INDOOR CLIMATE DESIGN FOR A MONUMENTAL BUILDING WITH PERIODIC HIGH INDOOR MOISTURE LOADS

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ABSTRACT

The paper presents a study of the indoor climate of a monumental building with periodic high indoor moisture loads. Several scenarios of the past performance and new control classes are simulated and evaluated. The results include the influence of hygric inertia on the indoor climate and (de)humidification quantities of the HVAC system. It is concluded that: (1) The past indoor climate can be classified as ASHRAE control C with expected significant occurrences of dry (RH below 25%) and humid (RH above 80%) conditions; (2) ASHRAE control C is not suitable for the new hall. The climate control classification for the new hall ranges from B to AA.; (3) The demands on the HVAC system to facilitate pop concerts in the new hall are 40 kW heating power, between 100 and 200 kW cooling power, between 40 and 80 kW humidification power and 125 kW dehumidification power; (4) In case of control class AA, placing additional hygroscopic material has no significant effect. In case of control class B, the placing of additional moisture buffering material (5 air-volume-equivalents) does not decrease the (de)humidification power and it decreases the (de)humidification energy by 5%.

KEYWORDS

Indoor climate, moisture load, model, simulation, monumental building

1. INTRODUCTION

A monumental theatre, formerly used as a cinema, is renovated. The interior of the theatre, containing monumental paintings, wood and plaster, is well preserved. It is concluded that the past heating of the building had no significant impact on the monumental interior. A new destination of the renovated theater is to facilitate (pop) concerts. This will cause a much higher indoor moisture load as before. An important demand is that the indoor climate may not deteriorate compared to the past situation. Currently the building is under construction, so measurement of the original situation is not possible. Therefore simulation is the only tool that can be used to check the indoor climate performances of the past situation and new designs. The objectives of this paper are twofold: (I) Demonstration of the use of a new simulation and visualization tool by: Characterization of the past performance of the indoor climate; classification for the new climate control and calculating the required HVAC capacities. (II) A preliminary study of the effect of moisture buffering on the (de)humidification energy of the HVAC system. The outline of the paper is as follows: Section 2 presents background information on the building and its monumental interior, performance criteria for the indoor climate and the used simulation tool HAMLab. Section 3 provides simulation results of the past indoor climate of the Luxor hall and new designs with and without placing additional hygroscopic material, using the new visualization chart. In Section 4, a discussion on the simulation results is presented. Section 5 shows the conclusions.

2. BACKGROUND

The current building and its monumental interior

The Luxor theatre, designed by Willem Diehl, was built in 1915 at Arnhem (Netherlands). The main hall (volume about 1800 m^3) has no windows. The outdoor walls are made of brick (0.8m) with air gap. The roof is made of tiles. It's monumental interior consists of a wooden stage frame, gypsum/wooden ceiling artifacts and paintings on wood and paper. Figure 1 provides an impression of the building and the hall.

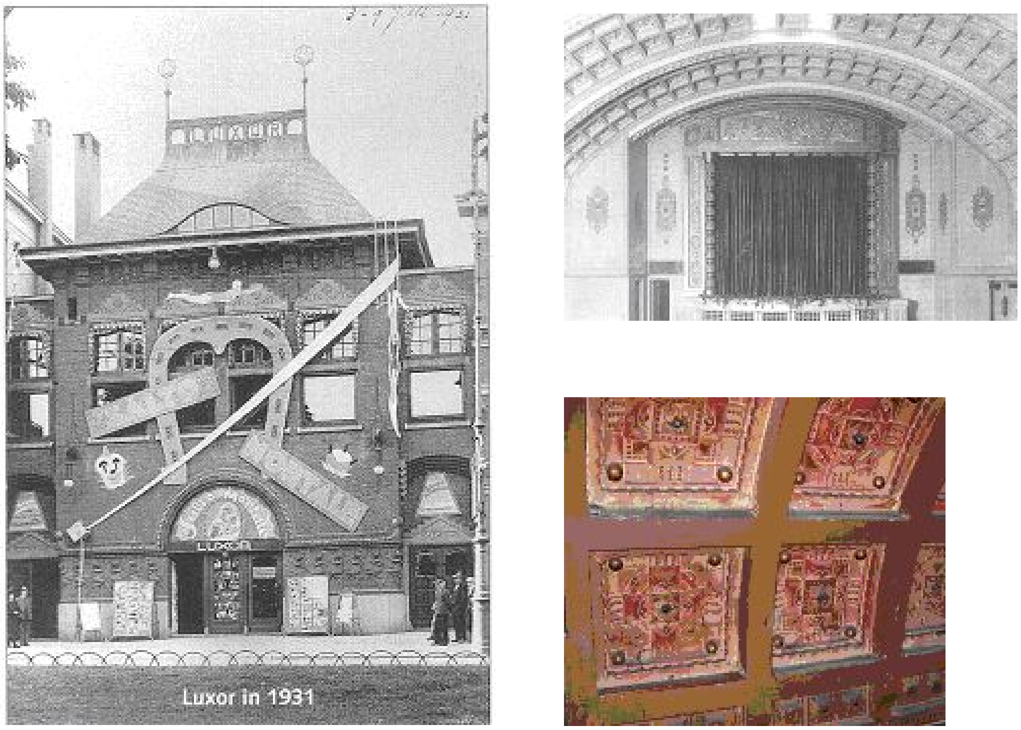

Figure 1: Left: The Luxor Theatre in 1931; Right top: The monumental wooden stage frame; Right bottom: Gypsum/wooden ceiling artifacts.

The performance criteria and classification of the indoor climate

The performance criteria for the indoor climate are based on control classes (ASHRAE 1999). Details can be found in Section 3.

