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NON-INVASIVE METHODS IN DIAGNOSIS OF WALL DAMPNESS DEGREE IN SACRAL BUILDINGS

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Abstract

The article contains a description of sacral buildings wall dampness causes. It shows the optimal condition of internal microclimate regarding rooms designed to exhibit historical items. Analysed methods are diagnostic of wall moisture by non-invasive methods. The thermal image examination with the use of microwave electromagnetic radiator was carried out. Two samples of brick were tested; they were exposed to the radiation at the total time of 90 seconds. The nominal power of the radiator was PN=900W. The author analysed other sources of heat radiation. He changed microwave radiation to infrared radiator, and thus the examination was easier and safer. The results shown in the article are the temperatures and infrared radiator test results. The aim is to determine time constant of various radiator work methods. The aim of the analysis was to show temperature distribution at given distances from the radiator, which enabled constant temperature distribution at certain stages of the device running.

Keywords: brick walls, dampness, thermographic method, electromagnetic radiator, infrared radiator

NIEINWAZYJNE METODY DIAGNOSTYKI STOPNIA ZAWILGOCENIA MURÓW OBIEKTÓW SAKRALNYCH

Streszczenie

W artykule zamieszczono opis przyczyn zawilgocenia murów z cegły ceramicznej obiektów sakralnych. Przedstawiono optymalne warunki mikroklimatu pomieszczeń przeznaczonych do ekspozycji obiektów zabytkowych. Poddano analizie metody diagnostyki zawilgocenia murów metodami nieinwazyjnymi. Przeprowadzono termograficzne pomiary laboratoryjne z wykorzystaniem mikrofalowego promiennika elektromagnetycznego. Badaniom poddano dwie próbki cegieł, które wystawiono na oddziaływanie promieniowania w całkowitym czasie 90s za pomocą manometru. Moc znamionowa promiennika wynosiła PN=900W. Autor poddał analizie inne źródło promieniowania cieplnego, zastąpił promieniowanie mikrofalowe promiennikiem podczerwieni, co ułatwia pomiary i zwiększyło bezpieczeństwo całego pomiaru. W artykule zamieszczono wynik temperatur i badań promiennika podczerwieni w celu wyznaczenia stałych czasowych przy różnych sposobach jego pracy. Celem badania było zobrazowanie rozkładu temperatur w założonych odległościach, co umożliwiło ukazanie bryłowego rozkładu temperatury w danych chwilach pracy urządzenia.

Słowa kluczowe: mury ceglane, zawilgocenie, metoda termograficzna, promiennik podczerwieni i elektromagnetyczny

1. INTRODUCTION

The motivation to address the problem of wall dampness diagnostics was based on many years of my experience and observations: what problems and what mistakes are made in building works regarding waterproof isolation of historical buildings; what problems and technical limitations appear in diagnosing wall dampness of historical objects; what mistakes are made in the process of making secondary diaphragms. The vast experience has shown the repetition of the same mistakes made by various contractors as well as similar technical problems in diagnosis. The effects of badly made horizontal insulation are usually visible to tenants / owners only when unwanted phenomena such as wall destruction are unfortunately advanced and therefore need considerable financial and technical means to do necessary repairs.

Due to the microclimatic conditions in buildings which affect the condition of frescoes and other elements of interior decoration of sacral buildings, the role of constant non-invasive moisture conditions control is crucial. It should be relatively cheap (many measurements throughout the year) quick and easy to use (without sophisticated and expensive equipment or special synchronising procedures nor special staff training or numerous measurement series).

Therefore, a new method of a physical and chemical wall condition diagnosis may lead to avoidance of numerous limitations, hesitation and mistakes but on the other hand to simplicity and low costs. The method should detect irregularities of the horizontal insulation in its initial phase which in turn may decrease the cost of repair or minimise mistakes made during isolation works.

The causes of dampness may be [4]:

- Precipitation;
- capillarity of groundwater;
- condensation of steam or sanitary installation breakdowns;
- technological processes connected with erecting buildings.

