, achieved even better results with 97% of the time between 35 and 55% RH. The analysis work performed also, crucially, allowed the stability of RH to be investigated in detail. Results from the analysis (Figure 9) showed that there would be a significant number, around 29%, of 24 hour periods where the RH change is greater than 10%, however it also showed that periods with RH changes greater than 20% would be rare, around 1% of all 24 hour periods. This level of performance was accepted by the V&A. In fact, the performance in practice is expected to improve on this since moisture storage and exchanges with the building fabric, which were not part of the dynamic thermal modelling results (they were separately studied by other means) will act to moderate these variations.

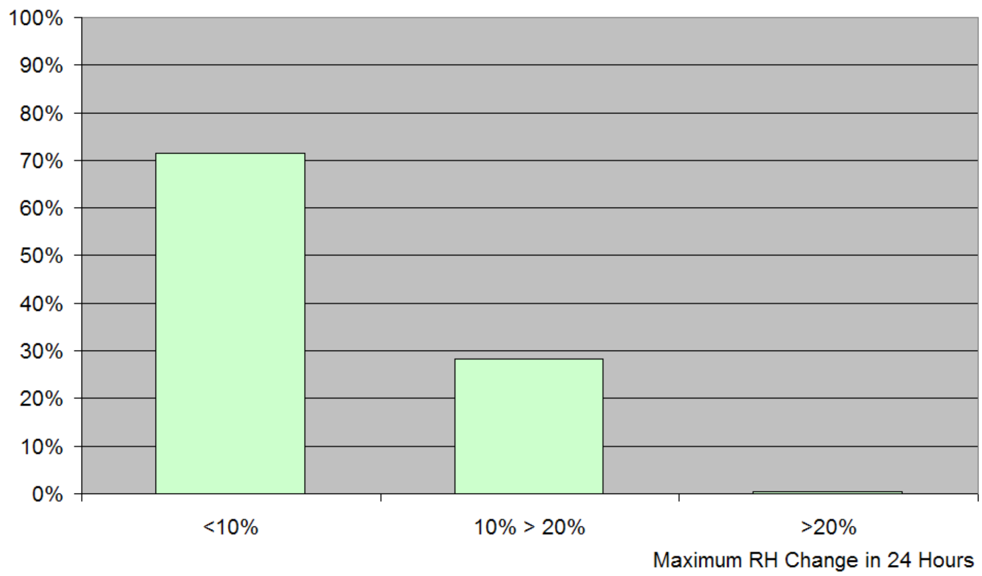

Figure 9. Frequency of Occurrence of Changes in RH within 24 hour Periods

REALITY

Any analysis is limited by the accuracy of the input. In this case there are two key assumptions that impact on control of %RH; air infiltration and occupancy. Sensible assumptions were made in the analysis but neither can expect to be estimated accurately; the air infiltration rate in an historic, leaky building is impossible to know, occupancy levels will change from hour to hour and day to day in a way that cannot be guessed or sensibly modelled. These factors will ensure that reality does not match the analysis. However the analysis should provide an indication of the conditions that will be achieved, particularly in relation to the stability of %RH, even if absolute values may vary considerably.

ENERGY SAVING

Removing air conditioning, particularly cooling and humidification systems, from the project gives a significant reduction in energy use, around 30%, when compared with a traditional close controlled mechanical air conditioning system. This is illustrated in Figure 10.

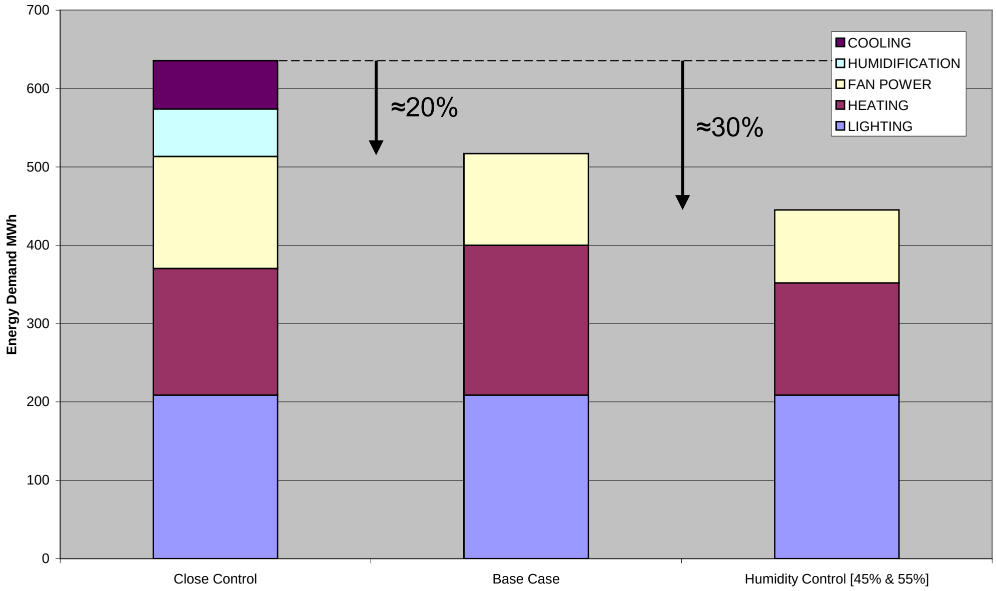

Figure 10. Energy Savings

CONCLUSION

The novel approach to environmental control is based upon a revisionist view of setting environmental design criteria which has been championed by the V&A museum's now departed director Mark Jones and others at forums such as the Bizot Group (References 2, 3 & 4). As such the project is an important test bed for both the museum, and the wider industry, and their movement towards reduced energy use and greater sustainability. It is estimated that the passive control strategy gives around a 25 to 30% energy saving compared to typical museums and galleries.

The passive approach developed provides a level of control compatible with the conservation requirements of the project, it requires less capital investment in terms of mechanical equipment and leads to reductions in energy usage, running costs and carbon dioxide emissions of the galleries.

REFERENCES

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