The modeling tool HAMLab

HAMLab (Heat, Air & Moisture Laboratory) is used as simulation tool (van Schijndel & Hensen, 2005). It is implemented in the scientific computation software MatLab. HAMLab provides a collection of models, functions and data to assist scientific computations in the research area 'whole building HAM response and control'. It is also one of the tools involved at the current IEA Annex 41. In this paper, HAMLab is mainly used to simulate indoor climates. Background information on the physics and implementation is provided by (van Schijndel & de Wit, 2005). Validation results are published in: (Schellen 2002), (van Schijndel & de Wit, 2003), (van Schijndel & Schellen 2005).

3. SIMULATION RESULTS

Climate Evaluation Chart (CEC)

All simulated scenarios are presented by Climate Evaluation Charts (CEC). Because there is a lot of information in the chart, an explanation of the CEC is presented now. Figure 2 presents an typical example of a CEC. The interpretation of the chart is explained below (the data itself are not important at this moment)

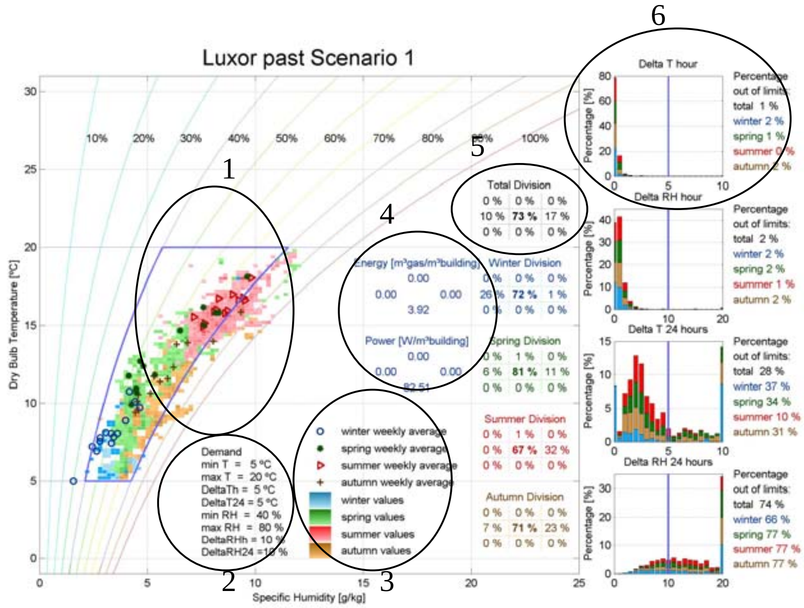

FIG. 2: Example CEC.

Note: Some parts of the CEC rely on color

The <u>background</u> of the chart is a standard psychometric chart for air, with on the horizontal axis: the specific humidity, on the vertical axis: the temperature and curves for the relative humidity. <u>Area 2</u> shows the <u>demanded performance</u> (demands) on: (1) climate boundaries: maximum and minimum temperature and relative humidity (min T, max T, min RH and max RH) and (2) climate change rate boundaries: maximum allowed hourly and daily changes (DeltaTh, DeltaT24, DeltaRHh, DeltaRH24). <u>Area 1</u> shows the climate boundaries and the simulated climate of one (Dutch standard test reference) year. The simulated climate is presented by seasonal (Spring from March 21 till June 21, etc.) colors representing the percentage of time of occurrence and seasonal weekly averages. The colors visualize the climate distribution. For example, a very stable climate produces a narrow spot, in contradiction to a free floating climate which produces a large cloud. <u>Area 3</u> provides the corresponding legend. <u>Area 5</u> shows the total percentage of time of occurrence of areas in the in the psychometric chart (9 areas). In this example 73% of the time the climate is within the climate boundaries; The area to the left (too dry) occurs 10% of the time, the area to the right (too humid) occurs 17% of the time. The climates in the other 6 regions do not occur. <u>Below area 5</u> the same can be found for each season. <u>Area 4</u> shows the energy amount (unit: m^3 gas / m^3 building volume) and required power (unit: W / m^3 building volume) used for heating (lower), cooling (upper), humidification (left) and dehumidification (right), assuming 100% efficiencies. In this example the energy amount is 3.92 m^3 (gas / m^3 building volume) and required power is 82.51 (W / m^3 building volume) used for heating. Cooling, humidification and dehumidification are zero in this example. <u>Area 6</u> presents the occurrence in percentage of time outside the climate change rate boundaries. In the example the demand of maximum allowed hourly change of temperature of 5 (^{o}C/hour) is shown as a blue line. The distribution per season is provided together with the percentage of time of out of limits. In this example, area 6 shows that only 1% of the time, the hourly temperature change rate is out of limits.

This is also specified for each season. Below area 6 the same can be found for the other climate change rate boundaries. All simulation results will be presented below.

Simulated scenarios
All simulations are performed using a test reference year for the Netherlands. The past performance is simulated using two scenarios, representing past periodic and intensive use of the hall. The goal of these scenarios is to simulate worst-case conditions. The results are used for comparison with new control class designs. The future use of the hall includes (pop) concerts. This will cause a much higher moisture load in the hall. This effect is included in all future scenarios. The simulated control class scenarios (ASHRAE, 1999) start with the lowest class, representing the same type of HVAC system as in the past and end with the highest class, representing precision control. Furthermore, extra scenarios are included with the use of additional hygroscopic material. The goal of these scenarios is to study the effect of moisture buffering on the indoor climate, energy amount and required power. After presenting all scenarios the results will be discussed in Section 4.

