PRESENTATION ON

**“INFRARED THERMOGRAPHY AND ITS APPLICATION IN CIVIL ENGINEERING”**

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 **Contents:-**

|  |  |  |
| --- | --- | --- |
| **SR NO** | **TITLE** | **PG NO.** |
| 1. | ABSTARCT | 3 |
| 2. | INTRODUCTION | 4 |
| 3. | INFRARED THERMOGRAPHY-AN EFFECTIVE TOOL | 4 |
| 3 a.  | APPLICATIONS | 5 |
| 3b. | CONSTRUCTION THERMOGRAPHY | 6 |
| 3 c. | PRINCIPLES | 6 |
| 3 d. | ADVANTAGES | 10 |
| 4. | CONCLUSION | 11 |
| 5. | REFERENCES | 11 |

 **ABSTRACT**

Infrared thermography is a modern measuring method for the examination of redeveloped and non-renovated buildings. Infrared cameras provide a means for temperature measurement in building constructions from the inside as well as from the outside. It has been shown that infrared thermography is also applicable for finding the exact position of heating tubes or for discovering the reasons why mould is growing in a particular area. Several techniques based on high-resolution infrared thermography have been so far developed to provide an effective and non-destructive test to assess the integrity of historical buildings, masonry and historical masonry, and wooden art crafts. Perhaps the most exciting technology to hit the construction industry is the application of infrared radiation thermography. For many years, there have been multiple uses of this technique in other industries, especially medical, security, and military applications. However in the construction industry, it is chiefly used for detection of [water leaks](http://www.basementquestions.com/drainage.php), [moisture penetrations](http://www.basementquestions.com/fdnwaterproof.php), [mould detection](http://www.basementquestions.com/mold.php), [heat and energy losses](http://www.basementquestions.com/radheat.php), and [structural integrity inspections](http://www.basementquestions.com/bowedwalls.php).

**INTRODUCTION**

Infrared thermography is one of the non-destructive thermal methods which is becoming ever more popular in non-destructive testing of materials and structures since it is completely noncontact and may be faster than many other techniques that are being used.

Thermal methods generally consist of the thermal stimulation of the object (under examination) and monitoring of its surface temperature variation during the transient heating or cooling phase. The analysis of heating and cooling processes during and after warming up with an internal or external heat source is well established technique for the characterization of composites and metallic material.

In Civil Engineering, the application of infrared thermography is not limited to passive investigations of the quality of thermal insulation of building envelopes. Defects like voids in concrete or masonry, delaminations at interfaces of composites which have different density, heat capacity and/or heat conductivity in comparison to the bulk material can be localized and characterized.

Infrared thermography, due to its non-contact character that allows for quick 2D surface mapping, represents a powerful tool for non-destructive evaluation (NDE) of materials and structures. Notwithstanding this, Infrared thermography is still not completely exploited.

In contrast to the conventional use where natural temperature gradients are utilized, the NDT-applications take an active approach. A heat pulse is applied and the surface temperature is monitored and analysed. Typically, the temperature distribution at the surface at the time of maximum contrast is used for the detection of any defects.

The most important condition for infrared thermography to provide useful results is that a temperature difference or thermal contrast ΔT, exists between the feature of interest, e.g. people on a scene or an internal flaw on a specimen; and its surroundings. A second condition is to have the appropriate thermal imaging equipment to produce thermal images or thermograms. It is necessary to count with an experienced thermographer to interpret thermographic results.

**INFRARED THERMOGRAPHY-AN EFFECTIVE TOOL**

## What is infrared thermography??

Thermography is nothing but the temperature profiling of a surface or point. As the name suggests, infrared thermography is based on Infrared(IR) technique. The principle underlying this technique is that every object emits certain amount of IR energy and the intensity of this IR radiation is a function of temperature.In an electromagnetic spectrum the IR region appears between 0.8 micron to 1000 micron wavelength. This wavelength of IR spectrum is more than that of a visible spectrum. The IR energy which can directly represent the surface temperature can be detected and quantified by the help of IR scanning system.

Infrared thermography is the technique of converting infrared energy (radiant heat) into an image that a person can see and understand. We ordinarily see in visible light. We can compare infrared to visible light - they are not the same, but they are analogous. You are familiar with the idea of a video camera creating images on video monitors or television. The electronics in the camera convert the light energy that enters the lens into a video signal, and displays that signal on a monitor or TV. You see shapes, colors, textures, shadows, and reflective surfaces in the image as a result of the camera's ability to capture light.



This infrared image may look "odd" because you ordinarily see in visible light. This image shows the radiant heat rather than light. The light areas are warmer than the dark areas. Notice the temperature scale to the left of the picture.

In a similar way, an infrared camera creates an image by converting radiant heat energy into a signal that can be displayed on a monitor (and later printed).

