A Sound Indoor Climate for a Museum in a Monumental Building

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ABSTRACT

Museums are often housed in monumental buildings, most of which were not built for this purpose. For preservation of artifacts in a museum, the indoor climate is often restricted to a very narrow interval for temperature, but most of all for relative humidity. This restricted indoor climate originally dates from the 1970s. Unfortunately, restricted museum climates do not fit well into old buildings. The indoor surface conditions near cold walls under winter conditions lead to mold growth and other deterioration of the wall surfaces. Moreover, the museum conditions of artifacts near cold walls are not in line with museum recommendations.

To show the building physical effects of a restricted indoor museum climate on old buildings, case studies were carried out in several Dutch museums. Buildings and their HVAC systems were analyzed in a methodical way. For at least one year, temperature and relative humidity were recorded in different rooms and at different external wall surfaces of the museums. Additionally, outdoor climate, CO_2 concentration, ventilation, and infiltration measurements were performed.

The results of this measurement campaign reveal that there were a large number of indoor climate conditions that did not satisfy the originally formulated restricted climate. There was a large contrast between target indoor museum climate and measured resultant indoor climate in rooms and near external walls.

The target indoor climate in museums that are housed in monumental buildings should be reconsidered. A multidisciplinary network of people involved with indoor climate in museums (conservators; museum, monumental building, and HVAC consultants; and building physicists) has been set up to formulate new guidelines for the indoor climate in Dutch museums. The current ASHRAE guidelines are introduced as an assessment tool for measured climates; results are used to determine the usability of ASHRAE in the Dutch situation and to optimize indoor climate and system performance.

INTRODUCTION

In 2005, the State Inspectorate for Cultural Heritage wanted to know the quality of the indoor climate in Dutch State museums. Furthermore, they were interested in the indoor climate with respect to the original demands on it. The Eindhoven University of Technology (TU/e) started a measurement campaign on the indoor climate in three state museums. The results of these case studies were eye opening. Where a great deal of effort was put into creating an indoor climate with very narrow restrictions on indoor temperature and relative humidity, a number of results were very disappointing. The study concluded that it may not be possible to combine very strict indoor climate conditions with old monumental buildings without improving the thermal quality of the external envelopes.

After the study, it was decided that the recommendations for the indoor climate in Dutch museums, and especially state museums, should be reconsidered. A museum indoor climate network was formed, a PhD study was begun at the TU/e, and recommendations were reformulated.

This paper begins with the measurement and classification method. Then the development of guidelines is discussed. After that, the ASHRAE guidelines are used as assessment

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criteria. Some results of case studies are given. Finally, some conclusions and recommendations are made.

MEASUREMENT AND CLASSIFICATION

For the PhD study, 21 museums were chosen based on their difference in building construction and climate system. Figure 1 displays a schematic overview. Buildings are divided using a scale of complexity of construction: number of materials and method of construction.

For the climate system, type of ventilation (natural/mechanical), thermal potential (heating/cooling), hygrical potential (humidifying/dehumidifying), medium type (water/air/electricity), and control (thermostatic/hygrostatic/both/computer controlled) are also translated into levels of complexity. In all museums, the same approach is used, including permanent measurements of *T* and RH with an interval of 10 minutes over a period of at least 1 year.

DEVELOPMENT OF GUIDELINES

Until now, Dutch museums used guidelines from the Netherlands Institute for Cultural Heritage (ICN). These guidelines, with recommended values for air temperature and relative humidity, were based on the maximum security and lowest risks for humidity-sensitive valuable materials. Museums used these values even for rooms where those materials were not exposed.

Most of these guidelines are derived from *The Museum Environment* (Thomson 1978) dating back to 1978. In this edition, 55% RH is recommended as a safe mean value for mixed collections, with acceptable deviations of plus or minus 5% RH. Thomson indicated that these deviation values were not based on pure research, but that they were values that were feasible for HVAC systems from that time.

The mean recommended 55% RH value was based on the yearly mean expected indoor RH value in buildings in Northern Europe with expectations that fluctuations around 55% RH might be largest without causing damage.

