Applied Energy 158 (2015) 446–458

Contents lists available at ScienceDirect

Applied Energy

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

Energy conservation in museums using different setpoint strategies: A case study for a state-of-the-art museum using building simulations

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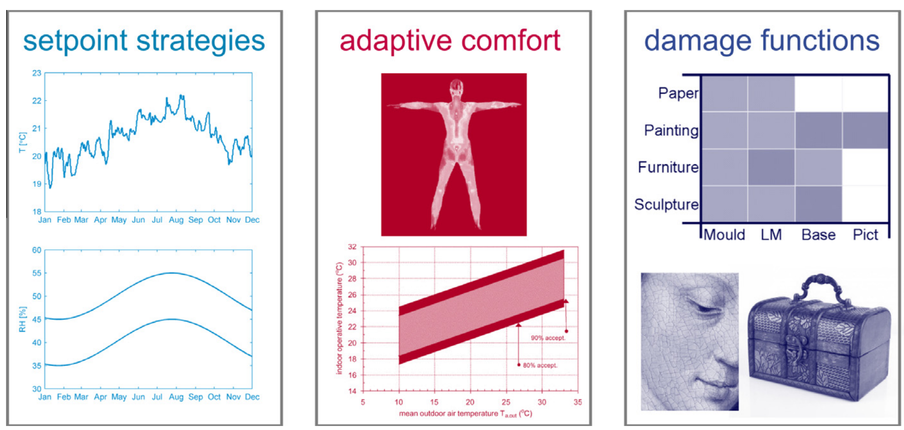
HIGHLIGHTS

- A hygrothermal building model is constructed for a state-of-the-art museum in Amsterdam.
- Building simulations are performed to assess different setpoint strategies for *T* and RH.
- The optimum setpoint strategy may reduce building's energy demand drastically (77% compared to the reference situation).
- The optimum setpoint strategy improves thermal comfort and collection preservation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 October 2013
Received in revised form 17 July 2015
Accepted 15 August 2015

Keywords:
Energy conservation
Museum
Indoor climate
Building simulation
Preservation

ABSTRACT

Museums are dedicated to protect their artwork collection and to display the collection as safely as possible. Amongst other things, the indoor climate is of utmost importance to minimize collection degradation. Many museums employ tight climate guidelines, allowing only small fluctuations of indoor temperature and relative humidity, resulting in the following problems: huge energy consumption, the need for high-capacity HVAC systems, additional stress on historical buildings. This simulation study investigates the energy-saving potential of different setpoint strategies. Damage functions were used to assess the degradation risk of the collection and an Adaptive Temperature Guideline was used to assess thermal comfort. A state-of-the-art museum in the Netherlands was modeled and the indoor climate and energy consumption were simulated, including heating, cooling, humidification and dehumidification. Maximum savings, compared to a reference situation, of 82% may be achieved. However, the optimum strategy yields a saving of 77%, significantly improves thermal comfort and decreases chemical degradation.

1. Introduction

In the late 1980s, museums in the Netherlands paid little attention to collection preservation. Therefore, the Ministry of Health and Culture launched the Deltaplan [1] in 1990 to initiate a paradigm shift by identifying areas for improvement, including indoor

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http://dx.doi.org/10.1016/j.apenergy.2015.08.044
0306-2619/

climate conditions. Consequently, museums installed Heating, Ventilation and Air Conditioning (HVAC) systems to control the indoor climate and provide a safer environment for the collection.

No indoor climate specifications were defined in the Deltaplan. So, new guidelines [2] were developed and international guidelines [3] were adopted that allowed only small fluctuations of indoor temperature (*T*) and relative humidity (RH). This was completely in line with the international developments on museums' indoor climates that are comprehensively reported by Brown and Rose [4]: "..., these figures (specifications) have not arisen from detailed research leading to a clear understanding of the effects of humidity on organic material, but are in fact codifications of pre-WWII customs and practice, modified by the practicality of indoor environmental control in specific climates." The climate guidelines developed, in an international setting, along with technology: not the collection, nor the building requirements, but the capability of the HVAC systems determined the level of conditioning. Consequently, the indoor climate was getting more and more strictly conditioned during the twentieth century.

Another evolution may be described as *from flexible guidelines to prescriptive specifications*. This is illustrated by the highly influential work of Thomson: the first edition [5] gave an excellent summary of the knowledge up to 1978, presenting climate specifications embodied in the text that provided useful information to facilitate museum staff to adapt the specifications to their specific needs; the second edition [6] included an appendix summarizing the climate specifications in two pages, making it possible to consult these specifications without reading the book and not fully understanding the underlying knowledge. So, the specifications became more prescriptive, regardless whether they would make sense for a particular application [7].

