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Conservation climate analysis of a church containing valuable artworks

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Abstract

The OLV Hemelvaart church in Watervliet dates back from the 16th century and contains valuable panel paintings and wooden artefacts. They need to be preserved in a stable conservation climate. However, due to the old air heating system, the indoor climate is not stable at all. The air heating system creates sudden strong rises in temperature and due to the position of the supply and extraction grilles, the warm air is not evenly distributed throughout the church. Furthermore, the church suffers from moisture problems such as rain penetration and rising damp. In view of improvement measures to the heating system, from March 2012 to March 2014, the temperature and relative humidity was measured on different locations in the church. The ASHRAE conservation classes were used to analyze the data. Both a frequency analysis and an analysis of the short term and seasonal fluctuations of temperature and relative humidity were performed.
It was found that the relative humidity of the indoor air was far too high for conservation purposes: during more than 50% of the time a value above 75% was registered in the middle of the church. During a period of two months, the church was permanently heated in order to improve the conservation climate. Compared to the intermittent heating regime, permanent heating caused a more stable climate: the relative humidity level exceeded 75% during 20% of the time, but it remained almost constantly between 60% and 75%. This was attributed to the church walls that acted as a constant moisture source during heating.

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Keywords: Conservation climate; relative humidity; permanent heating; intermittent heating; ASHRAE

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1. Introduction

1.1. Condition of the church and artworks

The parish church in Watervliet deals with major moisture problems, caused by the bad condition of the building envelope. The ground water rises up into the walls and rain penetrates through the façades. The church also suffers from clogged roof-gutters, causing major rain water flows across the walls. There are also traces of frost damage and salt formations. Despite these problems, some valuable artworks are exposed in the church. E.g. Panel paintings dating back from the 16th century and baroque wooden artworks can be seen [1]. Figure 1a shows white spots caused by fungus on the baroque wooden pulpit. This reveals that high levels of relative humidity occur very often. Besides that, figure 1a also shows a broadened joint, proving that these artworks suffer from re-occurring low relative humidity levels in the indoor climate. This is also revealed by the stucco layer on the walls and the surface of the panel paintings. Pieces of the top layers are crumbled off or show cracks. Previous research in other churches showed that these damages are often caused by an old air heating system [2].

1.2. Current air heating system

The church is heated once every two weeks with an old air heating system. The supply and extraction grilles are positioned in a chapel, at the north side of the church (Fig. 1b and c). This system causes major fluctuations in temperature and relative humidity, which give rise to damage to the artworks in the church. Furthermore, due to the positioning of the grilles, the system causes draught and stratification throughout the church. The supply grilles are positioned above the extraction grilles, causing a short circuit of warm air close to the north chapel. On top of that, at one side the warm air is blocked by the wooden pulpit (Fig 1c). The system is controlled by a thermostat that is positioned on the outer corner, in between the grilles (Fig. 1b). The air heating system is only turned on when events are organized in the church. From January 2014 until March 2014, an attempt was made to keep the indoor climate permanently at a high temperature. Unfortunately, the measurements showed that the air temperature at the supply grille fluctuated constantly between 25°C and 50°C [1].

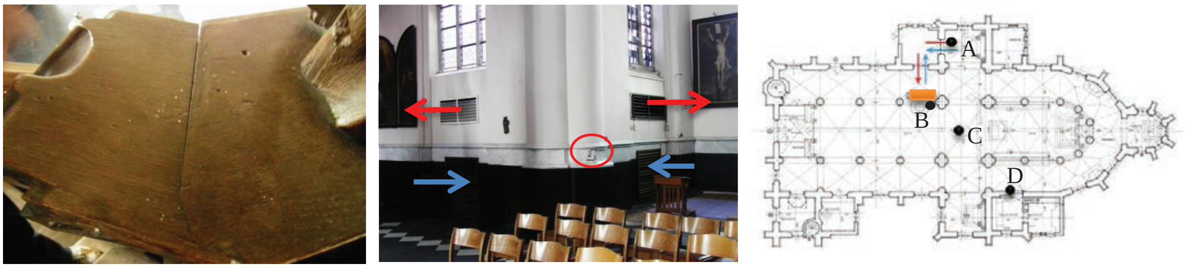

Fig. 1: (a) White spots and broadened joint at the pulpit. (b) Extraction and supply grille air heating system. The red arrow is warm air blown into the church, from the supply grille. The blue arrows symbolise the extracted air, coming through the extraction grille. The thermostat controlling the system is encircled on the figure. (c) Ground plan of the church. The red and blue arrows show the location of the supply- and extraction grilles. The orange block is the pulpit, obstructing the warm air to flow to the middle of the church. The black spots show the location of the loggers discussed in this paper. (A: Logger at supply grilles. B: Logger at the pulpit. C: Logger in the middle of the church. D: Logger behind a panel painting, at the south wall [1]

