Optimal thermographic procedures for moisture analysis in buildings materials

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ABSTRACT

The presence of moisture in building materials causes damage second only to structural one.

NDT are successfully applied to map moisture distribution, to localise the source of water and to determine microclimatic conditions. IR Thermography has the advantage of non-destructive testing while it allows to investigate large surfaces. The measures can be repeated in time to monitor the phenomenon of raising water. Nevertheless the investigation of moisture in walls is one of the less reliable application of Thermography IR applied to cultural heritage preservation. The temperature of the damp areas can be colder then dry ones, because of surface evaporation, or can be warmer, because of the higher thermal inertia of water content versus building materials. The apparent discrepancies between the two results are due to the different microclimatic conditions of the scanning.

Aim of the paper is to describe optimal procedures to obtain reliable maps of moisture in building materials, at different environmental and microclimatic conditions.

Another goal is the description of the related energetic phenomena, which cause temperature discontinuities, and that are detected by thermography. Active and passive procedures are presented and compared. Case studies show some examples of procedures application.

Keywords: environmental conditions, evaporative flux, moisture, building materials, IR thermography

1. INTRODUCTION

Thermal scanning is applied to buildings to collect information regarding component elements, their shape, their physical characteristics, and their state of decay. Is based on analysis of the thermo-hygrometrical anomalies that affect structures. Thermovision is mainly used for investigation of surface defects (0-3 cm). One of the most frequent applications on historical building deals with moisture diffusion. Moisture damage is secondary only to structural damage as cause of decay in ancient buildings. The presence of water in structure and its changes of state (vapour-liquid) are responsible for the damage of materials, for damage of supplies inside the buildings and even for sickness of people who lives in. Same materials can be damaged differently depending on environmental conditions and, particularly, to the level of water contained inside the wall. Water content in walls is a fundamental information regarding the decay analysis in cold climatic condition; usually water content is a key factor when temperature stays below zero for several months. In those cases the water volume grows as frost and generates pressure within porous of the wall materials, therefore generating cracks in the structure. In northern Europe and America, the temperature stays below zero for long period during winter: in addition to the damage already described the water in the insulation material coating causes thermal bridge the building. In temperate climatic area during winter, the thermal inertia, due to the thickness of the ancient walls (usually more then 50 cm), prevents the frost of water content inside the wall. Damage is concentrated on the surface (few cm depth), due to the continual cycles of frozen-defrost. An additional issue related to moisture is the water transition between the wall and the surrounding environment.

The investigation of moisture in walls is one of the more unreliable application of Thermography IR applied to Cultural Heritage preservation. The temperature of the damp areas are colder then dry ones (a), because of surface evaporation, or warmer (b), because of the higher thermal inertia of water versus building materials. The apparent discrepancy between the two results of detection (a) and (b) is due to the different microclimatic condition of the scanning[i].

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Aim of the paper is to define optimal procedures to obtain the reliable map of moisture in building materials, at different environmental and microclimatic conditions. Other goal is the description of the related energetic phenomena causing the temperature discontinuities, which are detectable by thermography.

In the contribute passive and active thermography are compared in order to define best application of each modality.

2. THERMOGRAPHY PROCESS

Thermography works well to localise damp zones (ii), either in the passive way (no external heating) or in the active one (heating from outside of the building) (iii).

2.1. Active approach

2.1.1 Localisation of major thermal capacity areas

In temperate climatic area during winter, the thermal inertia, due to the thickness of the ancient walls (more then 50 cm), prevents the water content inside the wall to ice. Damage is concentrated on the surface (few cm depth) because of both the continual cycles of frozen-defrost and the growing salts deposits on the sub-superficial layers. On the other hand, in northern Europe and North America, the temperature stays below zero for long periods during winter: in addition to the damage already described the water in the insulation coating causes thermal bridge in the building. Finally, wetted building materials may cause healthy problems in a longer run.

The water content in the building materials keeps the heat in case of protracted heating – e.g. solar radiating(iv). The damp areas have a higher thermal capacity than dry ones. So warmer areas can be detected without performing any artificial heating.

2.1.2 Water content and thermal properties of the materials

Moisture in porous materials (like construction ones) spreads into the pores to their filling. Water has higher specific heat (4-5 times) and higher thermal conductivity (20 times more then the air content in the empty pores) than common building materials. Water radically modifies density ρ, specific heat c_p and thermal conductivity *k*. All these three factors increase according to the water increasing.

Thermal inertia (effusivity *e*) is a physical parameter that contains all the three factors. It can be easily determined by means of active thermographic tests.

$$e = \sqrt{k\rho c_p} \tag{1}$$

Materials with different values of c_p k ρ could be characterised by measuring surface transient temperature in the heating process. The "active method" is based on the measure of the energy input and the temperature increase on the heated surface. The test supplies a constant energy flux by radiation to the sample surface. The surface temperature is measured by a long wave thermocamera that acquires thermal images at a rate of 0.2 Hz.

