Conservation Heating to Control Relative Humidity and Create Museum Indoor Conditions in a Monumental Building.

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ABSTRACT

For the conservation of an important museum collection a controlled indoor climate is necessary. One of the most important factors is controlling relative humidity. Museum collections often are part of the interior of a historic building. In most cases the installation of an expensive air-conditioning system may cause damage to the building and its historic authenticity. Furthermore humidifying may lead to dramatic indoor air conditions with mould and condensation effects on the cold indoor surfaces or even internal condensation in the construction. One way to overcome this problem is to make use of so-called 'conservation heating'. A humidistat to limit relative humidity controls the heating system. Conservation heating control was first tested in an experimental set-up in the laboratory and experience was gained in a historic building in the Netherlands. Control strategies and regimes were tested both by experiment and by simulation. The simulation model is validated by measurements. In the historic building the indoor climate was monitored during a long period. The preservation conditions of the indoor climate on the collection and the monumental building were evaluated. The indoor climate for preservation of a monumental building and its monumental interior may be improved by conservation heating. The human comfort however may decline. Furthermore it is a simple and energy efficient system which requires low maintenance.

KEYWORDS

Conservation heating, relative humidity, humidistat, historic building.

INTRODUCTION

Originally, historic buildings did not have any other heating system than open fire or some kind of local heating system. Sometimes a central heating system was installed afterwards. Measurements in one of the most valuable historic buildings prove again that heating during the cold period leads to low indoor RH, causing damage to interior and objects (Neuhaus et al. 2004). Outside the heating season high RH often occurs, also causing risk for damage to interior and objects e.g. by mould growth (Erhardt et al. 1994). In most cases the possibilities to fully control relative humidity in a historic building, e.g. by installing a full air-conditioning system, is limited. Installing mechanical systems and ducts always will cause damage to the building and its historic authenticity. The high installation, maintenance and running costs are not even mentioned. Furthermore humidifying devices may lead to dramatic indoor air conditions with high surface humidity and condensation effects on the cold indoor surfaces of the exterior walls, single glazing and roofs, or even condensation in the construction (Schellen 2002).

The principle of conservation heating is controlling the heating system using a humidistat device (Staniforth et al. 1994). High relative humidity is prevented by starting heating. Reaching low relative humidity during the cold season is prevented by limiting heating to maintain a certain lower temperature setpoint. The use of this control however is restricted. In summer it may be necessary to start heating and during wintertime it may be necessary to limit heating, causing thermal discomfort of occupants. In the Netherlands there is little experience with conservation heating. The objective of this research is to determine the suitability of conservation heating in the Dutch climate and optimizing the control strategy.

OBJECTIVES

Prior to testing on site in a historic building comprehensive laboratory testing was performed. First objective of this pre-testing was to develop a general validated simulation model for conservation heating to gain insight in the effect on the indoor climate, control strategies, needed heating capacities and optimal setpoints. Furthermore was investigated how to provide limited comfort during the use of conservation heating. Simulations were performed using the heat and moisture model HAMBASE (Wit 2006) coupled to Matlab Simulink (The Mathworks 2006). These tests included an experiment in a building on the campus with well determined physical boundaries and well defined material properties.

Second objective was to gain experience in the needed materials and instruments for the experimental setup in the real monument by building a set-up in the test-site on the campus.

Third objective in the research was to construct a heat and moisture simulation model for the historic building to predict the suitability of conservation heating for this specific case. The building model is validated with measurements from earlier monitoring.

Fourth objective is testing with an experimental setup in the real monument. Testing started during the cold winter months and will be continued for a full annual cycle. During these tests valuable data is gained to fine tune models with and to gain more experience on the interaction between climate and building physics.