1.3. Measurement set-up

The indoor climate of the church was measured from March 2012 to March 2014. Ten loggers recorded air temperature (T) and relative humidity (RH) on several places in the church, with a time interval of 10 minutes [3]. Four of them are discussed in this paper (Figure 3c). Logger A was placed near the air heating system in the north side aisle, while logger B and logger C were located respectively at the pulpit and the altar in the central nave of the church. Logger D was placed at the south wall, behind a valuable painting. For this study, measurements from March 2013 till April 2014 were analyzed [1]. As mentioned above, in this period permanent heating occurred from

January 2014 until March 2014. Therefore, both intermittent and permanent heating were compared to see the effects on T and RH throughout the church.

2. Frequency analysis

2.1. Methodology

A frequency analysis was performed in which was counted how many times the measured RH reached respectively more than 60% and 75% [4]. The RH-level of 75% is the maximum RH-level to avoid biological degradation of the wooden artefacts. The RH-level of 60% was stated as the crucial RH-level to avoid non-elastic deformations of panel paintings [4]. A distinction was made between the period with intermittent and permanent heating, to evaluate if permanent heating contributes in decreasing the RH-level throughout the church.

2.2. Results

During the period of intermittent heating, RH-levels higher than 75% were registered more than 50% of the time in the middle of the church and at the supply grille (Fig 2). During permanent heating, the percentage RH-values above 75% decreased to 17% in the middle of the church. At locations closer to the supply grille, only 4% of the measurements showed a RH > 75%. In this way, permanent heating had a positive influence on the indoor climate. However, when compared with the amount of data that contained a RH > 60%, it was found that the RH-level remained almost constantly between 60% and 75% during permanent heating. In contrast, during intermittent heating, a RH-level of 55% and lower occurred between 5 and 10% of the time in the middle of the church hall. Only at the supply and extraction grills, values beneath 55% RH were registered during 60% of the time.

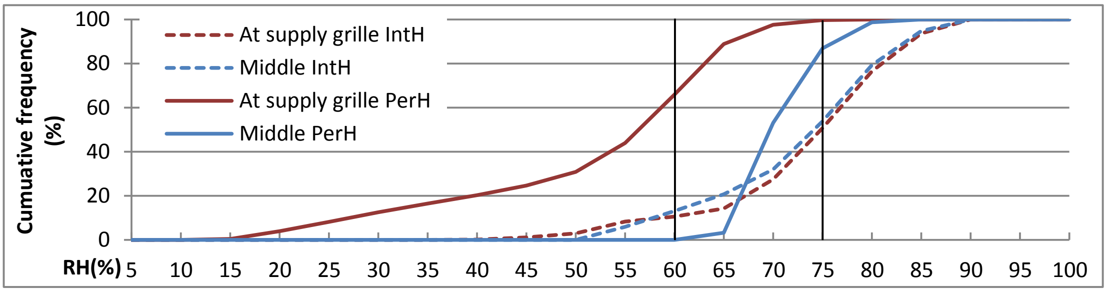

Fig. 2: Cumulative frequency of the measured RH at the supply grille and the middle of the church. Periods with intermittent heating (IntH, dashed line) and permanent heating (PerH, full line) were analysed separately. When the church was permanently heated, the RH in the middle stabilized. Values above 75% RH and beneath 60% RH appeared less often [1].

Consequently, permanent heating caused a certain stabilization of the RH in the middle of the church. Extreme high and low values of RH were less common. An explanation probably lies in the walls of the church, which acted as a constant moisture source during heating and thus low RH levels [5]. In the analysis of the heating effects (§4), it was found that the absolute humidity levels rose simultaneously with the temperature. This revealed that the moisture in the walls started to vaporize when higher temperatures occurred in the church, making low RH-levels occur less frequently during permanent heating.

3. Climate evaluation based on the ASHRAE climate conservation classes

3.1. Methodology

To evaluate the T and RH fluctuations in the church, the ASHRAE climate conservation classes were used. This standard formulates five climate conservation classes with different allowed ranges of T and RH fluctuations. According to ASHRAE, a church building can obtain class B if the indoor climate satisfies the T and RH requirements listed in table 1. Within class B, requirements are formulated for daily and seasonal T and RH fluctuations, as well as an absolute minimum and maximum T and RH limit. The measurement data were compared with these requirements. The analysis resulted in a percentage of days from the measurement period during which the indoor climate satisfied the ASHRAE climate conservation requirements.

