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The Temperierung heating systems as a retrofitting tool for the preventive conservation of historic museums buildings and exhibits

I sistemi di riscaldamento radiante come strumento per una conservazione preventiva di edifici museali storici e dei materiali esposti

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SUMMARY

Temperierung refers basically to wall heating through pipes mounted in or on the inside of the walls. In the context of heritage preservation the Temperierung system was mainly developed by the State Office for Non-State Museums in Bavaria for heating and climatization of museums and exhibit buildings. Based on the ongoing research project „Temperierung as a Tool for Preventive Conservation – An Assessment" a close and interdisciplinary collaboration is established between building physicists, conservators and practitioners from 18 selected museums under the lead of the State office for non-state museums in Bavaria. The paper highlights the different existing Temperierung systems within the project, main components of the system and different types of application. The main principles of the technique are explained and compared to more commonly known heating systems like convector/radiator heating and wall/floor heating. Preliminary results of the measured indoor climate and effects of the Temperierung heating system of several chosen museums are presented. The impacts of the indoor climate to the conservation of artifacts, influenced by Temperierung heating, are discussed with typical methods of indoor climate assessment and with conservational assessment. The detailed and neutral description of Temperierung heating gives a basis for planners and persons in charge for retrofitting historical museum buildings. Temperierung systems and their use have a potential for preventive conservation of the historic building and the preservation of the artifacts inside.

RIASSUNTO

I sistemi di Temperierung (*Temperierung heating*) sono stati sviluppati dall'Associazione dei Musei non statali in Baviera (*Nichtstaatliche Museen in Bayern*) per riscaldare e climatizzare musei e sale espositive dei musei di territorio (*Freilichtmuseen*). I lavori di ricerca del progetto sui sistemi di Temperierung come mezzo per la conservazione preventiva (*Temperierung Heating as a Tool for Preventive Conservation – An Assessment*) vengono svolti in stretta collaborazione tra addetti alla fisica della costruzione, restauratori e 18 musei scelti. I lavori sono diretti dell'Associazione dei Musei non statali della Baviera. In questo paper vengono presentati i diversi sistemi di Temperierung usati nei musei bavaresi. I diversi sistemi di installazione e le loro funzioni vengono discussi. I principi di funzionamento dei sistemi di Temperierung vengono paragonati a quelli dei sistemi di riscaldamento a radiatori, convettori e riscaldamento a pavimento. I risultati degli studi sul clima e sul del comportamento termico negli ambienti dei musei bavaresi con sistemi di Temperierung vengono discussi. Le conseguenze del clima dei sistemi di Temperierung sul materiale esposto vengono osservate e valutate. Nella cornice di questo progetto è stato inoltre sviluppato un nuovo metodo per il controllo del comportamento dei materiali esposti. La descrizione dettagliata dei sistemi di Temperierung e del loro influsso sul clima negli ambienti museali ha lo scopo di rifornire informazioni per progettisti e responsabili dei lavori di ammodernamento dei musei in edifici storici. I sistemi di Temperierung offrono un enorme potenziale per la conservazione preventiva dei monumenti e dei materiali esposti.

Key words: Temperierung, historic building, preventive conservation, indoor climate, heating

Parole chiave: edifici storici, conservazione preventiva, clima interno, riscaldamento

1. INTRODUCTION

Temperierung refers basically to "wall heating through pipes mounted in or on the inside of the walls" (EN 15759-1, 2011). In the field of heritage preservation, the Temperierung system was mainly developed by the State Office for Non-State Museums in Bavaria. The main protagonist and developer of the Temperierung heating system and its principles was Henning Großeschmidt, a member of this state office. Temperierung has been recommended as a heating and climatisation system for enhanced climate stability in museum buildings. However, the impacts of this empirically developed system on the buildings, their indoor climate and the housed collections have not been subject of a systematic scientific investigation yet. The Temperierung heating system or method of Temperierung is described in e.g. (Großeschmidt, 1992, 1996, 2000) und most recently in (Großeschmidt, 2004). The description of early types of Temperierung systems like wall frame Temperierung can be found in (Assmann and Großeschmidt, 1988) and also in (Großeschmidt, 1992). In this literature there are only positive effects postulated which are critically discussed by other authors, e.g. (Arendt and Hausladen, 1992) or (Gronau, 1996). One of the main critic concerns is the often postulated attribute of Temperierung as an energy saving measure. The most recent major piece of literature about