METHODS

Modeling conservation heating

The indoor climate is simulated using HAMBASE. The control strategy in the humidistatically controlled room is based on the flowchart as given by Figure 1 and modeled using Simulink (Schijndel et al. 2003). First is checked if the room temperature is higher than the set minimum temperature Tmin. If not so, the heater is switched on. Next is checked if the temperature is below the set maximum temperature. If not so the heater stays off regardless of RH conditions. If temperature is between the setpoints of minimum and maximum temperature, the controller continues to check if correction of RH is acquired by checking if the current RH is higher than the set maximum RH. If so, the controller switches the heater on until the relative humidity is below RHmax or the temperature Tmax is reached. In historic

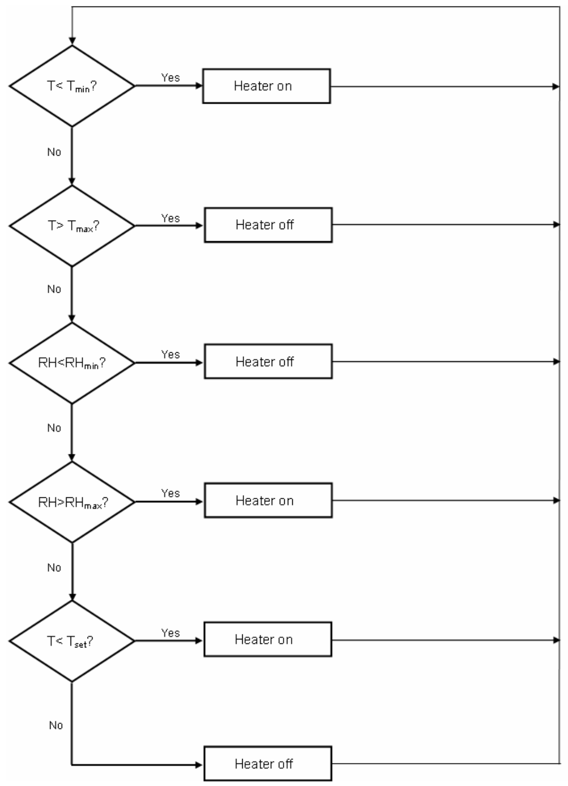


Figure 1 Flowchart of conservation heating with limited comfort function

buildings where human comfort is needed, the possibility is investigated to provide limited thermal comfort by slightly expanding the controller. If RH is between RHmin and RHmax, heating is possible to raise indoor temperature and increase thermal comfort. The heater will stay switched on until RHmin or the desired comfort temperature Tset is reached.

