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Cyclododecane for mounting of surface sensors for monitoring of historic buildings

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In heritage buildings, monitoring of the hygrothermal behaviour of building components and of the indoor climate is often necessary for conservation purposes. In many cases, measurement on sensitive building surfaces is required, which necessitates direct contact between the sensor and the surface over the entire measurement period. Commonly-used mounting systems cannot be removed without damage to historic surfaces.

This paper describes a new system for mounting sensors on valuable historic surfaces, developed in cooperation with conservators and building physicists. Various materials and methods were tested in the laboratory and in situ for applications indoors and outdoors. Cyclododecane (CDD) was used as a protection layer to protect original surfaces, and also as a contact layer for accurate measurement. Since CDD is a volatile binding medium, sublimation must be hindered until the measurement period has ended by covering with a diffusion-tight material. CDD can be a solvent for some materials, so conservators should ensure that no reaction occurs between the covering layers, the CDD and the historic surface. The development of the covering layers and their application methods is presented in this paper.

The effect of this new reversible mounting system on measurement accuracy is also examined and discussed. The system has been applied and monitored several times in museums and castles. The historic surfaces were assessed afterwards for damage or residues. The system is almost completely reversible and does not affect measurement accuracy significantly.

1 Background

In times of discussion about climate change and its impact on historic buildings, more research is carried out regarding questions of indoor climate in historic buildings. For conservation and building physics purposes measurement data need to be collected.

These data are used for building physics issues, such as building simulations, as well as for conservation concerns. Therefore, a wide variety of measurement equipment types is necessary. For the current research project 'Temperierung heating as a tool for preventive conservation – an assessment', measurements in 18 participating museums, most of them located in historic buildings, were planned.[1]

In the field of building physics and preventive conservation, the measurements of most interest are usually air temperature, relative humidity, surface temperature and heat flux. A wide range of materials for mounting of measurement equipment is in use, including epoxy resin, conductivity paste, and many kinds of tapes, screws and nails. For historic buildings, hot melt adhesive is often used. This works well on even, solid surfaces: it is easy to use and seldom produces losses. Unfortunately, this method is problematic on powdery and unstable surfaces, as the glue cannot bond reliably: it connects well to the upper layers, but in the layers underneath, cohesion failure with considerable material losses takes place.

These conventional mounting procedures all induce losses to the original building fabric or leave residues with unknown ageing behaviour (Figure 1). Most buildings where this kind of monitoring is carried out are historic, with interior decoration and surfaces in their original condition that require special protection. The European Standard EN 15758[2] notes that measuring surface temperatures is potentially risky to objects but does not contain any detailed description of how to measure on sensi-

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[1] Temperierung is "'wall heating through pipes mounted in or on the inside of the walls"…[and] has been recommended as a heating and climatization system for enhanced climate stability in museum buildings' (Bichlmair *et al.* 2015: 80).

[2] Conservation of Cultural Property – Procedures and instruments for measuring temperatures of the air and of the surfaces of objects; German version DIN Deutsches Institut für Normung e.V. (2010).

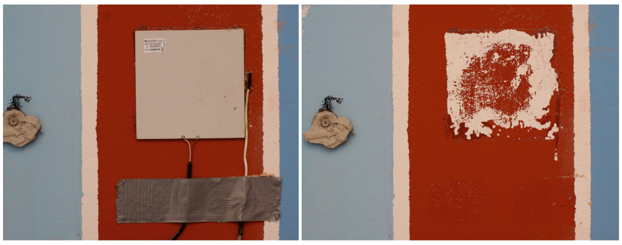

Figure 1 A conventional mounting system in a building at the Fraunhofer test facility, Holzkirchen: (a) during installation; (b) showing the losses and residues caused by removal.

tive surfaces. For this reason, some measurements may not possible or can only be carried out on reconstructions and subordinate parts of a building (Camuffo 1998).

2 Our approach

The challenge for our small group of conservators and building physicists was to develop a new method for mounting sensors on historic surfaces that does not cause any harm. The method should not affect the measurement accuracy and should ensure that the sensor is in good contact with the wall, with no air pockets in between. The sensors for measuring surface temperatures must remain in place for the entire measurement period (at least 13 months). Mounting methods should work for sensors placed both indoors and outdoors. The method should be flexible enough for use with surface temperature sensors, which are comparatively small, as well as for heat flux measurements, which need a large contact area (12 × 12 cm).

From the conservator's point of view only reversible materials should be used as far as possible (Emmerling 1992) – and materials should remain removable even after they have been in place for some time or under adverse conditions, for example on a weathered façade. The materials used directly on the historic surfaces have to fulfil the highest requirements concerning ageing stability, re-solubility and have to be damage-free. Our measurements were planned for at least 13 months, but no longer than 25 months. During that time, the sensor installations could be controlled regularly every 5–7 months. Often, hot melt adhesive was used for mounting of sensors in historic buildings, as it was the least damaging method and is easy and quick to use. It is important, therefore, that any new method is also easy and not too time-consuming to use.