An adequate theoretical model of heat transfer allows processing the temperature increase of the surfaces during the test. In the case of building materials both low conductivity and thickness (some cm) allow to use a simple solution of the heat transfer equation in the approximation of adiabatic and semi-infinite medium. The sample is considered homogeneous and isotropic, with a uniform superficial temperature T_0 at initial time. A uniform heating flux **Q** for a short time (few minutes) has performed. That heating allows to consider adiabatic (without significant heat losses) the temperature evolution. In this conditions the expression of the surface temperature is(v):

$$\frac{T - T_0}{Q} = \frac{2\sqrt{t}}{\sqrt{\pi k \rho c_p}} \tag{2}$$

where the thermal inertia can be singled out and represents the angular coefficient of the square root of the time versus the temperature increasing (ΔT).

$$e = \frac{2Q}{\sqrt{\pi}} \frac{\sqrt{t}}{\Delta T} \tag{3}$$

Nevertheless only the measured value of thermal capacity allows to obtain the water content

$$W = \frac{c_{pd} - c_p}{c_p - c_{pw}} \tag{4}$$

where C_{pw} is the specific heat of water, C_{pd} of the dry material and C_p (referred to the moist material) can be determined, according to (1), only if the thermal conductivity of moist materials is known.

The measure of thermal diffusivity a allows to obtain *k*, the conductivity of moist material, that can not be measured directly.

$$\alpha = \frac{k}{\rho c_p} \qquad \text{and in this way} \qquad c_p = \frac{e}{\rho\sqrt{\alpha}} \tag{5}$$

Nevertheless α, at the present state can be obtained only in lab, on specimens. Therefore the method is unlikely used on the field, to determine the water content.

2.1.3 The reference method

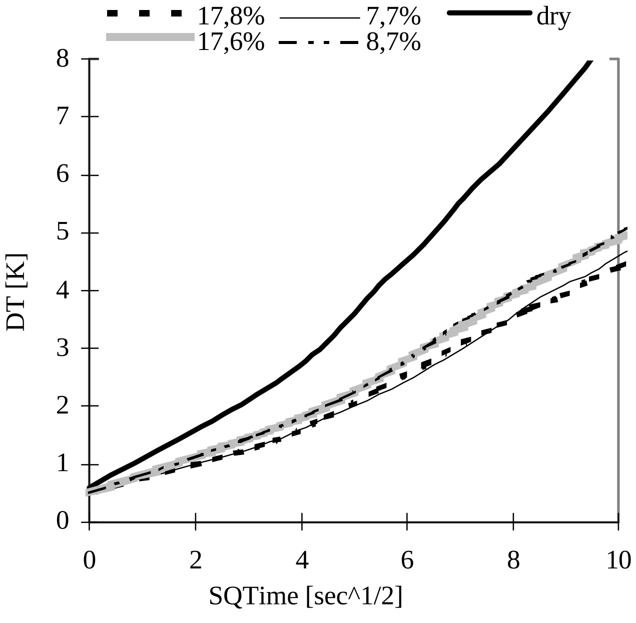
The test can be simplified using dry materials as reference if the absorbed energy is constant both in time and in space. In this case (called “reference method” [vi]) the measure of the energy absorbed is not required. A major absorbivity due to the water content in damp materials allows to evaluate their thermal inertia. Therefore the value of thermal inertia of a sample, of unknown water content, gives good indication about its water content if compared with the thermal inertia of a dry sample.

2.1.4 Materials and methods

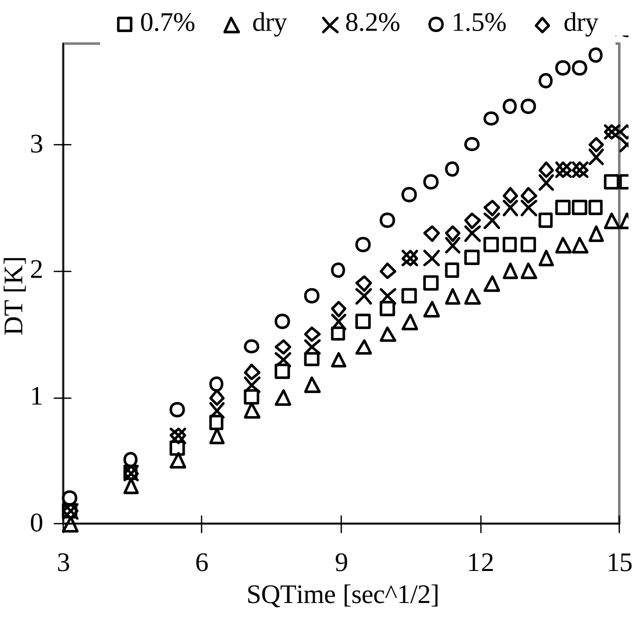
Five brick cores with different water content were the samples under test. The bricks had homogeneous characteristics of weigh, volume and thermal properties (emissivity and absorption). The samples (30 cm^3) were dampened and placed in airtight containers for 48 hours. The specimens were heated by lighting (two halogen lamps, 500W, colour spectrum 3300°K), at under control conditions. The lamps were set symmetrically at 60 cm from the surface. The power of the heating on the surface was around 800 W/m^2. The heating was long 2 minutes, and the frequency of the recording images was 5/sec. The measures were repeated changing the displacement of the samples, to survey differences of heating due to the lamps. The absorption gap due to water content was estimated in about +20%.

