Conservation Heating for a Museum Environment in a Monumental Building

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ABSTRACT

For the conservation of an important museum collection in a historic building a better controlled indoor climate may be 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 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 verified by measurements. In the historic building the indoor climate was monitored during a long period. 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.

INTRODUCTION

Originally, historic buildings did not have any other heating system than an 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 inner parts of the construction (Schellen 2002).

The principle of conservation heating is controlling the heating system using a humidistat device (Staniforth et al. 1994). Literature on conservation shows that control of relative humidity is more important than control of temperature (Michalski 1998). With conservation heating, relative humidity is stabilized by selective heating. 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.

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OBJECTIVES

The main objective of this research was to determine the suitability of humidistat-controlled heating in the Dutch climate. The Netherlands have a maritime temperate climate with a cool winter, warm summer and an uniform precipitation distribution, *Cfb* according to the Köppen climate classification system (Köppen 1931). In Figure 1 the Dutch outdoor climate for the year 2006 as measured in De Bilt is plotted in the psychrometric chart.

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 on the effect on the indoor climate, control strategies, needed heating capacities and optimal setpoints. An additional objective was to investigate how to provide limited comfort during the use of conservation heating.

Second objective was to gain experience using the needed materials and instruments for the experimental set-up 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 this particular historic building to predict the suitability of conservation heating for this specific case. This building model is validated with measurements.

Fourth objective was testing with an experimental set-up in the real monument. Testing started during the cold winter months and was continued for a full annual cycle. During these tests valuable data and more experience on the interaction between climate and building physics were gained.

METHODS

Modeling conservation heating

Simulations of the indoor climate were performed using the heat and moisture model HAMBASE (Wit 2006) coupled to Matlab Simulink (The Mathworks 2006). The control strategy in the humidistat-controlled room is based on the flowchart as given by Figure 2 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. It is important to limit *Tmax* in order to avoid overheating of the room, e.g. during summertime. 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 buildings where human comfort is needed, the possible provision of limited thermal comfort by slightly expanding the controller is investigated. 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.

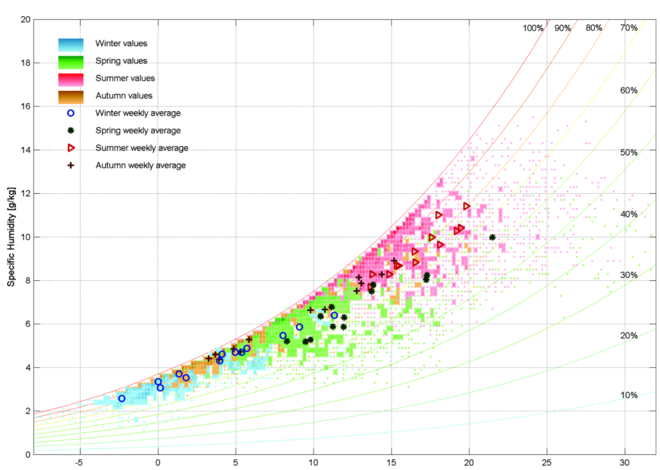

Figure 1 *Dutch outdoor climate data plotted in the psychrometric chart for the year 2006.*