2. CLIMATIC CONDITIONS OF HISTORICAL ELEMENTS

The optimal parameters of microclimatic conditions of the rooms designed to exhibit or store historical objects are affected by various conditions connected with materials, structures or age of the objects. The items stored in sacral rooms are characterised by various sensitivity levels to microclimatic parameter changes in internal microclimatic conditions.

The main factor influencing the condition of historical objects is internal relative moisture. The most optimal level of the parameter ranges between 60 and 70%. The objects stored in damp conditions characterize with certain balanced moisture, which maintained, allow for steam exchange between the material and surrounding environment. Due to the different amounts of water in various materials, the change of its volume and dimensions may vary, thus it may lead to the degradation of the historical item. To maintain the buildings as well as the items inside in good condition, the stability of the internal conditions is necessary. The amplitudes of temperature and dampness immensely affect the premature destruction of items in sacral buildings.

I have been checking the moisture conditions in St. Mary Magdalene church in Cieszyn, Poland for many years. This work encouraged me to create a new method of moisture measurement which should be non-invasive, quick, inexpensive and easy to use.

Fig. 1. St. Mary Magdalene church in Cieszyn, Poland – a baroque building

3. DIAGNOSIS OF WALL DAMPNESS

Diagnostics evaluates the shape of an object with the use of certain symptoms - diagnostic signals. In literature, there are various diagnostic methods covering the topic of dampness. They can be divided into two general areas:

a) Invasive methods (the drier-weight traditional method, with the use of a weight-drier, carbide)

b) Non-invasive (the electric, thermographic or nuclear method)

The latter can be divided into:

b1) Electrical methods:
- electrical resistivity method
- dielectric method based on frequency dispersion of dielectric penetration
- microwave
- impedance tomography

b2) Methods based on measurements of thermal features:
- λ-probes
- Method of non-stationary linear heat source
- Thermo-vision
- Video-graphical optic methods

b3) Nuclear methods:
- X-ray of delta radiation
- Neutron
- Nuclear magnetic resonance

b4) chemical methods:
- Chemical compounds
- Indicator methods

Due to the specification of historical buildings, I see the need to create a method which allows for non-invasive, accurate and quick examination of wall dampness. Regarding the costs, it is important to invent such a method which gathers as much information as possible and is simple and cheap in its application to real buildings. By the simplicity of the diagnosis, the author understands the simplicity of the equipment – the hardware (diagnostic signal sources, probes, power sets, communication sets) of the diagnostic devices.

From the exploitation point of view, it is important not only the evaluation of general state of buildings but also the identification and localization of the cause of the condition. The information of the level and expenditure of moisture and the localization of sources leads to evaluation and taking actions in order to regain the previous desirable state. Thus, the aim is to limit the research to the area of exploitation diagnosis.

There are in the literature (3), non-invasive electrical methods, which are in application. However, they do not show a 3D picture (surface and crossover) of the level of dampness. Additionally, the results of the conductivity measurements, excluding humidity, are the functions of concentration and the chemical content of salt in walls. Certainly, there are methods of increasing the accuracy such as implementing so called hypothetical function of measure scale, but moisture measurements are limited to small wall sections. Besides, the methods are found inconvenient in practical application because of their complex hardware.

The known dampness diagnostic methods (neutron and roentgen), due to their costs are designed for laboratory and scientific research.

Due to the growing interest in the area of application of nowadays contactless technology in thermal area measurements based on thermal imaging and computer modelling is, according to the author, an interesting direction of diagnostic examination in civil engineering. The diagnostic devices in this case are convenient and simple to apply and are based on remote radiation sources (may be powered by the web or a generator) and an autonomously powered thermal imaging camera. The quality analysis of the results of the experiment may be performed outside buildings.

4. THERMAL IMAGING DIAGNOSIS OF WALL DAMPNESS DEGREE

The radiation of an object is the function of its temperature (1, 2); thus, the thermal imaging measurements may be used to evaluate the examined structure. To determine the dampness of an object it is necessary to know the function that bonds the amount of energy radiated by the source at the wall, the energy dispersed in space between the source and measuring matrix as well as the temperature of the object.

