G Model
CULHER-3060; No. of Pages 8
ARTICLE IN PRESS
Journal of Cultural Heritage xxx (2016) xxx–xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Original article

Microwave and radio wave supported drying as new options in flood mitigation of imbued decorated historic masonry

Christoph Franzen[a,*], Matthias Zötzl[a], Ulf Trommler[b,1], Christian Hoyer[b,c,1], Frank Holzer[b,1], Björn Höhlig[c], Ulf Roland[b,1]

[a] *Institut für Diagnostik und Konservierung an Denkmalen in Sachsen und Sachsen-Anhalt e.V., Schloßplatz 1, 01067 Dresden, Germany*
[b] *Helmholtz Centre for Environmental Research – UFZ, Department of Environmental Engineering, Permoserstr. 15, 04318 Leipzig, Germany*
[c] *Leipzig University of Applied Sciences, Faculty of Civil Engineering, Karl-Liebknecht-Str. 132, 04277 Leipzig, Germany*

A R T I C L E I N F O

Article history:
Received 19 November 2015
Accepted 14 April 2016
Available online xxx

Keywords:
Drying
Historic masonry
Dielectric heating
Microwaves
Radio waves

A B S T R A C T

For mitigation of the impact on flood-damaged cultural heritage buildings and sites, solely conservation-compatible and noninvasive strategies can be applied. All procedures have to take into account not only the specific situation after flooding but also the material properties and the characteristics of the artwork related to the building. After a heavy flooding event damaging the monastery Marienthal in Germany demonstration studies were proceeded to evaluate heritage-adequate treatment strategies for the drying of a decorated chapel. To respect and preserve the original gypsum stucco interior drying in certain temperature limits had to be respected. Particularly, direct volumetric heating methods were employed working with electromagnetic waves in the frequency ranges of either microwaves or radio waves. The studies comprised heating tests on site and experiments on a heritage-representative masonry specimen. It could be shown that the removal of water could be significantly enhanced by both techniques. Radio wave heating was demonstrated to allow a more homogeneous and better controlled treatment in comparison to microwave application, which is especially relevant in case of sensitive materials such as gypsum. With respecting that limits the techniques can be applied in combination with efficient removal of moisture from the ambient air by ventilation in order to reduce the drying time thus limiting subsequent damage of the heritage building.

1. Introduction

On August 7th and 8th, 2010, the monastery of Marienthal (Fig. 1) was heavily affected by a flood event of the nearby Neisse River. Several days of very heavy rains had raised the river levels in the entire Neisse region at the national border between Germany and Poland. Retaining reservoirs could not hold the water any more resulting in a flood wave running along the river basin. Although notably flood protection arrangements including mobile protection parts had been installed after an earlier event the disastrous flood of 2002 the actual flood mark exceeded the expected level and entered the rather protected monastery areal. Most of the rooms in ground level and namely the church, the cloister and many rooms of the convent were deluged by between 1.5 to 2.3 m in height depending on the absolute floor level. It was the highest flood event in the history of the convent. Some of the valuable cultural mobile parts could be rescued in due time by some nuns but immobile parts got heavily affected. It took about one day for the main water to run off. Mud and floating refuse were left behind. Naturally, all lower building masonry parts were heavily moistened (Fig. 1).

River floods are the main risk being related to climate change for heritage buildings in Europe [1–3]. Thus, there is an increasing need to cope with heritage-compatible mitigation strategies to better respond to climate change risks. The special challenge in the context of heritage buildings is the sensitivity of the materials and the artwork related to them.

For sustainable retrofitting and restoration of the damaged building structures such as in Marienthal, appropriate and preferentially prompt drying of the masonries is a precondition in order to avoid consequential damage, e.g. by mould formation. On many buildings where protective plaster so called “Sanierputz” had been applied on the outer facades within the last decade, the plaster had to be removed completely. The main function of a “Sanierputz” is to ensure an undamaged masonry appearance of problematic walls by impeding salt transport to the surface. Due to the efficient prevention of the capillary water transport to the surface as

* Corresponding author. Tel.: +49 0 351 48430 410; fax: +49 0 351 48430 468.
E-mail addresses: franzen@idk-info.de (C. Franzen), ulf.roland@ufz.de (U. Roland).
[1] Tel.: +49 0 341 235 1762; fax: +49 0 341 235 45 1762.

http://dx.doi.org/10.1016/j.culher.2016.04.007
1296-2074/

Fig. 1. Convent Marienthal at Neisse River with the chapel St. Michaelis ("Michaeliskapelle", *left*), situation after the 2010 flood event at the monastery area (*middle*) and in the chapel St. Michaelis with the maximum water level clearly visible by the darker color (*right*).

