MATERIAL REPSONSE

Bratasz, L.; Kozlowski, R. and Camuffo, D. Pagan E. Impact of indoor heating on painted wood: Monitoring the altarpiece in the church of Santa Maria Maddalena in Rocca Pietore, Italy. *Studies in Conservation* 52, 3 (2007), pp. 199-210. http://heritage.xtd.pl/aboutus/LB_Camuffo.pdf

In the church of Santa Maria Maddalena in Rocca Pietore, Italy, the dimensional response of the wooden altarpiece to variations in indoor temperature and relative humidity (RH) was monitored between December 2002 and March 2005. Measurements demonstrated that only the external layer of wood, several millimetres thick, continually absorbs and releases water vapour following external variations in RH. For massive elements this leads to strong gradients in the moisture content through wood, a restraint of the dimensional change and a development of stress, which is the main threat to the integrity of wood and the decorative layer. Particularly strong RH variations and related high stress levels were produced by the intermittent heating system based on the inflow of warm air. To incorporate requirements for preservation, heating Systems must provide a localised comfortable temperature in the area where people are without changing the natural climate of the church as a whole. (Author's abstract)

Bratasz, Lukasz; Kozlowski, Roman. Laser sensors for continuous in-situ monitoring of the dimensional response of wooden objects. *Studies in conservation* 50, 4 (2005), pp. 307-315. http://heritage.xtd.pl/aboutus/LaserSensors2005.pdf

Reports the application of triangulation laser displacement sensors to the continuous in situ monitoring of the response of wooden cultural objects to variations in temperature and relative humidity. The sensors are robust, fast, and precise; provide noncontact measurements; and are capable of operating in the field. They have been applied to monitor the response of the altarpiece in the church of S. Maria Maddalena in Rocca Pietore, Italy, to fluctuations in temperature and relative humidity caused by the use of the heating system. Complex short-, medium-, and long-term responses of a variety of carved wooden elements have been recorded. (Author's abstract)

Bratasz, Lukasz; Slawomir, Jakiela and Kozlowski, Roman. Allowable thresholds in dynamic changes of microclimate for wooden cultural objects: Monitoring in situ and modelling. In *ICOM Committee for Conservation: 14th triennial meeting, The Hague, 12-16 September 2005: Preprints .* Sourbès-Verger, Isabelle, James & James: Earthscan, London (2005), pp. 582-589.

Triangulation laser displacement sensors have allowed for precise in situ measurements of short-, medium-, and long-term dimensional responses of sculpted wooden elements to variations of temperature and relative humidity. They show that

massive wooden elements are endangered by mechanical damage. Most numerical modeling of the phenomenon quantified gradients of moisture contents and related stress distributions for a cylindrical object, imitating a wooden sculpture, subjected to a range of microclimatic fluctuations reflecting real-world situations. The obtained stress levels permit the determination of allowable thresholds in the magnitude and rate of the air parameter fluctuations which the wooden objects may ultimately endure without irreversible deformation or damage. (A.A. - AATA)

Brimblecombe, Peter. Effects of the cultural environment. *Cultural heritage conservation and environmental impact assessment by non-destructive testing and micro-analysis.* van Grieken, René; Janssens, Koen H. A., A.A. Balkema, Rotterdam (2005), pp. 11-18.

Discusses how factors in controlled and uncontrolled environments contribute to certain types of damage on culturally significant objects. The author affirms that a better understanding of these factors will improve the effectiveness of preventive conservation and further asserts that these factors should be studied so as to propose thresholds, guidelines, or standards for improving environmental control and monitoring procedures. For example, the study of thermodynamic and kinetic processes between the environment and materials can optimize the models for proposing deterioration mechanisms. The article presents a table with some of the factors that influence deterioration processes, such as erosion, soiling, thermal decomposition, and hygrometric stress. In addition, the article discusses how damage, classified by the mode in which it occurs, can be organized into the three broader categories of impulse, dose, and cyclic processes. (ICCROM)

Camuffo, Dario; Pagan, Emanuela Impact of daily and seasonal Temperature and Relative Humidity cycles on wooden artworks (presentation at 6th Indoor Air Quality 2004 Meeting (IAQ2004) Padova, Italy, 10-12 November 2004). (2004) http://www.isac.cnr.it/iaq2004/pdfabstract/Camuffo_2abstract.pdf