The infrared energy emitted from an object is directly proportional to its temperature. Therefore temperatures are accurately measured by the infrared camera. The ability to measure temperature from an IR image is called radiometry. This requires sophisticated and expensive electronics. The ability to measure a temperature anywhere on the image is available only on the high-end cameras like the [Flir PM280](http://www.irisinfrared.com/How%20Does%20It%20Work.htm#AboutCamera).

**Application:-**

Infrared thermography is a fast, responsive and accurate technique. Its typical applications include but are not limited to detecting

1. Hidden moisture in building envelope — roofs, walls and floors

2. Air leakage through windows, doors and other parts of building envelope

3. Mold, mildew and termite damage in buildings

4. Lack of insulation in walls and roofs, lack of mortar pilaster in masonry walls, blister in FRPapplication, etc.

The modern infrared thermal camera is portable and allows the consultant to assess areas of distress in an efficient manner. However, knowledge about infrared thermal science is a pre-requisite to ensuring that the data are collected and interpreted correctly.

**A Few Guidelines :-**

• The best time to perform an infrared thermographic evaluation to detect hidden moisture is soon after sunrise or after sunset.

• Most building materials, such as brick, wood, steel and concrete, have an emissivity (E-value) close to 1. The E-value determines its ability to radiate infrared energy, which the thermal cameras convert to temperature. However, materials such as aluminium have a very low E-value and require special calibration to generate a useful thermal image.

• The most powerful and common heat source is the sun. Without the sun, man-made heat sources, such as a heat gun or even a hair dryer, can be used to heat the object locally when necessary to create a temperature differential so that the problem condition can be detected.

• Proper interpretation of the thermal images and developing repair solutions require a good understanding of infrared thermal science and relevant forensic engineering expertise.

**Construction thermography:-**

The main application of infrared thermography in the civil sector lies in construction thermography. Fortunately, most materials used in the building industry have emission coefficients between 0.90 and 0.96. Therefore good assessment of thermal properties of a building can be made with only one exposure with the same ε . Post-processing of the thermograms for zinc or copper clad components can then still be done with the computer. A basic condition for using thermography on buildings is a difference of 20 K between the inside and the outside temperatures. In the literature 10 K are sometimes considered enough. It means that examinations of buildings are reasonable only during the winter when the surrounding temperature lies around the zeropoint. Inside exposures are of greater significance because atmospheric conditions such as wind, rain, snow or sun as well as conditions of the building itself like ventilated facades have an effect on the results of the exposure. While heatbridges can be seen from outside, there are cold bridges observable inside. Furthermore, it is possible to find leaking or plugged heating systems, badly done insulation or hidden timbered framework, which has been plastered over. Pictures, taken with thermographic cameras, are admitted in court because they provide unambiguous proof of botched construction works. Construction firms benefit from them as well since they can photograph critical areas in order to design targeted constructional measures before reconstructing old buildings. Infrared exposures can be filed together with regular photographs of the same object and tables with thermographic results for later analysis.

**Principles:-**

According to the fundamental Law of Planck all objects above absolute zero emit infrared radiation. This radiation only becomes visible to the human eye when the temperature is above about 500°C. Infrared monitoring equipment has been developed which can detect infrared emission and visualize it as a visible image. The sensitive range of the detector lies between 2 and 14 microns. The 2-5.6 micron range is generally used to visualize temperature between 40°C and 2000°C and the 8-14 micron range is used for temperature between -20°C and ambient temperatures.Thethermograms taken with an infrared camera measure the temperature distribution at the surface of the object at the time of the test. It is important to take into consideration that this temperature distribution is the result of a dynamic process. Taking a thermogram of this object at an earlier or later time may result in a very different temperature distribution. This is especially true when the object has been heated or cooled.

The detectability of any internal structure such as voids, delaminations or layer thicknesses depends on the physical properties (heat capacity, heat conductivity, density, emissivity) of the materials of the test object. Naturally any interior ’structure’ has an effect on the temperature distribution on the surface. If the temperature changes on the surface there is a delay before the effect of this change occurs below where a defect such as a void occurs. The longer the time delay before the temperature changes, the greater the depth of the defect below the surface. Generally anything deeper than 10 cm will only show after a long period of time (>1 hr) after the temperature change has occurred.

Since the infrared system measures surface temperatures only, the temperatures measured are influenced by three factors:

1. subsurface configuration.
2. surface condition.
3. environment.

As an NDT technique for inspecting concrete, the effect of the subsurface configuration is usually most interesting. All the information revealed by the infrared system relies on the principle that heat cannot be stopped from flowing from warmer to cooler areas, it can only be slowed down by the insulating effects of the material through which it is flowing. Various types of construction materials have different insulating abilities or thermal conductivities. In addition, differing types of concrete defects have different thermal conductivity values. For example, an air void has a lower thermal conductivity compared with the surrounding concrete. Hence the surface of a section of concrete containing an air void could be expected to have a slightly different temperature from a section of concrete without an air void.