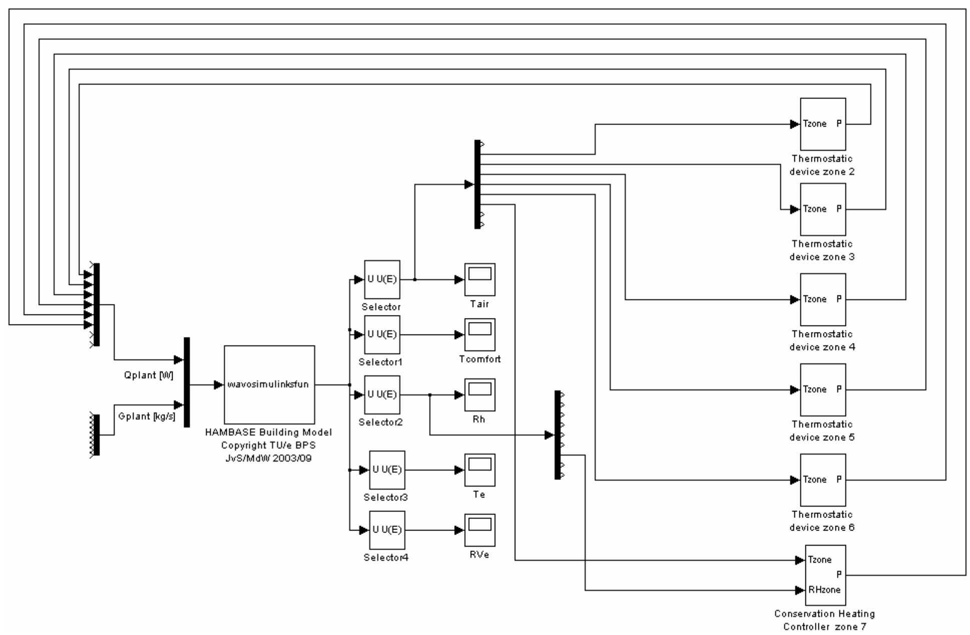


Figure 2 The complete Simulink model

An image of the complete Simulink model is given in Figure 2. The largest block contains the HAMBASE building model. The blocks at the right side are the conservation heating controller and conventional thermostatic devices of the different zones of the model. The structure of the conservation heating controller is shown in Figure 3. The inputs of this block are temperature and RH of the to be controlled zone. Dependent on the input values the condition is checked if heating is required according to the conditions as given in Figure 1. The output of the controller is zero or, if heating is required, the set heating capacity for this zone.

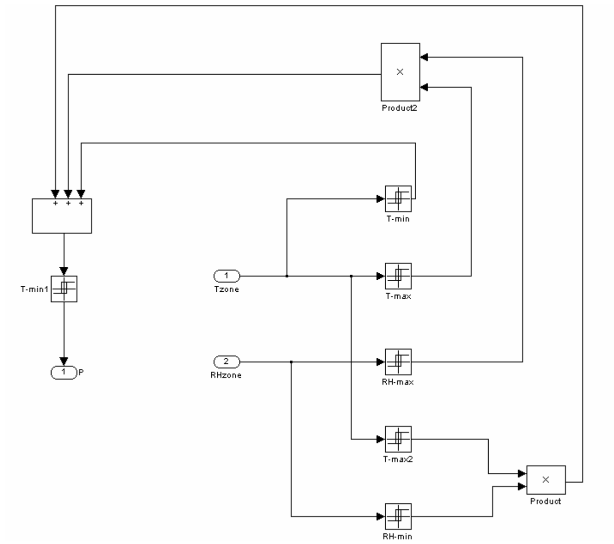


Figure 3 Structure of the conservation heating controller in Simulink

Setpoints of both controllers are given in TABLE 1. Settings of the thermostatically controlled room are set to a constant temperature of 17°C to avoid fluctuations. Air exchange rate in the rooms is not measured and is set to an estimated value of 0.8 times per hour.

TABLE 1

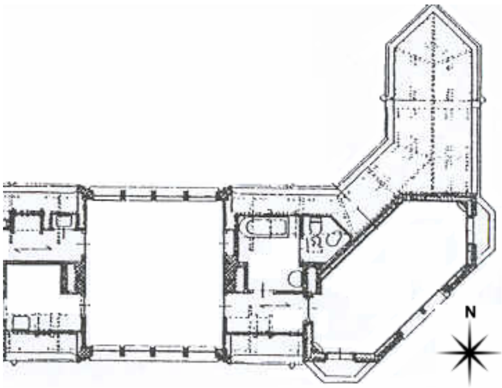
Setpoints for the controller devices in the model

Thermostatically controlled room		Humidistatically controlled room	
Start daytime	8 a.m.	Tmin	10°C
Start nighttime	10 p.m.	Tmax	25°C
Tday	17°C	Tset	17°C
Tnight	17°C	RHmin	45%
		RHmax	55%

Experimental set-up

For an experimental set-up two similar rooms in the historic building were selected on the first floor. The building is T-shaped and made out of masonry with concrete floors and single glazing. During testing this part of the building was unused and doors and windows remained closed. There were no known moisture sources in the building.