a key function of the plaster, drying of the totally wet masonry is all but impossible. However, the chapel of St. Michaelis (Fig. 1) has a regular plaster on the outside, which was advantageous in the drying context. Therefore, there was no constraint to remove the outside plaster. In contrast, the situation inside the chapel was much more demanding because the wall is completely decorated with a historical stucco gypsum plaster as false marble interior. Saving the original material in place was of paramount importance in preserving cultural this heritage. Beside the sensitive stucco gypsum plaster, the masonry composition also included brickwork and rubble masonry. Against this background, the investigations consisted of analysis and test applications at the chapel accompanied by investigations on a special test specimen. The test specimen allowed destructive sampling and check also critical conditions for the application of drying methods without damaging of the heritage material. The false stucco marble consists in large parts out of Gypsum ($CaSO_4 \bullet 2H_2O$), which begins dehydration in the range from 42–60 °C [4]. Although gypsum shows almost no shrinkage after drying and dehydration, rewetting leads to clear increased volume [5]. This swelling effect influences the bond properties with the substrate material due to different expansion and can cause delamination.

In order to exploit the positive temperature effect on vapor pressure and diffusivity of water inside the materials, two innovative heating methods being based on a similar working principle were tested. Dielectric heating allows absorption of electromagnetic energy in the volume of a material as in the case of a kitchen microwave (MW) oven. While the heating in the MW range (frequency of some GHz) is mainly based on the permanent reorientation of water molecules in the external electrical field and the related frictional interaction with their microscopic environment, radio-frequency (RF) or radio wave (RW) heating working with MHz frequencies mainly makes use of other polarization processes within the solid material [6–8]. Due to the longer wavelength in the meter range and the absence of interference effects in relevant scales, RF heating usually leads to better homogeneity of heating and larger penetration depths. As a result, RF heating has been already successfully applied for soil remediation [9–11], civil engineering [12,13] or for controlling the temperature of packed-bed reactors in chemical technology and gas treatment [14,15]. Additionally, due to the interaction mechanism being based on different polar structures in comparison with MW, RF heating can also be used to heat dry and "MW-transparent" materials [16,17]. Despite the experiences of MW and RF applications, the use for drying of heritage buildings is ambitious and, therefore, worth investigating which was the intention of this study.

2. Materials and methods

2.1. Moisture analysis

Moisture content of the masonry parts originating from the site as well as from the masonry test specimen described later was investigated by means of gravimetrical drill-powder analysis. Drilling with an aperture of 12 mm was executed stepwise in order to win depth profiles. The obtained powder samples were collected in sealed containers and brought to laboratory for gravimetric moisture determination with drying at 105 °C until constant weight [18]. It has to be taken into account that also dry masonry shows water contents to about 1 wt.-%, due to interaction with the ambient air humidity [19].

2.2. Temperature detection

In order to avoid interference of the temperature measurement with electromagnetic fields, fiber optical temperature sensors (OPTOcon, Dresden, Germany or Neoptix, Quebec, Canada) using the temperature-dependent variation of the band gap of a GaAs semiconductor crystal as sensing principle [20] were applied. In all experiments, such sensors were placed in a representative manner within the masonry structures. The accuracy of the temperature measurement with these sensors was about ± 0.3 K.

When carrying out MW heating inside and outside the chapel, temperature sensors were positioned in three depths. For the tests inside the chapel, the sensors were set at depths of 5 cm, 10 cm and 15 cm, measured from the plastered surface of the masonry. Thus, the first measuring depth was situated 1 to 2 cm behind the stucco plaster. For the experiments outside, the sensors were placed in depths of 5 cm, 10 cm and 40 cm, measured from the brick surface of the masonry as the outer plaster had been removed. Temperature results inside were recorded in time intervals of 150 s during the 20 min of application during the MW experiment and in intervals of 5 min for 20 min after shutting off the MW application. Except of these experimental periods, the recording interval was 5 min during the experiment lasting 7 h in total.

In the tests with the masonry test specimen, temperature sensors were placed in different depths so that a representative measurement of all layers (stucco gypsum plaster, lime mortar and brickwork) was ensured.

For a thermal investigation of the wall and specimen surfaces, a Varioscan 3021ST (JENOPTIK Laser Optik Systeme GmbH, Jena, Germany) came into use. The infrared camera works with Stirling cooled detector exhibiting a thermal resolution of ± 0.03 K using the spectral range from 8 to 12 μm. Additionally on site temperature control of the surface area was done by Trotec IC060 (resolution 0.08 K).

2.3. Masonry test specimen

For the laboratory tests, a test specimen representing the situation of the real site in Marienthal was built. This structure consisted of eight layers of solid bricks linked by a hydraulic lime mortar. The front side was decorated with marbled stucco fully comparable to the material that is found in the chapel (Fig. 2). An experienced plasterer, also responsible for the restoration actions on site,

Please cite this article in press as: C. Franzen, et al., Microwave and radio wave supported drying as new options in flood mitigation of imbued decorated historic masonry, Journal of Cultural Heritage (2016), http://dx.doi.org/10.1016/j.culher.2016.04.007