New recommendations for the indoor museum climate go back to the relation between *T* and RH and possible damage to objects of value—a risk assessment approach (Micklenburg and Tumosa 1999; Micklenburg et al. 2004; Ankersmit 2009). In these recommendations, not only the value and sensitivity of objects are important, but also the possible damage to buildings and their exterior envelopes. Based on these considerations, the optimal determined indoor climate does not always have to be the most stringent.

A four-step approach is used in these new recommendations:

1. **Determination of the Value of the Collection and Building.** Possible measures to reduce climate risks for collections have to be weighed against the changed values

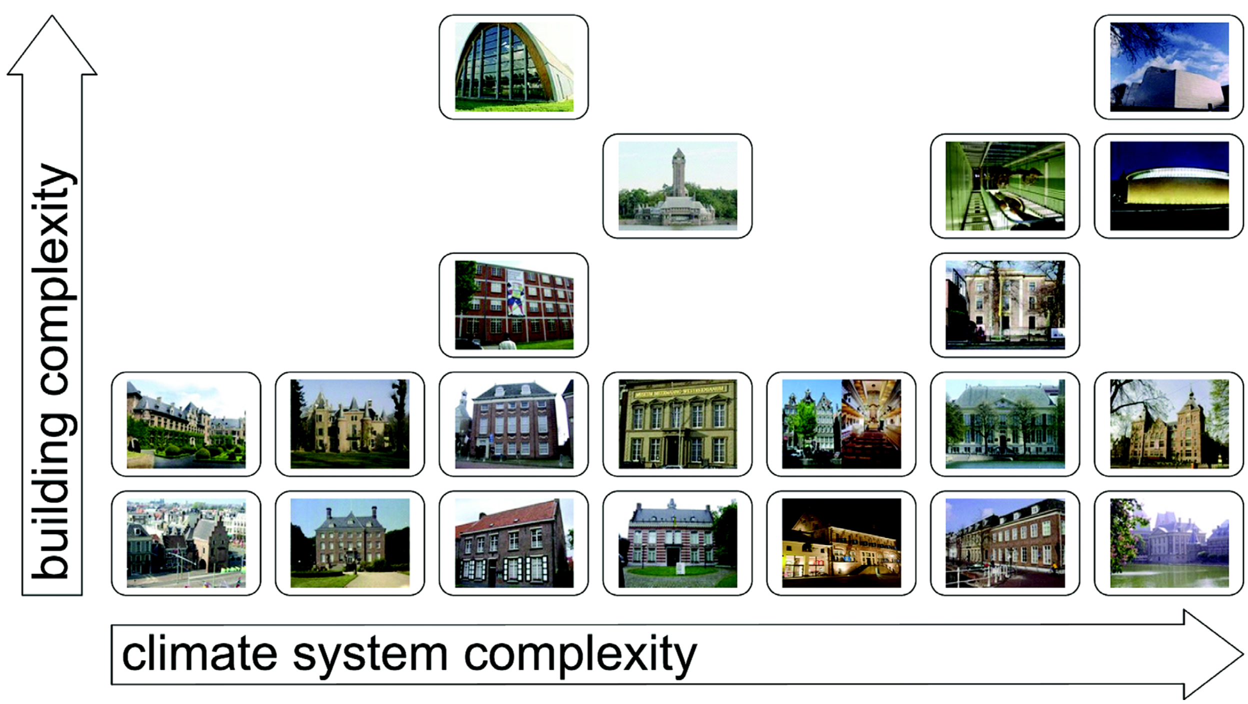

Figure 1 *Twenty-one museums in The Netherlands, chosen based on their complexity in building construction and climate system.*

for the building and collection. The introduction of an HVAC installation or the use of display cases, for example, may change the historical value of a room.