The hall used as cinema The hall was heated and ventilated by an air system. During a performance (duration 4 hours, 200 sitting people producing 17 kW heat and 2.5 g/sec moisture) the system provided an estimated ventilation rate of 10 ACH. During the day (duration 10 hours, 2 people) this was estimated as 2 ACH and 1 ACH for the rest (including infiltration). In order to estimate the past indoor climate, two extreme scenarios are simulated. The assumption is made that the past indoor climate was somewhere between the next two past scenarios: (1*) periodic use of the hall*: 2 times a week a performance, the hall is only heated during these performances. Furthermore a minimum air temperature of 5 ^{o}C is maintained. (2) *intensive use of the hall*: 6 times a week a performance, the hall is also heated during the day. A minimum air temperature of 10 ^{o}C is maintained. The results are presented in figure 3 and 4.
A control class C design All new designs have to facilitate: (a) 2 concerts a week (duration 4 hours, 700 moving people producing 63 kW heat, 27 g/sec moisture) with a designed ventilation rate of 10 ACH; (b) 3 meetings a week (duration 4 hours, 100 people producing 8 kW heat, 1 g/sec moisture) with a designed ventilation rate of 10 ACH; (c) During the day (duration 10 hours, 10 people, 2 ACH) and 1 ACH for the rest (including infiltration).
First, a control class C design will be evaluated. Class C, defined as ‘prevent all high risk extremes’, usually consists of basic heating and ventilation. Two scenarios are presented: (1) *HVAC system: heating, ventilating, without additional hygroscopic material*, (2) *HVAC system: heating, ventilating, with additional hygroscopic material*. The results are presented in figure 5 and 6 (Note: There are no ‘percentages out of limits’ presented in these CECs, because (ASHRAE) control class C does not specify a limitation of the allowable change rates).
A control class B design Also, a control class B design will be evaluated. Class B, defined as ‘precision control, some gradients plus winter temperature setback’, is usually a HVAC system, including cooling and (de)humidification . Two scenarios are provided: (1) *HVAC system: climate control, without additional hygroscopic material*. (2) *HVAC system: climate control, with additional hygroscopic material*. The demanded performance and results are presented in figure 7 and 8.
A control class AA design Finally a control class AA design will be evaluated. Class AA, defined as ‘precision control, no seasonal changes’, is usually a high-tech HVAC system, including cooling and (de)humidification. One scenario is presented: *HVAC system: climate control*. The demanded performance and results are presented in figure 9.

Periodic use of the hall

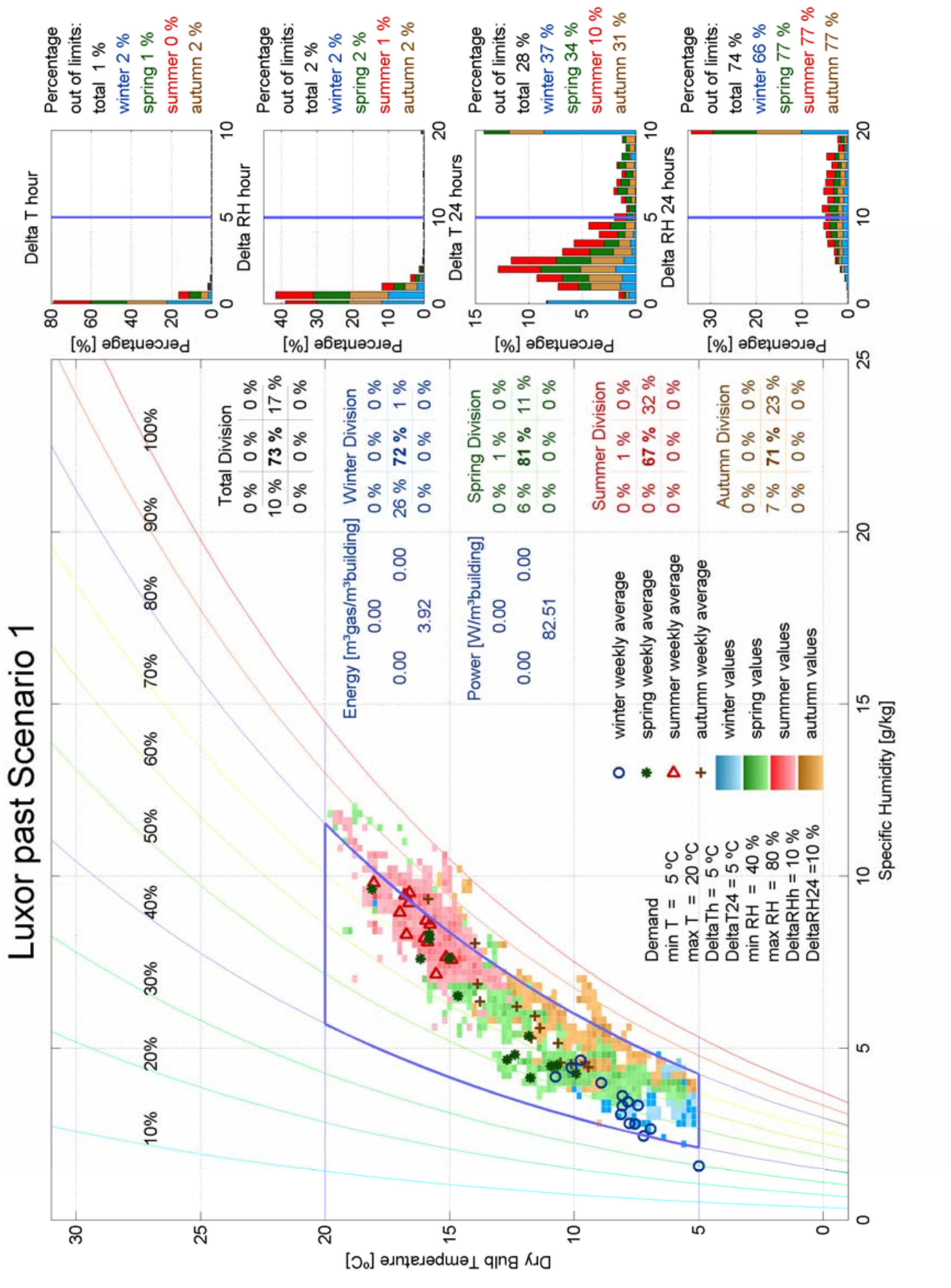

FIG. 3: The CEC of Scenario 'periodic use of the hall'