Further lab measures were carried out to test the method on a large scale model. The model of an ancient wall was built in the lab of DCSA, Politecnico di Milano. Pebbles, bricks, lime mortar as materials for the inner structure. A double layer of lime mortar plaster coats the surfaces. A 3D survey supplied the irregular thickness of the not plane plaster. A pipe system, insert in the wall during the building, allowed to fill with waters the wall in a short time. The same measure procedure was repeated. Many cycles of heating have been performed on the model and on five brick cores -at different water content - to compare reference and passive methods (fig. 1-3). The devices employed were: thermocamera -AGEMA 900, Humbug environmental probes - RH%, T°C.

Graphs 1, 2 show the results. The values of angular coefficients related to graphs are in tab. 1



Graph 1 Reference method applied on solid brick cores.



Graph 2 Reference method applied on Wall scale model

Water content	dry	17,8%	17,6%	8,7%	7,7%
Angular	0,85	0,42	0,47	0,48	0,45

coefficient					

Tab. 1: values of angular coefficients related to graphs 1

The ratio of **e** between the dry specimen and the wet one is 0.45, rather near to the literature value 0,66 ([iii]), when Q increases of 20% (due to the major absorption of radiation, above all in the infrared range).

The method does not survey the differences of water content if more then 7%, as it appears in the graph 1. The differences of angular coefficient of the lines may depend on not homogeneous radiating. As verification the position of the specimens have been changed, at the same heating condition: actually the variations of angular coefficients changed, related to the new position of the specimens.

The dependence of effusivity on the water content is not clearly defined (theoretically and from lab tests), nevertheless the data obtained by lab tests and specific literature allow to point out that the change from dry to wet condition (saturation) increases effusivity of about 80% (brick). Effusivity changes are not enough remarkable to indicate the variation of water content, above all on the field, where the margin of uncertainty ranges 20-30%.

2.2 Passive approach

2.2.1. Localisation of surface evaporative flux

In the case of evaporation, so frequent at less then 45°Latitude([vii]), the high value of latent vaporisation heat, causes the cooling of the moistened surfaces([viii]).

The evaporation most of all depends on Relative Humidity (RH) of the air near the surface, on its Temperature (T°), on the water content in the material, on its chemical-physical characteristics and on soluble salts content. The influence of T° and RH on the evaporation speed can be studied only keeping microclimatic conditions under control.

2.2.2 The evaporative flux in wall energetic balance.

The measure of wall surface temperature allows to obtain a precise and quantitative indication of the evaporative rate when an opportune model is defined for the energetic balance on the wall surface in dependence of air temperature, environmental radiation, the speed of the wind and the relative humidity. In dry building materials the energy loss caused by the evaporation is insignificant compared with the total energy transferred over the surface. Conduction from the inner wall is neglectable when determining its superficial temperature in the time characteristic of the thermographic scan of the wall (few minutes). This effect is amplified in the ancient wall because of its thickness and the use of solid bricks. Regarding the energy associated with the mass transfer within the wall (water and salts) it is less significant then the energy lost by evaporation. In fact the amount of heat carried by a certain quantity of water from a point to another of the wall is approximately two orders of magnitude less then the energy required to evaporate the same quantity of water.

If we take into account the effect of a forced evaporation in the energetic balance of the wall surface it causes a thermal imbalance Q, which can be observed as a decrease of some degree of temperature. This is essentially compensated by the increase of convection and conduction. If the heat loss caused by the evaporation is constant the cooling effect of the wall can be calculated knowing the equilibrium temperature among the different kinds of heat exchange.

Furthermore in the aforesaid conditions of strong evaporation the energy loss causes a decrease of temperature dT in a time dt upon all the evaporating surface according to the inverse proportion to its mass on superficial unit (superficial density of mass m) and to its specific heat.

$$F\ l\ \mathbf{dt} = \mathbf{Q_{ev}} = \mathbf{mc\ dT} \qquad (6)$$

Water content may be evaluated in function of thermal capacity of the damp masonry c_pm. The solution of (6) gives c_pm, if all the kinds of thermal exchange on the surface are defined ([viii]).

2.2.3 Evaporative flux computation.

The evaporative flux is obtained at the balance between the kinds of thermal exchanges This happens when the temperature assumes the equilibrium value T_α. The expression of the flux assumes therefore the form:

$$\phi_{mev} = \frac{-\varepsilon\sigma T_\alpha^{\ 4} + \alpha\varepsilon_a\sigma T_a^4 + h(T_a - T_\alpha) + k^*(T_{int} - T_\alpha)}{\lambda_{ev}} \qquad (7)$$

