Applied Energy 88 (2011) 712–723

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Relationship between indoor thermal comfort conditions and the Time Weighted Preservation Index (TWPI) in three Brazilian archives

E.L. Krüger [a,*], W. Diniz [b]

[a] Universidade Tecnológica Federal do Paraná, Av. Sete de Setembro, 3165-CEP, 80230-901 Curitiba, PR, Brazil
[b] IPHAN-Inst. do Patrimônio Histórico e Artístico Nacional, Brazil

ARTICLE INFO

Article history:
Received 25 April 2010
Received in revised form 28 July 2010
Accepted 12 September 2010
Available online 8 October 2010

Keywords:
Preventive conservation
Storage conditions
Indoor thermal comfort
Paper archives

ABSTRACT

There are many factors that affect paper degradation in archives, but air temperature and humidity under inadequate storage conditions are among the most important ones. Such inadequate conditions will trigger biological, chemical and physical processes that may enhance the degradation of papers. On the other hand, users of libraries and archives, where documents are stored, require adequate indoor conditions for carrying out diverse activities. In this paper we analyze the performance of archives with regard to paper and document storage conditions, also given in terms of the Time Weighted Preservation Index (TWPI), against overall comfort conditions, according to ISO 7730 and to the Building Bioclimatic Chart. For that purpose, five different settings were chosen, corresponding to indoor and outdoor conditions of three Brazilian archives, located in diverse climatic regions (Curitiba, 25°25′S 49°16′W, Belo Horizonte, 19°56′S 43°56′W and Rio de Janeiro, 22°50′S 43°10′W). The monitoring period comprehended 12 months, with a mid-term data collection. Results showed that there is a significant difference in storage conditions among different locations, even though there is a similarity in indoor thermal comfort conditions. A compromise solution should be sought between storage conditions and human thermal comfort parameters.

1. Introduction

Depending on the type of material to be stored in a given archive, an object can undergo alterations and, as a consequence, degradation, in three different manners: changes in dimensions, chemical reactions and biological degradation. The physical phenomena causing dimensional alterations are the expansion and contraction of organic materials, due to air temperature and humidity variations. Moisture absorbing materials, such as wood, bone, ivory, parchment, textiles, basketry and adhesives, swell in high ambient relative humidity of the air, consequently suffering deformation, movements of parts, cracks, rupture of fibers and under low relative humidity, such objects suffer a contraction. The phenomena resulting from chemical reactions originate from elevated temperature and moisture content of indoor air, causing corrosion of metals, oxidation, discoloring of paintings, acid hydrolysis of cellulose in papers, weakening of textiles, etc. Biological phenomena, however, are responsible for biological activities in all organic materials, as the result of a lack of ventilation and air changes in the presence of high temperatures and humidities. Humidity is the basis for the growth of microorganisms.

Particularly temperature and humidity conditions have a direct effect on stored materials, requiring a set of actions to meet the collection's requirements, with the aim of preserving Cultural Heritage. Considering the high costs of permanently running HVAC systems, a viable and less costly alternative could be the implementation of passive strategies, eliminating or at least reducing the need of a permanent air-conditioning of the indoor space.

The purpose of this research was twofold: on one hand, to evaluate different Brazilian archives located under diversified climatic conditions by means of indoor and outdoor air temperature and humidity measurements, when compared to recommended standards of the field of Preventive Conservation and, on the other hand, to verify whether for a limited monitoring paper degradation would take place. The initial idea was to observe paper degradation as an aid to check the applicability of the recommended standards under natural aging conditions, considering that most of the traditional recommendations for paper storage, including the Time Weighted Preservation Index (TWPI), were developed from controlled, artificial aging experiments. Since aging of paper under ambient conditions is a very slow process, it is rather difficult to evaluate and predict with absolute certainty the effect of storage conditions based on the accelerated aging results. The motivation for carrying out this research was to find ways to make international standards more flexible and suitable for archives situated in tropical and subtropical regions.

* Corresponding author. Tel.: +55 41 33104725; fax: +55 41 33104712.
E-mail addresses: ekruger@utfpr.edu.br (E.L. Krüger), wivian@aadiniz.com (W. Diniz).