Sun blinds were closed for about 60% during testing (



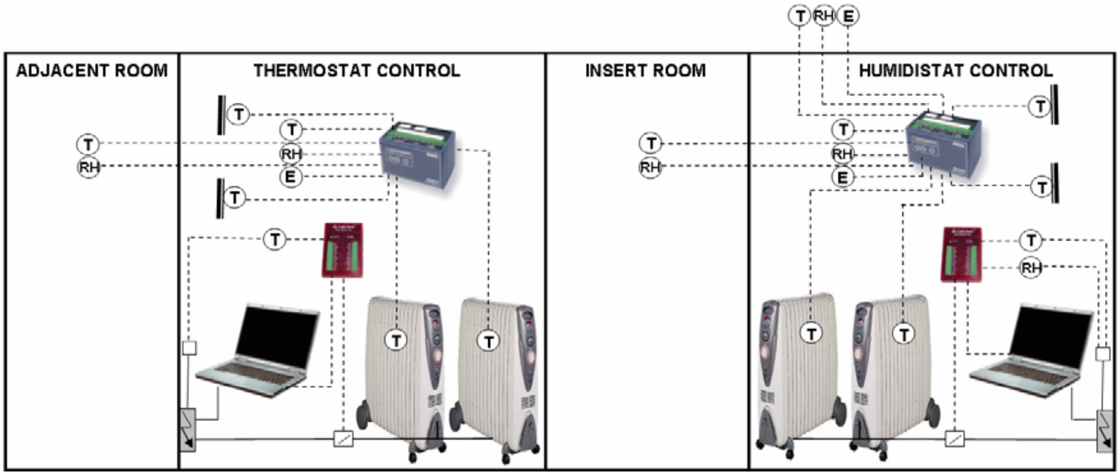
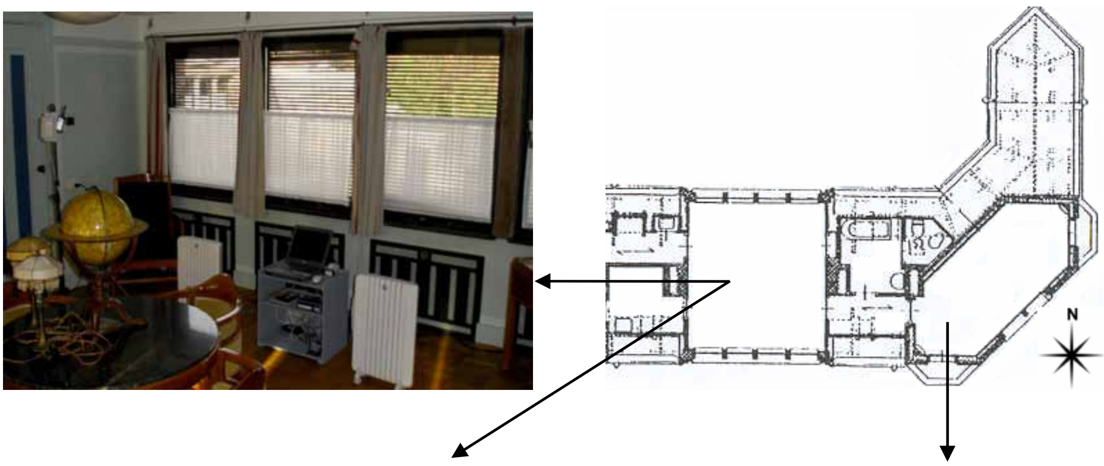


Figure 4). The configuration used for the experimental set-up consisted in each room of a laptop computer for control, three oil filled electrical heaters of 3 kW each and a combined T/RH-sensor. The existing central heating system was switched off for these rooms. In one room the set-up was installed to heat the room according to conservation heating. The software was programmed according to the flowchart as shown in Figure 1. Every 10 seconds the software ran a loop with current temperature and relative humidity as input.