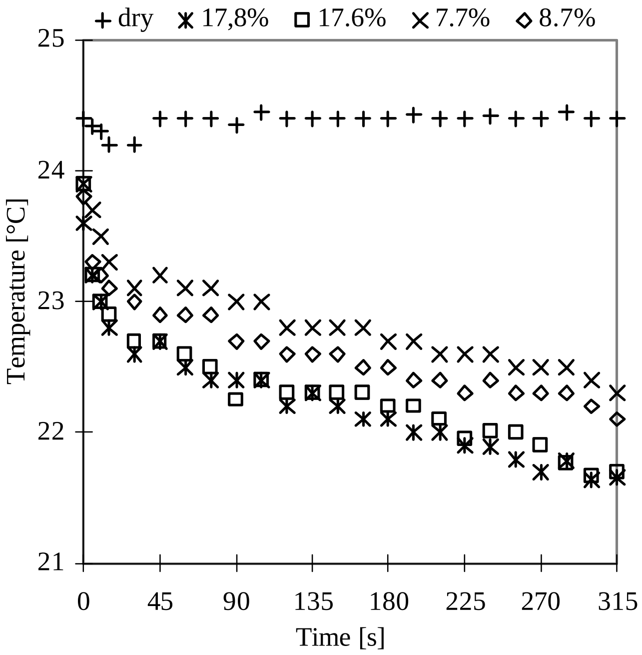
where: ε and ε_a = mean emissivity of the sample in its existence range and environmental efficacy emissivity; σ = Stefan-Boltzmann constant (5,57 x 10^{-8} W/m^{2}K^4); α = absorption coefficient of the wall surface, T_a= environment temperature; T_{int} = inner temperature of the wall; h= convective exchange coefficient; k* conductive coefficient; λ_{ev} = water heat vaporisation ; Φ_{ev}= evaporative flux (kg/m^{2}s).

Where the terms due to the radiation exchanges can be estimated with good precision considering zones lacking in evaporation, but in the same conditions of radiation. Temperature reaches T_α in times of the order of 10^2-10^3 sec for the brick samples of small dimensions (30 cm^3) under investigation.

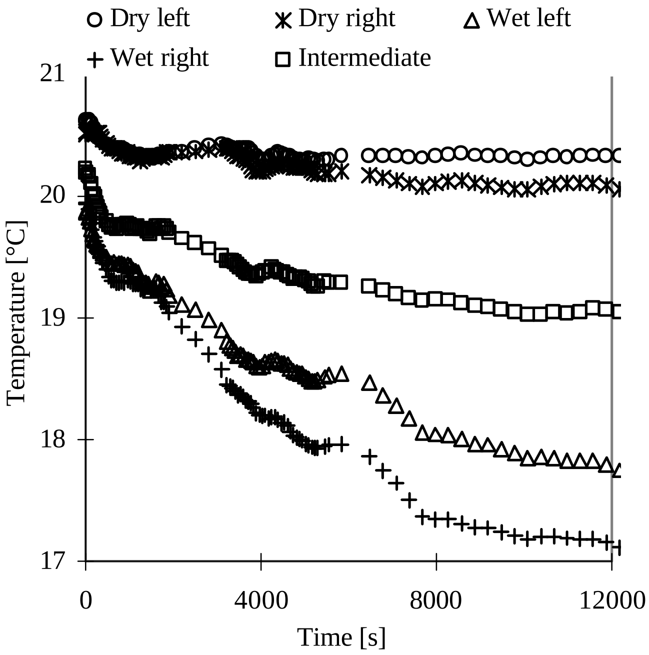
2.2.4 Material and Methods

The tested samples were the same brick cores as above (paragraph 2.1.3) with different water content (17.8% 17.6% 8.7% 7.7% and dried in hot air). The samples (30 cm^3) were dampened and placed in airtight containers for 48 hours. For the continuation of experiments we used a climatic chamber (fitotrone) that allows to range environmental variables: temperature (10-40 C), RH (20-98%), air speed (0.1-5m/s) and lighting (0-5000 lux). The environmental conditions chosen for every experiment were 0 lux, air speed 0.1 m/s (which would minimise the convection's effects), air temperature of 25° C, and relative humidity kept constant at 50%. The samples were subsequently isolated on the bottom and lateral side with a waterproof membrane. A balance (precision 10^{-3} gr) in a climatic room measured their weight drop in continuos. In order to estimate the conditions of radiation inside the room some dry samples were put beside the damp samples, with same shape and emissivity.

The cooling due to evaporation was recorded by a thermocamera (AVIO 2000 SW) (Graph 3). The evaporative flux of each sample was measured continuously by a precision balance connected to PC. The samples achieved balance temperature in about 5 minutes. The flux values were calculated according to (7), using the temperature measures, and keeping in account the environmental radiation and convection. The comparison between data is shown in tab 2. The same experiment has been carried out on the model of wall (see previous paragraph). Graph 4 shows the thermal curves of cooling. In this case the evaluation of evaporative flux is more difficult because of the unknown coefficient of environmental convective exchange and non-homogeneous surface of the wall, even if it is possible to identify the balance temperature of the areas with different water content.



Graph 3 Evaporative cooling on brick cores



Graph 4 Evaporative cooling on scale wall model

	17,8%	17,6%	8,7%	7,7%	Dry
Weighed flux	$4,76*10^{-5}$	$4,40*10^{-5}$	$0,98*10^{-5}$	$1,06*10^{-5}$	0,00
Calculated flux (eq. 7)	$4,55*10^{-5}$	$4,50*10^{-5}$	$0,80*10^{-5}$	$0,82*10^{-5}$	0,00

Tab. 2

2.3 Thermographic procedures and optimal condition of shot

The application of thermography to buildings is scarcely supported by specific rules in force. In Italy ISO 9252/88 is the only recommendation edited, and specifically regards Thermography employed to detect energetic loss. The standard is based on the results of IRIS-CNR research group (1985) and it refers to procedures relative to out of date device. The authors present a first report on the procedure in use, based on their experiences, to improve and to contribute to the debate in course in the international committee and research groups devoted to NDT procedures. The approach is exclusively functioned to moisture detection by the presented method.