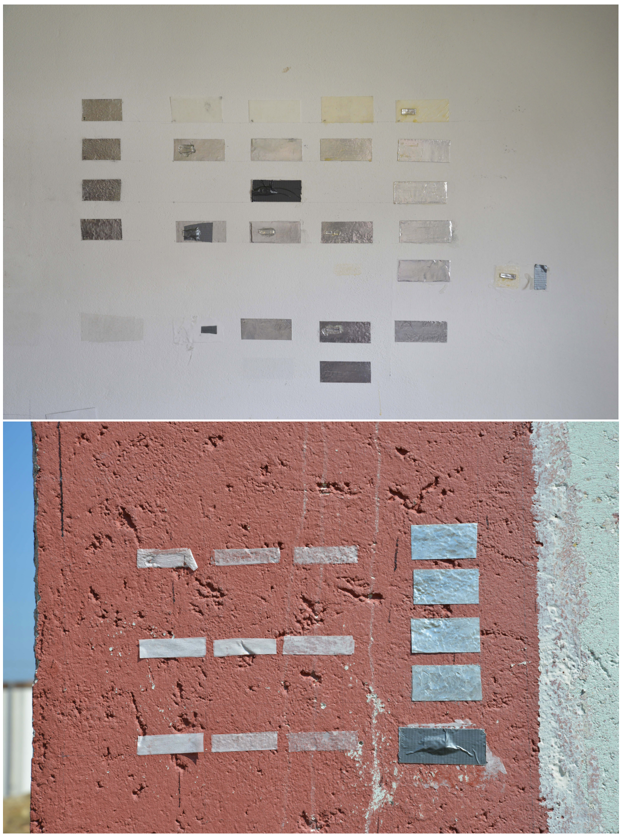

Figure 2 Indoor and outdoor tests of different materials and systems at the Fraunhofer test facility in Holzkirchen.

Numerous tests were carried out in a test house at the Fraunhofer Test Facility in Holzkirchen (Figure 2). Within the tests, different setups were considered: heat flux measurement, surface temperature sensor, mounting of cables or whole data loggers on various surfaces. The basic approach, as well as the different methods, were published in (Raffler/Bichlmair/Kilian 2015), with a main focus on indoor measurements.

From the beginning, cyclododecane (CDD) was considered for mounting the heat flux meter. Conventional mounting techniques for heat flux meters use conductivity paste or epoxy resin, both of which cause significant damage to the surface or leave residues (conductivity paste usually contains a high amount of silicone oil).

CDD was chosen because it is known to have the slowest evaporation rate of all the volatile binding media used in conservation. After a first test application, it was clear that it would be necessary to inhibit the CDD from subliming, in order to prolong the useful lifetime of the mounting system. The expected lifetime for this system was not known initially, but it was estimated to be three months.

3 Development

For laminating the CDD, different materials and methods were tested. Hangleiter and Saltzmann (2005) suggest using aluminium tape with paper or a non-woven fabric made of polypropylene. The aluminium tape is stuck to the fabric or the paper, which is then soaked with melted CDD. Afterwards, the laminated tape can be ironed onto the object surface. A slightly modified version of this system was tested for our first mountings. We found that the soaked paper sandwich can only be stored for a few days and the CDD layer from the soaked paper is often not thick enough for textured plaster surfaces. We carried out tests to evaluate how to apply CDD to the wall with less effort than brushing the melt and without using solvents. Using CDD from a spray can and melting it with an iron showed good results.

In our modified method, aluminium tape is stuck to Japanese paper and the CDD is sprayed directly on the wall from a spray can, using a mask to isolate the application area. The laminated tape/paper is then ironed onto the wall. If aluminium tape is too reflective, it can be covered with white plastic tape after the ironing is completed.

The adhesive used in the aluminium tape is usually unknown and could react with the CDD during the ironing process. Since it is known that CDD can react with plastic materials (Jägers and Sicken 2012) and produce residues, all plastic materials in direct contact with the hot CDD melt should be avoided.

To use CDD for mounting surface sensors and heat flux meters on historic surfaces, some things had to be changed (Figure 3). Aluminium foil is now used instead of aluminium tape, and Japanese paper (25 g/m^2) is used instead of polypropylene fabric or paper towels. The various layers are bonded with epoxy resin. The upper side of the patch is covered with thin Japanese tissue paper (11 g/m^2) in order to modify the emissivity coefficient of the aluminium foil and enable the sensor to be mounted with hot melt adhesive. After the epoxy resin has hardened, the new aluminium laminate system is cut into appropriately-sized pieces for the different measurement tools or sensors.