The accuracy of the thermal imaging measurement is influenced by the condition of the examined area, including its roughness. During the measurements, on the same thermal image screen there is measured the thermal area which can be made of various objects of various emissivity. The emissivity of an object depends on the length of its wave, temperature and kind of material, state of surface, observation direction and polarization. In the measurements it is necessary to know the emissivity of the examined object, which determines its ability to emission radiation due to roughness of the surface, material, and the radiation wave length in which the thermal image device is registering.

Nowadays the sensitivity of common converters in thermal image cameras is 0,1K (there can be distinguished points on the screen whose temperature varies by 0,1K).

Although during examinations of buildings, the main diagnostic information is the difference of the temperature among the particular screen objects, rather than the absolute temperature value. The parameter is influenced by the matrix sensitivity of an electromagnetic radiation detector of the camera. The source of energy provided to the examined wall may be an infrared radiator or a microwave head.

5. FULL BRICK WALL DAMPNESS THERMAL IMAGE MEASUREMENTS

5.1. Laboratory thermal image measurements with the use of microwave electromagnetic radiator

My aim was to do laboratory examinations and obtain information about the usefulness of the method of thermal wave forced by electromagnetic energy wave with the use of a microwave head in historical buildings dampness level diagnostics. The measurements were performed using parts of full ceramic brick, which had been extracted from the foundation walls (during the restoration of the building) of St. Mary Magdalene church in Cieszyn, Poland. The heat energy was supplied by electromagnetic radiation of 2,45 GHz frequency. The examination covered two samples of brick, which were exposed to radiation of a magnetron for the total time of 90 seconds. Each sample was placed in the radiator chamber in the horizontal direction (vertical) as shown in fig. 2. The energy of microwave radiation was delivered to the object in a way which penetrated it throughout. The object always faced magnetron with one side (the view from the source is showed at fig. 2) in the total length of 10 cm. The rated power of the radiator was PN=900W. The thermal images were registered with a FLIR ThermaCAM T-400 with the FOL18 lens and period T=15s.

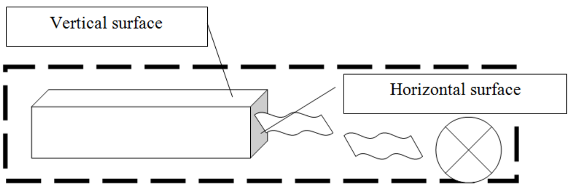

Fig. 2. The direction of placing the brick sample in relation to the magnetron lamp

During the measurements the efficiency of the lamp was approximately 200 μGy. After extracting from the apparatus, the samples cooled down. Therefore, their temperature was checked again before placing them in the microwave chamber. The full ceramic brick moisture distribution measuring station is shown in fig. 3.

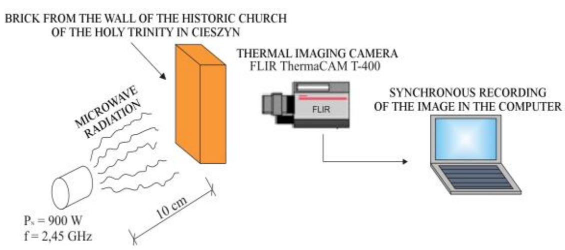

Fig. 3. The scheme of the brick moisture distribution measurement apparatus

After the radiation process was finished, the sample was taken out from the measurement apparatus and the temperature distribution on the surface of adjacent and the opposite to radiated side was registered. The obtained thermograms were edited and the raw example results are shown on fig. 4 - 7.

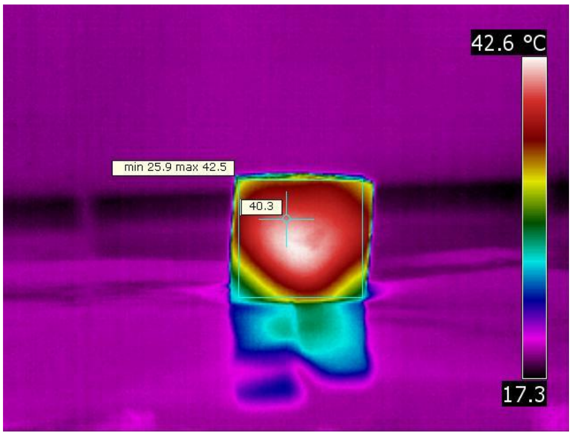

Fig. 4. Heating the sample, t = 15 s, horizontal plane

Fig. 4 – 7 show the temperature distribution on the bricks; the temperature of damper samples is higher because they get warm more quickly using the heating factor in the form of microwave radiation.

