The indoor climate in historic buildings without mechanical ventilation systems

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ABSTRACT

A study of the microclimate in four rooms in historic buildings reveals the different priorities, and, therefore, the different climatic data, needed by museum conservators, compared with people studying human welfare. In particular, it is important for conservators to know if a low pollutant concentration indoors is due to a clean outdoor climate, a low air exchange rate or pollutant absorbent artwork on the interior walls of the building. Relative humidity is a quality of the indoor climate that the conservator will try to hold within narrower bounds than those considered important to human health. A study of a historic archive shows how the structure of the room, the nature of the stored materials and the custodian's decisions combine to influence the indoor climate. An important result of this study is that the data cannot be usefully interpreted without continuous measurement of the air exchange rate in comparable detail to the measurements we routinely make of temperature, relative humidity and pollution concentration.

INDEX TERMS

Temperature; Humidity; Indoor/outdoor pollution ratio; Natural ventilation; Museum

INTRODUCTION

Many European museums are located in historic buildings. Without mechanical ventilation systems, it is the geographical location, the properties of the building envelope, the building materials, and the use of conventional heating, which determine the inside climate. The climate parameters temperature, relative humidity (RH) and air pollution, are all important in the preservation of cultural heritage objects. The low winter RH in heated buildings can cause mechanical damage to objects, through shrinkage of organic materials. High relative humidity will accelerate chemical deterioration, as will high temperature. The air pollutants SO_2, NO_2, NO_x, or O_3, originating from outdoors, will engage in surface deterioration processes, such as corrosion, or hydrolysis.

In this study, we describe the indoor climate of a historic building in Northern Europe (a room of the National Museum of Denmark), and one in Southern Europe (The Alcazar Castle, Spain). The Alcazar in Segovia is one of Spain's top tourist attractions. The castle was largely reconstructed after a fire in 1862. The walls are of limestone blocks, often over a metre thick, covered with stucco. We have studied two of the public rooms. The 'Cord Room' is on the north side, with large windows and no heating or climate control of any kind. It is largely unfurnished and is a part of the tour circuit rather than a place where visitors linger. The room on the south side is the 'Military Museum'. It is considerably warmer, partly from being on the south side but also because of the showcase lighting. The third room discussed in this article is the 'Military Archive', which is located in a room previously used as a dungeon, on the north side, between the nearly vertical rock of the castle hill and an outer wall of masonry. This room is not open to the public.

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The National Museum of Denmark, in central Copenhagen, is Denmark's primary cultural history museum. It was built as a royal palace in 1744 and has been a museum since 1846. The room we have measured 'Room 134' is a small room built as an alcove off a long corridor with a row of windows. The outer wall is of brick, about 30 cm thick.

Figure 1 The sites. Top left: Alcazar Castle. Top right: Alcazar Military Archive. Bottom left: Alcazar Cord Room. Bottom right: National Museum of Denmark room 134.

THE MEASUREMENTS

We have measured temperature and relative humidity at all four sites. We have also measured concentrations of SO_2, O_3, NO_2 and NO_x in the three public rooms. Data for the outside climate and pollution were obtained from nearby measuring points. Climate data were collected at hourly intervals, as hourly mean values.

SO_2, O_3, NO_2 and NO_x concentrations were measured outdoors and indoors with open-tube diffusive passive samplers (Analyst®), with a sampling period of approximately 1 month.

RESULTS

Air Pollution

Table 1 lists the average indoor/outdoor (I/O) ratios of the pollutants, for the two sites. The averages are calculated from ten successive concentration measurements, performed over 1 year. Table 2 lists the average outdoor pollution concentration for the two sites.

Table 1 Average indoor/outdoor (I/O) pollution ratios in the Alcazar Castle for the 1-year period 20.9.2001 to 17.9.2002, and in the National Museum of Denmark for the 1 year period 17.9.2001 to 16.9.2002

Location	SO_2	O_3	NO_2	NO_x
Military Museum (ALC)	0.21	0.18	0.72	0.69
Cord Room (ALC)	0.25	0.17	0.72	0.52
Room 134 (NMD)	0.18	0.05	0.66	0.81

Table 2 Average air pollution concentrations (μg/m^3) in the Alcazar Castle for the 1 year period 20.9.2001 to 17.9.2002 and the National Museum of Denmark for the 1 year period 17.9.2001 to 16.9.2002

Location	SO_2	O_3	NO_2	NO_x
Alcazar Castle	2.2	84.4	9.7	14.3
National Museum DK	1.9	64.5	33.2	45.0

Temperature and Relative Humidity

The climate measurements in the three public rooms are presented as graphs covering the year from September 2001 to September 2002 (Figures 2–4). The outside values are printed in grey, the inside in black.