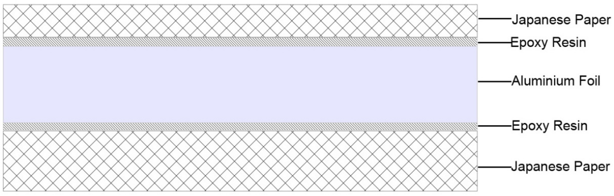

Figure 3 Diagram showing the aluminium laminate.

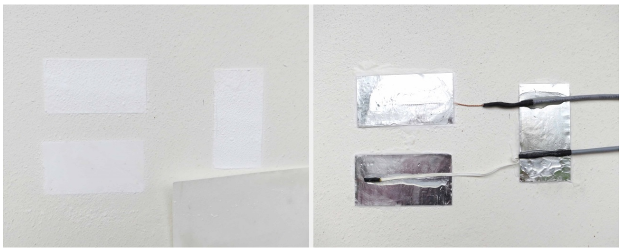

Figure 4 Mounting procedure with CDD sprayed on the wall and then melted.

4 Application

The best method for applying the sensor mounting system with CDD is determined by the historic surface. It is evident that the surface should not be sensitive to moderate heat and pressure and should be unlikely to react with the molten CDD (which has the properties of a non-polar solvent). Usually, a solvent test with white spirit or other non-polar solvent can show how the historic material is likely to behave with CDD. To be sure, a test application of the CDD is also recommended.

The CDD is either painted onto the aluminium laminate before use or sprayed directly onto the wall using a mask, where this is possible. The piece of laminate is then put in place, covered with a sheet of Melinex and pressed with a small flat-iron to melt the CDD (Figure 4). The molten CDD adheres the piece of aluminium laminate to the historic wall surface. Any surplus CDD melt can be removed off with blotting paper. The exterior surface of the aluminium laminate is then cleaned by wiping with white spirit. The sensor can then be mounted onto the aluminium: usually hot melt adhesive is used for temperature sensors and epoxy resin for a heat flux meter.

5 Effect on measurement quality

The mounting systems that are conventionally used for sensors in building physics use adhesives with high conductivity to ensure accurate measurement and minimise the effect of the adhesive on

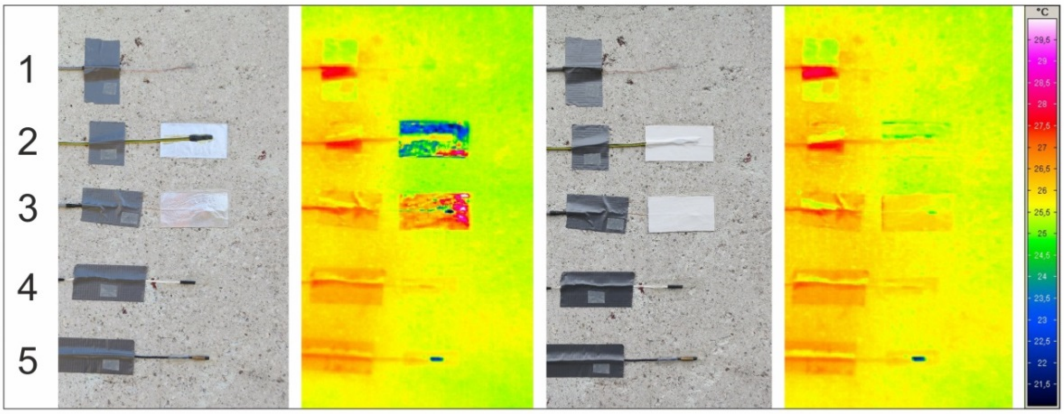

Figure 5 Test setup on an exposed west façade (left visible light and infrared images). The two mounting systems with aluminium (2 and 3) were later covered with white tape to approximate the radiating behaviour of the other systems (right visible light and infrared images).

temperature or heat flow values. Our new, reversible method for mounting sensors required additional layers of paper, CDD and aluminium to protect the original building surface. A question therefore arose about the effect of these layers on the measurement results.

5.1 Test set-up

In a real case mock-up, two test series were prepared. One test series was implemented indoors (Raffler *et al.* 2015). The second test series contained five different types of sensor mountings for outdoor temperature measurements. The influence of the outside climate was tested on an exposed outdoor wall on the west façade of a test house located at the Fraunhofer IBP Outdoor Test Facility Holzkirchen. The test building was heated to 20 °C indoors during the winter, but was not air-conditioned during the summer. The measurements taken were our first attempt at systematically assessing different mounting methods for sensors. Our main research questions were: what was the long-term behaviour of each mounting system; and how did their measurements deviate from a typical outdoor surface measurement?