2. **Indoor climate and possibilities of the building.** As can be seen from the case studies, there is a limit to the tolerance of old and monumental buildings regarding allowable RH values. To maintain stringent RH values in these buildings, very drastic building physical measures must be taken regarding things such as inside insulation and airtightness.
3. **Risks to collection**. For each part of the exposed collection, the risks for degradation linked with several climate classes (ASHRAE 2007) have to be determined. Three degradation mechanisms should be considered: chemical, physical, and biological degradation.
4. **Indoor climate control.** An analysis of the most efficient measures to maintain a certain recommended climate around objects of value should be carried out. Models like HAMBASE (de Wit 2006) may be helpful.

ASHRAE MUSEUM CLIMATE ASSESSMENT

The 2007 *ASHRAE Handbook—HVAC Applications* (ASHRAE 2007) provides clearly distinguishable climates when looking into the risks and benefits for mixed collections. These guidelines (Table 1) can also be used to assess measured climate classes.

From indoor climate measurements, yearly average temperature and relative humidity are determined. These averages are used as a historic annual average. Also, the seasonal average (three month running average) is determined for both temperature and relative humidity. According to ASHRAE, temperature setpoint should fall between 15°C and 25°C for comfort reasons. For collection purposes, however, the temperature is allowed to be lower than 15°C. Therefore, the choice is not to include these temperature restrictions.

Each climate class is now considered separately. The seasonal drift is compared to the allowed drift and changed accordingly. The value for the allowed short fluctuations is used to shift the running average up and down; this determines the actual bandwidth.

Figure 2 gives an example of comparing a data set to ASHRAE climate Class A with an allowed seasonal change in RH (in Table 1 this is called "As"). Graphs 1 show temperature and humidity over time. Graphs 2 show the calculated yearly average and the seasonal (three month) running average using Equation 1 for temperature (RH calculation is similar):

$$T_{running,\,i} = \frac{1}{n+1}\sum_{a=i-\frac{1}{2}n}^{i+\frac{1}{2}n} T(a) \qquad (1)$$

where

$T_{running}$ = seasonal running average temperature, °C
n = number of data points in one season, dimensionless
i = current data point in data range, dimensionless
a = data point in original temperature data, dimensionless

Table 1. ASHRAE Climate Classes AA, A, B, C, and D [4]

<table>
<tr><th>Setpoint or Annual Value</th><th colspan="3">Maximum Fluctuations and Gradients in Controlled Spaces</th></tr>
<tr><th></th><th>Class of Control</th><th>Short Fluctuations
Plus Space Gradients</th><th>Seasonal Adjustments
in System Setpoint</th></tr>
<tr><td rowspan="6">50% RH (or historic annual average for permanent collections)