Intensive use of the hall

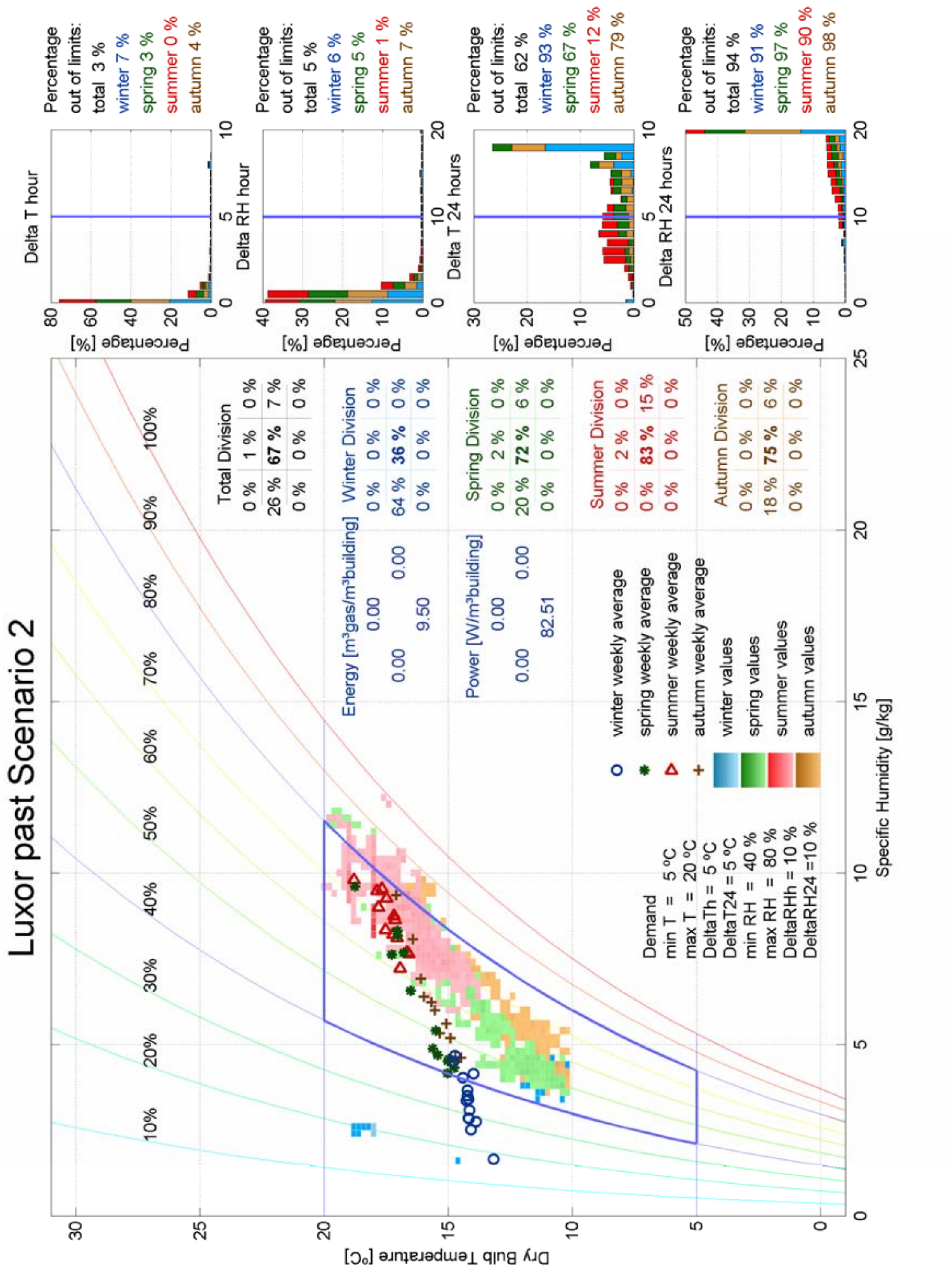

FIG. 4: The CEC of Scenario ‘intensive use of the hall’