The climate in the archive is shown in Figure 5, for a shorter period in April to May 2001, which displays some peculiarities of its microclimate. The bold lines are the inside climate.

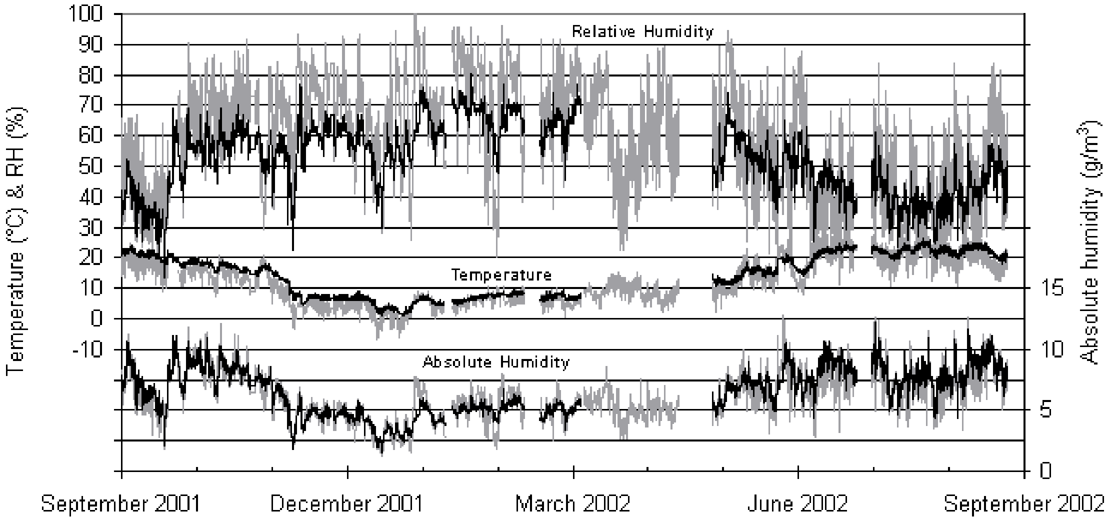

Figure 2 Alcazar Castle, Cord Room.

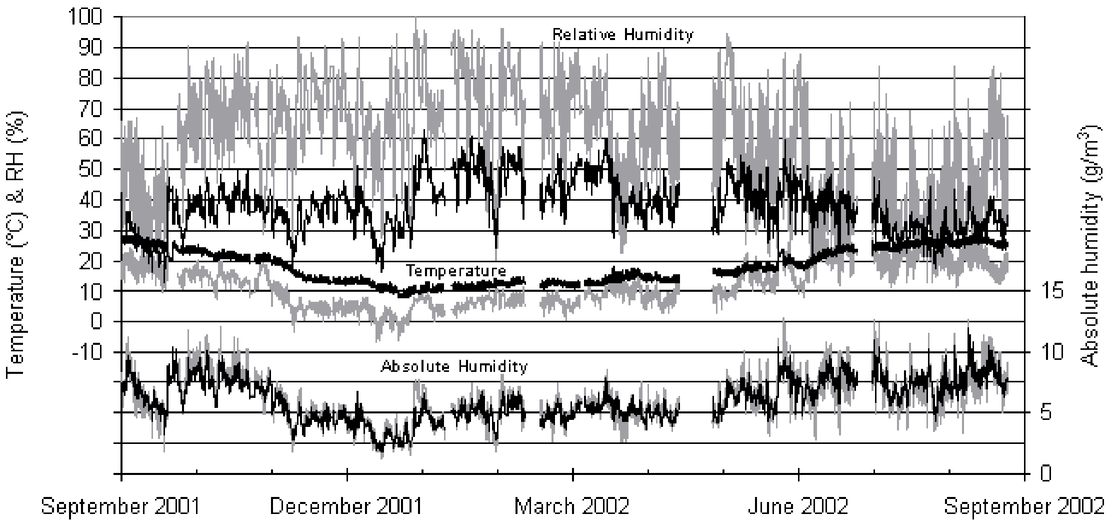

Figure 3 Alcazar Castle, Military Museum.