2.3.1.Generality

The examination of all the documents available regarding the project and the components of the structure is a mandatory prerequisite. A survey of the materials, of their damage is required, in order to know the actual state of the surface to investigate. These data allow to localise the inquiring areas on which the operator will apply the specific modality of investigation (see following paragraphs) and even the integration with other testing.

The investigation of damp areas is based on the comparison between the thermal behaviour of dry and damp areas: therefore in the same shot there can be both zones, at the same condition (of heating or, in passive method, of the environment surrounding).

Spot heating (e.g. hot pipelines, electric cables, plaster delaminations, stains or coloured parts) may affect the results.

Winter heating inside the building could prevent to detect moist areas:

- the heating tends to dry the wall in case of residual low-medium water content,
- thermal bridges due to thin walls, their non perfect connection, windows and doors, etc, may cause false alert

A preliminary scanning requires to shot all the surface of the wall, to set camera parameters and to detect the most evident anomalies. Further shots, closer to the surface, allow to analyse the investigated defects.

2.3.2 Active thermography

Reference method

In case of surface not exposed to sun radiation, the operator has to provide artificial heating on the field, as like above-mentioned about lab test. In this case the reference method supplies experimental data.

- Plan of the scanning

- The thermal analysis has to be applied on small but homogeneous zones.
- LW thermocamera provide best results (the scanning has to be shot during the heating).
- Frequency of images not less then 1/sec
- Reference and investigated areas have to be shot in the same pictures.
- The surfaces have to be as homogeneous as possible: same materials, colour, roughness, reflectance, etc, for both the reference and the damp areas.
- Accuracy during the heating is mostly required.

- Heating set up

- The heating has to be mostly homogeneous both on the wet and on the reference areas. Lighting is the best modality. The operator has to dispose even number of halogen lamps, symmetrically to the investigated areas.
- The camera has to be settled perpendicularly to the surface, and the sequence of recording depends on the speed of heating. Slow and low heat transfer is possible, due to their low conductivity. Differences of the thermal behaviour (revealing damp and dry zones) have to be pointed out in a short time, before reaching the energetic balance between radiation from lamp/environment and the wall. Powerful heating (1000 W/m^2) is required to increase the temperature of surface at least of 4-5 degrees in the time as short as possible (few minutes).

- Post process

Adequate software allows to analyse the sequence of the thermal image during heating. The thermal curves support the comparison between damp and dry surfaces. In lab data process the curve is obtained from the average values of small areas chosen inside the investigated surface. In case of not homogeneous surface the choice of these areas may affect the final results, because the optical characteristics of the surface alter the heating absorption due to water content.

Outside shot (without artificial heating)

- High air RH% and wind pressure do not affect the reliability of the test; anyway optimal environmental conditions, as like clear sky, no rain, T° not below 0°C, are favourite.
- In case of the source of the heating is natural (sun), the orientation of the surface is fundamental to plan the scanning. Depending on the disposition even the same external elevation could be radiated in different hour and for different time.

Shadow due to other buildings or to projections may affect the thermal images. All these factors have to be recorded before scanning, in order to calculate the best time of the shot.

- The scanning has to be shot in emissive phase, after the end of the radiation.
- No artificial heating is required.

- Post process

Thermal analysis software may supply qualitative analysis and the study of the thermal profiles of the areas investigated.

2.3.3 Passive thermography

- Plan of scanning

- Thermal scanning has to be applied at steady state condition.
- The surface has to be kept out of direct heating for approximately 12 hours before the scanning.
- Environmental or microclimatic condition may prevent a reliable scanning: the operator has to measure microclimatic and environmental T° and RH% continuatively during the scanning.
- In case of critical condition some solutions are possible to increase the level of transpiration so to improve measurements (e.g.: increase the temperature, so to decrease RH; dry air close to the surface, etc.)

- Environmental conditions

The most appropriated environmental conditions required to increase the level of transpiration so to improve measurements are:

- low RH in the air layers in contact with the surface (lower then 80%)
- air temperature not below 6-7 C°.
- strong draught generating air movement

-Post process

After Thermal analysis supported by specific software, further image elaboration improves the qualitative results.

In every case a specific palette of colours or grey levels has to be studied in order to point out the differences between damp and dry zones.

3. CASE STUDIES

The following examples show applications of active and passive thermography.

Integrative tests were carried out in most of the cases, e.g. gravimetric tests, to quantify the water content in the areas where surface temperature was anomalous[ix]. Integration of these tests gives advantages of the mapping speed of moist distribution, obtained without touching the walls (by thermography), and the quantitative knowledge of the water content on the surface and inside the wall (by gravimetric method). The results of weighting test are not only related to the dried specimen but, if the results of the thermography show an homogeneous surface temperature distribution, also to all the investigated areas. The strict connection with lab tests allowed to perform the most adequate technique on the field.