Temperature set between 15°C and 25°C

Note: Rooms intended for loan exhibitions must handle setpoint specified in load agreement, typically 50% RH, 21°C, but sometimes 55% or 60% RH</td><td>AA
Precision control;
no seasonal RH changes</td><td>±5%RH, ±2 K</td><td>RH no change;
Up 5K; down 5 K</td></tr>
<tr><td rowspan="2">A
Precision control;
some gradients or
seasonal changes, not both</td><td>As
±5%RH, ±2 K</td><td>Up 10% RH;
Down 10% RH;
Up 5 K; down 10 K</td></tr>
<tr><td>A
±10% RH, ±2 K</td><td>RH no change;
Up 5 K; down 10 K</td></tr>
<tr><td>B
Precision control;
some gradients plus
winter temperature setback</td><td>±10%RH, ±5 K</td><td>Up 10% RH;
Down 10% RH;
Up 10K but not above 30°C, down as low as necessary to maintain RH control)</td></tr>
<tr><td>C
Prevent all high risk extremes</td><td colspan="2">Within 25% to 75% RH year-round;
Temperature rarely over 30°C, usually below 25°C</td></tr>
<tr><td>D
Prevent dampness</td><td colspan="2">Reliably below 75% RH</td></tr>
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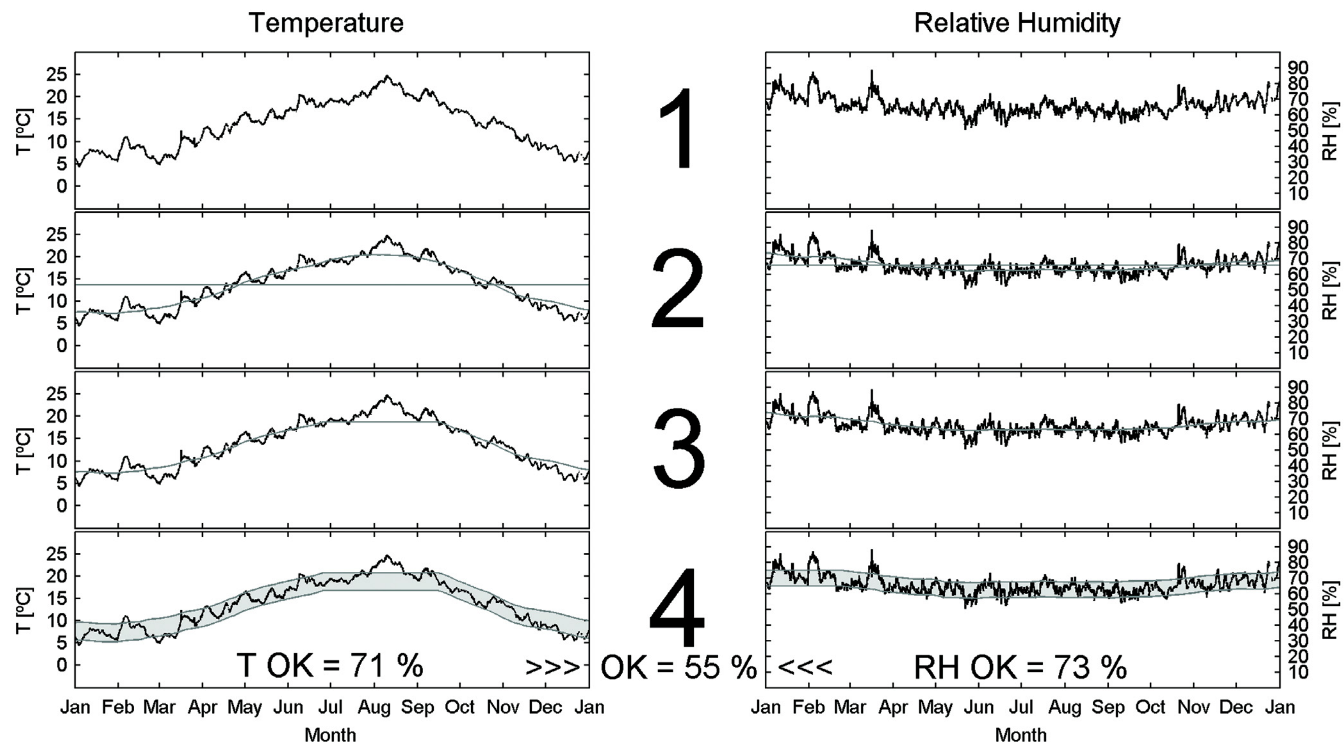

Figure 2 *Measured temperature and humidity compared to ASHRAE class As: (1) shows temperature and humidity, (2) shows yearly average and seasonal running average, (3) displays seasonal running average limited conform ASHRAE A, and (4) shows total bandwidth (curve #3 plus and minus short fluctuations) and percentage of data in this bandwidth.*

In Figure 2, Graphs 3 display the limited running average: seasonal temperature increase is limited to 5 K (occurring in July, August, and September) according to ASHRAE Class A. Graphs 4 show the minimum and maximum curves by moving the limited running average up and down based on short fluctuations. This takes into account changes in T and RH that are faster than one season. The graph also displays the percentage each parameter is within the limits (the grey zone). In the middle, the percentage that both parameters are OK simultaneously is displayed: 55% in this particular case.