Table 1. Requirements for ASHRAE climate conservation class B [6].

Class	Daily fluctuations	Seasonal fluctuations	Min	Max
B	T: ± 5 °C	T: ±10 °C		T: 25-30 °C
	RH: ± 10%	RH: ± 10%	RH: 25%	RH: 75%

To calculate the allowed short term fluctuations for climate class B, the moving average over three months was used. By doing this, also seasonal influences were incorporated in the evaluation of the daily fluctuations. To evaluate the seasonal fluctuations, the allowable range was calculated based on the average T and RH over the whole measurement period, calculated per measurement location. E.g. in the middle of the church, the values of T and RH were respectively 13.3 °C and 72.5%. The measured daily minimum and maximum T and RH were then compared against the allowed daily and seasonal fluctuations.

3.2. Results

3.2.1. Daily fluctuations

When the church was occasionally heated, the indoor climate did not meet the requirements for class B during 55% of the days. This was mostly due to a high RH level above 75%, as can be seen on figure 3b for the logger near the pulpit. The allowed limits were also exceeded when a high T and low RH occurred. These situations appeared mainly during winter, when the air heating system was switched on during services, e.g. between 8/04 and 8/06 and 8/10 and 8/11, marked on figure 3. Figure 3b also shows that high RH-levels above 75% could not be avoided during days with heating.

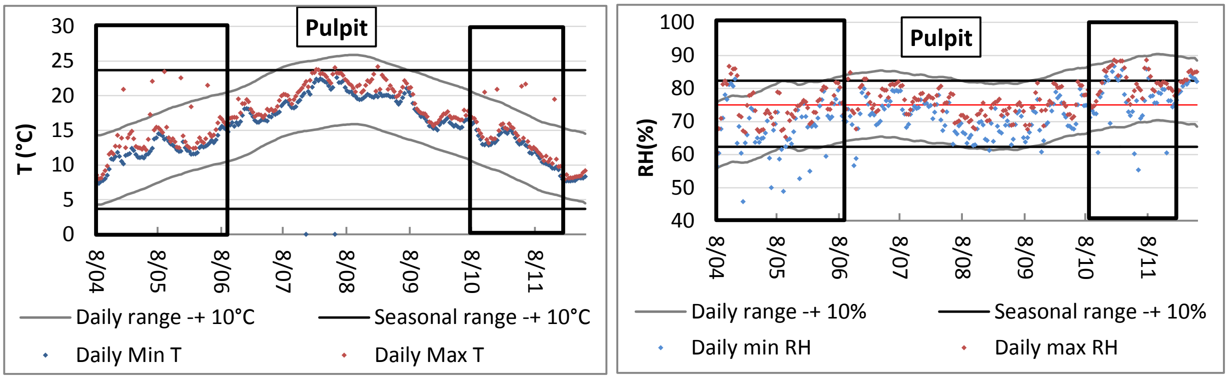

Fig.3: (a) Temperatures during intermittent heating from the logger near the pulpit. The daily ranges were only exceeded when the heating system was switched on. (b) RH during intermittent heating from the logger near the pulpit. Lower RH values appeared when the air heating system was switched on. High RH values above 75% (red line) appeared almost every day. The seasonal ranges were based on the total average measured T and RH, which was respectively 13.7 °C and 72.3%. The rectangles mark the period in which the church was heated [1].

With permanent heating, the percentage of days during which the RH requirements were not met, increased at the supply grill. This was caused by an unstable air temperature of the heating system itself. On the other hand, the RH became more stable in the middle of the church. While the RH at the supply grille varied constantly between 20% and 70%, the RH in the middle of the church remained between 60% and 80%.(Figure 4a and 4b). This means that locations further away from the supply grille, experienced less influence from the heating system. Thus, permanently heating the church was not sufficient to obtain a uniform T and RH-level throughout the indoor climate church, but the climate stabilized in the center of the church.

Despite the stabilization of the indoor climate in the middle of the church with permanent heating, values above 75% RH still occurred at all measurement locations in the church. So, permanent heating did stabilize the indoor climate, but the old air heating system was still not sufficient to avoid high RH levels. On top of that, the temperature of the heated air fluctuated constantly between 17 °C and 50 °C during permanent heating (§4, figure 5), which resulted in intolerable T and RH fluctuations at the various measurement locations. In order to stabilize the indoor climate, the installation of a new reliable heating system is advised.