Figure 5 shows the outdoor test sensors under both visible and infrared light (the latter is to show the temperature distribution). The mounting systems are numbered 1–5 on the image. System 1 is a PT100 sensor without covering, attached closely to the wall plaster with hot-melt glue. This served as the reference sample, since this mounting method is the most ideal, and therefore most common, surface temperature measurement setup. Systems 2 and 3 are new mounting systems using volatile binders. The necessary vapour barrier for the volatile binder consists of an aluminium foil laminate: sensor 2 is applied with hot-melt adhesive on top of the aluminium foil laminate; and the sensor in system 3 has been applied directly to the wall and embedded in CDD and then covered with the aluminium foil laminate. Aluminium has a different reflectance from the wall materials, which influences the measurement (the left two images of Figure 5). The aluminium foil was therefore covered with an additional layer (in this case white tape), in order to approximate the reflectance (and in consequence the coefficient of emissivity ϵ) of the surrounding wall. Subsequently, Japanese paper was used to cover the surface of the foil, as explained in Section 6 below. Systems 4 and 5 are glued with hot melt adhesive to a layer of Japanese paper, which was glued with Plextol to the wall plaster. All of the sensors are PT100 temperature sensors with or without a covering. The sensor in system 5 is covered with a metal tube, and its different reflectance is visible in the righthand infrared image in Figure 5.

An infrared image of the wall shows that the surface temperature differs by a maximum of about 0.7 Kelvin in the vicinity of the sensors. The thermal sensitivity of the IR camera is 0.03 K. The thermographic image in Figure 5 was made with a coefficient of emissivity ϵ of 0.9 on 19 July 2013 at 11am, when the west façade was still shaded. The PT100 sensors are calibrated at several temperature points. The calibration value is ±0.1 Kelvin, and the uncertainty of calibration is 0.03 Kelvin.

6 Reflection of the materials

The influence of the surface reflection was assessed more in detail. Initially, the aluminium compound was just covered with a white tape, but this was further developed with a covering of Japanese paper. For outdoor applications, the short-wave reflection influences the temperature more intensely than long-wave reflection does. Figure 6 shows the measured reflection of four different materials: aluminium foil, aluminium laminated with Japanese paper, and white and black paper. The left image shows the reflection of short-wave radiation, with white paper and aluminium foil typically showing a high reflection. The aluminium laminate also has a high reflectance, whereas the black paper shows a typically low value that corresponds to a higher energy absorption for sunlight. The right image shows long-wave reflection, with high reflection values for aluminium foil and very similar low values for the aluminium laminate and black and white paper. A low reflection value ρ corresponds to a high emissivity ϵ and absorption α, known as Kirchhoff's law, expressed as $1 - \rho_\lambda = \epsilon_\lambda = \alpha_\lambda$, where all variables depend on the wavelength λ (ISO 1996). The short-wave behaviour (sun radiation) is different from the long-wave behaviour (thermal radiation). The varying short-wave reflections of the different materials (left graph in Figure 7) are mainly responsible for deviations of the measured surface temperature between the different mounting systems when the global radiation (sun radiation) is high. For the aluminium compound, the measured coefficient of emissivity for shortwave radiation is $\epsilon_{\mathrm{shortwave}} = 0.21$, the measured coefficient of emissivity for long-wave radiation is $\epsilon_{\mathrm{longwave}} = 0.90$. These values are typical for building materials such as brightly painted plasters or white paper.

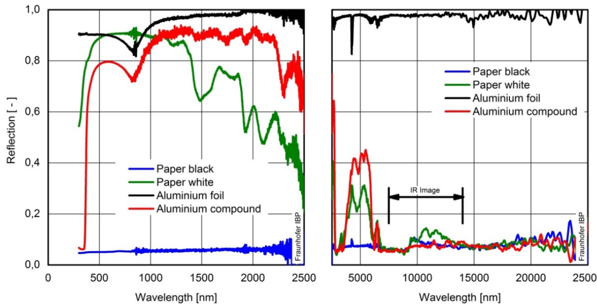

Figure 6 Measured reflection of the new aluminium laminate in comparison with three other materials.

7 Surface temperature measurement and long-term behaviour

The surface temperature measurements started on 17 July 2013 when five different sensor mounting systems were installed. The data was recorded every minute and is shown in Figure 7. As before, system 1 is the reference sensor, system 2 has the sensor on top of the aluminium laminate (which has been applied to the wall with CDD), system 3 has the sensor embedded in CDD and covered with aluminium foil, and systems 4 and 5 have the sensors on top of Japanese paper. Two days later (on 19 July) an additional layer of white tape was glued on the top of systems 2 and 3. The left hand graphs in Figure 7 show the effect of this tape on sensor 2, as its measurements change from following those of the reference (sensor 1) before the tape is applied, to tracking those of sensor 3 (after the tape is applied). Overall, the white tape layer causes lower temperatures to be observed compared with the reference. This is caused by a different short-wave reflection value and the additional heat transfer resistance of the tape. All systems react sharply to the solar radiation, with systems 4 and 5 being most influenced by this.