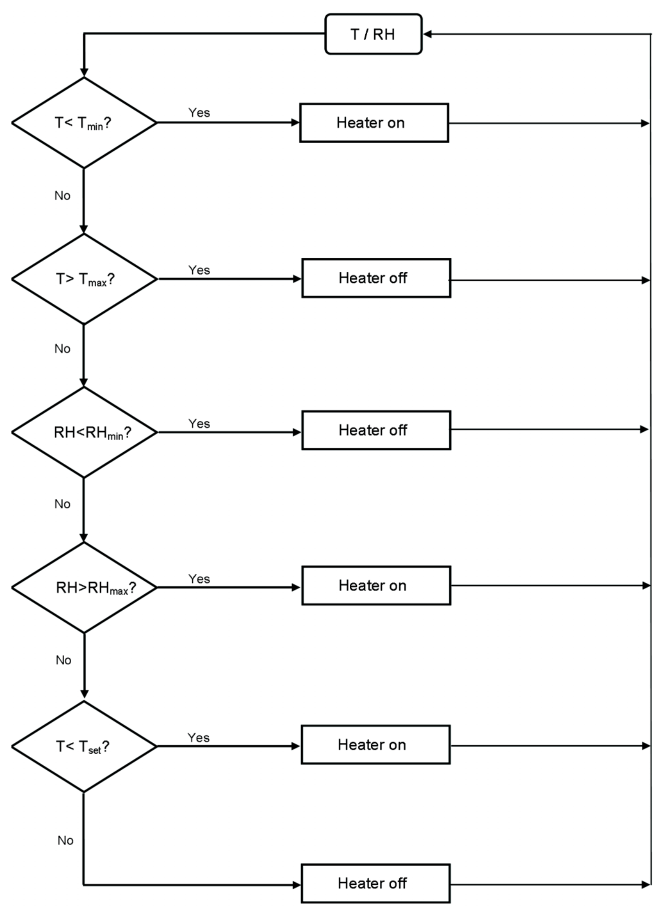

Figure 2 *Flowchart of conservation heating with limited comfort function.*

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 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 2. The output of the controller is zero or, if heating is required, the set heating capacity for this zone.

Setpoints of both controllers are given in Table 1. RH boundaries of the humidistat-controlled room are set to 45% and 55%. These values are chosen to maintain indoor climate conditions between 40% - 60% RH, which gives a moderate risk of mechanical damage to high-vulnerability artifacts (Kelter 2003). Settings of the thermostat-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.

Experimental Set-Up

For an experimental set-up two 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 this part of the building. Sun blinds were closed for about 60% of the window area during testing (Figure 3). The configuration used for the experimental set-up consisted in each room of a laptop computer for control, three electric oil-filled radiators of 1 kW each and a combined T/RH-sensor. The radiators where placed 1 meters off the outside wall. T/RH sensors are mounted on a tripod about

Table 1. Setpoints for the Controller Devices in the Model

Thermostat-Controlled Room		Humidistat-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%