In the first of the case presented, the damp areas were pointed out by both of the two different phenomena (thermal inertia and evaporative flux) acting at the meantime and at the same microclimatic condition. All of these cases are settled in northern Italy

3.1 G. Donizetti Institute of Music, Bergamo

The historical building is settled in the centre of the city. The actual shape is due to the progressive joint of close buildings. The differences of elevation of the same floors denounce that the original structures (made of different buildings) remained under the restructure of the facade. The major damage is related to the presence of water at the ground floor and in the cellar, and its distribution follows the anomalies of the building.

Objective of the analysis: map of moisture diffusion, evaluation of water content in the walls, finding the source of infiltration or rising damp.

- Results

Passive thermography was applied. It revealed that the major concentration of water was in the first room of the cellar. Both the walls under the main street and the inner yard were damp. A curious difference may be noted: the wall (fig. 5, wall “A”) presents a constant water diffusion from the bottom to the top, and the damp areas appear warm. In the opposite wall (fig. 6, wall “B”), the moisture is localised above all in two large spots, colder then the surrounding surface.

According to the distribution mapped by thermography in “A” wall the plaster’s water content resulted 8.9%-12.2% (saturation value: 19%), limestone’s 9.6% (saturation value =25%) brick’s 6-13% (saturation value = 19%). In “B” wall water content achieves higher values: 17.5-27% plaster; 24% limestone, clay 28%, brick 24%. The microclimatic condition were critical during the scanning: 13°C, RH 76%. At this condition evaporative flux is quite inhibited, it is detectable only where “running” water is emerging at the surface.

The conclusion was that the “A” wall was affected by damp coming from the contact with the earth (under the street level), while in the “B” wall, additionally to the damp due to the earth, two main infiltrations were localised, due to two leakages in the old pipelines.

3.2 Santa Maria delle Grazie, Milano

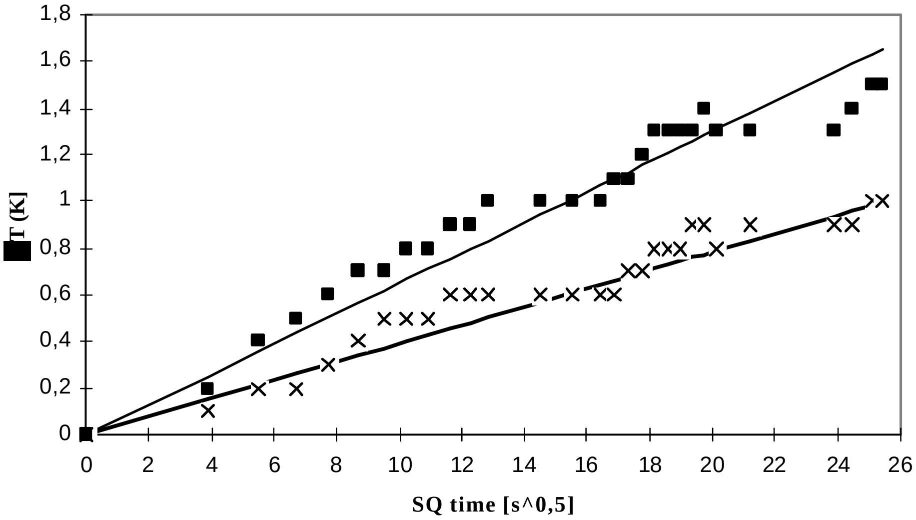
The walls of the famous cloister (home of Leonardo’s Last Supper fresco) were affected by rising damp. The cement-lime mortar of the plaster, applied during the last restoration, prevents evaporation of water content. Nevertheless the damage affects the basis of the wall (below 80-100 cm from the ground).

Objective of the analysis: identify the line of rising damp, verify the correspondence between visual state of damage and moisture distribution.

Results

The images were shot at critical condition (T°8-9°C; RH 89%, clouds): evaporative flux was furthermore inhibited. Active reference method has been applied.

The light but continuous heating inside the rooms was evident in the damp part of the wall even in the preliminary passive shot. Following graphs show the thermal curves obtained during the heating. The curves of the two zones have clear differences (Dry area = squares, damp = crosses). Weighing test, performed on samples from the surface, resulted 6.5% (area 1, at the bottom)- 5.6 % (area 2, 1.2 m up to the floor) of water content (plaster, saturation value = 14%).



3.3 Santa Maria in Cantuello, Ricengo (Cremona)

A colder strip was detected at 2.5 m up to the floor, in the niche of Angel’s statue. Optimal microclimatic conditions allowed to detect the areas where evaporative flux were acting (T=15°C, RH=60%). In that point the brick wall was affected by an infiltration, due to a solid deposit of earth on the edge of the roof. A sod overgrown with moss coats the roof of the little niche and it is responsible for the infiltration.

3.4 Martinengo Parrish (Bergamo)

This church is settled in the Po plane, it presents damages due to raising damp: all the frescoes up to 1-1.5 m from the ground level were destroyed. A thermographic campaign was carried out in May ‘98 to detect the situation of the actual level of the rising damp. The zones interested in the rising damp coincided with the most damaged ones. The thermographies were shot in a dry sunny day with 28° C outdoor temperature and 22°C inside, during the measure the relative humidity varied between 55% and 68%.

