Fraunhofer Institut
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# IR Thermography of Buildings

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# Short version of the final report

The aim of the project was to systematically study the influence of environmental conditions and the specifications of the equipment on the results of thermographic visualisation of hidden building faults. The reliability of the method had to be improved.

Most of the investigations were experimentally, using test constructions with deliberately incorporated faults. Thermographic measurements, combined with conventional long-term meteorological and surface temperatures measurements, led to conclusions which have been presented in a guide for users.

In the framework of this project, the use of thermography to detect hidden faults in buildings was studied for the first time systematically under typical non-stationary conditions, with solar insolation, or surfaces subjected to controlled heating. Advantages and disadvantages as well as favourable and unfavourable situations have been identified and discussed in the instructions prepared for users.

# Instructions for the users of infrared thermography for the identification of building faults at non-stationary temperature conditions

## 1. Recommended equipment

Regarding the wavelength range, for applications in the inspection of building envelopes (relevant temperatures -20°C to 80°C), thermographic systems working in the so-called long-wavelength atmospheric window (8 – 14µm) are suitable. One reason for this is that the maximum of the infrared radiation emitted by bodies with these relevant temperatures lies in the corresponding wavelength range. The second reason is that the transmittance of the atmosphere is much higher in the long-wavelength atmospheric window, as compared to the short-wavelength window (3 – 5µm). The long-wavelength region is thus better suited for measurements outside and over a longer distance.

For applications of thermography to detect hidden building faults, a high temperature resolution (better than 0.1°C) and the associated good quality of the image are necessary. As thermographic systems with a single detector (so-called “scanner”, as they scan the object using a mechanical system) still offer better temperature resolution than the new Focal Plane Array systems with a detector matrix, they ought to be used for the application discussed. The cooling system should ensure the recommended temperature resolution.

A further important parameter is the spatial resolution of the system. 1.5 mrad (at an object distance of 1 m, a region with a diameter of 1.5 mm corresponds to 1 pixel) is a value characteristic for good, commercial systems, which should be given for the application under discussion.

The camera and all accessories should be suitable for outdoor operation.

# 2. Influence of ambient conditions

## 2.1 General recommendations

Measurements should not be made when it is raining or the air humidity is very high. A certain amount of infrared radiation in the range 8 to 14µm is absorbed by water molecules. If a water film covers the surface which is to be measured, the surface emissivity can be altered, and lead to an incorrect measurement result. In addition, evaporating water drops can lower the local temperature values on the surface.

Regarding the wind, measurements should be made during uniform wind conditions with velocities below about 2m/s. High wind speeds can lead to turbulent conditions and a non-uniform temperature distribution over the surface because of local variation in the convective heat transfer.

Other external causes of temperature differences over the surface to be analysed should also be avoided. Here, partial shading of the surface and reflections of other objects must be mentioned. The effect of reflections from the surroundings is higher in the case of low surface emittance values. Usual rendered surfaces have high emittance values, about 0.9.

## 2.2 Typical days

Recommendations for thermographic measurements during different seasons and for different weather conditions are given below.

**1.** Large temperature difference between indoors and outdoors, very little or no solar radiation; typical for: **winter day, overcast**

These are the conditions which are generally favoured for thermographic measurements.

Measurements are performed on the basis of the temperature difference between the inside and the outside of the building under conditions which are as constant as possible. Faults which lead to a significant local variation of the thermal transmittance (U-value) of the wall ( thermal bridges, e.g. a gap between insulating panels filled with mortar) will be easily identified. Faults which affect the thermal transmittance of the wall only negligibly (for example, variations close to the surface of the system such as a depression in or misalignment of insulating panels) often cannot be detected when these weather conditions prevail.