Temperierung, bilingual published in German and English, is a collection of articles by (Boody et al. (ed.), 2004). There are no critical articles in this collection about disputed effects of Temperierung. In (Krus and Kilian, 2012) and also (Künzel, 2009) it is concluded, that Temperierung is rather not energy saving, but this should be lower in ranking compared to the positive effects for preservation. Many authors describe a positive effect mostly in sense of conservation heating in general to the building, but not in terms of preventive conservation to artifacts due to the indoor climate influenced by Temperierung. Only a few investigated the effects of Temperierung to the indoor climate and evaluated the indoor climate for the questions of preventive conservation in detail (Kilian 2004). The cold wall effect, first discovered and described in (Ranacher, 1995) and (Ranacher, 2004) can have serious negative impact on paintings hanging on outside walls. Temperierung is recommended to prevent this cold wall effect.

Under this prerequisites the research project „Temperierung as a Tool for Preventive Conservation – An Assessment" has been implemented in the year 2011. The project is based on a close and interdisciplinary collaboration between building physicists, conservators and practitioners from 18 selected museums in Bavaria, under the lead of State Office for Non-State Museums in Bavaria. All participating museums have been newly equipped or retrofitted with a Temperierung heating system between 1987 and 2011. The impacts of these Temperierung heating systems on the indoor climate and on the collections will be assessed within the project. On one hand, the influence of the Temperierung systems on building components and indoor climate are investigated and assessed from the building physics point of view. On the other hand, the assessment of the impact from the indoor climate generated by the different Temperierung systems on the preservation of the collections is the subject of the conservator's examination. Criteria for choosing single artifacts are – besides their material – the extent and quality of existing documentations and the duration of the exposition towards a climate created by a Temperierung system. Changes of the state of preservation within a provable time span should be reproducible documented and evaluated.

2. TEMPERIERUNG SYSTEMS OF THE PARTICIPATING MUSEUMS

2.1. Temperierung Systems

The arrangement of the heating pipes of a Temperierung system is in its basic layout located at the base of the outer wall. The different identified systems are grouped into three main groups and three sub groups. Altogether nine systems are described in Table 1.

Table I – The Temperierung systems can be grouped in three main groups (main application) and nine subgroups

Main groups	Sub groups
Heat pipe In-wall	In-wall in brick wall
	In-wall in studwork (dry walling)
	In-floor
Heat pipe On-wall	Tight contact to the wall, pipe in mortar bed
	Minor contact to the wall, pipe mechanically mounted
	With distance to the wall surface mounted
	With distance to the wall surface, behind a panel
Heat pipe in wall frame	Closed wall-/floor frame
	Open wall-/floor frame

The three main systems are schematically shown in figure 1: in-wall heat pipe, heat pipe in front of the wall and heat pipe behind an additional frame similar to hybrid air-heated panel heating. The different effects of heat transmission are also schematically illustrated. The heat transfer occurs by direct heat conduction through the building component e.g. wall, heat transfer by convection and radiant heat transmission. The Temperierung system behind a wall frame has a special cavity construction for warm air heating. It is an older system and not actual built anymore due to high costs of an additional frame and to the conservational problem of hidden original surfaces.

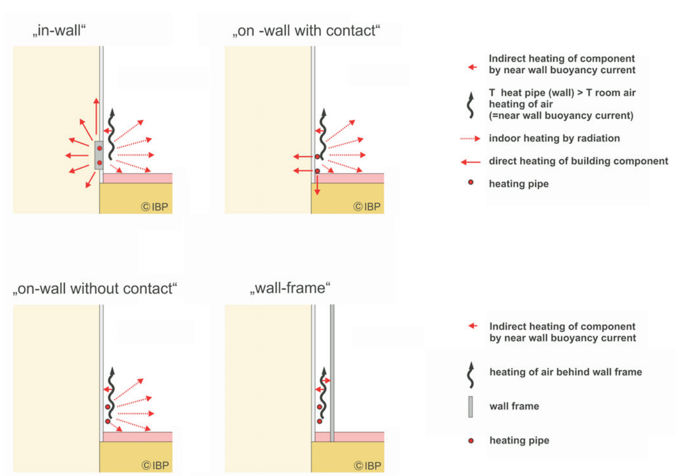

Figure 1 – Different build in situations of Temperierung systems: in-wall heat pipe, heat pipe in front of the wall with and without wall contact and heat pipe behind an additional frame. The effects of each Temperierung system are very simplified shown