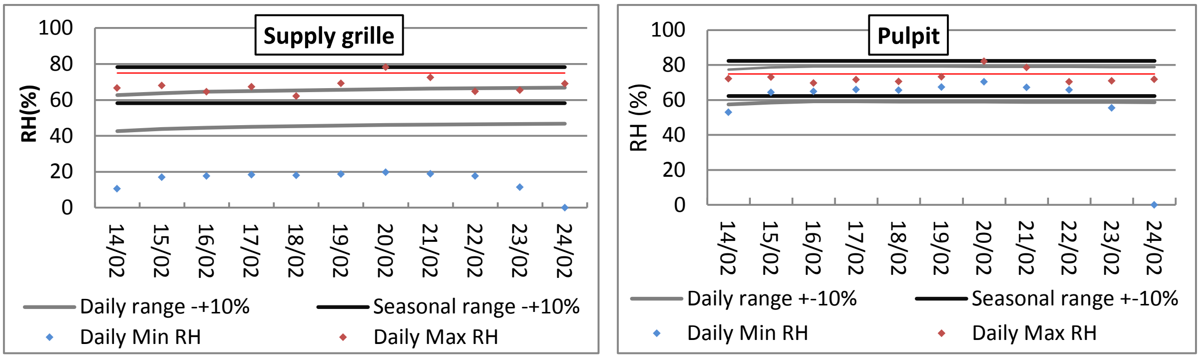

Fig. 4: (a) RH-values during permanent heating near the supply grille. (b) RH-values during permanent heating near the altar. Despite of the permanent heating, high values above 75% RH (red line) kept appearing in the middle of the church (altar) [1].

3.2.2. Seasonal fluctuations

The same conclusion was drawn when comparing the measured daily maximum and minimum T and RH to the allowed seasonal T and RH fluctuations. Locations closer to the supply grille, had fewer days where the seasonal requirements for class B were fulfilled (Figure 4). At these locations more low RH-values were measured. This was true for both the period with intermittent and permanent heating. At the supply grille itself, during almost none of the days with permanent heating the requirements for a conservation climate were met. The temperature reached levels up to 50 °C daily (§4, Figure 5). This caused RH drops to approx. 20%, while the allowed seasonal fluctuations were 68,3% ± 10%. The latter value was the average measured RH from March 2013 until April 2014, including both intermittent and permanent heating (Figure 4a).

3.2.3. Conclusion

Permanent heating helped stabilizing the RH in the middle of the church. E.g. when only taking the allowed daily fluctuations of climate class B in account, the percentage of days in which the indoor climate stayed within this ranges was increased from 80.4% to 87.8%. Measurement locations closer to the supply grille, showed lesser percentages of days in which the requirements were met. The same conclusion can be drawn when also taking the minimum and maximum allowed values of T and RH of class B in account (table 1). E.g. for daily fluctuations, the percentage rose from 31.0% to 67.3% in the middle of the church. The same trend is visible for seasonal fluctuations. These lower percentages were mainly caused by occurring RH values above 75%, when taking all requirements in account.

On the other hand, when looking at the temperature requirements, almost all days met the requirements for class B in the middle of the church. Only at the supply grille, these requirements were exceeded, due to a badly programmed air heating temperature.

4. Effects of heating up the church

As mentioned in the introduction, the indoor climate of the church is destabilized by the old air heating system. Permanent heating slightly improved the situation in the middle of the church, but caused low RH values at the supply grille. Overall, the permanent heating regime was still not sufficient for the conservation climate to meet the ASHRAE requirements. When looking closer to the effects of heating up the church, it was found that the warm air remained near the supply and extraction grilles. Moreover, the absolute humidity increased proportionally with the temperature in the church (figure 5). This was probably caused by the walls of the church that acted as a continuous vapor source when the church was heated [5].

In this analysis, it was also found that permanent heating caused smaller fluctuations in T and RH in the middle of the church and at the south wall. But, as the heating system was continuously in operation, these small cycles occurred constantly (figure 5). So, according to ASHRAE requirements, the climate was indeed more stable. But one can ask if smaller but continuous cycles are less damaging for panel paintings than a major fluctuation of ±20 °C appearing once a while. Both regimes should be avoided for the conservation of materials susceptible to fatigue.

