TARGET MICROCLIMATE FOR PRESERVATION DERIVED FROM PAST INDOOR CONDITIONS

ŁUKASZ BRATASZ, DARIO CAMUFFO AND ROMAN KOZŁOWSKI

ABSTRACT

A novel approach is proposed to establishing target indoor microclimates suitable for the preservation of organic materials susceptible to fracture and deformation, such as wood and paints. It assumes that it is impossible to establish a priori the best RH level for the conservation of mixed collections containing organic materials as over many decades they have adapted to a particular indoor environment within which they have been preserved. Therefore, the proposed strategy focuses on replicating the past average levels of RH and specifies bands of tolerable short-term fluctuations superimposed on these average levels. It is proposed to cut off 16 % of the largest, most risky fluctuations, which corresponds to one standard deviation in the distribution of the fluctuation amplitudes. Further, it is proposed to reduce the width of the target band of tolerable fluctuations by taking into account how much the fluctuations depart from the average seasonal RH level. The procedure is illustrated by three case studies of historic churches representative of different geographical locations, construction materials and patterns of use.

INTRODUCTION

A novel approach is proposed to establishing target indoor microclimates for organic materials susceptible to fracture and deformation, such as wood and paints. Both temperature (T) and relative humidity (RH) are key control variables to ensure their proper conservation. For the sake of brevity, the discussion in this paper is limited to RH, but the approach would be the same for T. Changes in RH induce changes in the equilibrium moisture content (EMC) as the organic materials absorb and release moisture to adapt to the continually changing environmental conditions. The variations in EMC produce dimensional changes which may lead to high levels of stress and mechanical damage. Furthermore, too high or too low RH levels represent rapidly growing risks of various types, such as biological attack, rapid corrosion or low humidity desiccation and fracture of fragile materials.

The conventional museum practice is to recommend a continuous control of RH to as constant a level as possible. The optimum RH set-point is usually specified within the 50-60% range. The National Trust Specifications for Conservation Climate Control [1] are a well known example. An alternative approach presented in this study assumes that it is impossible to establish a priori the best RH level for the conservation of mixed collections of organic moisture-absorbing materials, as over many decades they have adapted to a particular indoor environment within which they have been preserved. Such adaptation might have involved a certain degree of permanent change, as deformation or fracturing, releasing internal tensions in the materials generated by the variations of RH. A compression set of wood, demonstrated by Mecklenburg et al. [2] is a case in point. Such capacity of the organic materials to adapt can be termed a memory of the past microclimate. If this particular past microclimate is suddenly changed, a climatic shock can occur leading to damage, even though the new conditions may be considered better for preservation.

Therefore the proposed strategy focuses on specifying optimum target microclimates which would replicate the past average level of RH if this proved not harmful in terms of mould growth, for the high humidity region, or desiccation and mechanical failure for dry environments. Further, the target band of tolerable RH fluctuations will be specified. Specifying tolerable RH fluctuations is important, as gradual small changes in the museum objects lead to damage at the micro level – a fatigue of historic materials - well before any visual damage appears. Such continuous accumulation of slight changes, rather than infrequent serious damaging events, accounts for much of the deterioration processes observed in museums. Eliminating fluctuations exceeding some critical amplitude would restrict the fatigue.

Given the individual differences between microclimates, which depend on the characteristics of buildings and the specific climate outdoors, target indoor microclimates based on past conditions have been so far recommended in general and descriptive terms. The Italian Standard UNI [3] on

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indoor environments, which stresses the need to replicate the long-term local climate and to keep the T and RH variations to a minimum, has been a good case in point. This study is proposing analysis of the past indoor T and RH data to predict the target microclimate in terms of average values and fluctuation band. The past microclimatic data for a building or a room should be available for a period of at least one year. The proposed analysis can be universally applied both to natural microclimates in buildings with no heating or forced ventilation and to artificial microclimates in buildings where, for instance, heating systems have been operated.

Results

The procedure is illustrated by three case studies of historic churches.

Case study 1

The wooden church of Saint Michael Archangel, Dębno, Poland. This building is unheated – a relatively open structure with an indoor climate strongly governed by the outdoor weather due to a high rate of air exchange between inside and outside

Figure 1 shows plots of indoor RH for the Dębno church. The RH data (the jagged blue line) were sampled every fifteen minutes for one year, beginning in June and ending in May the subsequent year. The sampled data were smoothed by calculating the running average in the two adjacent one month periods (red line) to obtain the seasonal variability. The yearly average is 71%. An increase in winter up to 80% and a decrease in warm period down to 55% are observed.

