Energy efficient HVAC control in historical buildings

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 132 (2017) 891–896

Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Energy efficient HVAC control in historical buildings: a case study for the Amsterdam Museum.

Karin Kompatscher[a], Silke Seuren[a], Rick Kramer[a], Jos van Schijndel[a], Henk Schellen[a*]

[a]*University of Technology Eindhoven, 5600 MB Eindhoven, The Netherlands*

Abstract

Museums are often located in historical buildings. To provide suitable housing in a historical building for a museum, these buildings are usually adapted to suit the need for object preservation through HVAC control. Maintaining a strict indoor climate and limiting short fluctuations in indoor temperature and indoor relative humidity reduces risk on objects. However, this also results in a rather high energy demand and therefore rather high costs. Previous research showed the energy conservation possibilities for a museum with state-of-the-art building envelope by adapting setpoint strategies. A gap in literature is present in applying these strategies in historical museum buildings. The aim of this study is to make use of different setpoint strategies to provide an indication of possible energy conservation for a historical museum building with respect to object preservation and thermal comfort.

The method used consists of a measurement campaign to establish the current indoor climate and a simulation study with different climate control strategies. The simulation study provides possibilities to assess energy efficient control strategies with preservation of valuable museum objects in mind. The Amsterdam Museum serves as a case study during this research. With the data obtained during the measurement campaign, a hygrothermal zone-simulation model was calibrated. The results of the different climate control strategies present the energy saving potential for historical museum buildings. It is concluded that using the adaptive thermal comfort guideline for temperature during opening hours, and letting the collection criteria developed by ASHRAE's climate classes determine the relative humidity during the day, can save up to approximately 15% for a historical museum building without increasing the risk to the collection.

Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics.

Keywords: Museum environment; HVAC control; ASHRAE climate classes; Energy conservation; Historical building

* Corresponding author. Tel.: +31402475323.
E-mail address: k.kompatscher@tue.nl

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics
10.1016/j.egypro.2017.09.703

1. Introduction

Historical buildings often serve as locations to accommodate museums, depots, and archival functions. These buildings are usually adapted to suit the need for object preservation through Heating Ventilation and Air-Conditioning (HVAC) control. According to assumptions made in the past, keeping a constant temperature (T) and relative humidity (RH) will reduce risks on objects [1]. However, maintaining this strict indoor environment causes rather high energy costs and, in the case of historical buildings, the strict indoor climate is often not reached and may be dangerous for the preservation of the building itself [2].

Previous research has shown that changing the setpoint strategies of the indoor climate conditions will likely reduce the energy needed [3]. The research focused on ASHRAE's climate classes and their possible energy savings if applied to a museum environment [4]. This previous simulation study was extended by performing in-situ measurements in a state-of-the-art museum building [5]. Results showed a potential energy saving of approximately 50% by accepting the strictest ASHRAE climate class compared to the even more strict current requirements.

The objective of the present study is to quantify the energy demand through computational simulations for a historical museum building with corresponding building envelope. A case study provides experimental data to calibrate the model parameters. The model will determine the energy demand of the building. Setpoints for indoor temperature and indoor relative humidity are determined by ASHRAE's climate classes and the adaptive temperature guidelines (ATG) for museums. The ATG is a thermal comfort model based on human adaptability. Most of the ATGs use data from climate chambers or office buildings and their occupants. A recent study provides a first attempt at creating an ATG for museums [6].

2. Methodology

2.1. Case study Amsterdam Museum

The case study in this research is the Amsterdam Museum located in Amsterdam, the Netherlands. Since 1975, the museum is housed in a former orphanage located in the historical city center of Amsterdam. Over four centuries the orphanage was located in this 15th-century historical building. From this period, important rooms were preserved like the Regentenkamer (Regents room). The museum installed an all-air HVAC system to maintain a favorable indoor climate for museum objects. Certain rooms like the Regentenkamer are conditioned by their own air handling unit (AHU). Since the ventilation strategy is not CO_2-based, a fixed amount of 10% fresh air is conditioned and added to recirculated air during opening hours. Full recirculation is used as ventilation strategy during closing hours. This study focuses on energy conservation of the Regentenkamer, though indoor climate measurements have been carried out throughout the entire museum. The objects housed in the Regentenkamer – paintings, wooden ceiling and furniture – are considered the most valuable of the museum.

2.2. Data acquisition

In the period of July 2015 until March 2016 measurement data of the outdoor climate and indoor climate of the exhibition room were acquired. Due to maintenance, only data from December 2015 until March 2016 was used for the calibration of the simulation model.

Outdoor T and RH were measured at the museum location in Amsterdam with a logging interval of 10 minutes. Hourly values for diffuse solar radiation (W/m^2) and direct solar radiation (W/m^2) were retrieved from the Royal Netherlands Meteorological Institute's database for the location Schiphol Airport [7]. This weather station is located approximately 10 kilometers southwest of the museum.