Museums, galleries, and other exhibition rooms suffer from cycles in T and RH, which are responsible for dimensional changes and internal tensions to artefacts, which in the long run may have a cumulative effect, or even in some occasions may exceed some thresholds after which some structural parts may break. This is relevant for hygroscopic and fragile materials, and especially when the artefact is composed of a number of such parts bound each other. A threshold has been established for chemical pollution in museums, not yet for microclimate cycles. By definition, the interval of allowed variability in T and RH between 0 and a safety level below an established threshold in T and RH is considered of "well being" for the conservation. The values falling outside this interval might be considered in a risky area. Several authors have faced this problem under different hypotheses and points of view, with laboratory tests or case studies. Although any choice of values might be controversial, an empirical

approach is here presented. (Author's abstract)

Erhardt, David; Mecklenburg, Marion. Relative humidity re-examined. In *Preventive conservation: Practice, theory and research: Preprints of the contributions to the Ottawa Congress, 12-16 September 1994.* International Institute for Conservation of Historic and Artistic Works, London (1994), pp. 32-38.

The determination of an optimal value of relative humidity for the preservation of museum objects is more complex than for other environmental factors. Relative humidity affects the preservation of objects in many ways, and effects vary for different types of object. Relative humidity affects the rates of chemical reactions, and the values of physical properties such as size, strength, and stiffness. Extremes of either low or high relative humidity can be damaging. Changing the relative humidity may decrease damage due to one factor while increasing damage due to others. This article examines ways in which relative humidity affects the degradation processes of different types of material, the limits each factor places on allowable values of relative humidity, and how each factor influences preservation within the allowable range. The type of collection, its use, and constraints imposed by the building housing the collection are also considered. The ""optimal" relative humidity is not a specific value upon which all considerations converge, but a range chosen as a compromise in an attempt to minimize the total effect of numerous reactions and processes. (Author's Abstract)

Erhardt, David; Mecklenburg, Marion F.; Tumosa, Charles S. and McCormick-Goodhart, Mark. Determination of allowable RH fluctuations. *Newsletter (Western Association for Art Conservation)* 17, 1 (1995), pp. 19-23.

A brief introduction to work undertaken by the Smithsonian Institution to determine the allowable range of relative humidity fluctuations that museum objects can tolerate without mechanical damage. The authors present stress-strain curves at various relative humidities for cottonwood, as well as plots of relative humidity values which produce yielding or failure in restrained cottonwood as a function of equilibrium relative humidity. They do not provide measurements and calculations for other materials, though the results are comparable. The authors conclude that the allowable fluctuation is a function of the relative humidity to which the object is equilibrated and that the relative humidity with the maximum allowable fluctuation varies with material. Though the allowable fluctuations can be quite different for different materials, all the allowable fluctuations are larger than those generally presently recommended. (M.Gi.

Erhardt, David; Mecklenburg, Marion F.; Tumosa, Charles S. and McCormick-Goodhart, Mark H. The determination of appropriate museum environments. *The interface between science and conservation.* Bradley, Susan, British Museum, London (1996), pp. 153-163.

The choice of a range of temperature and relative humidity (RH) for the general museum environment must be based on a number of factors related to the materials and construction of objects in the collection. These include critical transitions of the materials (such as glass transition and deliquescence points), physical and mechanical properties, chemical reactivity, and the effects of environmental changes within the allowed range. Changes caused by environmental fluctuations can be shown to be generally reversible (nondamaging) within a relatively wide (±10 to 15%) range in the moderate RH region. A range that is safe for the general collections and minimizes the number of inevitable exceptions can be determined. Other factors such as building design and construction, local climate, energy costs, and available funds and time can then be considered to develop a climate control strategy that maintains the climate within the safe range while conserving energy, funds, and effort. (W.A.O. (A.A.