Very low irradiance values ( below 20 - 30W/$m^2$) usually do not affect the detectability of building faults. In spite of this, the irradiance represents a potential source of uncertainty, as it leads to an effect opposed to the one determined by the temperature difference between indoors and outdoors. Wether these effects cancel each other, so that a temperature difference caused by the fault cannot be measured on the surface, depends on the fault to be detected, the temperature difference between the interior and the exterior and the irradiance value. If measurements at low irradiance values cannot be avoided image sequences should be recorded over 1 to 2 hours for varying irradiation (at sunrise or sunset). Even if the two effects cancel for a short period, the faults will still be visualised during the registered sequence under typical variable conditions.

**2.** Large temperature difference between indoors and outdoors, high irradiance values without pronounced fluctuations; typical for: **winter day, sunny**

These conditions should be chosen to examine faults which do not lead to a significant variation of the local thermal transmittance of the wall and which are localised near the wall's surface (depressed or misaligned insulating panels). Because the local variation of the thermal transmittance is small, the effect of the temperature difference between the interior and the exterior on the temperature distribution over the outside surface is also very slight. The locally high values of the heat flux at the surface during irradiation will make these faults visible.

Faults which locally alter the thermal transmittance of the wall significantly (thermal bridges) ought to be measured preferably before sunrise or after sunset (discussed under point 1) during cold weather.

**3.** Large temperature difference between indoors and outdoors, high irradiance values with pronounced fluctuations during the day; typical for: **winter day, intermittent clouds**

Short-term fluctuations of the solar irradiation lead to corresponding variations of the surface temperature. During thermographic measurements, these fluctuations lead to a rapidly changing image of the facade. Because of repeated heating and cooling of the facade, thermographic measurements are not reliable when made during fluctuating sunshine, and should be avoided regardless of the season.

During cold weather, the effect of the variable irradiation will be superposed on an opposing effect, generated by the temperature difference between the interior and exterior of the building. The latter effect is more or less pronounced, depending on the influence of the respective fault on the thermal transmittance of the analysed wall.

**4.** Small temperature difference between indoors and outdoors, high irradiance values, without pronounced fluctuations during the day; typical for: **summer day, sunny**

Thermographic measurements to detect hidden faults in building facades can also be made in summer, when the outside air temperature lies a little below the room temperature during the night and above it during the day. Not only faults which affect the thermal transmittance of the facade significantly, but also faults located near the wall's surface can be visualised when the solar insolation does not vary on a short time scale. Measurements should preferably be performed during periods of high irradiance and large temperature differences between the interior and the exterior (with the outside temperature above the room temperature), as the results of the two influences reinforce each other in this case. Thus, during the moning phase between 10 and 12 o'clock, when all temperatures are rising, it is possible to get a good image, both of faults which differ from the undisturbed surroundings mainly on the basis of differing capacitive effects (e.g. misaligned insulation panels), and structures which are visualised as thermal bridges, on the basis of the temperature difference between the inside and the outside (e.g. dowels). Measurements during the cooling phase at sunset are relevant mainly for structures which differ from their surroundings due to capacitive effects, as the temperature difference between the inside and the outside has already decreased.

It must also be mentioned that thermographic measurements for the visualisation of building faults, which are made while the sun is shining, are sensitive to perturbations. The exterior surface is strongly heated, but wind, fluctuations of the irradiance or partial shading can easily lead to variations in the temperature distribution on the same order of magnitude as those determined by the faults to be detected. For this reason, if measurements are made under sunny conditions, the recommendation is to record image sequences over at least 1 hour, rather than single shots.

**5.** Small temperature difference between indoors and outdoors, low or fluctuating solar irradiance over the day;   typical for: **summer day with overcast sky or intermittent clouds.**

Thermographic measurements should not be performed, when the temperature differences between the exterior and the interior of the building are small (outdoor temperatures which are lower during the night and higher during the day then the room temperature) and the irradiance values are low and/or fluctuating. Faults leading to a substantial local variation of the thermal transmittance of the wall may possibly be visualised during the night, when the temperature difference between the exterior and the interior of the building amounts to more than 5°C for some hours.