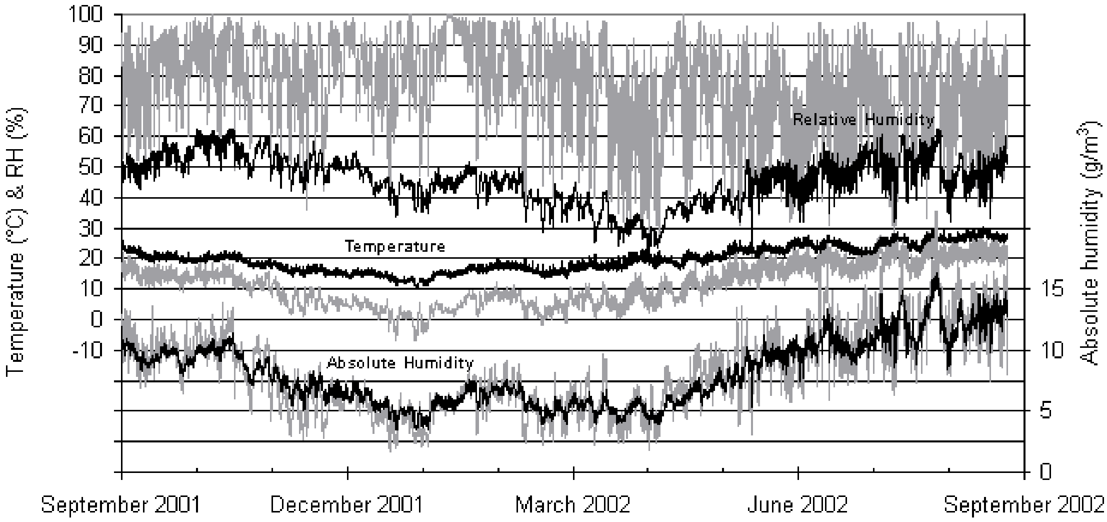

Figure 4 National Museum of Denmark, Room 134.

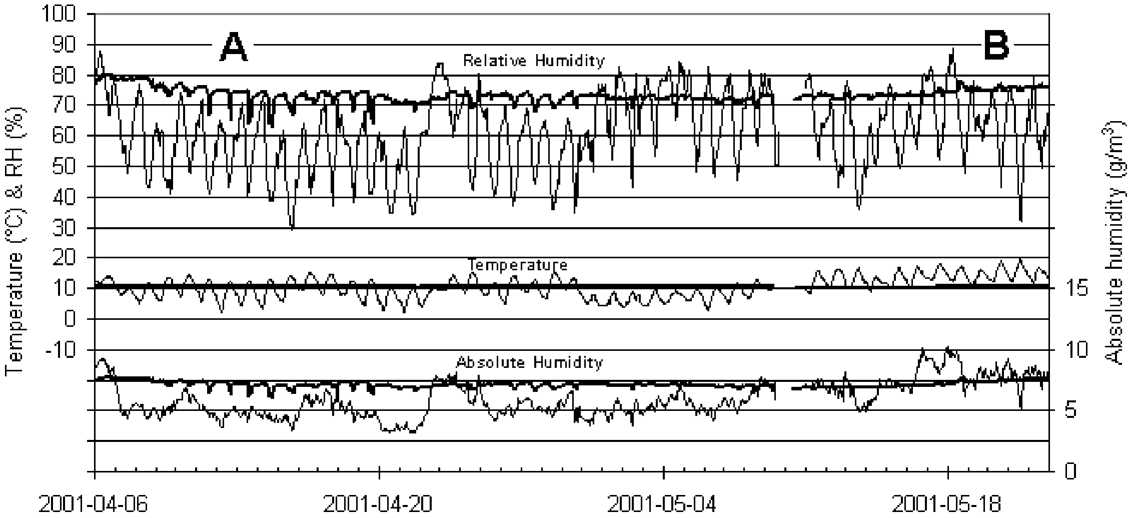

Figure 5 Alcazar Castle, The military archive.