HVAC system: heating, ventilating, without additional hygroscopic material

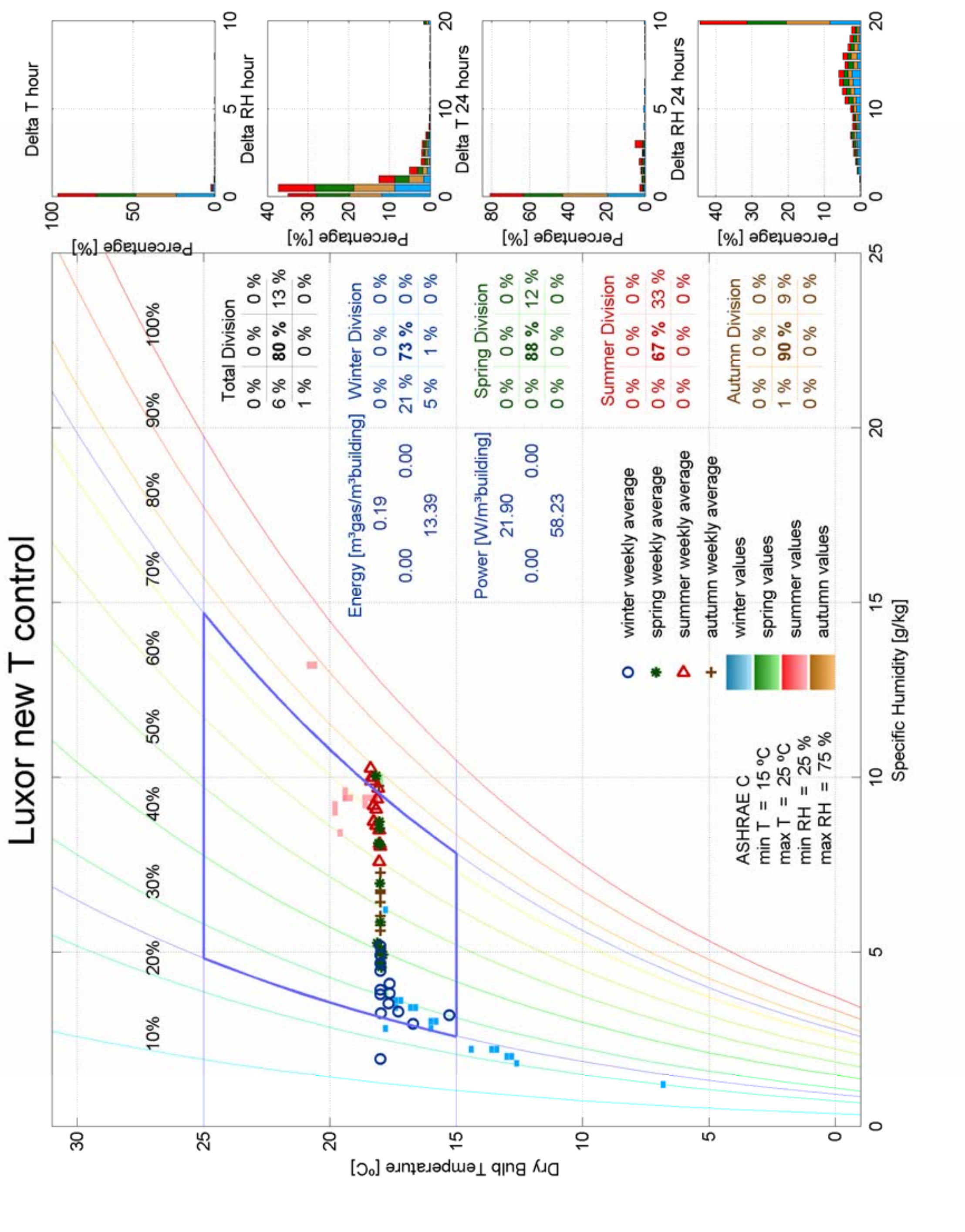

FIG. 5 The CEC of Scenario ‘control class C design without additional hygroscopic material’

HVAC system: heating, ventilating, with additional hygroscopic material

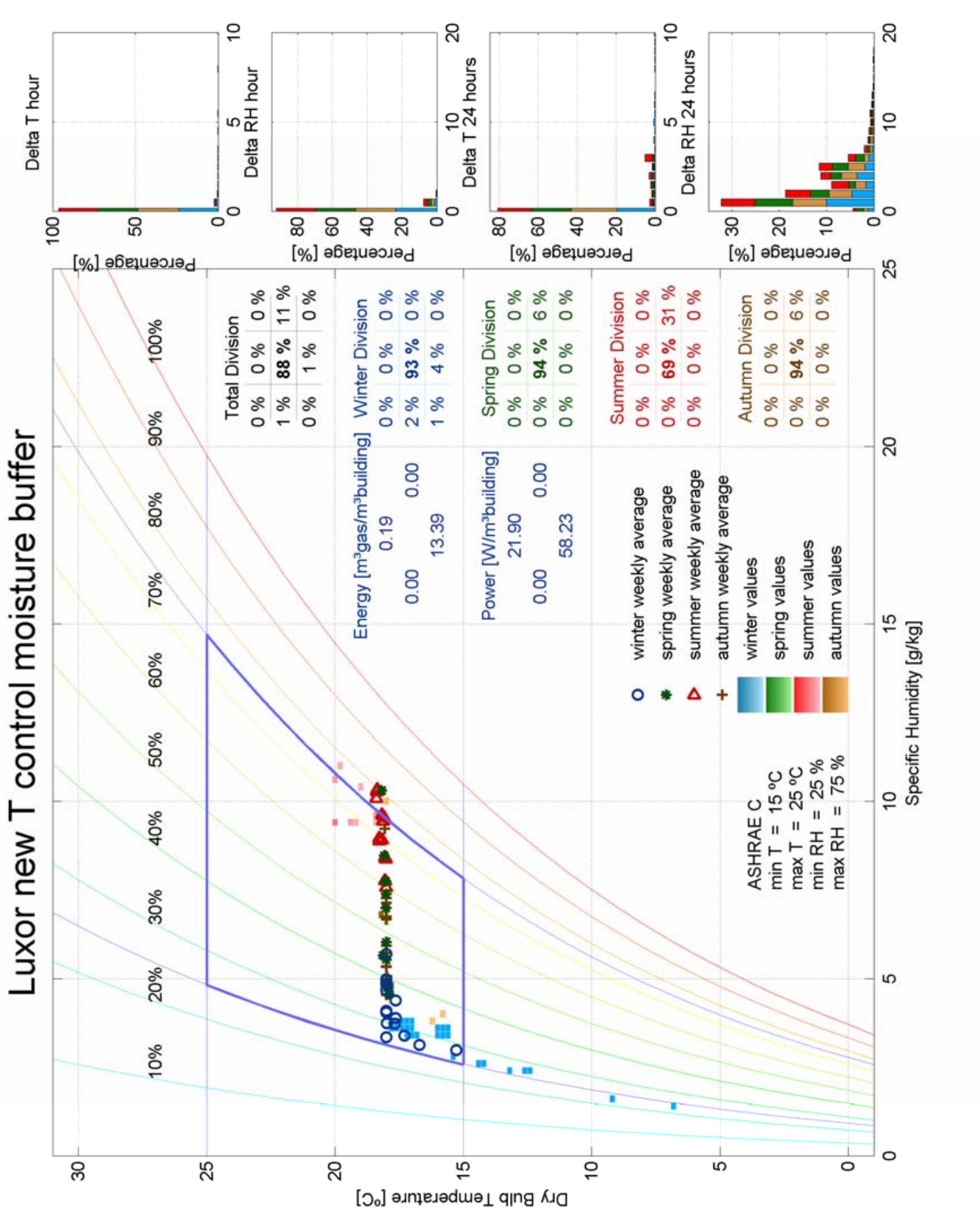

FIG. 6: The CEC of Scenario ‘control class C design with additional hygroscopic material’