The indoor climate parameters were measured with combined T and RH sensors from ELTEK [8]. The sensors have an accuracy for T of ±0.4 ˚C and RH accuracy of ±2% (20-80%) and ±4% (0-100%). The logging interval was 10 minutes. The indoor climate of the Regentenkamer was measured by 7 sensors. Four of the sensors are located at the supply and outlet of the AHU. Two sensors were put in the room to collect the indoor climate conditions for T and RH. The last sensor was mounted behind a painting to monitor the local climate near the object.

2.3. Building Model

A zone model representing the Regentenkamer was developed using HAMBASE [9]. This modeling and simulation tool was developed in MATLAB at the Eindhoven University of Technology. This tool is able to calculate heat and vapor flows in a multi-zone building model by a coupled indoor zone model and envelope model. Moisture storage in air and in furniture is included. Indoor temperature, indoor relative humidity and energy use for cooling, heating and (de)humidification can be simulated. Per zone a lumped variable will be calculated.

The measurement data collected over the winter period of 2015/2016 was used to calibrate the parameters of the model for the Regentenkamer in HAMBASE. The envelope of the Regentenkamer can be classified as a historical building envelope with improved air tightness and double glazing where possible. Lighting (850 W) and visitors (90 W per person) determine together the internal heat sources. Internal moisture sources are determined by visitors (1e-5 kg/s). Between 10AM and 5PM the sources are activated in the museum model.

With the developed model for this particular museum exhibition room, simulations were performed to determine indoor T and RH and energy demand for heating, cooling, and (de)humidification while adapting the indoor setpoints for T and RH.

2.4. Setpoint strategy modeling

A distinction between two sets of setpoint strategies has been made. The first set makes use of the ASHRAE climate classes to determine the setpoints for T and RH [4]. ASHRAE provides four climate classes which make a distinction between no risk to most objects (AA), small risk to highly vulnerable objects (A), moderate risk to highly vulnerable objects (B), prevent high-risk extremes (C), prevent dampness (D). Class B is considered appropriate for museum environments in historical buildings. Class A is divided into sub-class A_d, allowing no seasonal fluctuations but larger daily fluctuations, and sub-class A_s, allowing seasonal fluctuations but limited daily fluctuations.

The second set of T and RH setpoints is based on the idea that during opening hours the thermal comfort of visitors should determine the temperature setpoint. During closing hours ASHRAE climate classes can be used since no visitors are present. The T setpoint is determined by the lower and upper limit of the ATG for museums [6].

2.5. Object degradation assessment and thermal comfort assessment

In order to assess whether the setpoint strategies affect the degradation risk for objects, the specific risk assessment method of Martens was used [2]. Three degradation principles – biological, chemical and mechanical degradation – are evaluated based on four degradation phenomena: mould growth (M), lifetime multiplier (LM), base layer (BL) and pictorial layer (PL). These phenomena are represented by means of a color scheme. Green is considered save, orange results in possible damage, red stands for damage likely.

Thermal comfort can be assessed based on discomfort hours. Discomfort hours are the summation of hours registered outside the upper and lower limit of the ATG for museums. Thermal comfort is only assessed during opening hours of the museum, 10AM and 5PM.

3. Results and discussion

3.1. Model parameter calibration

Fig. 1 shows the calibration results comparing the simulation and measurement data. For temperature, the mean deviation and maximum deviation are 0.02 °C and 2.7 °C respectively. For relative humidity, these deviations are 1.3 % and 13 % respectively. Though the simulated daily trends seem similar, the model overestimates temperature, relative humidity, and absolute humidity. Since the trend and mean deviation are in good agreement the model is considered appropriate for the simulation study.

3.2. Setpoint strategy simulations

The first set of strategies evaluated is based on ASHRAE's climate classes for both T and RH.

Table 1 shows the results from the simulations, where reference stands for the current simulated indoor climate. The strategies are assessed on thermal (dis)comfort, object risk assessment and energy savings. Though energy demand decreases rapidly by allowing a less strict ASHRAE climate class, the discomfort hours for visitors increase. *Fig. 2* (a) shows the current situation (Reference) compared to the first set of energy efficient control strategies. An energy reduction starting from approximately 60 % can be seen. However, thermal comfort will worsen by the increase of discomfort hours. Mainly during winter, underheating hours determine these discomfort hours. In the less strict climate classes C and D, the specific risk assessment shows an increased risk for the base layer and pictorial layer of panel paintings. The energy savings are mainly caused by a lesser demand for heating and cooling since seasonal fluctuations are permitted.