Fig. 5. Heating the sample, t = 15 s, vertical plane

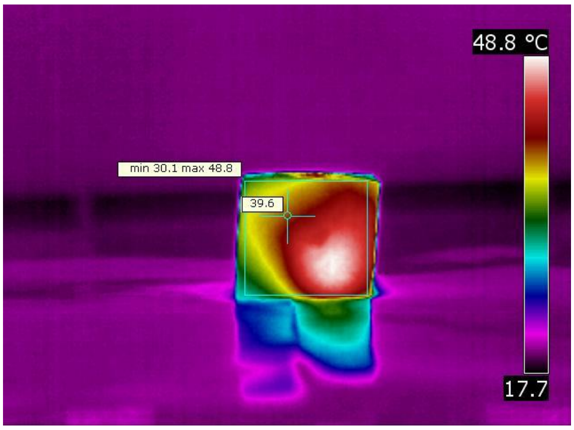

Fig. 6. Heating the sample, t = 30 s, horizontal plane

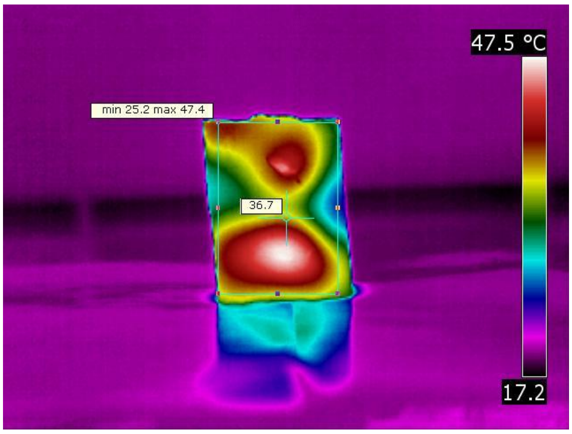

Fig. 7. Heating the sample, t = 30 s, vertical plane

The examinations showed that the power of the radiator was sufficient. In case of historical buildings examination, it is very important to determine the maximum value of the temperature to which an object can be heated during moisture distribution registration process. In the laboratory after 90 s of exposure (6 periods of heating), the maximum value of the temperature of the sample's surface was 50.3 °C.

The visible warmer and colder areas on the thermogram pictures describe bricks of similar moist condition. The difference in the temperatures registered is the result of spatial distribution of antinodes and nodes of the electromagnetic wave of the frequency f = 2.45 GHz. The method is potentially dangerous for researchers (exposure to microwave radiation) and requires safe construction of a microwave head.

5.2. Laboratory thermal image measurements using an infrared radiator

In order to increase the efficiency, another source of heat radiation was analysed; the microwave radiation was replaced by the infrared radiator to increase simplicity and safety of the measurements. For this purpose, the device under the examination was a 1000 W manual infrared radiator. The head of the radiator was pointed parallelly to the screen, made of cotton fabric, at the distance of 20, 30 and 40 cm. On the other side of the screen, at the distance of 1 m, a thermographic camera was placed. The registration of the thermal images was at 6 second intervals for the heating process and at 10 second intervals for the cooling process. After that the thermal images were edited and on this basis the contour plots and spatial surfaces were prepared. The plots were created for heating and cooling processes of the radiator.

The aim of the examination was to cover the distribution of the temperatures at the given distances of 20, 30 and 40 cm off the radiator. It enables a solid distribution of temperature in certain moments of work or cooling process of the device. Such examinations were to answer the question if a radiator can replace a climatic chamber heating from the research station (fig. 3).