HVAC system: climate control B, without additional hygroscopic material

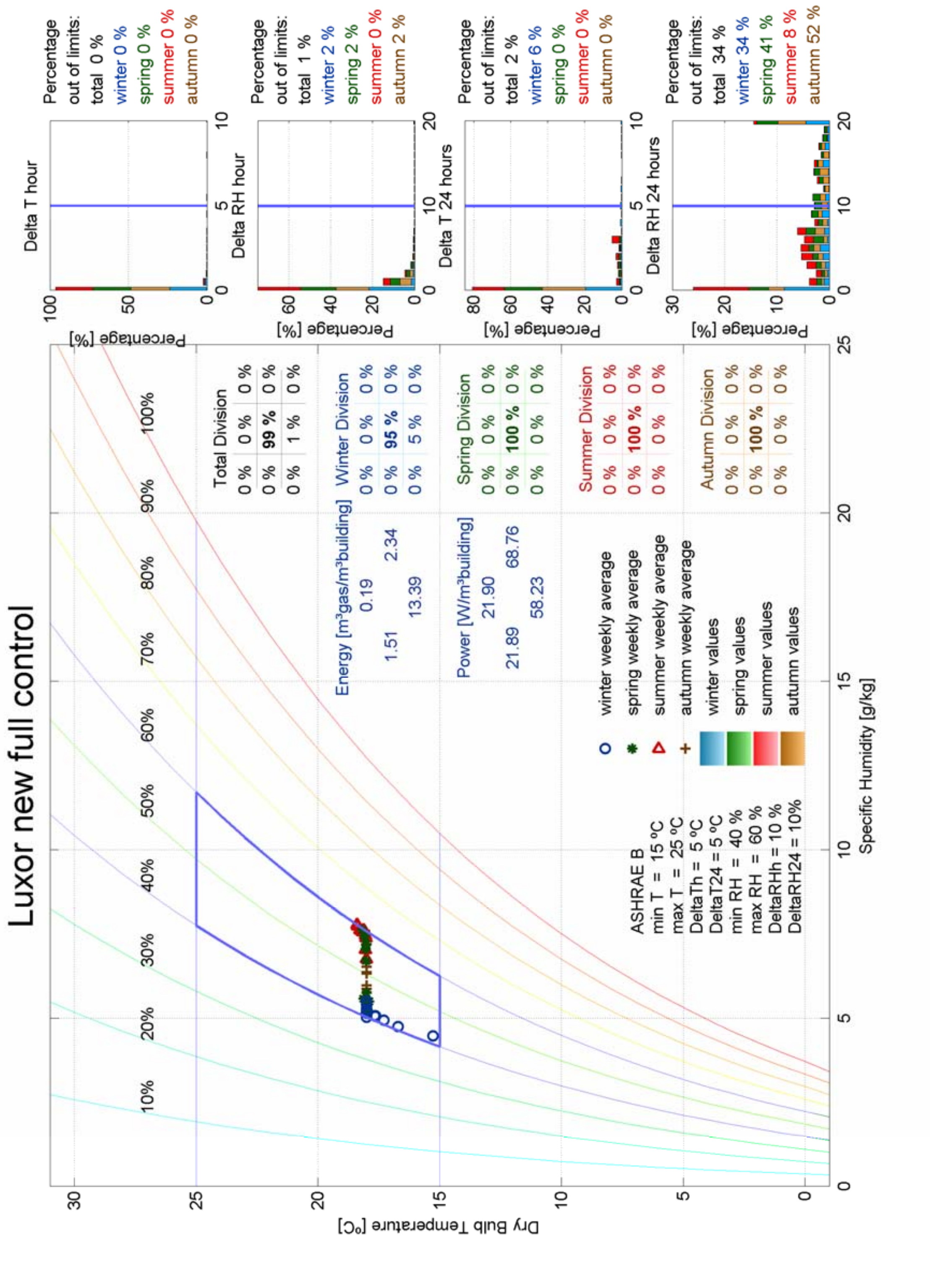

FIG. 7 The CEC of Scenario ‘control class B design without additional hygroscopic material’