In Table 1 the different Temperierung systems are grouped. Further systems exist which are basically similar and refer to the introduced systems. One variant, which is not explicitly shown here, is a heat strip mounted at the base of the walls, because this type is not used in any of the surveyed museums. One further not distinguished criterion is the heat medium. Mostly hydronic warm water heat pipes are used but also electric heating cables are common. Sometimes electric powered hydronic warm water systems are in use. The example in figure 2 „in-wall“ and “on-wall” with and without direct wall contact are the most common systems, which are today mostly applied. In (Großeschmidt 1992) the in-wall solution is already constituted as the “endpoint of development” and “ideal solution for solid constructions”. Wall frame Temperierung systems similar to hybrid air-heated panel heating are divided in open and closed systems depending whether the room air has direct contact to the heat pipe or not. For the different Temperierung systems different ways of heat transfer occur. It is depending on whether the heat releasing device e.g. heat pipe, is in direct contact to the wall or not. Without wall contact, the heat transfer occurs via convective heat transmission and radiant transfer. The efficiency of heat release of the heat pipe depends on the combination and share of the different heat transfer mechanisms. In case of wall contact there is an additional heat transmission via heat conduction. The type of contact is essential to the possible share of the heat transfer by conduction. For Temperierung systems with strong contact as like heat pipes in-wall, the heat transfer occurs directly by conduction. Only as secondary effect there is a convective heat transmission at the surface of the wall that is heated. This effect occurs also with heat pipes on-wall if they are covered with mortar, and also with heat pipes on-wall if they are in contact with the wall with mechanical mounting but then in a lower order. Secondary effects may occur by heated up wall regions adjacent to the heat pipe or heating surface.

2.2. Differences of Temperierung to other heating systems, technique of Temperierung and conservation heating

The differences to conventional heating systems like panel heating or radiator heating can be indistinct if a Temperierung system is planned and built similar to these systems. If the system is planned in wall with several heat pipes arranged one upon other or side by side it may be similar to conventional wall heating or panel heating. Main characteristic to Temperierung systems is not a full area application but a lengthwise application as a heating stripe, even if there is an area effect to the wall, as described by (Großeschmidt 1992). By use of mini radiator heater or heat pipe radiator or several heat pipes above each other or side by side on-wall without wall contact mounted, a Temperierung system can be similar to a conventional radiator heating. The supply water of radiator heating system is operated at the same or even higher temperature level than for Temperierung is required. A distinct attribute of radiator or convective heating compared to Temperierung is a concentrated heat release with optimized convective heat transfer. For a Temperierung system with correctly chosen dimensioning it is characteristic to limit the convective heat release, to avoid disadvantageous effects on conservation and energy consumption which may arise with to intensive convective heat release. In earlier Temperierung systems like skirting heating with mini convectors this negative effect was not understood thoroughly enough and therefore not considered yet.

Also there are differences to conservation heating. As mentioned before conservational heating is used for stabilizing indoor humidity to a save range to prevent mold growth (Blades and Rice, 2011). Conservation heating uses the property of water vapor of varying its partial pressure in air with the level of temperature. Simplified said, conservation heating will reduce relative humidity by heating up the indoor air. With less heating, relative humidity will rise up to the value of the natural level of the unheated building. This results in a seasonal sliding temperature behavior of the indoor climate with a more or less stable relative humidity. This can be also a goal for Temperierung heating. The conservational heating is typically understood for heating only the indoor air. This may be done by any heating system, adequate for the particular building. Heating up building components is not intended. Conservational heating with radiators or convectors may also have disadvantages in a poor microclimate around the heating device because of concentrated heat release and in consequence hot and dry microclimates and dust movement.

Considering all of these principles, Temperierung can be clearly distinguished to other heating systems and can be defined as an own heating system with its own technique and principles.

2.3. Examples of application and target room temperature

Temperierung systems are used in miscellaneous types of buildings and applications. The range for use of Temperierung systems reaches from keeping buildings frost free up to heating rooms for thermal comfort for e.g. office use or drying out building components. When moist components in a historic building are heated, the Temperierung system is used for drying out, keeping dry or preventing surfaces from suffering dew point condensation. In this use room temperature is usually of minor priority compared to conservation and damage prevention. One further main use is the preservation of exhibition buildings in open air museums (Assmann and Großeschmidt, 1988). Conservational aims for preservation of building substance and interior are dominating. Mostly a minimum temperature or sufficient temperature lift up is attempted. The Temperierung follows in this case the goals of conservation heating. For use in museums with exhibition of sensible objects more constant and often higher temperatures for visitor comfort are demanded. Further is distinguished between constant temperatures and allowing seasonal sliding temperatures especially in very cold periods. The choice of the target temperature or allowing sliding room temperatures is decisive for dimensioning Temperierung systems. Table 2 distinguishes and groups the different types of application and target temperatures. Temperierung systems are often composed for different goals. Temperierung can be used for component heating and/ or thermal bridging heating. In museums an additional goal is stabilizing the moisture of indoor climate. In some cases unfavorable combination or dimensioning of Temperierung may lead to inappropriate indoor climate or high energy consumption.