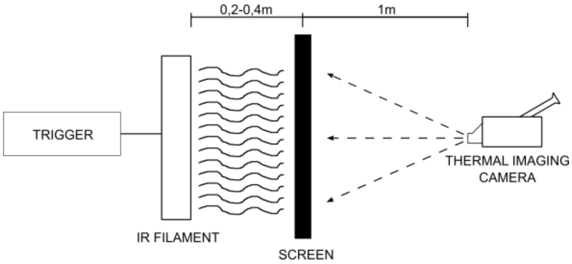

Fig. 8. Schematic distribution of the radiator and thermographic camera during the research

For the radiator the time constants for different work modes were determined. Abbreviations were given to the following work modes:

– "Work 1" – the work of constant radiator work mode in the environment temperature.
– "Work 2" – the constant work after heating the radiator and shutting it down for 1 second.
– "Work 3" – the work in cycle, the first cycle of the temperature of the environment. Both times of the radiator being on and off were the same: 1.4 s.
– "Work 4" – the constant work after the radiator warming and shutting it down for 2 seconds.
– "Work 5" – the work in cycle after warming the device and shutting it down for 1.1 second. The time in which the radiator was on and off was equal to 1.1 second.
– "Work 6" – turning on the radiator after warming it and cooling for 5 seconds.
– "Work 7" – the work in cycle, the radiator before the first cycle was at the environmental temperature. Time of the first running was 1.1 second, the time of the second running was 0.8 second, the next runs – 0.7 seconds. The first break of the work cycles was 0.9 second, next were 0.8 seconds.
– "Work 8" – the work in cycle, after warming the device. The switch-on and shut down times were equal – 0.6 second.
– "Work 9" – the constant work after warming the device and cooling it for a 1 minute.

The table covers, in case of work in cycles, the time constants for each period in which the radiator was switched on.

The use of the pulsating method of heat wave supply to the examined wall makes the filaments of the heat radiators work in unstable heat conditions and their resistance changes considerably. This causes the fact that the radiated active power is different from the theoretical power calculated as multiplication of voltage constant real value and electric current constant real value in a particular period of time of the activity of the radiator. The differences between the theoretical and real power derive from the existence of the time constant of the radiator filament getting hot, which in turn depends on the initial temperature (thus the cooling time after the previous pulse) of the filament (fig. 9 and 10). Taking the power time constant of every pulse into account is problematic in a mathematic model. That is why the designed method uses one heat pulse supplied to the wall till the historical object reaches its borderline temperature.

Table 1. The temporal constants for the particular modes of work of the radiator

Operating mode	**Time constant**
	S
Work 1	0,375
Work 2	0,52
Work 3	0,437; 1; 1,125; 1,125
Work 4	1,26
Work 5	1,33; 1,22; 1,22; 1,22
Work 6	0,55
Work 7	0,5; 1,49; 1,49; 1,49
Work 8	2,875; 2,875; 2,875; 2,875; 2,875; 2,875; 2,875;
Work 9	0,269

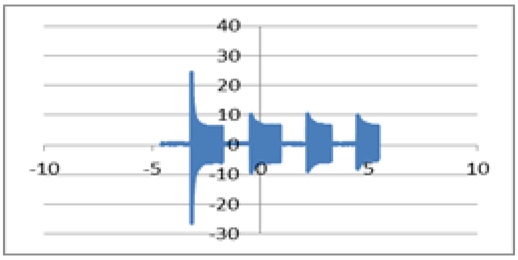

Fig. 9. The process of the radiator filament getting hot during the cycle work beginning with a cold single radiator

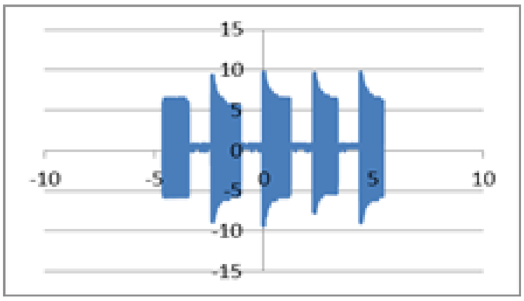

Fig. 10. The cycle work of a hot single radiator

The designed method of wall dampness evaluation of historical buildings with the use of a single heat pulse is easy to use because in needs:

- attaching the cylindrical cover of a radiator (heat tube) to the wall
- switching on the power supply and waiting till the wall reaches its borderline temperature
- eliminating the heat tube from the range of the thermal imaging camera and automatic picture recording with the thermal imaging camera till it reaches the ambient temperature (or for example 10 minutes)

- transferring the results of the measurement to a program processing the research results.