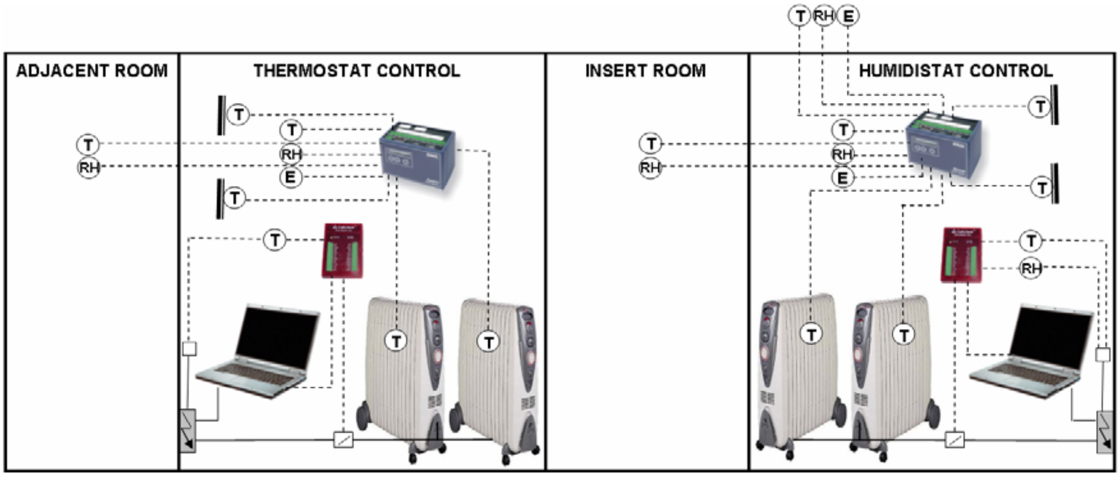


Figure 4 The upper left image shows the set-up in the thermostatically controlled room. A floor plan of the two rooms the set-up was installed in is given by the upper right image. A schematic representation of the configuration of the test set-up is also given

In another similar room the set up was installed to thermostatically heat the room. Setpoints of both controllers were likewise as shown in TABLE 1. The thermostatically controlled room day temperature is set to the same value as the night temperature. This is done to avoid deliberate fluctuations of RH in the historic interior and thereby limiting the risk of any damage done to the interior during the experiment. The electrical radiators were controlled by a simple on/off switch. Additional heat production was limited by using only a laptop computer per room to control the heaters. In the rooms under investigation indoor air temperature, surface temperature of window and wall, relative humidity and incoming solar radiation were monitored. In adjacent rooms air temperature and relative humidity was measured. Outdoor temperature, relative humidity and solar radiation were also monitored.

RESULTS

Conservation heating model

Figure 5 shows simulation results of relative humidity from January 14th to February 14th 2006 of the humidistatically controlled room in the historic building. Simulation results are validated with measurements. Minor discrepancies occur possibly due to the estimated air exchange rate of 0.8. Visible is that with a Tmin set to 10˚C it is not possible to maintain a minimum of 45% RH due to the low vapor ratio of the outdoor air, which mostly occurs during wintertime (Figure 5: 22/01 – 04/02). Over the simulated period Tmin has to be lowered to about 4˚C to maintain 45% RH in the Dutch climate.