This method of comparison is carried out for each class in the ASHRAE table. Although the average T and RH are the same for all climate classes, the differences in allowed seasonal change and bandwidth make sure that for each climate class a different result is obtained. An example of comparison is shown in Figure 3. The black lines display the original data. The grey lines are the minimum and maximum values allowed for each climate class, thus creating a grey area in which the climate is okay according to each ASHRAE specification. In the middle for each climate class a percentage is given. This is the amount of time each class is met (T and RH simultaneously within bandwidth).

In this way, the indoor climate in different rooms or positions in a museum is classified. According to the collection risks and needs, one can decide which are the best positions in a particular museum for typical collection parts.

RESULTS FROM CASE STUDIES

In the results of many case studies a common problem was that the assumed indoor climate for the preservation of the objects was in conflict with the preservation of the external façade. Some examples are given below.

Museum Our Lord in the Attic, Amsterdam

Museum Our Lord in the Attic in Amsterdam is a 17th century building. The museum houses a number of original 17th century authentic rooms and a church shelter. TU/e, together with ICN and The Getty Conservation Institute (GCI), made an extensive analysis of the indoor climate in Maekawa et al. (2007). For conservation of objects, the indoor humidity climate is controlled to about 60% RH by local humidifiers and dehumidifiers, which are used throughout the building. The combination of this rather high relative humidity in combination with low winter surface temperatures of the glazing often led to condensation. These frequent condensation events caused wood rot at the wooden frames just below the glazing. Moreover, some of the wooden beams in the building started to rot at the end of the beams where these are

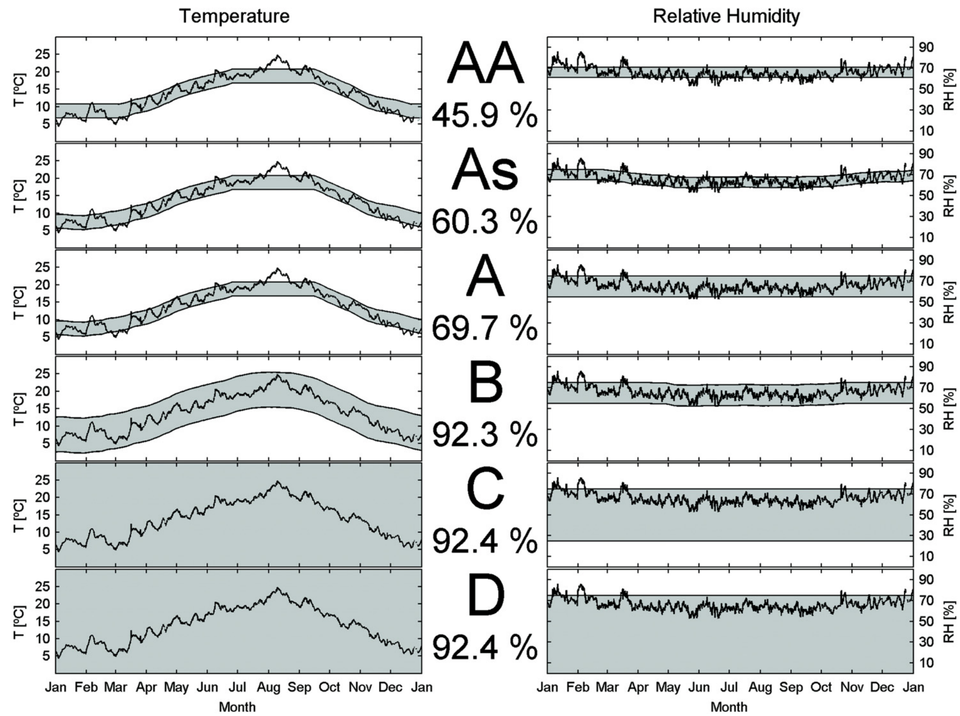

Figure 3 *Comparison of one year of data to ASHRAE climate classes AA to D. The middle percentages correspond to the amount of time the class is met.*

supported by the wall. A number of these beams already have been repaired with epoxy.