Table II – Examples of types of application and room target temperature of Temperierung heating

Room-temperature [°C]	Types of use	Main aim of use	Example of use
≥ 20	Room heating constant	Thermal comfort	Exhibitions with longer stays of visitors
< 20	Room heating with seasonal sliding	Stabilizing relative humidity	Exhibitions with longer stays of visitors
> 4	Stabilizing moisture / Minimum temperature	Avoiding mould growth / freezing damages	Open air museums, Exhibition buildings
-	Heating of thermal bridges	Avoiding condensation of moisture	Brick walls, components with contact to ground
-	Heating of building components	Drying/ keeping dry of building components	Components with contact to ground

2.4. Temperierung as a compatible solution for retrofitting of historic buildings

In historic buildings, and much more in listed buildings, retrofitting of technical devices is often difficult. In order to prevent buildings from substance losses of original building material or retain the original appearance and impression of rooms, technical devices are difficult or almost impossible to implement.

The technique of Temperierung offers a compatible solution for historic and listed buildings. The main solution with in-wall heat pipes can be also compatible as on-wall solutions of heat pipe mounting. The choice of the particular Temperierung system should be planned thoroughly and consider all important aspects for the particular building. To pay regard to all aspects of cultural heritage preservation and of stakeholders needs is difficult. The different and often contradictory goals of preventive conservation of building envelope, human thermal comfort, local microclimate for human comfort and preservation of artifacts are difficult to fulfill at the same time.

Figure 2 shows some examples of an in-wall and on-wall solution in two museum case studies, the Franconian Museum Feuchtwangen and Museum Oberammergau. In both historical buildings with valuable interior, Temperierung systems are implemented.

The Museum Feuchtwangen was built as a residential building (German "Bürgerhaus") in the 16th century. It was rebuilt for museum use in 1924 and is in use since 1926 as museum (Klemm 2008). In 2001 the museum was renovated and retrofitted with a Temperierung heating system. The building is still in a poor state. The museum was therefore renovated, partly restored and enlarged in 2006. During renovation of the rooms with tapestry, made in the 1920ies, the on-wall Temperierung was removed for renovation and laid in-wall underneath the renovated tapestry (Vogt 2006). One prerequisite was to retain the original tapestry. This was only possible with a restorers help. Although there occurred substance loses of the original wall, this was accepted. With the retrofitting measure of the on-wall Temperierung above the skirting a very cautious solution was implemented which is able to fulfill the predetermined goals. The original view of the room is not disturbed and has been improved compared to the on-wall solution. A consistent local microclimate by heating of thermal bridging prevents the building envelope of high local relative humidity and condensation.

Built in 1905 and opened as a museum in 1910, the Oberammergau Museum houses a valuable collection of regional woodcarvings. The building was retrofitted with a Temperierung heating in 2003. The solution is here an on-wall Temperierung without wall contact. The distance to the wall reduces the direct heat conduction to the wall. The heat pipes are painted in the color of the wall.

Figure 2 – Different installation situations of Temperierung systems. The left picture shows left an on-wall heating pipe disappearing in-wall at the corner to the right wall with tapestry in Museum Feuchtwangen. The middle picture shows an on-wall solution with wall contact in Museum Feuchtwangen above the skirting. The right picture shows a heat pipe in front of the wall without wall contact in the Museum Oberammergau

Every visible technical device will disturb the original appearance of a room and therefore is a disadvantage for presentation and education. Compared to common radiator heating Temperierung pipes on-wall are far less disturbing. The example of the on-wall solution in Feuchtwangen with wall contact above the skirting board is nearly invisible. For the valuable orginal tapestry the in-wall solution was preferred, but this was only made possible with simultaneous restoration of the tapestry and installation of the pipes. The installation in Oberammergau is an on-wall installation without wall contact. This is the most simple and low-cost way of installing heat pipes with the least substance losses, but it is affecting the aesthetic aspect of the historic interior.