4. DISCUSSION

The comparison between the methods appears in the following tab. The authors compared the results obtained only on the investigated materials (plaster and brick)

	Active Method (detection of major inertia areas)	**Passive Method (detection of surface interested by evaporative flux)**
Advantages	Direct measure of the water content (on lab samples)	Direct relation between evaporative flux and damage of the surface. No heating required. Applicable on wide surface
Limitations	Difficulty to obtain high and homogeneous heating. Reference Method: the measures are relative to a dry area.	Dependence on environmental and microclimatic condition
Dependence on Soluble Salts	Yes; soluble salts may change surface absorption	Yes; flux evaporation decreases where soluble salts are present
Speed of the Test	Speedy measures on the field, quantitative results requires post processing phase	Speedy measures on the field, quantitative results requires postprocessing phase
Sensibility to the Water Content	Low-Medium: 10% for porous materials	Low-Medium: 10% for porous materials
Dependence on Environmental Conditions	No	Yes
Cost	Low	Low

5. CONCLUSIONS

Both the systems allow to map the moist areas. An advantage of the passive system has an easier extension to large surface. It connects directly the evaporative flux and the damage. It allows early diagnosis of the zones more to risk for the degradation identifiable thanks to the presence of high evaporative flux. Those zones, where moisture even if not still rendered evident from connected pathologies, will be manifested with certainty in case not take part to modify the variable that determine it. Moreover the illustrated methods can be used also to monitor and to test the restoration intervention on buildings.

The unsolved problems are linked to the on field application (reference method) and the dependence on the environmental and microclimatic conditions (passive method). Particularly in the active procedure on the field: the heating modality (homogeneity), the measures of thermal diffusivity (without collection of samples) and the limitation of math model applied.

In the passive modality the study of influence of environmental condition has to be carried out, to find a direct correspondence between the variables, and to obtain a valid measure of evaporative flux.

In that way experimental set up will be disposed to measures environmental variables mainly affecting thermographic process.

Author’s note: E.R, wrote paragraphs 1, 2.3, 3.1, 3.2, 3.3, N.L.wrote paragraphs 2.1, 2.2, 3.4; together 4,5

Figures

Thermographs of the five brick cores, placed in a insulating frame.

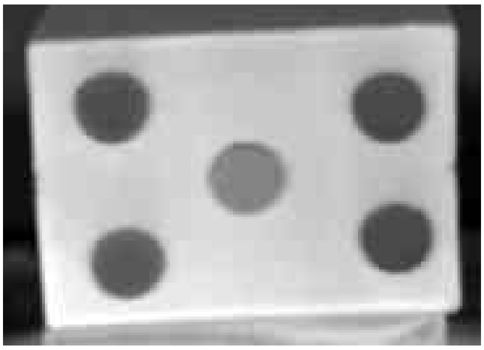


Fig. 1: during lighting and

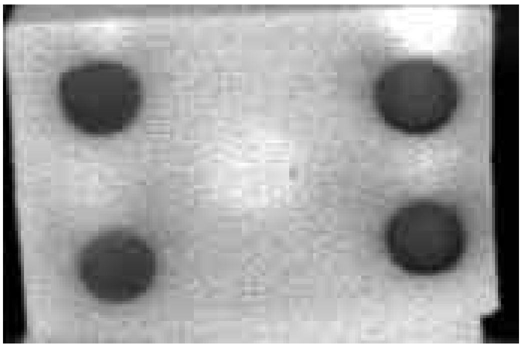


Fig 2 and without heating during evaporative cooling

Fig 3: Active thermography: moisture diffusion during heating, the damp areas are colder because of the major thermal inertia

Fig.1-3, Thermocamera AGEMA 900 LW

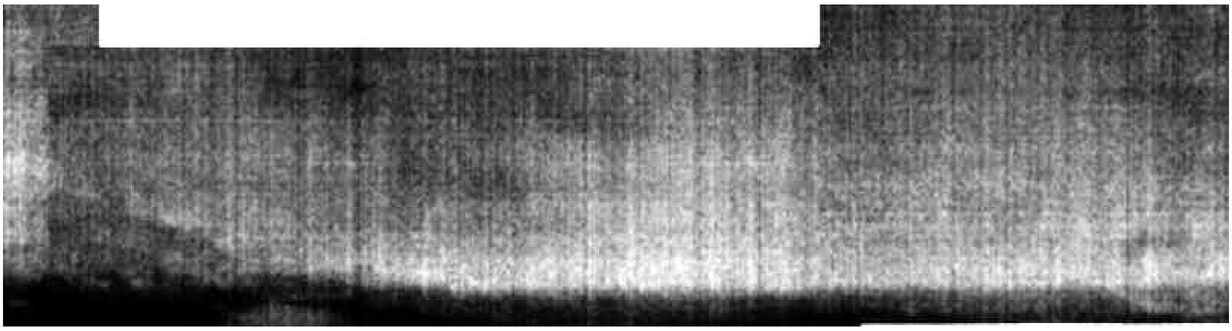


Fig 4: Music Institute Donizetti, Bergamo. Wall “A” in the cellar; passive thermography, the rising damp affecting the bottom of wall corresponds to the warmer areas. Fig 5-6, Thermocamera AGEMA 570 LW