The seasonal variability is quite considerable when it is compared with the museum standards for indoor climate stability, exemplified in this paper by the National Trust (NT) specifications. The upward deviation observed exceeds the allowable increase by 7%, specified as the first alarm level by NT. Moreover, in absolute terms, the maximum seasonal deviation of RH in the church attains the upper limit of 80% above which attention should be paid to the risk of mould growth. The downward deviations during the spells of dry weather in spring or summer come close to the decrease by 18%, specified as the second alarm level by NT.

The short-term RH fluctuations, superimposed on the seasonal variations, are shown in Figure 2. They were extracted from the raw RH data by subtracting

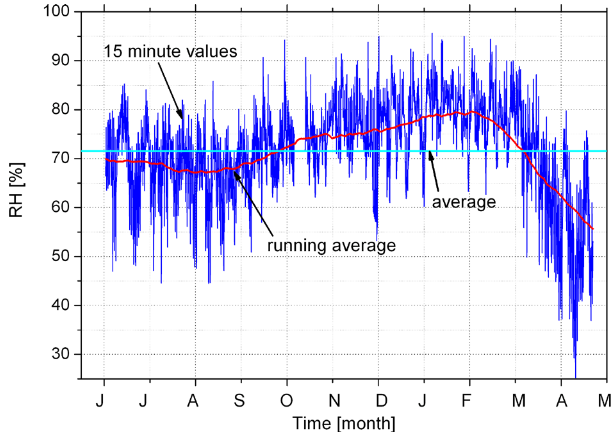

Figure 1. Dębno wooden church. Indoor RH during one year measured at fifteen minute intervals (the jagged blue line) and a general seasonal RH tendency (smooth red line) obtained by calculating the two-month running average of the readings. The yearly average is marked by a horizontal line.

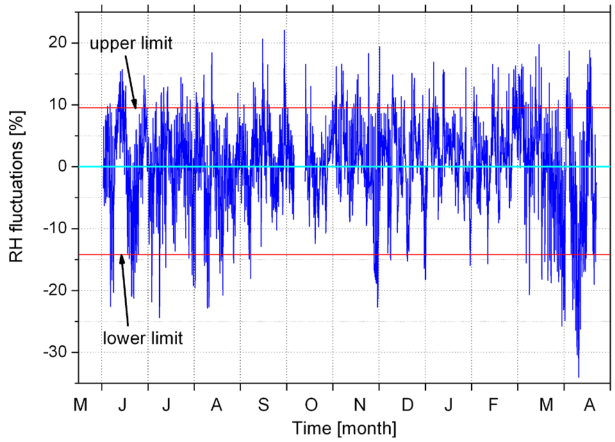

Figure 2. Dębno wooden church. The short-term variations of RH around the general seasonal tendency.

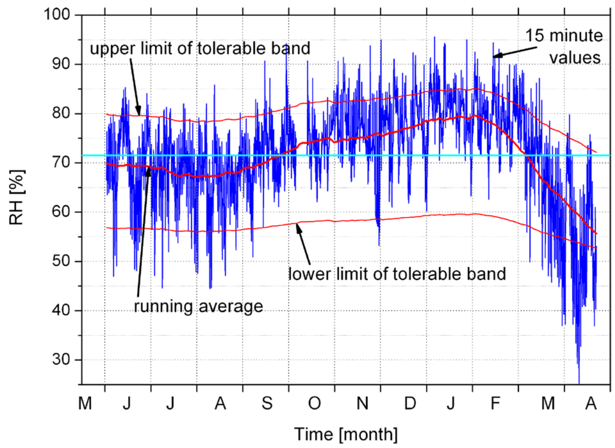

Figure 3. Dębno wooden church - target band of tolerable fluctuations (marked by two red lines) compared to the observed variation in RH.

the running average from the instantaneous RH (blue line minus red line in Figure 1). The lower and upper limits of the tolerable band, marked as red lines, correspond to the 8th and the 92nd percentiles of the fluctuations, respectively. This means that 16 % of the largest, most risky fluctuations are cut off, which corresponds to one standard deviation in the distribution of the fluctuation amplitudes. As a result, the target band is based on the 84% of fluctuations recorded in the past. The choice of the target band width is arbitrary, but it corresponds to a common statistical reference.