3. CONSERVATION EXAMINATION – METHODICAL APPROACH ON THE EXAMPLE OF THE OBERAMMERGAU MUSEUM

The Standards for museum climate developed since the 1880ies continuously towards a closer and closer range. The recommendations for museum climate are mostly empirically developed (Holmberg 1995, Kilian 2013). A compilation of the international climate standards since the 1970ies is given by (Bratasz 2013). Nowadays 20 °C and 50 % r. h. with only slight differences are consistent worldwide. Classifying the indoor climate according to its potential risks for artifacts is a relatively new concept e.g. in the ASHRAE-Standard for Climate in Museums and Archives (ASHRAE 2007). For historic buildings and as well for the purpose of energy saving, these commonly known “safe” ranges for temperature and relative humidity are at the moment under discussion (Ashley-Smith 2013; Burmester, Eibl 2013). How far may these ranges be extended without serious damage to objects? With recent research, the effects of changes in relative humidity, a more sophisticated risk assessment of short- and long-term fluctuations and the investigation of single materials until their fatigue failure, will get more into focus. Theoretical limits have to be scrutinized critically and there is strong demand for further research on the effective impacts of indoor climate to real exhibits.

The Temperierung system was developed for Museum buildings housing valuable objects without any other heating or climatization technique. It is also used in these houses for enhanced climate conditions; even an ASHRAE Class A climate can be reached, if the system is run in a proper way by trained personal. The quality of a climate in a building with a Temperierung system is not only determined by the Temperierung, there are many other influences. While disasters have devastating effects on whole collections, they can be classified as singular events, like thefts, vandalism and transportations. For the preservation of the artworks, the indoor climate has to be considered with a special importance, because it constantly affects the collection, direct and indirect. Climatic induced damages can appear in museums with Temperierung systems, when the influence factors for the indoor climate are insufficiently controlled. Combining damage assessment of the collection with climate measurements makes identifying these influence factors possible. The indoor climate in the selected 18 partner museums of the current research project in Bavaria is influenced significantly by the Temperierung systems. Building conditions (building materials, air-tightness of the building, …), number and residence time of visitors in rooms, further building technology (e.g. humidification and de-humidification, ventilation systems, …) and the person, who is responsible for the facility management are, besides the outdoor climate, essential for the quality of the indoor climate and the object's microclimate (Kotterer, Großeschmidt 2008).

The conservation research in our project considers of two main aspects for the evaluation of the climate's quality: object conservation assessment and evaluation of the microclimate near the object.

In the first step, the perhaps most sensitive objects of the collection towards climate fluctuations were selected at visits of each museum. Then, the "climate history", inventories, all documentations of conservation treatments and lendings etc. of every single object have to be pointed out. According to sometimes existing photographs, new detailed photos are taken. For further imaging investigations, infrared thermography and UV-photography are used. Sometimes there are, depending on the situation, further possibilities for monitoring the progress of climate induced damages. Often, particles of paint layers are found on the cavetto or on the floor of the display case.

In the second step, the microclimate (temperature and relative humidity) at the object is measured with dataloggers for not less than one year. In this time span, the objects are regularly examined by a conservator focusing on any change. Detailed photographs are a big help for that work. Is there any change presumed, like losses or cracks, pictures are taken again. In that way, the central interest, the placement of a new damage on the timeline of an object's lifespan can be understood and backtracked.

Common criteria for the good housekeeping and preventive conservation, the material and details of the art technology are also considered for the evaluation of the climate. In that way, a long-time field study for the reactions towards climate fluctuations of certain materials will be carried out.

Materials

Organic hygroscopic materials are known to react particularly sensitive towards fluctuations of temperature and relative humidity. They include wooden objects and building components, canvas paintings, books, organs, textiles, ivory and leather (DIN EN 15757). For assessing the quality of the object's microclimate, the specific environmental conditions have to be regarded for a longer time-span. According to the DIN EN 15757 this is more than one year. In that way, the object's "historic" climate can be overviewed.

The characteristics of paint layers on textile or wooden support for climate fluctuations have been illustrated under laboratory conditions (Mecklenburg 2010a and 2010b; Bratasz et al 2011). Still unknown is, how the research in the laboratory on non-aged materials can be transferred to the complex, multilayer and aged materials of historic objects with preliminary damages and earlier conservation treatments. The validity of the common point of view to define cracks as relief zone can be challenged perhaps. Damages can expand on the borders of cracks more easily by an increasing diffusion of moisture in these areas (Kilian 2013). In environments with high relative humidity – over 70 – 75 % r. h. the risk for microbiological attack is significant higher (Sedlbauer 2001). Aging and decay of organic binders is proceeding faster, while coatings have less mechanical stability (Mecklenburg et al 1998).