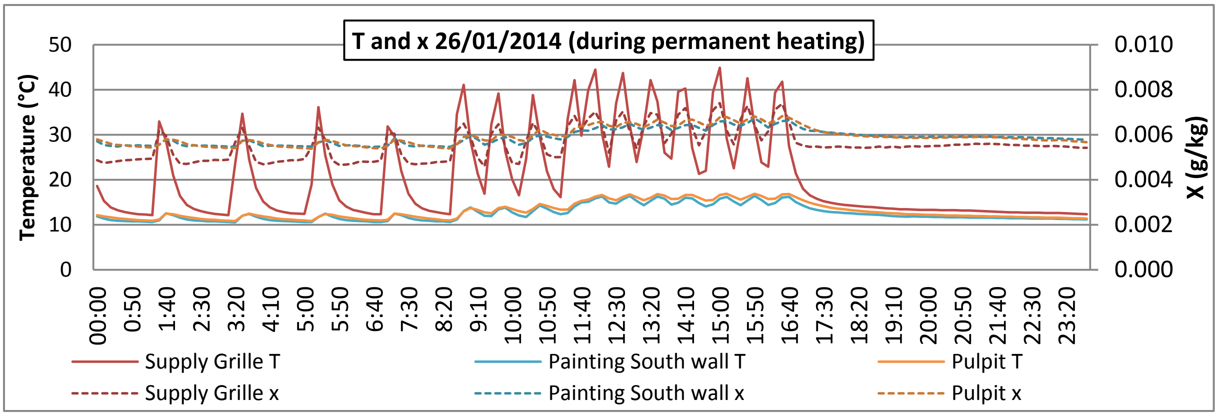

Fig. 5: Temperature (T, full lines) and humidity level (x, dashed lines) on 26 January 2014. The heating system was permanently in operation, but during the service (at 10:00), the temperature was set to a higher value. It can be seen that the humidity level followed the fluctuations of the temperature, on various locations throughout the church, e.g. at the pulpit and at a panel painting on the south wall [1].

5. Conclusion

According to the measurement analysis, the RH in the church was too high for conservation of wooden artefacts when the church was not heated. At every measurement location, a RH> 75% was registered. When the air heating system was switched on, the system caused major fluctuations in T and RH. However, the indoor climate could be slightly improved with permanent heating. It was proven that the indoor climate showed smaller RH fluctuations in the middle of the church: extreme high and low RH values occurred less often but the RH varied constantly within the allowed range. On the other hand, the amount of intolerable fluctuations increased at the supply grille. On top of that, permanent heating was still not sufficient to prevent RH-levels above 75%. Consequently, even a conservation climate (ASHRAE class D) with the lowest requirement (RH < 75%), is unachievable at the moment. So, continuous heating is only a solution when a constant air temperature can be held at all circumstances. Unfortunately, this also implies high energy costs [7]. To avoid these negative side-effects, adjustments and repairs to the building envelope should be considered first. These works could contain e.g. an improvement of the drainage system of the rainwater, repair work of the clogged roof gutters and injection of the walls to obstruct rising ground water. Only with these measures, climate class C (RH < 75% and >25%) seems achievable for the church building.

References

[1] Maroy, K. Vochtproblemen in historische gebouwen: klimaatanalyse en modellering in TRNSYS van de OLV Hemelvaartkerk te Watervliet. Master Dissertation; Faculty of engineering and Architecture, University Ghent; 2014; 24-67; (in Dutch).

[2] Schellen, H. Heating monumental churches, indoor climate and preservation of cultural heritage. Delft: TU Delft; 2002.

[3] Camuffo, D., Bernardi, A., Sturaro, G. & Valentino, A. The microclimate inside the Pollaiolo and Botticelli rooms in the Uffizi Gallery, Florence. Journal of Cultural Heritage, 2002, 3(2), 155-161.

[4] Mecklenburg, Marion F. Determining the acceptable ranges of relative humidity and temperature in museums and galleries, part 1. Structural response to relative humidity; 2007; 1-57.

[5] Larsen K.P. Climate control in Danish Churches. In P.T. A.K Borcheresen (Ed), Museum Microclimates; 2007; 167-174.

[6] Ankersmit, B. (2009). Klimaatwerk: richtlijnen voor het museale binnenklimaat (1 Ed. Vol. 1). Nederland: Amsterdam University Press; 2009. (in Dutch).

[7] Artigas, J.A comparison of the efficacy and costs of different approaches to climate management in Historic buildings and museums. Master Dissertation. University of Pennsylvania; 2007.