DISCUSSION

Temperature and RH

The most notable feature of the climate in the three public rooms is that the outside and inside water vapour concentrations are nearly equal. The difference between inside and outside RH is, therefore, defined by the temperature difference. The Cord Room, which has no artificial heating, has a RH that follows that outside, but at a slightly lower value because of the slightly higher indoor temperature. The Military Museum and the National Museum room have a RH which is considerably reduced in the cooler months by the heating. In both rooms, the temperature is allowed to drop below the human comfort ideal in winter, but this keeps the RH within the ‘comfort zone’ of the exhibited objects, and the fabric of the buildings.

The reduced daily amplitude of the indoor RH cycle is partly due to the more constant indoor temperature, partly to the limited air exchange and partly to moisture buffering of the interior furnishing. Moisture buffering itself contributes to the temperature stability because of the heat absorbed and released on evaporation and condensation. Without measuring the air exchange rate, we cannot separate the separate contributions of these various stabilizing influences.

The effect of thermal and moisture buffering and air exchange are well illustrated by the shorter climate sequence from the military archive (Figure 5). The temperature moves very slowly towards the running average of the outside temperature, while the indoor water vapour concentration also moves slowly towards the outside value, heavily buffered by water exchange with the archived materials, mostly paper. The effect of ventilation rate is illustrated by the sharp downward pointing peaks in the indoor RH and water vapour concentration at point 'A' on the graph. These sudden changes are caused by the window being opened during office hours. At point A, this initiative is beneficial because it accelerates the trend towards a lower RH. At point 'B', the upward pointing spikes in the RH record reveal that moister outside air leaks in. This is not beneficial at all. The window should ideally be opened only when the outside water vapour concentration is lower than that inside.

Air Pollution

The urban National Museum is exposed to three times higher levels of nitrogen oxides than the semi-rural Alcazar. In contrast, there is 30% more ozone at the Spanish site than at the Danish site. At both places, SO_2 concentrations are low. Without mechanical filtration systems, the buildings still provide protection. This is due to the natural adsorption on surfaces, during the pollutants' journey towards the galleries. SO_2 and O_3 were reduced at both sites, with an inside/outside ratio (I/O) in the order of 0.05–0.25, while NO_2 and NO_x were less reduced (I/O between 0.52 and 0.81). The pollution data, which were collected from three of the four localities, cannot be interpreted unambiguously. There is the typical pattern of relatively high ratio of indoor to outdoor concentration of oxides of nitrogen and a much lower ratio for sulphur dioxide and ozone. The low values indoors can be due to slow air exchange, or to absorbent surfaces in the room. From the point of view of human health, a low concentration is a good thing; from the point of view of a museum conservator a low concentration could indicate fast reaction between a vigorous flow of contaminated air and the absorbent and reactive surfaces of irreplaceable museum objects.

CONCLUSION

The three locations within the Alcazar Castle are climatically more diverse than the difference between the Alcazar Military Museum and the room in the National Museum of Denmark, 2000 km to the north.

The microclimate in a room is controlled by the outside temperature and moisture concentration, the thermal inertia of the building, the moisture buffering by furniture and the ventilation rate.

The I/O pollution ratios give us a hint of the ventilation rate, but the variable absorption of surfaces prevents us using pollutants as indicators of ventilation rate. We cannot establish whether the decrease of pollutants indoor is due to the shielding effect of the building envelope, or due to adsorption on inner surfaces. As the absolute humidity is equal outdoors and indoors for Alcazar's Cord Room, Military Museum, and at the Danish National Museum, this suggests that the air exchange rate is relatively high. But if the exchange rate is high, the lower indoor pollution concentrations must mainly be due to removal of pollutants by surface reactions. Deliberate use of the air pollution adsorption potential of inner surfaces in rooms, is an interesting approach to air quality control. However, in the case where the walls are covered with artworks, it would be better to block the air pollutants before they ever reach the materials surface, by retarding the flux of pollutants into the gallery.

ACKNOWLEDGEMENTS

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REFERENCE

MIMIC project website: http://iaq.dk/mimic.