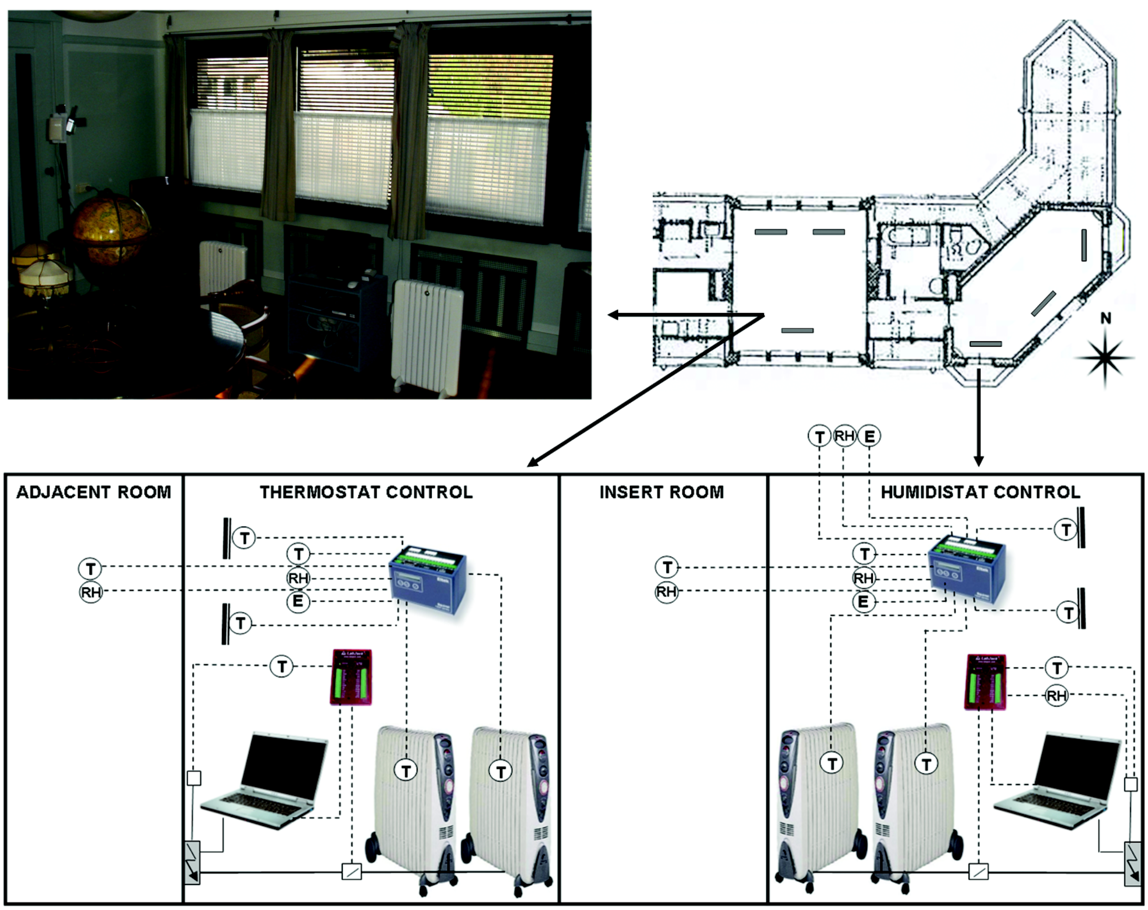

Figure 3 *The upper left image shows the set-up in the thermostat-controlled room. A floor plan of the two rooms where the set-up was installed in is given by the upper right image. This floor plan also shows the locations of the heaters. A schematic representation of the configuration of the test set-up is also given.*

1.50m high, in the middle of the room. 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 2. Every 10 seconds the software ran a loop with current temperature and relative humidity as input.

In another room the set-up was installed to thermostatically heat the room. Setpoints of both controllers were likewise as shown in Table 1. At first, the settings for the thermostat-controlled room were set to a day temperature of 20°C and 15°C during the night. After one week of testing, measurements showed high daily RH fluctuations up to 15% RH caused by the temperature setback at night. Therefore the thermostat-controlled room day temperature is set to the same value as the night temperature after one week. This is done to avoid deliberate fluctuations of RH in the valuable historic interior and thereby limiting the risk of any damage done to the interior during the experiment. The electric radiators were controlled by a simple on/off switch. Additional heat production was limited by using only one 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 4 shows simulation results of relative humidity from January 14th to February 14th 2006 of the humidistat-controlled room in the historic building. In this figure is zoomed in on a one month period to make the control strategy visible. Simulation results are verified with measurements. Minor discrepancies occur possibly due to the estimated air exchange rate of 0.8. Furthermore sensor accuracy plays a role. The accuracy of the used T/RH sensors is given in Table 2.

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 specific humidity of the outdoor air, which mostly occurs during wintertime (Figure 4: 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.

In Figure 5 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 5: 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 indoor air 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

Table 2. Accuracy of the Used Sensors for Measurement and Control

T/RH sensor type	Accuracy	
	Temperature, °C	Relative Humidity (RH)
Eltek GenII GC-10 (measurement)	± 0.15	± 1.4%
Vaisala HMD70Y (control)	± 0.4	± 2.0%

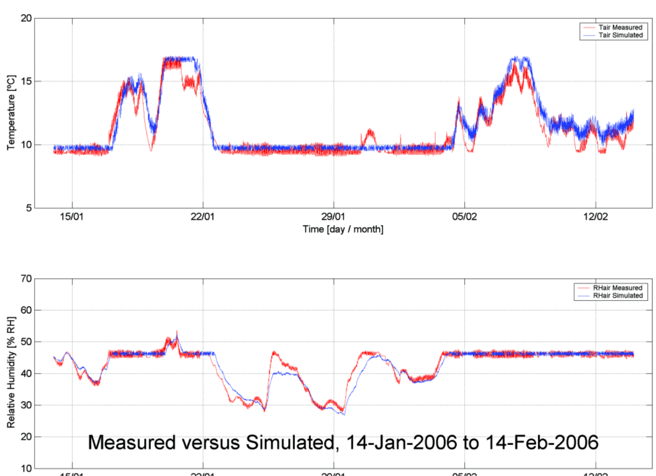

Figure 4 *Simulation results of temperature and relative humidity in the humidistatically heated room over the period from January 14 to February 14, 2006.*