HVAC system: climate control B, with additional hygroscopic material

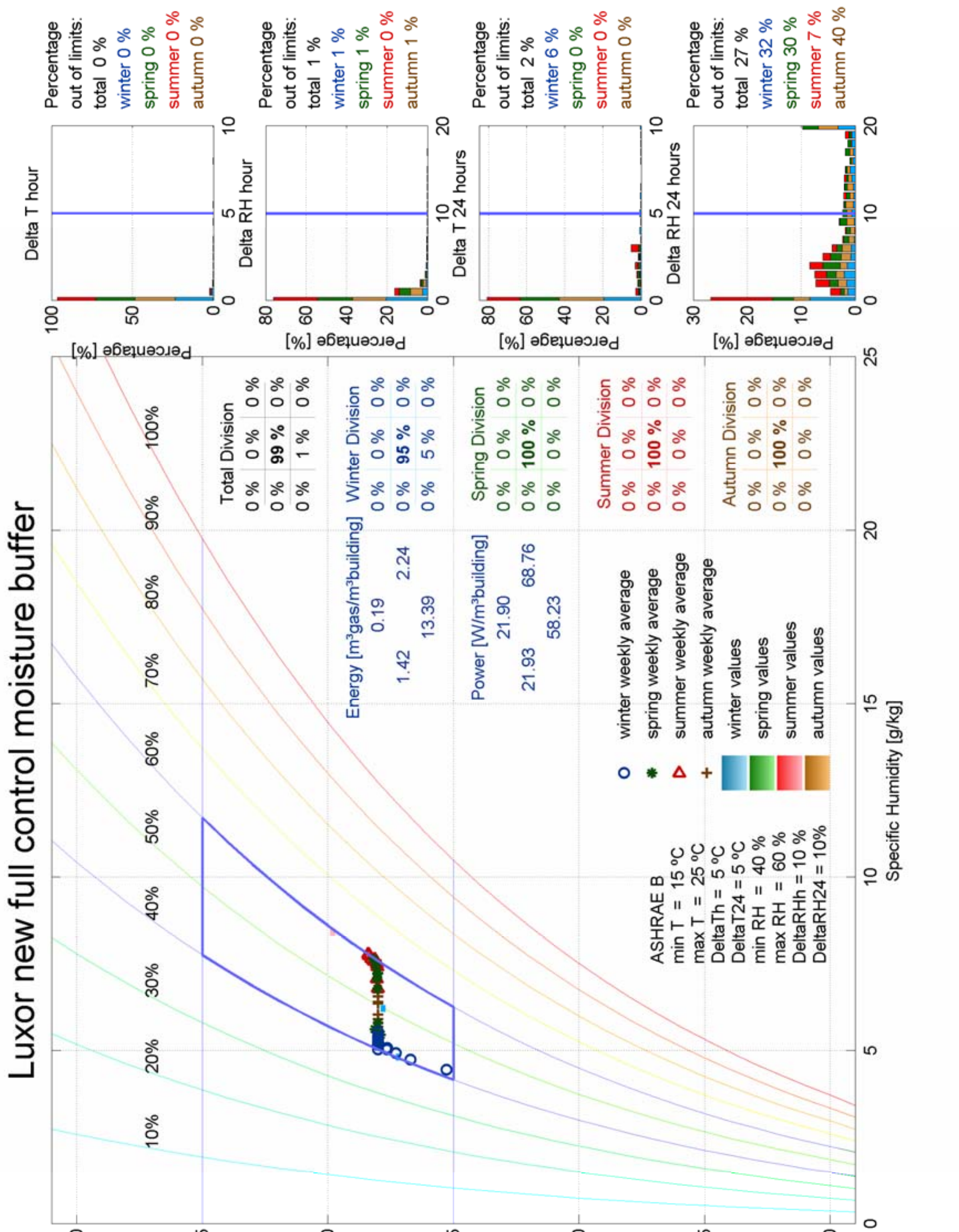

FIG. 8: The CEC of Scenario ‘control class B design with additional hygroscopic material’

HVAC system: climate control AA

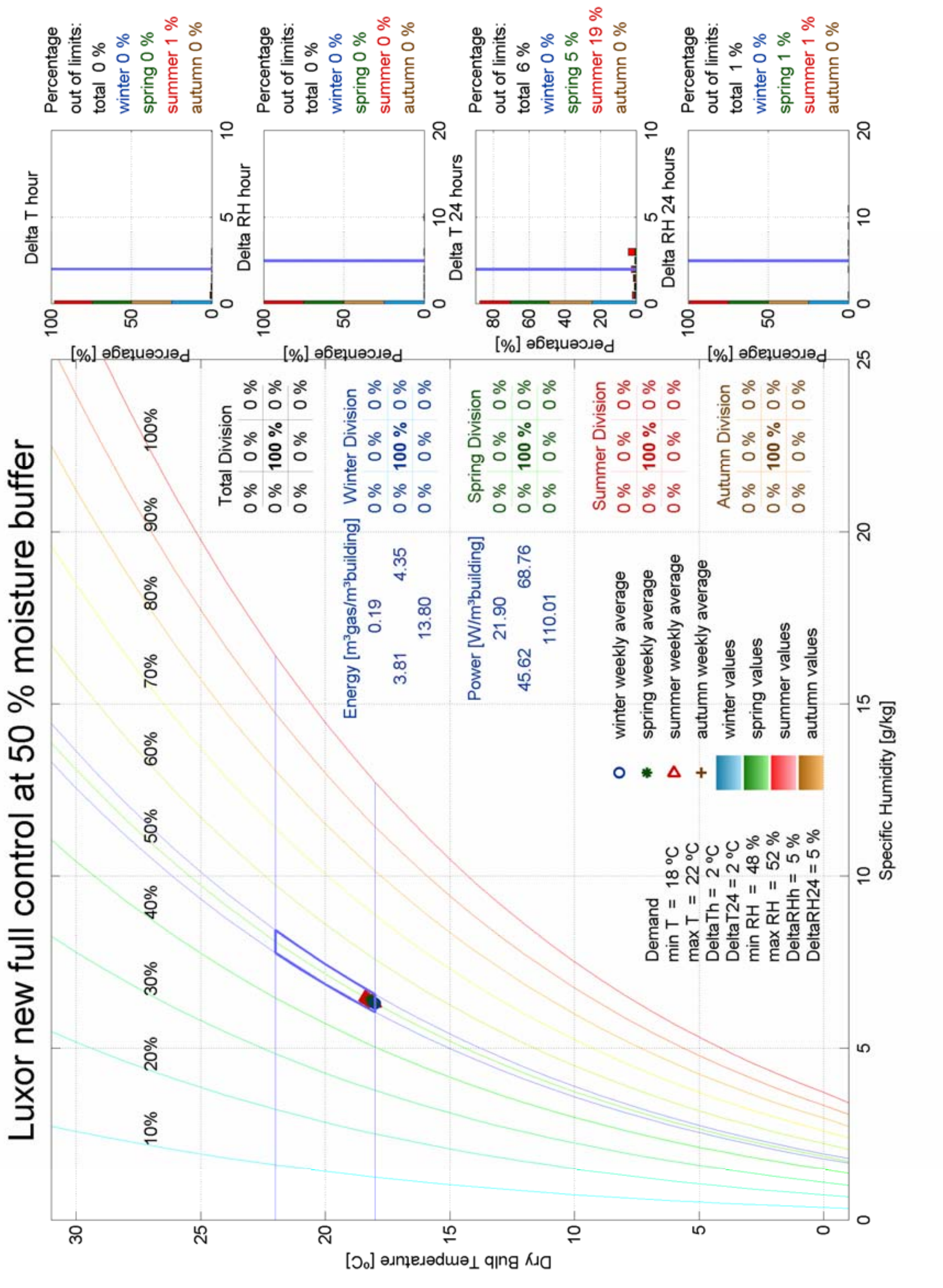

FIG. 9: The CEC of Scenario ‘control class AA design.