Jakiela, S; Bratasz, L. and Kozlowski, R. Acoustic emission for tracing the evolution of damage in wooden objects. *Studies in Conservation* 52, 2 (2007), pp. 101-09. http://heritage.xtd.pl/aboutus/StudiesCons52(2007).pdf

The monitoring of acoustic emission (AE) has allowed direct tracing of the fracturing intensity in wooden cultural objects exposed to variations in temperature (T) and relative humidity (RH). High-frequency components produced by the mechanical fracturing were extracted from the raw AE signals using the wavelet transforms. The accumulated energy of these components depended on the magnitude and rate of the RH variations. The AE activity became negligible below the allowable magnitude for the rapid RH variation established by numerical modelling, or when the time interval allowed for the RH variation was long enough. On-site AE monitoring of a wooden altarpiece in a historic church further confirmed the usefulness of the technique in tracing climate-induced stress in wood. The development of practical AE sensors to indicate risk to wooden objects in museums and at historic sites, or during their transportation, is discussed. (Author's abstract)

Knight, Barry. Predicting the unpredictable: how does the museum environment fluctuate? *13th triennial meeting Rio de Janeiro, 22-27 September 2002 : preprints.* Vontobel, Roy, Editor. James & James, London (2002), pp. 45-50.

In order to assess the risk to museum collections from their environment, museum personnel need to combine information on the strength of historic materials and on the response of historic artifacts to their environment with information on the frequency of extreme climatic events that might cause damage. This article illustrates

one approach to predicting the frequency of potentially damaging events from the analysis of environmental data. (AATA)

Kosciewicz-Fleming, Linda; Pearce, Michael. A case study of in situ monitoring of the dimensional response of painted wood to ambient relative humidity and temperature at the High Dining Room, Argyll's Lodging, Stirling. *Environmental Monitoring of our Cultural Heritage Sustainable Conservation Solutions. The Proceedings of the international conference on Environmental Monitoring of our Cultural Heritage - Sustainable Conservation Solutions 13-14 November 2003, Royal Museum Lecture Theatre, Edinburgh, UK.* Singh, Jagjit; Knight, Barry, Editors. Environmental Building Solutions Ltd, UK, (2003), Chapter 7.

Kozlowski, Roman; Bratasz, Lukasz Impact of heating system on the dimensional change of wood: A case study of the church in Rocca Pietore, Italy (presented at 4th Indoor Air Quality Meeting, 2003). (2003) http://iaq.dk/iap/iaq2003/2003_04.htm

A significant number of historic churches are heated in the cold period sporadically when used. The artificial climate produced by heating episodes is thought to have a great impact on the works of art preserved in churches. The rapid warming of the air causes a drop in the relative humidity and a release of moisture and shrinkage of artworks like paintings on canvas or decorative objects of wood. On the other hand, increased moisture content of the air generated by those using the church causes condensation on surfaces that remain cold like walls, ceilings or stained glass. FRIENDLY HEATING - a research project within the European Commission 5th Framework Programme was launched in 2002 to develop a novel heating system which is able to contain heat just in the area where people stay. The novel system will be set up and studied in a church in Rocca Pietore in the Dolomites in Italy for the extreme climatic conditions found there. An important aspect of the project will be careful evaluation of risk of damaging the church's polychrome wooden sculptures before and after the installation of the heating prototype. Dimensional response of wood to the fluctuations in ambient relative humidity will be monitored in situ with a range of sensors -linear inductive displacement transducers for non-decorated wooden structural elements, non-contact laser sensors for remote measurements of objects of artistic value and inductive sensors for monitoring movement of cracks in wooden elements. Strains and stresses within the material will be assessed. The paper will report on the results of the first winter campaign in the Rocca Pietore church planned between November 2002 and February 2003. (Author abstract)

Mecklenburg, M. F.; Tumosa, C. S. and Wyplosz, N. The effects of relative humidity on the structural response of selected wood samples in the cross-grained direction. In *Materials issues in art and archaeology IV: Symposium held May 16-21, 1994, Cancun, Mexico.* Druzik, James R.; Galván Madrid, José Luis; Freestone, I. C. and Wheeler, George, eds. (1995), pp. 305-324.

Mecklenburg, Marion F.; McCormick-Goodhart, Mark and Tumosa, Charles S. Investigation into the deterioration of paintings and photographs using computerized modeling of stress development. *Journal of the American Institute for Conservation* **33**, 2 (1994), pp. 153-170.