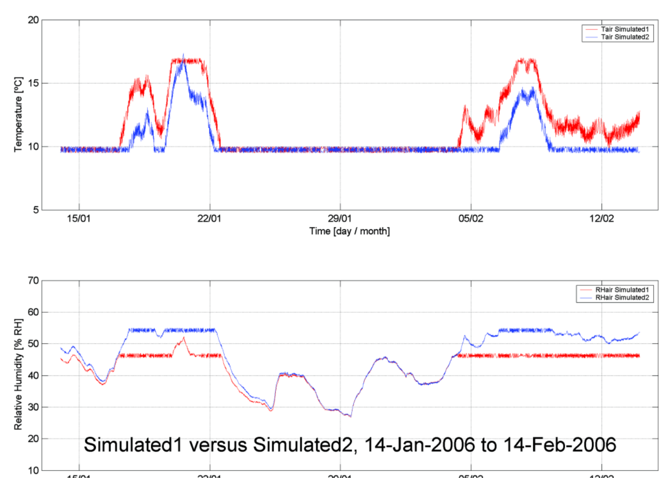

Figure 5 *Simulation results of RH when limited comfort is provided and when not*

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 3 annual energy expenditure of three different heating strategies in an identical room 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 conventional thermostat control.

Table 3. Estimation of the annual energy use in 2005 by HAMBASE considering the same room

Heating Strategy	Annual energy use [kWh]
Conservation heating without limited comfort function	4329
Conservation heating with limited comfort function	5431
Conventional thermostat-control*	6133

* Day temperature 20°C with 5 K setback between 10:00 p.m. and 8:00 a.m.

In Figure 6 temperature and RH of the test set-up and simulation are plotted in a psychrometric chart. This is done both for the thermostat- controlled room as for the humidistat-controlled room.

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

CONCLUSIONS

Conservation heating is an efficient 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 a conventional thermostat-control with a night setback. Apart from providing improved conservation conditions energy expenditure is far lower compared to conventional heating to provide thermal comfort. Improved comfort can be provided by limited heating when RH is between desired boundaries. This possibility is strongly dependent on the specific humidity (kg/kg) of the outdoor air.