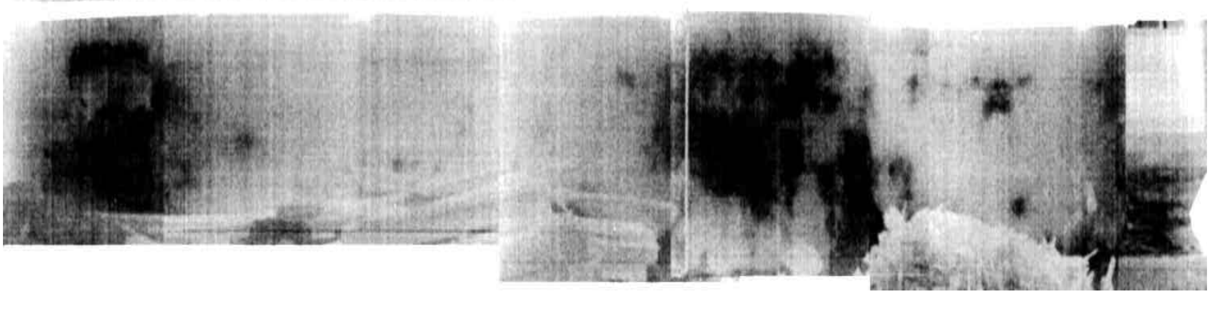


Fig 5: Music Institute Donizetti, Bergamo. Wall “B” in the cellar; passive thermography. Despite of the critical microclimatic condition (13°C, 76%RH) two infiltrations (due to pipeline leaks) are evident as colder areas.

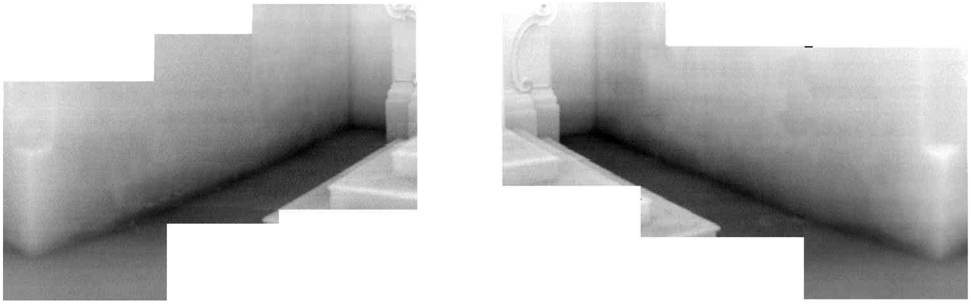


Fig 8: Martinengo Parish (Bergamo).The rising damp corresponds to the colder zones at the bottom of the walls.

Thermocamera AVIO TVS-2000 SW

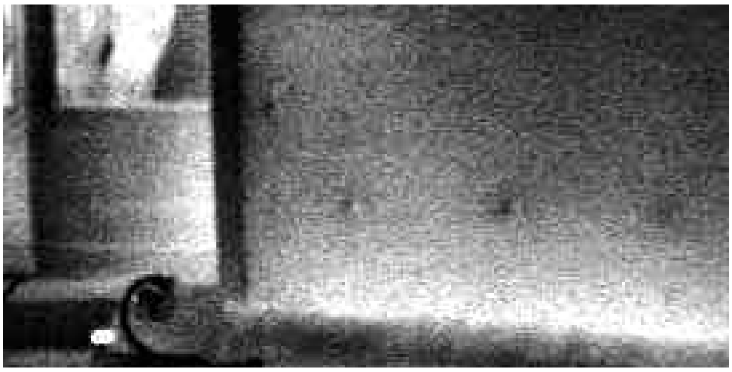


Fig. 6: Santa Maria Delle Grazie, Milano. Passive thermography of the damp bottom of the wall. The major thermal inertia of water content kept the light heating of the room after its turning off.
Thermocamera AGEMA 900 LW

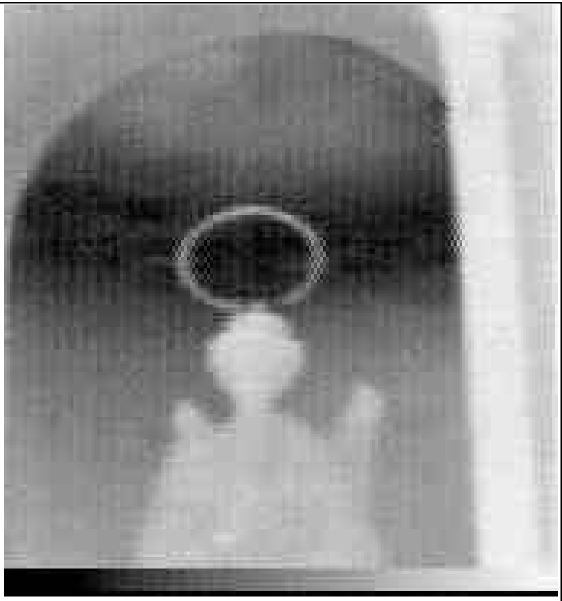


Fig 7: S.ta Maria in Cantuello, Ricengo (Cremona): passive thermography reveals a colder strip (40 cm large) behind the Angel Statue, 2.50 m up to the floor. A sod overgrown with moss coats the roof of the little niche and it is responsible of the infiltration.
Thermocamera AGEMA 489 LW

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