After almost one year, all the systems were still working and in reasonable good condition. The sensors still show the same behaviour in temperature course. To get more information on the effect of the mounting system and eliminate differences caused by material reflectivity, all the mounting systems were painted with the same white façade paint in order to produce identical surface reflection values for each mounting system (right-hand graphs in Figure 7). The graph from 25 April shows a much lower temperature

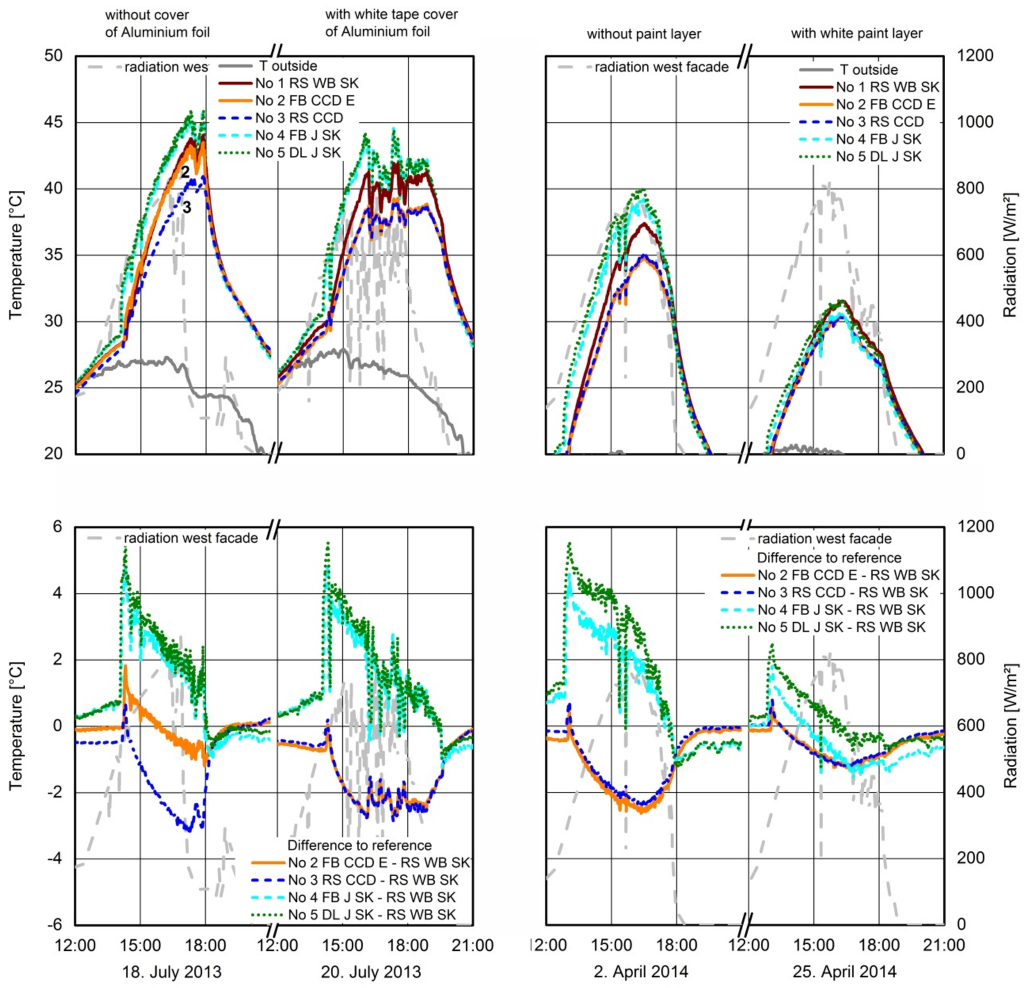

Figure 7 Temperature measurements in July 2013 before and after application of a white tape on systems 2 and 3 (top graphs), and in April 2014 before and after painting all systems with façade paint. The difference from the reference is shown for the same periods in the bottom graphs.

course overall despite almost identical outside temperatures and sun radiation. The reference sensor system drops by 5.9 °C and all the other systems come closer to the reference (bottom right graph).

Figure 8 (left-hand graphs) shows a day in September 2013 with much less direct sunshine on the west façade. The effect of the different mounting systems is still there but is much smaller. In autumn or winter, the deviation from the reference decreases to a maximum of ±0.5 °C during a day with low sun radiation (see the difference graph in the bottom left of Figure 8). The deviation of the mounting systems changes from higher values compared to the reference to lower values. In winter, when there is very low sun radiation on the west façade, this deviation decreases almost to the values observed for indoor measurements (approximately ±0.2 °C) (Raffler *et al.* 2015).