Table 2 provides an overview of the results for thermal comfort, object preservation and energy savings for the second set of evaluated T and RH setpoints. By implementing the ATG for museums as temperature setpoint and therefore include thermal comfort, a significant decrease in discomfort hours is visible. Expected, however, are almost no discomfort hours since the allowed indoor climate is limited by the ATG for museums. Little exceedances occur and provide a misleading number of comfort hours. The specific risk assessment does not show any increased risk for implementing these control strategies. Since implementing the ATG upper and lower limits as temperature setpoint boundaries show only a slight seasonal fluctuation the energy reduction is limited to approximately 10% for class A and a maximum of approximately 15% for class B which is still considered not increasing degradation risks for museum objects, see *Fig. 2* (b). The limited reduction in energy demand is mainly caused by the high heating demand. This demand assures suitable temperatures for thermal comfort during the winter period in a temperate climate. Note that *Fig. 2* shows only the building demand and the latent load of the (de)humidification energy demand.

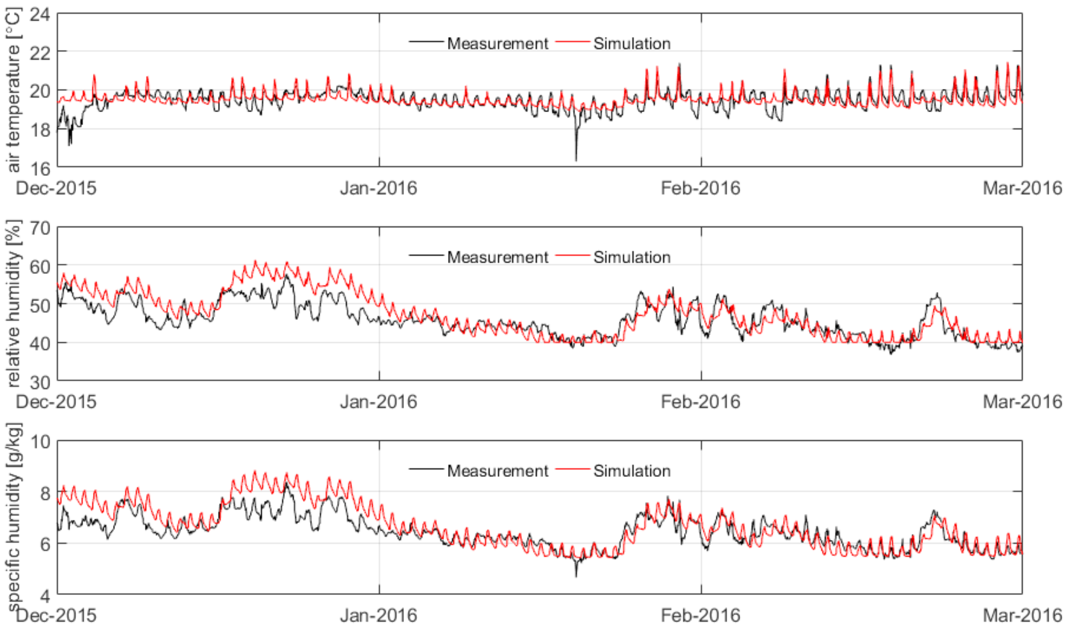

Fig. 1. Calibration results for temperature, relative humidity and absolute humidity.

Table 1. Simulated results for setpoint strategies based on ASHRAE's climate classes for the year 2015.

Strategy	Setpoints [4]	Maximum fluctuations and gradients		Discomfort [h]	Specific risk assessment [2]				Energy	
		Short fluctuations	Seasonal adjustments		M	LM	BL	PL	Total [kWh/m²/a]	Savings [%]
Reference	T_{sp}=20.5 ˚C R_{sp}=50 %	T_{sp}±1.5 K R_{sp}±10 %		1833		1.05			84.55	0
AA	AA	T_{sp}±2 K R_{sp}±5 %	T_{sp} up 5 K down 5 K R_{sp} no change	2081		1.02			32.59	-61
A	As	T_{sp}±2 K R_{sp}±5 %	T_{sp} up 5 K down 10 K R_{sp}= up 10 % down 10 %	2081		1.05			24.93	-71
	A	T_{sp}±2 K R_{sp}±10 %	T_{sp} up 5 K down 10 K R_{sp} no change	2081		1.05			22.05	-74
B	B	T_{sp}±5 K R_{sp}±10 %		2151		1.01			3.35	-96
C	C	T_{sp}<30 ˚C 25 %<R_{sp}<75 %		2154		1.02			0.63	-99
D	D	R_{sp}<75 %		2154		1.02			0.63	-99

Table 2. Simulated results for second set of setpoint strategies for the year 2015. Conditioned according to T_{sp} = ATG during opening hours and ASHRAE's museum indoor climate classes during closing hours; for RH_{sp} ASHRAE's climate classes are used.