Valuable paintings hang on the surfaces of the external walls. During winter, these surfaces are cold, and the relative humidity near these surfaces may be high. One of these paintings can be seen Figure 4. The middle picture shows an infrared thermal image. In this picture, the wall at the left side is relatively warm (red) and is an internal wall. The right side of the wall is relatively cold (blue) and, therefore, the wall changes into an external wall. The painting in front of the wall hangs on a cold external wall. The painting is warmed by the air, and a large temperature gradient can be detected from painting to wall. The right picture is a visualization of the relative humidity. The picture was constructed from the thermal image in connection with the humidity ratio from other measurements. This technique was introduced by Schellen (2002). Table 2 shows the results for the ASHRAE method; near the wall less optimal conditions occur.

Nowadays the humidity ratio in the museum is lowered in combination with a lower air temperature during winter.

Hunting Lodge St. Hubert

Hunting Lodge St. Hubert was designed by the famous Dutch architect Berlage and was built in the period of 1916 to 1922. The building and its collection are a so-called Gesamtkunstwerk. The building is one of the most valuable Dutch monuments, with a priceless interior. Because of this rich interior, there was concern about the indoor climate for preservation. Therefore this climate was monitored over the period of one year. For one of the rooms, the results of these measurements are displayed in a Climate Evaluation Chart (Martens et al. 2007) (see Figure 5). From the graph it can be concluded that during the heating season, relative humidities as low as 10% RH were recorded. These are dangerously low values for the preservation of wooden interior parts such as furniture. Because of the unique character of the interior, visible solutions to improve the indoor climate, such as show cases, humidifiers or HVAC systems, were not usable as alternatives. It was decided to test using conservation heating. The results of these tests were encouraging (Neuhaus and Schellen 2007); Table 3 shows that for each ASHRAE class a better result was obtained just by changing control of the heating system.

CONCLUSION

The museum society needs to let go of the idea of very strict climate guidelines. Each particular ca1se needs an approach in which optimum climate conditions can be determined, which need not be strict per se. Measurements are needed to assess current indoor climates. Effects of these climates on preservation of buildings and objects are determined and, when serious

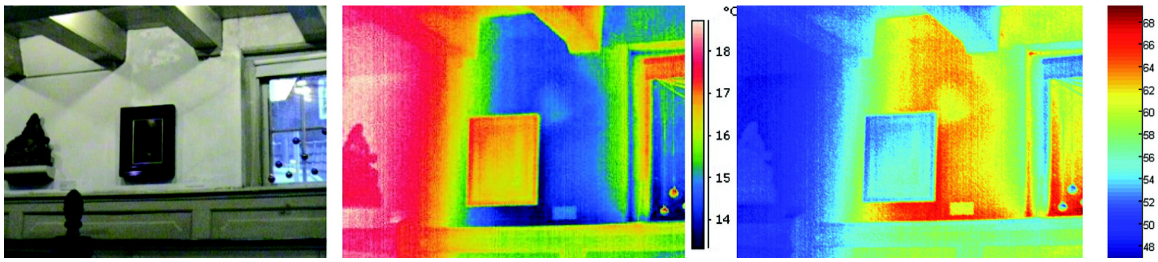

Figure 4 (Left) Painting hanging at an exterior wall, (middle) infrared thermal image, and (right) relative humidity near the painting.

Table 2. Comparison of Room and Wall Conditions, Percentage Compliance with ASHRAE Climate Classes

Position	AA	As	A	B	C	D
Room	35%	55%	65%	94%	100%	100%
Wall	38%	39%	58%	86%	99%	99%