To evaluate the accuracy of these systems, and their deviation from the reference system, measurements were taken every minute. The measurements show that the reversible mounting systems track the reference system closely. Without the influence of global (sun) radiation the different mounting systems show a similar behaviour to the indoor measurements, with an accuracy of about ±0.2 °C. When the global (sun) radiation is very low and the surface reflectance is the same, the deviation increases to ±0.5 °C. In summer, with direct sun radiation and different surface reflectance, the systems with CDD deviate from the reference system by less than ±3.0 °C. If the surface reflectance is made similar with façade paint, the accuracy of measurement is within ±1.5 °C of the reference measurement. The highest deviation from the reference system is shown by systems 4 and 5 – especially the

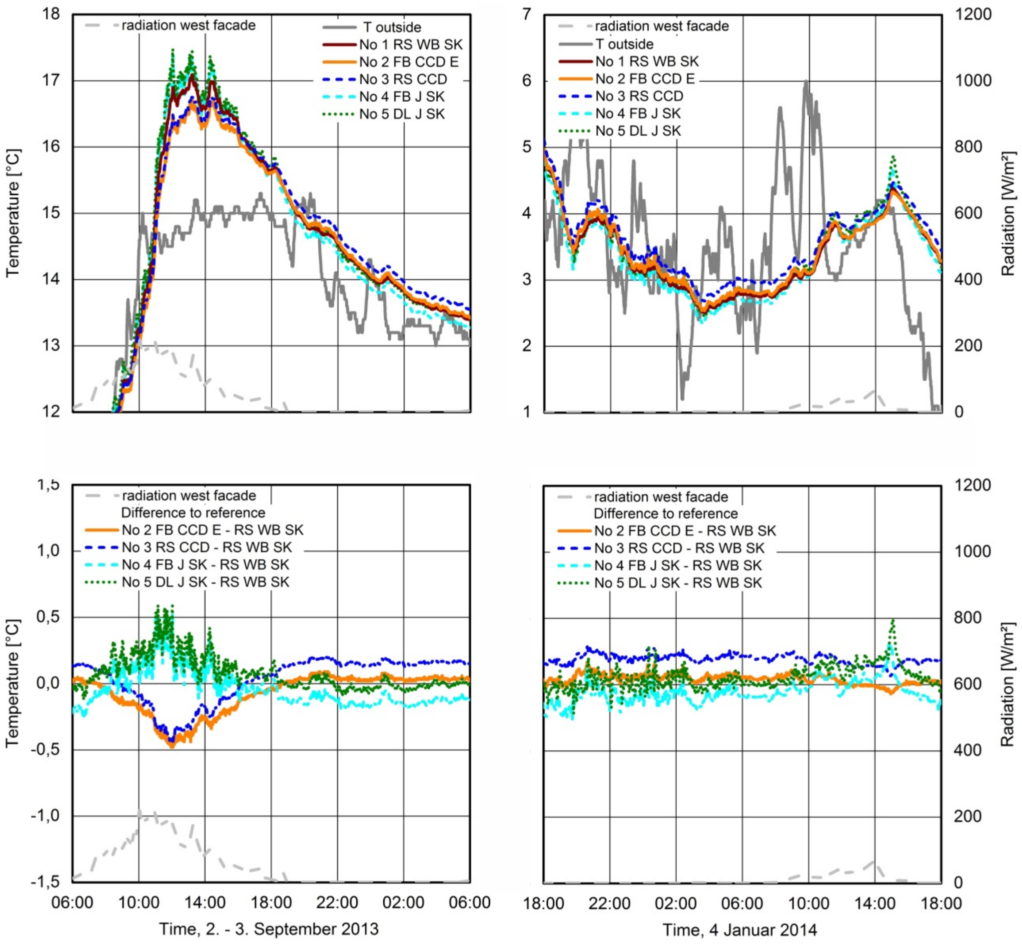

Figure 8 Temperature measurements made over a whole day in both September 2013 and January 2014 (top graphs). The deviation from the reference measurements decreases with lower solar radiation (bottom graphs).

latter, which has a thick metal tube covering the sensor. The differences between systems 2 (sensor on top) and 3 (sensor embedded in CDD) are small. In particular, their long-term behaviour (over more than one year on a full rain- and sun-exposed west façade) shows the reliability of the new reversible mounting system.