A measuring station to register the process of cooling a ceramic wall was prepared. For this purpose, a brick wall was built (38 cm thick, 150 cm wide and 200 cm high) using lime mortar and properties similar to those of historical sacral buildings. A measuring installation was made which consisted of a heat source – a 250 W infrared lamp 100 mm far from the wall in a cylinder of 160 mm diameter, a thermal image camera and a computer as a registering device. A moisture measurement of the dry wall was taken and later the wall was exposed to water (the wall was built in an isolated bath which was filled with water) and after three days following moisture measurements were taken. The edited results of the dry and damp wall measurements are shown in fig. 11. The graphs of the dry and damp wall moisture measurements show the difference in cooling of the wall depending on the dampness of the wall. The damper wall cools much more quickly than the dry wall. This method is very useful in monitoring changes in wall dampness (for example after making a horizontal diaphragm of a foundation wall), when we can check at certain times if the dampness degree of the wall goes down or up.

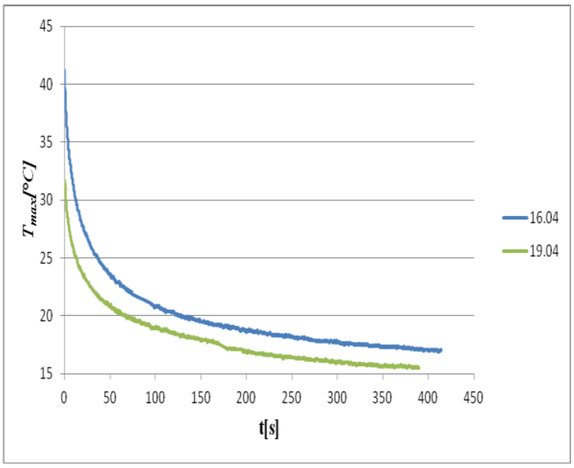

Fig. 11. The graph showing the cooling of the wall under examination (blue – the dry wall, green – the damp wall)

Additionally, a wall dampness test was done using a TESTO 616 hygrometer, a non-invasive measurement of of a dispersed field uses the ability of water molecules to change their volume, and in consequence to change the electromagnetic field. The electric field penetrates the material through a contact probe and creates a 5 cm deep measuring field in the material. The results of this measurement were very similar to the thermal image measurement using an infrared radiator. However, that examination was very time-consuming and had to be done very carefully because every placement of the device against the wall required the same pressure and that element was error-prone.

7. SUMMARY

The research has confirmed the usability of the method of the thermographic moisture measurement using an infrared radiator. The results obtained through the registration of the brick wall dampness change during its heating by infrared radiation are very useful in a wall dampness evaluation. Similar results have been obtained with the use of other measurement methods and that is why I am doing further research into the choice of the optimal heat source. This method is a quality method which means it does not determine the exact values of the wall dampness but only enables to evaluate, based on the initial measurement and the one done later, if the wall dampness has changed over time. The advantage of the method is that it is not necessary to know any physical parameters of the examined wall (which are most frequently not known), but make sure the examination is performed in specified, recurrent conditions. To confirm the validity of the obtained results, the author is the middle of preparing a physical and then mathematical model of the heat processes undergoing in the heated wall. With the help of such a tool, based on the data in the literature, the simulation for the dry and damped wall was performed. The results confirmed the difference of the examination of the dry and damped wall. The potential of the method is huge in diagnosis of brick wall dampness of historical buildings and enables the preparation of a 3D dampness map of entire walls which is a considerable achievement of my research.

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