## 2.3 Measurements of surfaces subjected to controlled heating

Measurements can be made on surfaces subjected to controlled heating. Heating with an array of IR lamps was tested. In principle, heating for at least 1 up to 2 hours, depending on the heating power, is recommended, so that the deeper layers also respond. The test wall should be thermographically investigated during the cooling phase. The measurement should not start earlier than half an hour after the heating process has been terminated. Waiting at least half an hour should avoid the compensation of the two opposing effects of heating and cooling on the temperature distribution on the test facade. Structures in the wall should become evident in temperature variations on the surface, and surface perturbations, which lead to a non-uniform appearance of the facade during heating, should vanish.

Not much experience has yet been gained with the visualisation of building faults on surfaces subjected to controlled heating. Because of the additional effort needed to provide the equipment for uniform heating of the surfaces, the measurements become more expensive. For this reason, it is preferable to perform measurements without heating the surface, where the conditions permit (depending on the orientation of the facade, possible partial shading or reflections from the surroundings).

It is not yet clear whether thermographic measurements of surfaces subjected to controlled heating will become a common technique.

# 3. Performing the measurement

For the thermographic visualisation of hidden building faults, equipment with high spatial and temperature resolution should be used, as has already been stated in the section referring to the recommended equipment.

The apparatus should be as near to the facade as possible, under optimal focussing conditions. When the equipment is near the facade, critical parts appear larger in the image. It is also possible to select a narrower temperature range for the representation in the image, so that also small temperature differences will be represented with contrasting colours, and faults will be easier to identify visually.

The finite spatial resolution also has an influence on the visualisation of hidden faults, which depends on the distance between the facade and the equipment. The average imaging resolution of the equipment indicates which true area corresponds to an image of 1 pixel. It depends on the field of view of the camera, the pixel resolution and the distance of the camera from the test object. Hidden faults lead to a temperature distribution over the facade's surface. If the distance of the camera from the facade is so large that the domain with the highest temperature values is not adequately resolved, then the measured maximum temperature difference will be smaller than for a measurement made from a closer position. This dependence of the temperature resolution of the equipment on the distance between the camera and the facade is a further reason to perform measurements with the equipment near the object to be analysed.

If it is necessary to inspect larger areas, surfaces of 1,5 up to $3m^2$ should be registered in a first step, and then the surface to be analysed should be further subdivided into smaller portions for separate registration.

If the camera is positioned perpendicular to a surface, which obeys Lambert's law (e.g. rough rendered surfaces), a correction of the measured temperatures to account for varying angles of emittance, within the camera's field of view is not needed. During the mechanical scanning, a larger area and a smaller emittance value compensate each other according to the cosine law. The temperature of the body will be determined correctly over the whole registered range.

If the inclination of the camera is varied, the image is distorted and the spatial resolution becomes poorer. Both effects are negative for the detection of hidden faults in buildings. Also, certain deviations from the correct temperature distribution must be expected. In the case of the application discussed here, if possible, the aim should be to work with symmetrical conditions (camera perpendicular to the surface). Although initial images for orientation are often made with the camera inclined, the detailed registration of the facade sections after subdivision should be made, if possible, with the apparatus perpendicular to the facade.

## 4. Computer-simulation of application-relevant situations

Application-relevant situations, for which no practical experience exists, can be simulated numerically. In most cases, 3-dimensional non-stationary calculations of heat conduction through complex facade constructions must be made. Only a few geometries can be approximated satisfactorily with 2-dimensional calculations.

The simulations are complicated and time-consuming. If they are justified by the importance and the financial framework of the application under discussion, they can be made on commission by scientific institutes with experience in such problems. A further disadvantage of the simulations concerns perturbations, which are important in reality, and which cannot (with reasonable effort) be simulated. This is the case for the measurements under sunny conditions, which are very sensitive to perturbations.

Practical experience and experimental investigations are more important for gaining the know-how needed to use thermography effectively for detecting hidden faults in buildings.