8 Long-term behaviour

In total, 20 surface temperature sensors and 2 heat flux meters were mounted with CDD and investigated. The lifetime for measuring equipment mounted with CDD was at first supposed to be around 3 months. Tests have shown that the internal temperature sub-surface building elements affects the durability of a mounting made with CDD, especially with regard to wall-heating systems. Figure 9shows the time elapsed since applying reversible mounting systems using CDD with different types of sensors and wall positions. The 22 installations are coded as follows: EG and OG refer to the floor; W stands for wall and B for bottom; HL indicates sensors in the vicinity of wall heating pipes; and DL, RS and FB name various types of PT100 sensors used for measurement with different types of glue (SK or E) for mounting the sensors to either the first described type of aluminium compound or the second type of laminate (marked as "new C").

If the building component or wall is not heated, the mounting works for an average of 20 months, indoors and outdoors. If the surface is warmed by heat pipes underneath the plaster (like Temperierung heating or wall heating), the CDD sublimes within a much shorter time span, which is determined by the difference between the internal surface temperature and the air temperature. If the difference is large, the lifetime of the mounting is only 6–15 days. If there is only a slight difference, when the heatpipe is mounted on the interior side of the wall and the sensor is mounted on the outside, the lifetime of the sensor mounting can be up

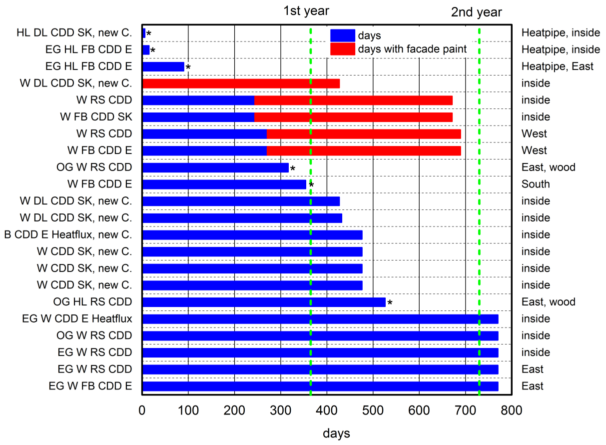

Figure 9 Lifetimes in days of the 20 surface temperature sensors and two heat flux meters mounted with systems using CDD, and their location in the building. The sensors that have fallen off by themselves are marked with *. All other sensors were removed before the lifetime of the mounting had ended.

to 526 days (shown in Figure 9 as OG HL RS CDD). Two sensors mounted on a wooden surface on an East façade showed a much shorter lifetime than the sensors mounted on plaster or painted plaster; as yet, the reason why the CDD sublimed much quicker from a wooden surface (or into it) than from a plastered surface is still unclear. Usually, a slow sublimation from the edges of the aluminium compound begins after some months. For this reason, the area of the aluminium compound should always be much larger than the surface area of the sensors.

9 Examples of field application

In the research project 'Climate for Culture', the famous Neuschwanstein Castle was investigated. Neuschwanstein Castle was built from 1868 to 1884 and opened to the public in 1886, some weeks after the death of King Ludwig II. Today, Neuschwanstein is one of the most famous castles in Europe, with 1.4 million visitors per year. This high number of visitors – in summer, around 6,000 per day – and its unique location within the rough alpine climate lead to preservation problems for the castle.[3]

Figure 10 Neuschwanstein Castle: the apse in the Throne Hall, and detail of the wall with the sensor.

A monitoring network was installed at the castle, in order gain more knowledge about the hygrothermal behaviour of the throne hall, to answer questions of preventive conservation and to provide reference data for building simulation. Air temperatures, relative humidity, heat fluxes and surface temperatures were measured at several spots in the throne hall (Figure 10).

To measure the surface temperature at the wall of the apse, which is entirely decorated with gilding and painting, it was necessary to use a mounting system which caused absolutely no damage. The sensors were mounted using the CDD system described above and remained there for 15 months.

10 Removal

Dismantling installations that use CDD as an intermediate layer is more simple compared to other mounting methods. If there is no need to dismantle the installation on a particular day, time will eventually remove the installation through sublimation of the CDD.

In most cases, when a measurement campaign is ending, all installations will be dismantled. The sensors mounted on the aluminium composite with hot melt glue can be removed mechanically or using solvents. When the sensor has been removed, the CDD can sublime from the edges of the aluminium composite, which will fall off after some time (Figure 11). If necessary, the aluminium composite can be separated from the CDD layer by peeling and/or warming. The remaining CDD will sublime from the wall after some time.

11 Residues and interactions

In the ongoing research project 'Temperierung heating as a tool for preventive conservation – an assessment', one of the buildings investigated was a farmhouse at the Glentleiten open-air farm museum in Upper Bavaria. The farmhouse called 'Fischerweber' was built in 1729, enlarged in 1789 and translocated to the museum from 1993 to 1999. The original furnishings from the

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[3] `http://www.neuschwanstein.de/deutsch/schloss/index.htm`

Figure 11 Removing a sensor: (left) sensor before dismantling with the CDD sublimed from the edge (arrow); (centre) sensor has been removed from the aluminium laminate; (right) aluminium composite and remains of CDD on the gilded and painted wall.