0306-2619/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2010.09.011

Nomenclature

PI	relative permanence of given paper or Permanence Index (non-dimensional)	TWPI	Time Weighted Preservation Index (non-dimensional)
T	air temperature (°C)	PMV	predicted mean vote (non-dimensional, according to a 7 point-scale)
RH	relative humidity (%)	M	metabolic rate (W)
ΔH	activation energy (kcal)	DF	decrement factor (non-dimensional)

In recent years, there has been a considerable effort in Brazil from research centers and governmental programs to promote energy conservation measures in many sectors. The *PROCEL Edifica* initiative is one of the main programs, funded by the National Government, aiming at the rational use of electricity in buildings. More recently, in 2009, a technical regulation focusing on energy efficiency was developed for commercial, services and public buildings (*Regulamento Técnico da Qualidade do Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos – RTQ-C*). Although Brazil's energy generation comes from renewable sources (about 45% of total energy production), there has been a trend over the last decade that non-renewable sources take hold of the bulk of the country's energy production [1]. In this sense, such initiatives contribute to reduce energy demand in the building sector, thus the determination of more appropriate storage conditions in archives can have an impact on the demand for air-conditioning and be also part of this context.

On the other hand, the evaluation of such spaces from the point of view of human thermal comfort is justified, considering the human occupancy of storage places (keepers and visitors). Under tropical conditions, it is not unusual that indoor conditions of libraries and archives will trigger respiratory diseases in occupants, in some cases due to fungi formation linked to inadequate storage conditions. In other cases, indoor thermal conditions may be too uncomfortable for users and a cause of absenteeism (keepers).

Recently spread information concerning fungi contamination in the Manguinhos Library [2,3], which belongs to the distinguished Brazilian institute Fundação Oswaldo Cruz, located in Rio de Janeiro, depicts an episode that lead to an interdiction of the building during several months of 2006–2007. Professionals and experts gathered thereafter to define strategies for improving indoor conditions, considering three different approaches: storage adequacy, hygienic measures and maintenance, and measures related to human health. Among the causes that lead to the fungi spread in the archive are: combination of high air temperatures and humidities following a rainy week, high daily indoor fluctuations of the indoor air temperature and concurrent repairs and interruptions in the existent HVAC system. The episode exemplifies the interaction between storage conditions and their impacts on occupants.

Considering the combined effect of air temperature and humidity in such spaces, the present paper investigates whether compatibility solutions are possible, from the aspects of human thermal comfort and paper storage conditions. Thus, the objective of this study is to monitor the change in storage conditions of archives located in three different climatic regions in Brazil and assess its impact on the overall thermal performance of each building and on human thermal comfort levels according to ISO 7730 [4]. A follow-up of this study is being carried out in university libraries, where paper (books, magazines, journals) and people share the same space.

2. Materials and methods

As aforementioned, one of the purposes of the research was to evaluate the adequacy of three different Brazilian archives in storing paper samples, by means of thermal monitoring inside and outside those archives. As a relevant aid for analysis, paper samples, which were bought commercially, were exposed to ambient and indoor conditions of the chosen archives for a given period of time and the physical and chemical decay rates were assessed. The detailed analysis of the observed paper decay rates after natural exposure is not part of the present analysis and will therefore not be discussed in this paper. In order to preserve the anonymity of the evaluated national and regional archives, they are termed in this paper "Archive 1", "Archive 2" and "Archive 3".

Paper samples were accommodated in small acrylic containers and exposed to different conditions of temperature and relative humidity in three Brazilian climate types: CFa (Curitiba, 25°25′S 49°16′W, 910 m above sea level), Cwa (Belo Horizonte, 19°56′S 43°56′W, 860 m above sea level) and Aw (Rio de Janeiro, 22°50′S 43°10′W, on the east coast), according to Koeppen–Geiger's climate classification [5].

Six different settings were originally chosen for exposing the paper samples, corresponding to indoor and outdoor conditions in each location. The period for the natural aging of the paper samples at such locations comprehended 12 months, with a mid-term data collection. In this paper we analyze the performance of such archives with regard to paper and document storage conditions, also given in terms of the Time Weighted Preservation Index (TWPI), against overall thermal comfort conditions, according to the Building Bioclimatic Chart and to ISO 7730 (PMV).

2.1. The box container

The small-sized container used for storing and exposing the paper samples consists of an acrylic box ($41 \times 41 \times 16$ cm, 4 mm thickness), naturally ventilated but provided with activated carbon filters on its openings (Fig. 1). Thomson [6] recommends the use of such filters as an efficient measure to control main pollutants, such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3). The acrylic walls have also been covered by a Solar Gard LX 70 film in

Fig. 1. The box container with datalogger outside the box.