The analysis of the data can be further refined by assuming that not only the amplitude of each fluctuation is significant, but also a particular average RH value on which the fluctuation is centred. A fluctuation centred around the yearly average, in this example 71%, may be assumed less damaging than the same fluctuation centred around a much lower (summer period) or higher (winter period) seasonal RH. In reality, the actual risk is due to the combined effect of the fluctuation and the seasonal RH level at the moment of the fluctuation. To account for the actual risk the fluctuations can lead to, the target band should be reduced when the conditions depart from the yearly average. In this procedure, the maximum allowable seasonal departure from the yearly average RH was assumed to be 20% upwards and downwards, following approximately the second alarm levels recommended by NT. Accordingly, the width of the RH fluctuation band was reduced by a weighting factor that changed linearly between 1, when the seasonal value was equal to the yearly average, and 0 when the seasonal value departed from the yearly average by 20% or more. The final specifications of the target microclimate for the church are shown in Figure 3.

After having introduced this further correction, the target band of tolerable fluctuations calculated from the RH data has a changing, asymmetrical width around the running average. The band becomes narrower when the seasonal RH level comes close to the upper or lower risky levels of 80 and 55% respectively.

Case study 2

The Basilica S. Maria Maggiore, Rome. A large, unheated, brick church

Figure 4 shows plots of indoor RH recorded in the basilica. The yearly average is slightly above 60% without marked seasonality. The running average oscillates irregularly in a very narrow range from 55 to 65%.

The analysis of the short-term RH fluctuations, superimposed on the seasonal variations, is shown in Figures 5 and 6. The data processing was identical as for case study 1.

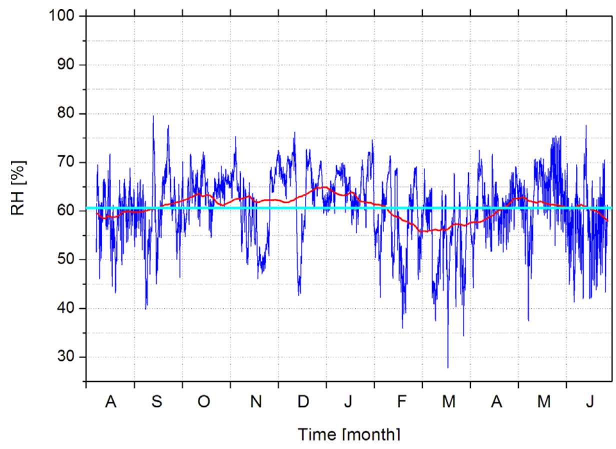

Figure 4. S. Maria Maggiore, Rome. Indoor RH during one year (blue line), with the average RH as described in figure 1.

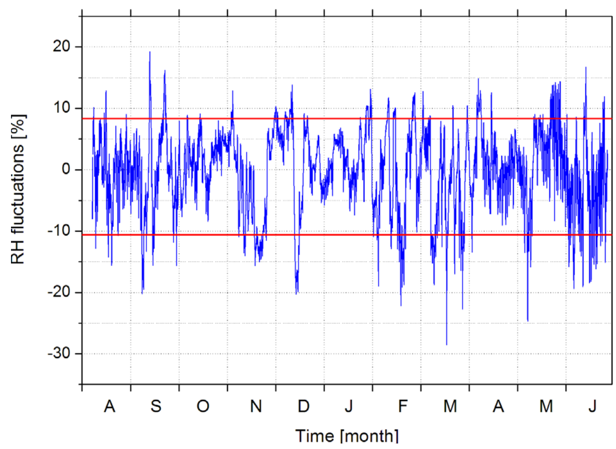

Figure 5. S. Maria Maggiore, Rome. Short-term variations of RH around the general seasonal tendency.

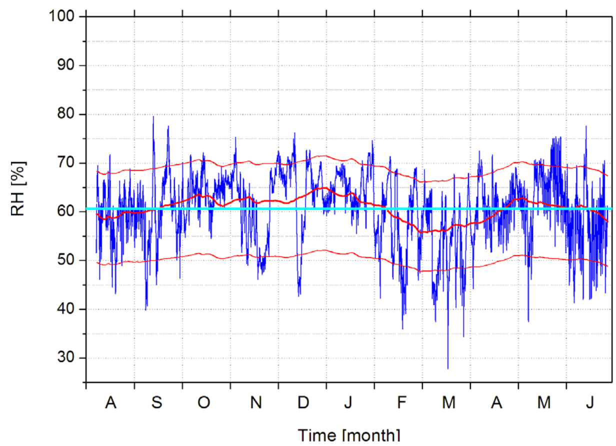

Figure 6. S. Maria Maggiore, Rome. Target band of tolerable fluctuations (marked by two red lines) compared to the RH variations observed.

