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Dynamic setpoint calculation including collection and comfort requirements: Energy impact for museums in Southern Europe

Rick Kramer[a]*, Jos van Schijndel[a], Henk Schellen[a]

[a] *Eindhoven University of Technology, Eindhoven, the Netherlands*

Abstract

Firstly, this study presents an algorithm for setpoint calculation of museums' indoor temperature (*T*) and relative humidity (*RH*) integrating collection requirements according to ASHRAE and thermal comfort requirements according to adaptive temperature limits that follow from a one-year long comfort study in case study museum Hermitage Amsterdam. Secondly, this algorithm is implemented into a building energy simulation model to assess the energy impact for various cases: Five levels of museum indoor climate conditioning are applied to four building quality levels (ranging from a historical building to a purpose-built museum building) using weather data from six locations in Southern Europe. A validated building energy simulation model of museum Hermitage Amsterdam was adjusted to represent the four building quality levels, and technical-reference-year (TRY) weather data of six locations were used. The conclusions: The algorithm enables smooth control of hourly and seasonal adjustments in *T* and *RH* setpoints; the algorithm boosts energy efficiency due to more effective use of the permissible ranges of *T* and *RH*; improving the building quality quickly follows the law of diminishing returns due to internal heat and moisture loads; supposing to result in the same collection risk, subclass A_s (with seasonal adjustments, but smaller hourly fluctuations) is more energy efficient than subclass A_d (no seasonal adjustments, but larger hourly fluctuations) for most locations.

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* Corresponding author. Tel.: +31402475613.
E-mail address: r.p.kramer@tue.nl

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1. Introduction

The indoor climate conditions of museums should provide adequate conditions to preserve the artefacts [1] and should provide thermal comfort to visitors and staff. In historical buildings with high cultural significance, the indoor environment may also be important to preserve the interior and building structure itself [2]. Hence, the indoor climate is important for a wide range of building types ranging from an uninsulated historical building with a low quality of envelope (QoE 1), to a highly insulated purpose-built museum building (QoE 4).

Appropriate boundary conditions for the museum environment are described in guidelines. For example, ASHRAE presents indoor climate classes for Museums, Galleries, Archives, and Libraries [3] including specifications for short-term fluctuations, seasonal adjustments, and permissible levels of indoor temperature (T) and relative humidity (RH), see Table 2. The climate classes range from class AA (precision control) to class D (limited control).

The notion of an optimal museum environment evolved in the 20th century to 'the more stable, the better' [4]. As a consequence, many museums chose the most stringent indoor climate class, e.g. ASHRAE Class AA, supposing this to be the optimum overall solution. However, besides other undesired consequences, conditioning the indoor climate of museums very stringently results in excessive energy consumption.

At the beginning of the 21st century, energy efficiency had become an increasingly important issue, e.g. [5–11]. However, a sophisticated setpoint control algorithm for the climate classes is missing: Museum staff need to translate the tabular specifications for hourly and seasonal adjustments into setpoint values. Additionally, seasonal adjustments are often implemented manually potentially resulting in abrupt changes in T and RH which may endanger the collection. Moreover, the permissible T and RH ranges and permissible drifts, e.g. seasonal changes, are used inefficiently.

This study presents a seven-step algorithm for T and RH setpoint calculation taking into account collection and thermal comfort requirements. Moreover, this paper aims to provide a broad insight into the energy impact for a variety of cases.

A detailed dynamic simulation model has been used of museum Hermitage Amsterdam, including the building, air handling unit (AHU), control systems, and visitors' heat and moisture gains. See [12] for information on development and validation. Then, the building model was adjusted to represent museums housed in four different building quality levels, ranging from a historical building (QoE 1) to a purpose-built museum building (QoE 4). Simulations have been performed using weather data of six locations in Southern Europe. For each variant, five levels of museum climate control have been simulated: a reference strategy (REF) comprising 21 °C and 50 % RH without permissible fluctuations, and four levels of climate control integrating thermal comfort requirements and collection requirements derived from ASHRAE classes AA, A_s, A_d, and B. The thermal comfort requirements follow from a comprehensive survey study in museum Hermitage Amsterdam [13].

2. Museum Hermitage Amsterdam

The current study builds upon previous studies [12–14] that are based on case study museum 'Hermitage Amsterdam'. Therefore, some background information is provided on that museum. The museum is opened seven days per week from 10 h until 17 h and has been welcoming, depending on the exhibition, 7,000 to 11,000 visitors per week. Aiming for a very stable museum environment, the employed indoor climate specifications were 21 °C and 50 % RH without permissible fluctuations during the measurements.

2.1. The building

The museum is housed in a late 17th-century building and in the past centuries, the building has been changed frequently. The most recent renovation dates from 2007 to 2009 when the building was transformed into a modern museum building (see Figure 1). Only the historical building facade was conserved. The building envelope was newly built inwards, including a cavity and insulation (total thermal resistance 3.7 m^2K/W), particularly focusing on airtightness (infiltration rate < 0.1 h^{-1}). Glazing has been replaced by double glazing with reflective coatings (U-