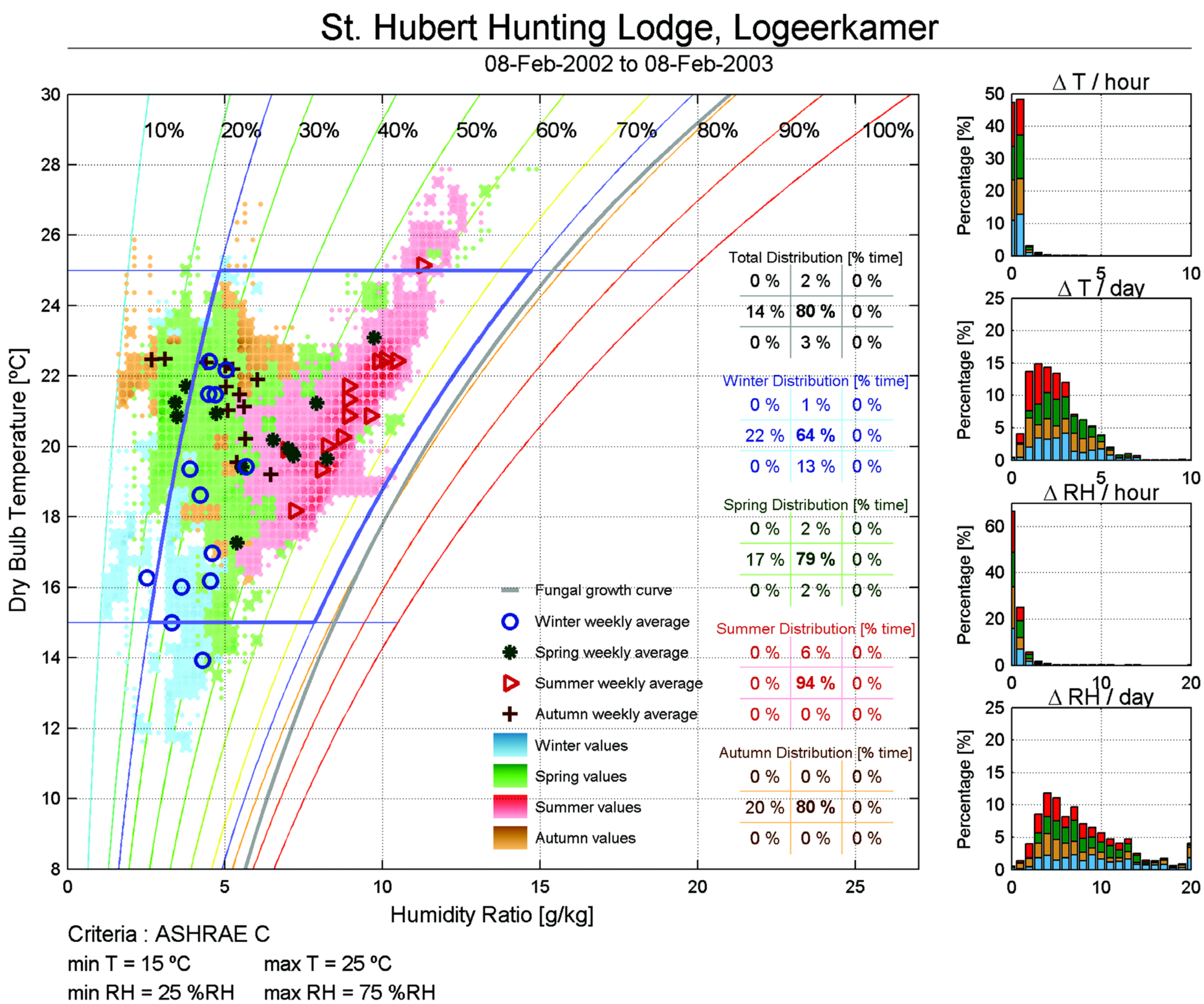

Figure 5 Climate Evaluation Chart of indoor conditions in the guest bedroom.

Table 3. Comparison of Thermostatic and Hygrostatic Heating—Percentage Compliance with ASHRAE Climate Classes

Heating System	AA	As	A	B	C	D
Thermostatic heating	15%	34%	31%	77%	93%	100%
Hygrostatic heating	21%	41%	47%	88%	100%	100%

risks occur, the climate can be tweaked to comply with a higher ASHRAE class. In 2011, a publication about influence of building type and climate system on preventive conservation is expected; also a more object-oriented approach is introduced herein. This approach focuses on biological, mechanical, and chemical degradation separately for some common objects in museums.

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