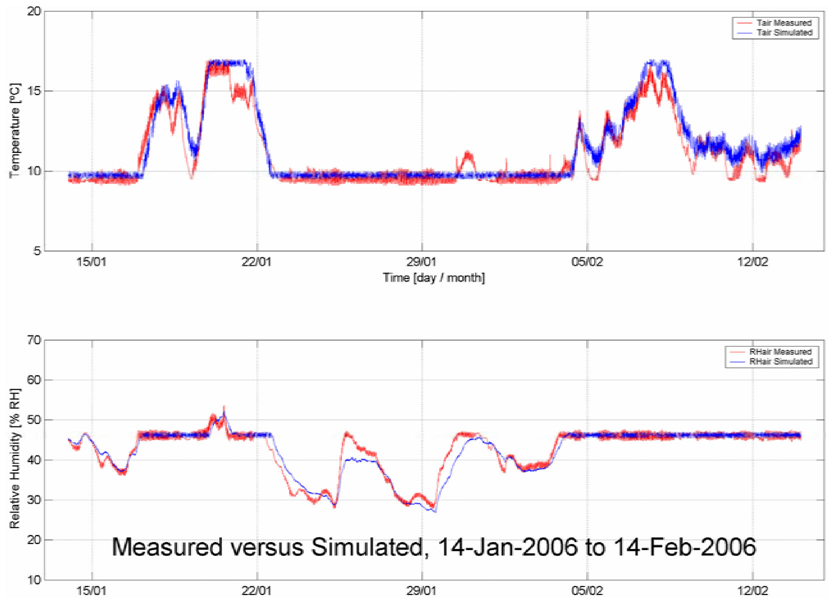


Figure 5 Simulation results of temperature and relative humidity in the humidistatically heated room over the period from January 14th to February 14th 2006

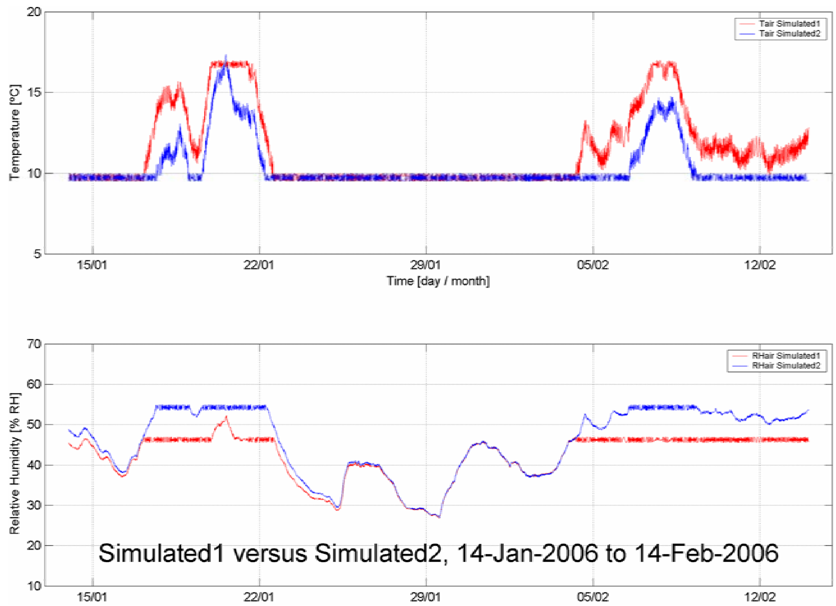


Figure 6 Simulation results of RH when limited comfort is provided and when not

In Figure 6 simulation results of RH and temperature are shown if the room is humidistatically heated with (simulation 1) and without (simulation 2) the limited comfort function. Without using the comfort function heating is only necessary to obtain the lower temperature limit or to limit high RH. During times that RH is between limits (Figure 6: 17/01–23/01 and 04/02-14/02), heating is started to reach the set value of 17˚C to provide limited comfort. The temperature level to which the room temperature can be raised is strongly dependent on the conditions of the outdoor climate however. If no comfort is desired heating is only necessary to maintain the lower temperature boundary or to lower RH. This results in a reduction of the use of energy and installation components which promotes longevity.

In TABLE 2 annual energy expenditure of three different heating strategies is compared. Values are obtained by simulation using the outdoor climate data of the year 2005. Results show that conservation heating without limited comfort function uses about 30% less energy in comparison to a thermostat control.

TABLE 2

Estimation of the annual energy use in 2005 by HAMBASE

Heating Strategy	Annual energy use [kWh]
Conservation heating without limited comfort function	4329
Conservation heating with limited comfort function	5431
Thermostatically controlled*	6133

*day temperature 20˚C with 5 K setback between 10 p.m and 8 a.m.

In Figure 7 temperature and RH of the test set-up are plotted in a psychrometric chart both for a thermostatically controlled room as for the humidistatically controlled room.