Strategy	Setpoints		Discomfort [h]	Specific risk assessment [2]				Energy	
	T [˚C] (opening hours [7]/closing hours [4])	RH [%]		M	LM	BL	PL	Total [kWh/m²/a]	Savings [%]
Reference	20.5	50	1833		1.05			84.55	0
AA	ATG/AA	AA	300		1.01			82.50	-2
As	ATG/As	As	300		1.02			79.80	-6
A	ATG/A	A	300		1.01			76.32	-10
B	ATG/B	B	240		1.01			71.54	-15
C	ATG/C	C	240		1.02			67.87	-20
D	ATG/D	D	240		1.02			67.82	-20

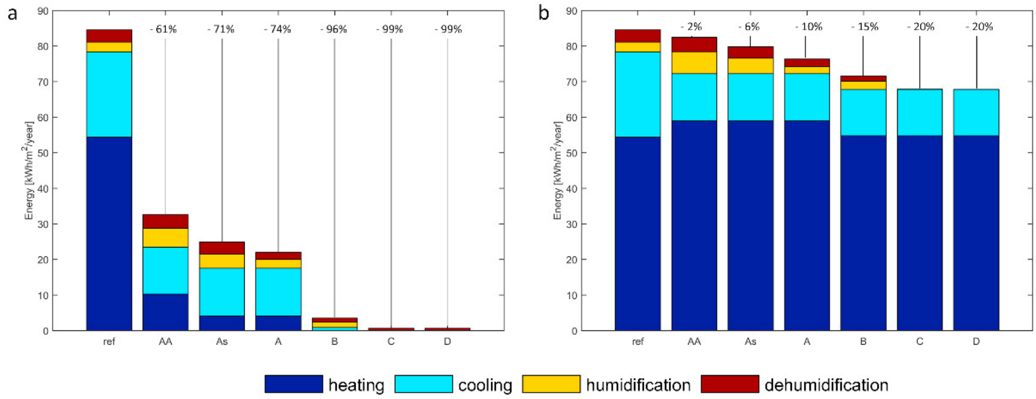

Fig. 2. (a) Specifications of energy demand and energy savings per ASHRAE climate class; (b) Conditioned according to T_{sp} = ATG during opening hours and ASHRAE's museum indoor climate classes during closing hours; for RH_{sp} ASHRAE's climate classes are used.

4. Conclusions

- Conditioning indoor climate T and RH according to ASHRAE's climate classes shows a significant decrease in energy demand compared to the reference study. Though climate classes AA - B provide a favorable indoor climate for museum objects preservation, discomfort hours for visitors and staff increase drastically.
- Allowing a seasonal adjustment for T within object-based climate conditioning provides a relatively large decrease in heating and cooling demand.
- Taking thermal comfort into account and condition during opening hours with the ATG for museums, energy savings become less compared to ASHRAE only control strategies. However, a significant decrease in discomfort hours is visible and the specific risk assessment shows no increased risk to object degradation principles.
- The influence of the quality of the building envelope on spatial stratification of indoor climate parameters needs further investigation.

Acknowledgements

The authors would like to thank the Amsterdam Museum for their co-operation. The authors also would like to thank the TU/e Building Physics and Services Laboratory for the experimental set-up.

References

[1] J. P. Brown and W. B. Rose, "Development of humidity recommendations in museums and moisture control in buildings," *APT Bull.*, vol. 27, no. 3, pp. 12–24, 1996.

[2] M. Martens, "Climate risk assessment in museums," Eindhoven University of Technology, 2012.

[3] R. Kramer, H. Schellen, and J. van Schijndel, "Energy Impact of ASHRAE's Museum Climate Classes: A Simulation Study on Four Museums with Different Quality of Envelopes," *Energy Procedia*, vol. 78, pp. 1317–1322, 2015.

[4] ASHRAE, *2011 ASHRAE Handbook HVAC Applications Building Operations and Management*. 2011.

[5] R. P. Kramer, M. P. E. Maas, M. H. J. Martens, A. W. M. van Schijndel, and H. L. Schellen, "Energy conservation in museums using different setpoint strategies: A case study for a state-of-the-art museum using building simulations," *Appl. Energy*, vol. 158, pp. 446–458, 2015.

[6] R. Kramer, L. Schellen, M. Doornbos, and H. Schellen, "Adaptive Temperature Limits for air conditioned museums in temperate climate regions based on measurements and 1200 + surveys," *Proc. 14th Int. Conf. Indoor Air Qual. Clim. (Indoor Air 2016)*, no. September, pp. 1–2, 2016.

[7] Royal Netherlands Meteorological Institute [Online]. Available: http://www.knmi.nl.

[8] Eltek [Online]. Available: http://www.eltekdataloggers.co.uk./.

[9] A. W. M. van Schijndel, "Integrated Heat Air and Moisture Modeling and Simulation.," Eindhoven University of Technology, 2007.