Case study 3

The stone church of Santa Maria Maddalena, Rocca Pietore, Italian Alps. In winter, intermittent warm-air heating for liturgical services.

Figure 7 shows a plot of RH in the Rocca Pietore stone church. The yearly average RH is 55%. The long-term RH variability shows a clear seasonal character. The average RH decreases by approximately 10% into the range between 40-50% in winter in contrast to 60-70% during the warm period. The heating episodes are visible as deep drops in the RH record. It should be noted that the seasonal RH cycle shows an opposite tendency when compared to the wooden unheated church in Dębno (case study 1). The decrease of the general RH level in winter is caused by heating.

The seasonal variability illustrated by the smoothed red line of Figure 9 can be compared again with the National Trust specifications. Both the upward and downward deviations from the yearly average of 55% only slightly exceed the 7% change considered as the first alarm level by NT. Moreover, the seasonal upward RH variation remains well below the upper limit of 80% above which the risk of mould growth appears.

The short-term fluctuations, superimposed on the seasonal variations, are shown in Figure 8. The lower and upper cut-off levels, the 8th and 92nd percentile respectively, are shown as red lines. They were calculated from climatic data of the warm periods only, during which the indoor climate can be considered natural, not disturbed by the heating episodes. The target band reduced by a weight factor, as in the previous case studies, is compared with the observed RH variations in Figure 9. It is obvious that the major problem to the climate stability in the church is the heating system operated sporadically, which generates short-term RH drops hugely exceeding the lower limit of the target band of tolerable RH variations derived from the natural climate of the church. Improvement in the heating system is the principal measure necessary to stabilise the climatic conditions.

The analysis of the past microclimates in the three churches studied is summarised in Figure 10. It places the target bands of tolerable RH fluctuations for the three historic churches on the scale of the average seasonal RH level from which the fluctuation starts. It can be noticed that the band width for the two Italian churches, which are relatively enclosed brick and stone structures, are similar and smaller than the band width for the wooden church, a relatively open structure more susceptible to the outdoor climatic variations. It is also obvious that the domain of tolerable RH fluctuations for the Dębno church is considerably shifted to a high RH region,

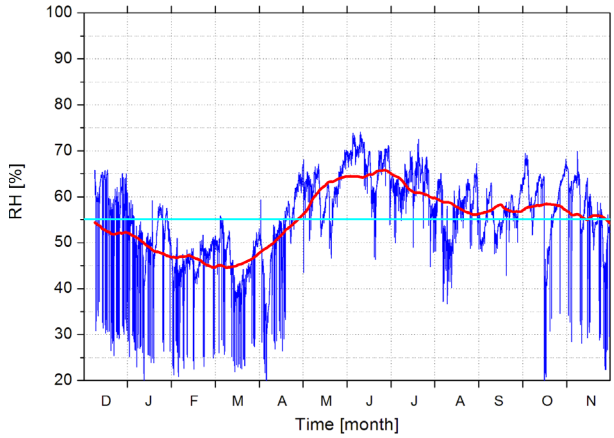

Figure 7. Rocca Pietore church. Indoor RH during one year , with average RH as explained in figure 1.

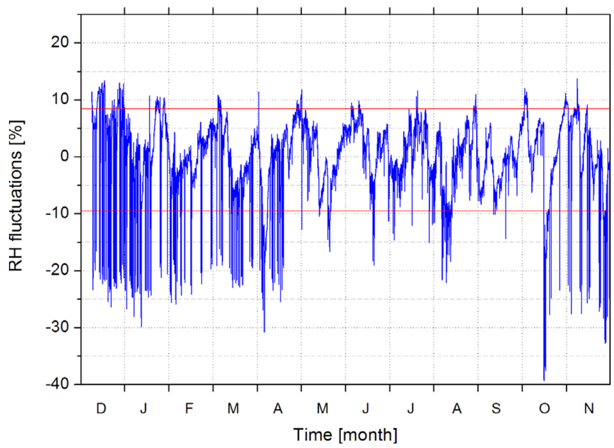

Figure 8. Rocca Pietore church. Short-term variations of RH around the general seasonal tendency.