The environmental effects of temperature and relative humidity on the mechanical response of paintings and photographs were examined using numerical methods and computer analysis. The basic mathematical approach is introduced that defines the material parameters necessary to conduct such an analysis. Methods of determining the material and dimensional properties of materials with comments on the effects of increasing measurement accuracy are discussed. Using measured material properties for paintings and photographs, complete computer analyses were conducted that modeled the physical response to changing temperature and relative humidity. The calculated results were compared to experimental test specimens subjected to similar environmental variations. (Author's Abstract)

Mecklenburg, Marion F; Tumosa, Charles. Mechanical behaviours of paintings subjected to changes in temperature and relative humidity. In *Art in transit: Studies in the transport of paintings: International Conference on the Packing and Transportation of Paintings, September 9, 10, 11, 1991, London.* Mecklenburg, Marion F, ed. National Gallery of Art, Washington, DC (1991), pp. 173-216.

Michalski, Stefan. Double the life for each five-degree drop, more than double the life for each halving of relative humidity. In *13th triennial meeting, Rio de Janeiro, 22-27 September 2002: Preprints.* ICOM Committee for Conservation and Roy Vontobel, eds. James & James, London (2002), pp. 66-72.

Data on accelerated aging and the effect of temperature and relative humidity (RH) are reviewed for paper, film, and magnetic media studies. The activation energy for most paper and film studies falls in the range (80 to 120) $kJmol^{-1}$. For decay in magnetic media binder and yellowing of dammar resin, the activation energies fall in a lower range, (60 to 80) $kJ\ mol^{-1}$. The average activation energy value of 100 $kJmol^{-1}$ implies a rule of thumb: double the lifetime for each 5°C drop, so 70 $kJmol^{-1}$ implies 7°C. A theoretical derivation from transition state theory suggests that these approximate rules are predictable and, hence, universal for materials in museums with chemical instability problems. The available data on RH dependence suggests that half the RH will more than

double lifetimes for acid hydrolysis. Hence, the title of this article holds generally for museums. A graph of constant lifetimes on the psychrometric chart is presented. (A.A. - AATA)

Michalski, Stefan. Relative humidity: a discussion of correct/incorrect values. In *ICOM Committee for Conservation 10th triennial meeting: Washington, DC, 22-27 August 1993: Preprints.* Bridgland, Janet, ed. ICOM Committee for Conservation, (1993), pp. 624-629.

Relative humidity (RH) specifications for museums became very stringent during the 1960s and 1970s, without detailed explanation. The Canadian Conservation Institute has reviewed the relevant data to answer common cost-benefit questions, not just to stipulate correct RH. Mechanical, biological, and chemical deterioration all rise sharply beyond 75% RH, and increase significantly for every increment to 100% RH. Fracture in rigid, constrained organic artifacts, given a relaxed state at some middle RH, becomes probable in one cycle only for a drop of -25% to -50% RH. Fatigue models imply that each reduction of fluctuations to one half of this critical value will reduce deterioration per cycle to 0.01%-0.00001%. Many flexible or sliding assemblies are immune since constraint is missing. (AATA)

Olstad, T. M; Haugen, A and Nilsen, T. *Polychrome wooden ecclesiastical art: Climate and dimensional changes* Norwegian Institute for Cultural Heritage Research, Oslo (2001).

Schellen, H. L.; Schijndel, A. W. M. van; Neilen, D. and Aarle, M. A. P. van. Damage to a monumental organ due to wood deformation caused by church heating. In *Research in building physics: Proceedings of the 2nd International Conference on Building Physics, 14-18 September 2003, Antwerpen, Belgium.* Carmeliet, J; Hens, H and Vermeir, G, eds. A.A. Balkema, Lisse; Exton, PA (2003), pp. 803-811.

Tumosa, Charles S.; Mecklenburg, Marion F.; Erhardt, David and McCormick-Goodhart, Mark H. A discussion of research on the effects of temperature and relative humidity on museum objects. *Newsletter (Western Association for Art Conservation)* 18, 3 (1996), pp. 19-20.

The article addresses the issue of climate control guidelines in museums. It suggests that it may be unnecessary to insist on rigid, complex, or expensive environmental control to ensure the stability of collection artifacts. Implementation of somewhat relaxed environmental recommendations with installation of simple systems that keep most buildings within the 35-65% relative humidity range with temperature at about 700°F would be sufficient to ensure the stability of most collections. It would also result in large savings in construction and maintenance and yield dramatic reductions in the use of energy. Thermodynamics dictate that more energy will be used in a tightly controlled, single set point system than in a system allowed to vary in a given range using multiple set points. (M.Gi.)