Then, from the 1990s the notion of risk management for preventive conservation was introduced [8–10]. Risk management enables museum staff to arrive at case specific climate specifications that make sense from a multi-disciplinary point of view (finance, building, objects, comfort). During the 2000s, Ankersmit [11] applied a risk-analysis procedure for museums, revealing that the employed climate specifications were too strict in many cases: museums are often housed in historical buildings, requiring a huge amount of energy to meet the strict specifications due to large heat losses. So, energy efficient control of the indoor climate has become a concern for many museums. However, insulating from the outside is no option because of the historical facades, and insulating from the inside has been done in the past, but often resulted in condensation problems [12]: the warm humid air interacts with the cold envelope. Moreover, abrupt climate changes may occur in the case of system failures [13].

Martens [14] showed that the degradation risks of museum objects in old buildings with a simple installation often do not significantly differ from the risks in historical buildings equipped with modern HVAC systems. Besides, very vulnerable objects may be placed in display cases. The question arose if the strict indoor climates are always necessary. Moreover, it is known that a strict indoor climate in historical buildings, despite large HVAC systems, is very hard to maintain: Ferdyn-Grygierek [15] performed a measurement campaign in Poland and concluded that *T* varied from 17 °C to 28 °C and RH varied from 20% to 75% despite the full air conditioning.

From 2005 energy efficiency in museums and historic buildings received more attention and from the year 2010 the amount of publications increased significantly, e.g.: studies on HVAC system design [16–19]; an overview of energy efficient measures in two state-of-the-art museums in Germany [20]; energy efficiency among many museums in Europe [21] and specifically Italy [22]; energy savings by optimized control of components [23,24]; studies that show the opportunities and limitations of passive conditioning [25,26]; local conditioning [27–29].

Limited researches investigated the influence of changing the indoor climate setpoints on the energy consumption of museums. Ayres et al. [30] simulated a fictive modern constructed museum using different outdoor climates located in the USA, investigating the operating costs using different setpoints. They concluded that a RH setpoint of 50% has the lowest energy consumption compared to 40% or 60%. The widening of the bandwidth of RH did not result in a significant reduction of the energy consumption. In contrast, Mecklenburg et al. [31] showed that increasing the RH tolerance from ±2% to ±7% reduces the energy costs by 55% based on measurements that were obtained from nine museums of the Smithsonian Museum, all located on the West coast of the USA. However, museums that employ tight guidelines for RH, also employ tight guidelines for *T*. Therefore, the significant savings presented by Mecklenburg are only realistic if both *T* and RH are controlled less strictly. Artigas [32] concluded that energy costs decrease exponentially with reduced level of control. Artigas' research was performed on five museums in the USA. All buildings had different constructions and climate control systems. Also seasonal fluctuations resulted in savings. Ascione et al. [16] performed computer simulations to investigate the effect of setpoint strategies for four different system configurations in an exhibition room of a modern museum in Rome, Italy. *T* setpoints depending on the season (21 °C in winter, 23 °C in summer, instead of constantly 22 °C) resulted in savings of 6–13%. Allowing larger RH fluctuations, 50% ± 10% instead of 50% ± 2%, resulted in savings of 40%. Another study by Ascione et al. [33] shows that a lower winter setpoint for *T*, 20 °C instead of 22 °C, and a higher summer setpoint, 26 °C instead of 24 °C, results in savings of 20% in winter, more than 40% in the intermediate season and 11% in summer. Results were obtained via computer simulations of a historical building located in Benevento, Italy. These researches show that studying setpoint strategies for museums is relevant since huge energy savings are possible. However, the results are very difficult to compare and are heavily depending on the type of HVAC system and system efficiencies.

The aforementioned studies focused only on energy consumption, but this study assesses also the collection preservation quality and thermal comfort of the simulated indoor climates. A state-of-the-art museum that is housed in a renovated historical building located in the Netherlands, is modeled and simulated. The goal is to lower the energy consumption by using various setpoint strategies.

The paper is organized as follows: Section 2 describes the methods, including a description of the case study building (2.1), data acquisition (2.2), the modeling (2.3), and how damage functions and the Adaptive Temperature Guideline are used to assess collection preservation and thermal comfort, respectively (2.4). Section 3 presents the results, Section 4 provides a discussion with conclusions and Section 5 presents recommendations for future work.

2. Methodology

2.1. The museum

The case in this study is a state-of-the-art museum that is located in Amsterdam, the Netherlands. The museum is housed in a late 17th century building. During the past centuries, many changes were made to the building, additional buildings were built and the layout was modified. Central heating was implemented in 1860. The building was substantially renovated in 1970 as it was transformed into a modern nursing home. The most recent renovation dates from the years 2007–2009 when the building was