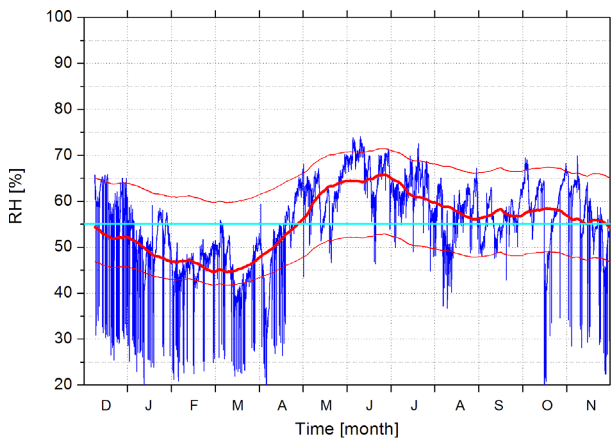

Figure 9. Rocca Pietore church. Target band of tolerable fluctuations (marked by two red lines) compared to the RH variations observed.

due to the much more humid climate prevailing in northern Europe. In turn, the domain of tolerable RH fluctuations for the Rocca Pietore church is extended to a low RH region, which is a direct result

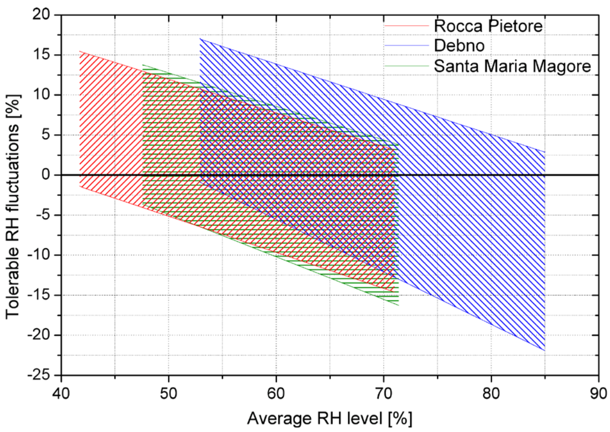

Figure 10. Tolerable RH fluctuations in the three historic churches as a function of the average seasonal RH level.

of low RH in the winter period in the past, due to the excessive heating.

The scheme in Figure 10 provides a practical example of the specifications for the tolerable RH fluctuations based on the knowledge of the historic climate of a specific object in its environmental context, measured for one year. The specifications have been derived from the past short-, mid- and long-term RH variability in the building, which is due to daily fluctuations, weekly weather changeability and yearly average level. They might provide a useful tool for preventive conservation, helping for instance to formulate the climatic specifications in loan agreements, the design specifications for low-level heating in winter or a regulation system for exchanging the indoor air when the outside conditions are favourable.

Conclusions

The three case studies of historic churches representative of different geographical locations, construction materials and patterns of use (unheated and heated) have provided examples of how past indoor conditions can provide useful information on the tolerable fluctuations in RH to which organic materials susceptible to fracture and deformation have acclimatised. The lower and upper limits of the target band of the tolerable fluctuations have been arbitrarily established as the 8th and 92th percentiles. This means that 16 % of the largest, most risky fluctuations are cut off, which corresponds to one standard deviation in the distribution of the fluctuation amplitudes. Although this is an arbitrary choice, the standard deviation is a useful, universally known statistical parameter, and can be proposed as a reasonable reference level in the recommendations. Further, the width of the target band of the tolerable fluctuations has been reduced by taking into account how much the fluctuations depart from the average seasonal RH level.

A similar approach of predicting the tolerable RH variability from the historic microclimate has been recently proposed by Michalski [4]. He has introduced the concept of ‘proofed RH or T’ which is the largest RH or T fluctuation to which the object has been exposed in the past. It is assumed that if the future climate conditions do not exceed the proofed values, the risk of mechanical damage beyond that already accumulated is extremely low. In particular, if the past fluctuation caused fracture of the object, the stress generated by the new fluctuations is released and the object will not undergo further damage. The approach proposed in this paper is based on a slightly different assumption that mechanical damage can be cumulative rather than catastrophic, therefore larger fluctuations, even if not exceeding the historic levels, can involve risk of damage. The risk is larger when the seasonal RH values depart from the yearly average. This has been taken into consideration by correspondingly reducing the tolerable levels of the fluctuations.

Authors

Łukasz Bratasz
Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences
ul. Niezapominajek 8, 30-239 Kraków, Poland.
ncbratas@cyf-kr.edu.pl

Roman Kozłowski
Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences
nckozlow@cyf-kr.edu.pl

Dario Camuffo
Institute of Atmospheric Sciences and Climate, National Research Council of Italy (ISAC-CNR)
Corso Stati Uniti 4, I-35127 Padova, Italy.
d.camuffo@isac.cnr.it

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