4. DISCUSSION OF THE RESULTS

4.1 Evaluation of the scenarios

Past performance

Both past performance scenario results show high RH change rates (up to 94% of time out of limits). Although this did not lead to visible damage to the monumental interior so far, it should be reduced to prevent future damage. Furthermore the scenario in figure 3 results in high humidity's (up to 17% of time is too humid) and the other scenario in figure 4, results in low humidity's (up to 26% of time is too dry). Both problems should be prevented in the future.

Control class C design

This design contains only heating and ventilation. Figure 5 shows that this is not an acceptable design because: (a) during the winter the RH is 21% of the time below 25% and (b) 40% of the time the daily RH fluctuation is above 20%. Figure 6 shows that both problems are solved if a very large amount of additional moisture buffering material (100 air-volume-equivalents) is placed. The amount of additional moisture buffering material is expressed in air-volume-equivalents (of the 1800 m^3 hall). This means 1 air-volume-equivalent (at 20 ^oC/50%) equals 14 kg of moisture. If wood fiberboard is selected as buffering material, 1 m^3 wood can buffer 12 kg moisture (daily change rate of Rh 20%, density wood = 300 kg/m^3, (de)sorption = 0.04 $kg_{moisture}/kg_{wood}$). 100 wood slices of 1 cm x 1m x 1m separated by 1 cm air gap fills 2 m^3 of space. Thus 100 air-volume-equivalent takes 230 m^3 of space. However, due to the monumental roof and walls, it will be very difficult to place such amount of buffering material. This means that moisture control will be inevitable.

Control class B design

This design contains full climate control with RH between 40% and 60%. Figure 7 shows that the only problem left is that still 34% of the time the daily RH fluctuation is above 20%. Figure 8 shows that if a reasonable amount of additional moisture buffering material (5 air-volume-equivalents, taking 12 m^3 of space) is placed, then: (a) it has only small effects on the humidification energy (decrease of 6%) and dehumidification energy (decrease of 4%); (b) it has no significant effect on the (de)humidification power and (c) the daily RH fluctuations remain too high. Note that these climate conditions are expected to be better than the past performance. One could argue that the monumental interior has not deteriorated in the past, so it probably will not deteriorated in better climate conditions. In this case control class B would be appropriate. But one can also argue that it is pure luck that the monumental interior has not deteriorated so far. In this case control class B would not be appropriate and a more stringent control class is required.

Control class AA design

This design contains full climate control with RH between 48% and 52%. This means there is almost no of moisture buffering due to the steady RH. Figure 9 shows that the climate meets the demanded performance very well. The disadvantages compared to the previous class B design are: (a) a much higher humidification energy (increase of 270%) and dehumidification energy (increase of 200%) and (b) a significant effect on the humidification power (increase of 200%) and cooling power (increase of 190%).

4.2 Evaluation of the moisture buffering effects on the HVAC performance

From figure 7 and 8 it follows that the humidification energy drops from 1.51 to 1.42 [m^3 gas / m^3 building volume] and the dehumidification energy drops from 2.34 to 2.24 [m^3 gas / m^3 building volume] by placing 5 air-volume-equivalents moisture buffering material. The next figure presents the (de)humidification energy as a function of the placed additional buffering material in more detail.

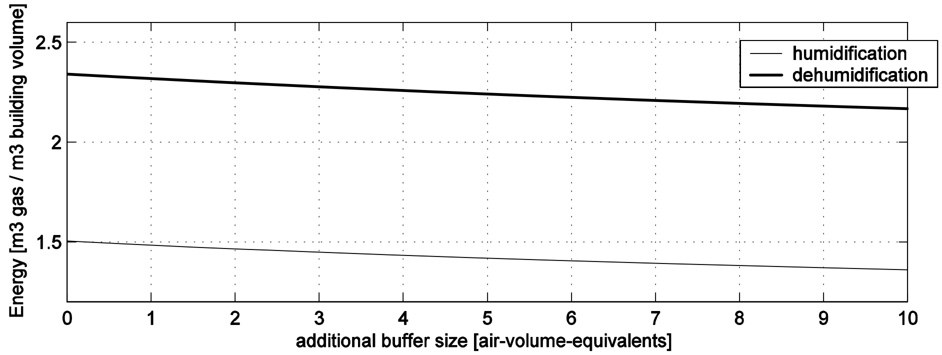

Figure 10. The (de)humidification energy as a function of the placed air-volume-equivalents.

Figure 10 shows an almost linear decrease of 0.01 [m^3 gas / m^3 building volume] per air-equivalent additional buffering material.

5. CONCLUSIONS

Revisiting the objectives of Section 1, it is concluded that:

Concerning the use of the new simulation and visualization tool: (1) The past indoor climate can be classified as ASHRAE control C with expected significant occurrences of dry (RH below 25%) and humid (RH above 80%) conditions. (2) ASHRAE control C is not suitable for the new hall. The climate control classification for the new hall ranges from B to AA. Further research in the form of detailed HAM transport calculations in the (monumental) constructions are needed select the appropriate class. (3) The demands on the HVAC system to facilitate pop concerts in the new hall are 40 kW heating power, between 100 and 200 kW cooling power, between 40 and 80 kW humidification power and 125 kW dehumidification power. All these quantities are based on 100% process efficiencies.

Concerning the effect of moisture buffering on the (de)humidification energy of the HVAC system: (4) In case of control class AA, placing additional hygroscopic material has no significant effect. In case of control class B, the placing of additional moisture buffering material (5 air-volume-equivalents) does not decrease the (de)humidification power and it decreases the (de)humidification energy by 5%.

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