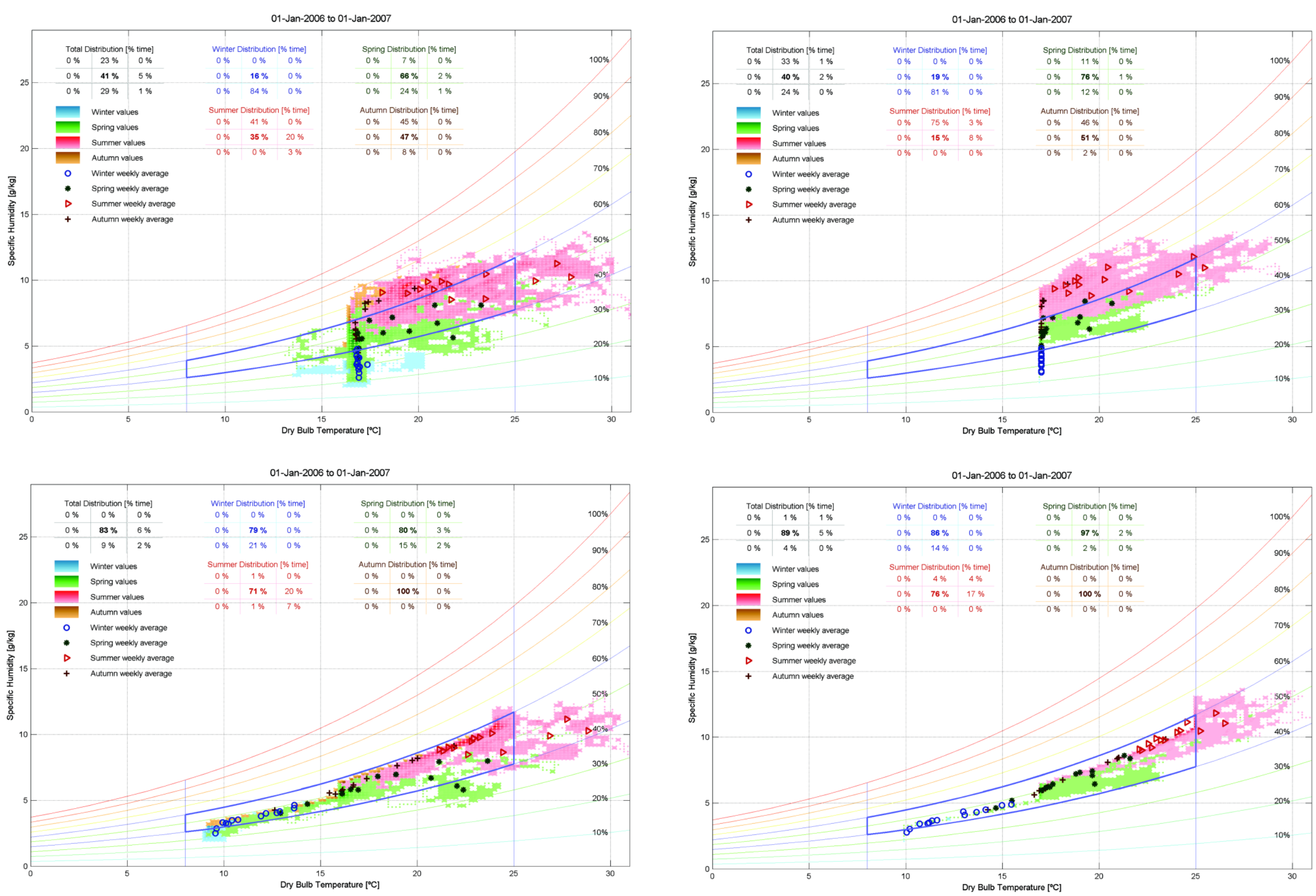

Figure 6 *Measured (left) and simulated (right) indoor climate for both the thermostat (above) and the humidistat-controlled room (below) over the period from January 1, 2006, to January 1, 2007.*

Conservation heating is ideal for historic buildings that are closed for the winter season and do not accommodate highly sensitive artifacts. The choice for the use of conservation heating depends on what is forwarded as being the most important: the comfort of visitors or the value of furnishing and artifacts. If conservation heating is applied in countries with a temperate maritime climate like the Netherlands, thermal comfort during the heating season is low. But if humidistat-controlled rooms are part of a tour, visitors are relatively active and could leave their coats on. If visitors in addition are informed about the system, *Tmin* can be set to a lower value of e.g. 10°C without causing large comfort problems.

If no thermal comfort is desired, values of the controller have to be selected for minimum use of the heaters, to be energy efficient and promote longevity of the system. Settings can differ per project and depend on both building physics and collection. The lower temperature setting has to be determined by assessing the temperature sensitivity of the collection, the presence of water filled pipework and the function of the room. Simulation results show that *Tmin* can be set to a lower 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 during times thermal comfort is desired. 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. Furthermore modeling is useful to determine optimal controller settings and gain insight in energy expenditure.

Our experimental set-up 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 many hygroscopic materials due to the release of moisture (Padfield 1996).

Future work consists of identifying in which climate conditions conservation heating is feasible and where not. Furthermore the effect of indoor moisture sources on the stability of the control will be researched using modeling and an air exchange rate measurement of the building where the test set-up was installed in will be performed.

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