1930s and 1960s are nearly completely preserved. Throughout the building, a Temperierung heating system was installed in 1999 and has been used for conservation heating since then. The house was opened to the public in 2001. For the research project, detailed measurements concerning the heating system, surface temperatures and indoor climate had to be carried out. The measurement installations are visible to visitors and need to be dismantled after the measurement period without causing noticeable change to the building. Different mounting systems were used for different surfaces and equipment.

At the East façade on the first floor, which is covered by wood panelling, surface temperatures were measured. The wood panelling is painted with a light yellow-brown, probably oil-bound colour, which is already heavily weathered. There, the surface temperature sensors were mounted using CDD covered with the aluminium laminate. During the usual maintenance cycle, some reaction between the mounting system and the paint was recorded. It appears that some reaction had taken place during the melting process of the CDD. It turned out that the paint layer is sensitive to all non-polar solvents, and the CDD had acted upon it as a solvent as well. This reaction led to a darkening of the surface, comparable to the effect which is seen when an area of paint contains more binding medium (Figure 12).

Figure 12 (left) CDD acting as a solvent and transporting colour particles at the Fischerweber farmhouse; (right) slowly subliming CDD after the installations at Neuschwanstein Castle have been dismantled. No surface changes are visible.

In the throne hall at Neuschwanstein Castle, no reaction between the wall decoration and the CDD was visible in plain light or in UV light.

12 Conclusion

Common mounting systems for surface measurements are risky to original surfaces. Following collaboration between building physicists and conservators, various new reversible systems were developed and tested. One of these systems uses CDD as a binding and coating medium. With the newly-developed covering material, which inhibits sublimation of the CDD, the mounting can remain on a surface for up to two years or even longer. The ageing properties of the CDD and how its ageing could influence its sublimation are still unknown and requires further research. Nevertheless, the mounting system using CDD has been applied successfully several times. In only one case was an adverse effect noted, where the CDD acted as a solvent and created stains on a weathered surface.

The influence on the measurement accuracy was investigated during the testing process as well. The difference for a mounting system using CDD (compared to the standard mounting system) is estimated to be ±0.2 K for indoor measurements (Rafler *et al.* 2015) and for outside measurements without influence of global (sun) radiation. The effect of the varying reflectance of the sensor and mounting systems increases directly with global (sun) radiation. When sensors are painted with façade paint, the deviation from the reference in direct sun is up to ±1.5 °C (without this paint coating, the deviation is estimated to be ±3.0 °C). The calibrated sensor accuracy is also ±0.1 K for indoor measurements. For measuring historic buildings, which have a natural inhomogeneity of temperature distribution and reflection characteristics, these measurement deviations are within an acceptable range.

The new aluminium laminate was developed to inhibit sublimation of the CDD, and as a material that is unlikely to react with the hot CDD melt. This laminate could be useful in other applications in the broader field of conservation.

In order to avoid any damage to historic surfaces, primary testing by conservators is necessary, considering that CDD can react with the surface in certain cases.

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Biographies

Susanne Raffler studied Restoration, Technology of Arts and Conservation Science at the Technische Universität München. In 2011–2012 she worked for the Bavarian Administration for Palaces, Gardens and Lakes as a Conservator for wooden objects and in the Castle of Linderhof to investigate climate-induced damage. From 2012 she was a research assistant at TU München with primary interests in preventive conservation, the influence of Temperierung heating systems for exhibits, and climate-induced pigment transformations. Since 2016, she has worked as a freelancer near Munich.

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Stefan Bichlmair studied Wood Technology at the University of Applied Sciences Rosenheim, followed by ten years of experience as an engineer at a building manufacturer producing pre-fabricated wood-frame walls. After gaining a Masters degree in wood technology, he made a scientific examination of the impact of indoor climates in the Linderhof Castle at the Fraunhofer IBP. Since 2010, he has worked at the Fraunhofer IBP. His main research interests are internal wall insulation for old and historic buildings, Temperierung heating systems and concepts for building climatisation, as well as assessments of indoor climate in castles, churches and museums.

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Ralf Kilian studied Civil Engineering and Restoration, Technology of Arts and Conservation Science at the Technische Universität München. Since 2005 he has worked at the Fraunhofer Institute for Building Physics, Holzkirchen, where he is responsible for cultural heritage research. His work deals with aspects of monument preservation and energy efficiency, with sustainability in retrofitting museums, as well as with the indoor climate in historic buildings and its impact on works of art. From 2009 to 2014 he was scientific coordinator of the large-scale EU-funded project 'Climate for Culture'. Ralf Kilian is an active Member of CEN TC 346 'Conservation of cultural property' and of the WTA.

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