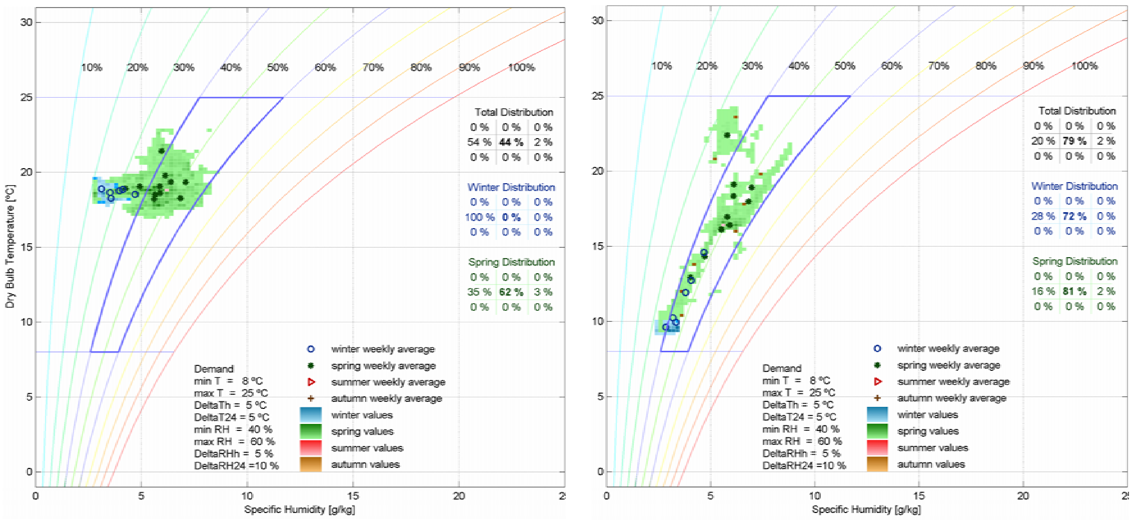


Figure 7 Measured indoor climate for both a thermostatically (left) and a humidistatically controlled room (right) over the period from February 17 to June 11th 2006

In the thermostatically controlled room low RH occurred during periods of low specific humidity (winter time). In the same periods RH in the humidistatically controlled room is higher due to a lower indoor temperature.

RECOMMENDATIONS

Tmin can be set to a low value of about 4˚C to obtain a lower RH limit of around 45% in the Dutch climate. When comfort is required during specific times, the limited comfort function can be used during conservation heating. By expanding the conservation heating controller with a timer it is possible to only heat extra when needed. In this case it is important to use a limiter to prevent quick heating of the room. The use of a limiter in the control is also recommended for situations that the installation restarts after e.g. a malfunction. Our experimental setup showed a side effect when having a room with humidistat control next to a room with thermostat control. This resulted in a wooden door that bend due to the difference in temperature and related RH. It is recommended to reduce these differences. Also literature shows that heating may run out of control in rooms with a small air exchange rate and much hygroscopic materials due to the release of moisture (Padfield 1996).

DISCUSSION

Conservation heating is a proficient technique to create preservation conditions in historic buildings in the Dutch climate. The largest benefit is elimination of extremes in indoor RH. Fluctuations in temperature and RH also are lower compared to thermostatic control with a night setback. Apart from providing improved conservation conditions energy expenditure is far lower compared to conventional heating to provide human comfort. Improved comfort can be provided by limited heating when RH is between desired boundaries. This possibility is strongly dependent on the water vapor ratio (kg/kg) of the outdoor air. Values of the controller have to be selected for minimum use of the heaters, to be energy efficient and promote longevity of the system. Setting can differ per project and are dependent on both building physics and collection. If no comfort is needed the lower temperature setting has to be determined by assessing temperature sensitivity of collection or the presence of water filled pipework. Simulation results show that modeling is a useful tool to predict the impact of conservation heating on the indoor climate. Furthermore modeling is useful to determine optimal controller settings and gain insight in energy expenditure.

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