Every object in a collection has an individual history, regarding the climate it has been stored in or its use. Michalski's proofed fluctuation concept is based on the idea that works of art experience several exposures to damaging climatic events during their lifetime. According to this theory, all fluctuations, which are smaller than a damaging climatic fluctuation, cause no further damage (Michalski 2007). This statement has to be verified within the project in real collections. Within the project particularly recent damages are recorded.

Investigations at the Oberammergau Museum

Numerous exhibits are on display since the opening of the museum in 1910. The mostly small-sized wooden sculptures are shown in original display cases. Most of the objects are well preserved; sometimes a smaller amount of climate induced damages is visible. To clarify, if these damages still proceed, the microclimatic conditions are measured and photo documentation is made. These pictures, especially macro-photos are controlled several times a year. With new appearing damages, the pictures are made again. Thereby, a propagating damage could be recorded. A crack in the paint layer of the 18th century model of the high altar piece of the Oberammergau church expanded and a piece of paint layer fell off. Elsewhere, the damages in the paint layer showed no progression. The climate monitoring in the altar model's display case shows, that the relative humidity is below 40 % RH in winter time, see Figure 3. Due to the low RH, losses of the paint layers on the wooden support can occur. The climate in the display case and the indoor climate in the exhibition room are rather stable. Choosing lower room temperatures during the winter time following the principles of conservation heating would improve the climatic conditions for the sensitive paint layers considerably. This would be possible during closing time in winter in November and from January to end of March when the museum is not opened to the public and thermal comfort is not required.

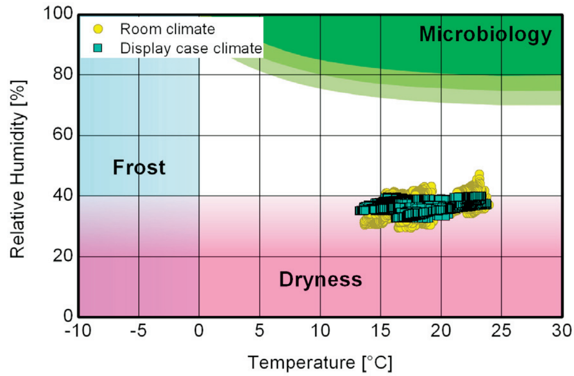

Figure 3 – Display case climate in context of the room climate. In the display case a model of the high altar piece of the Oberammergau church is exhibited. The data is the hourly mean of 10 minute interval measured data from 03.12.2012 to 15.05.2013

CONCLUSION AND OUTLOOK

Temperierung is a heating system especially for retrofitting historic museum buildings with requirements for preventive conservation of buildings and exhibits. Developed at the Bavarian State Office for Non-State Owned Museums, Temperierung heating is in use for about 30 years mostly in southern Germany, but also in other countries in Europe. Some advantages and disadvantages of Temperierung are still disputed. The most common Temperierung systems are introduced by examples from the research project „Temperierung as a Tool for Preventive Conservation – An Assessment" and their differences to each other are explained. Also, as an important step for clarifying effects and advantages of Temperierung, the different modes and types of application are introduced. To better define Temperierung heating as a self-contained heating system in contrast to other neighboring heating systems, the differences were accentuated and identified. The in-wall solution has advantages concerning aesthetic and educational aspects. Temperierung pipes on-wall are visible but appear mostly secondarily. The advantages are less encroachment to the substance and enhanced evidence of the historic building compared to other heating systems.

The conservation analysis of the effects is based on climatic induced damages. To understand the difficulties of such an analysis, the climatic history and current possible influences of artifacts are considered. The conservation investigations within the project will contribute to the knowledge about the behavior of collections in different climate conditions. The aim is to contribute to and expand the discussion about the "correct" museum climate with field studies on climate impact on different exhibition objects.

Beside the investigations on effects of Temperierung to preventive conservation, the energy consumption of the museum buildings is of main concern. The presented work is essential for further steps in the assessment of energy consumption of the system and heat release of Temperierung heat pipes. In situ measurements are already implemented for the different main systems of Temperierung in several museums. Additional laboratory measurements are in preparation to clarify effects on buoyancy driven air flow induced by Temperierung heating.

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