There are three ways of transferring thermal energy from a warmer to a cooler region:

1. conduction.
2. convection.
3. radiation.

Sound concrete should have the least resistance to conduction of heat, and the convection effects should be negligible. The surface appearance, as revealed by the infrared system, should show a uniform temperature over the whole surface examined. However, poor quality concrete contains anomalies such as voids and low density areas which decrease the thermal conductivity of the concrete by reducing the energy conduction properties without substantially increasing the convection effects. In order to have heat energy flow, there must be a heat source. Since concrete testing can involve large areas, the heat source should be both low cost and able to give the concrete surface an even distribution of heat. The sun fulfils both these requirements. Allowing the sun to warm the surface of the concrete areas under test will normally supply the required energy.During night-time hours, the process may be reversed with the warm ground acting as the heatsource. For concrete areas not accessible to sunlight, an alternative is to use the heat storage ability of the earth to draw heat from the concrete under test. The important point is that in order to use infrared thermography, heat must be flowing through the concrete. It does not matter in which direction it flows.

The second important factor to consider when using infrared thermography to measure temperature differentials due to anomalies is the surface condition of the test area. The surface condition has a profound effect upon the ability of the surface to transfer energy by radiation. This ability of a material to radiate energy is measured by the emissivity of the material, which is defined as the ability of the material to radiate energy compared with a perfect blackbody radiator. A blackbody is a hypothetical radiation source, which radiates the maximum energy theoretically possible at a given temperature. The emissivity of a blackbody equals 1.0. The emissivity of a material is strictly a surface property. The emissivity value is higher for rough surfaces and lower for smooth surfaces. For example, rough concrete may have an emissivity of 0.95 while shiny metal may have an emissivity of only 0.05. In practical terms, this means that when using thermographic methods to scan large areas of concrete, the engineer must be aware of differing surface textures caused by such things as broom textured spots, rubber tire tracks, oil spots, or loose sand and dirt on the surface.

The final factor affecting temperature measurement of a concrete surface is the environmental system that surrounds that surface. Some of the factors that affect surface temperature measurements are:

* **SOLAR RADIATION:** testing should be performed during times of the day or night when the solar radiation or lack of solar radiation would produce the most rapid heating or cooling of the concrete surface.
* **CLOUD COVER:** clouds will reflect infrared radiation, thereby slowing the heat transfer process to the sky. Therefore, night-time testing should be performed during times of little or no cloud cover in order to allow the most efficient transfer of energy out of the concrete.
* **AMBIENT TEMPERATURE:** This should have a negligible effect on the accuracy of the testing since one important consideration is the rapid heating or cooling of the concrete surface. This parameter will affect the length of time (i.e. the window) during which high contrast temperature measurements can be made. It is also important to consider if water is present. Testing while ground temperatures are less that 0°C should be avoided since ice can form, thereby filling subsurface voids.
* **WIND SPEED:** High gusts of wind have a definite cooling effect and reduce surface temperatures. Measurements should be taken at wind speeds of less than 15 mph (25 km/h).
* **SURFACE MOISTURE:** Moisture tends to disperse the surface heat and mask the temperature differences and thus the subsurface anomalies. Tests should not be performed while the concrete surface is covered with standing water or snow.

Once the proper conditions are established for examination, a relatively large area should be selected for calibration purposes. This should encompass both good and bad concrete areas (i.e. areas with voids, delaminations, cracks, or powdery concrete). Each type of anomaly will display a unique temperature pattern depending on the conditions present. If, for example, the examination is performed at night, most anomalies will be between 0.1° and 5°C cooler than the surrounding solid concrete depending on configuration. A daylight survey will show reversed results, i.e. damaged areas will be warmer than the surrounding sound concrete.

### Experiment:-

The experimental set-up to perform impulse thermography measurements is shown in Figure 1. It consists of a thermal heating unit (1), a structural element to test (2), an infrared camera(3) and a computer system (4) which enables real time data recording.

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| http://www.ndt.net/article/ndtce03/papers/p024/fig1a.gif[http://www.ndt.net/article/ndtce03/papers/p024/fig1bm.jpg(b)](http://www.ndt.net/article/ndtce03/papers/p024/fig1b.jpg) |
| Fig 1: Experimental device for impulse thermography in civil engineering: schematic sketch (a) and a photograph of the alignment (b). For details see text.  |

The thermal heating unit contains three infrared radiators, each with a delivery rate of 2400 W. The heating-up procedure is usually done dynamically by moving the radiators across the specimen surface to obtain the best possible homogeneous heating. Therefore, radiators are mounted in a line array and are moved automatically parallel to the surface at a distance of about 15 cm.

The cooling-down process of the surface is observed with a commercial infrared camera (Inframetrics SC1000). The camera contains a focal plane array of 256 x 256 PtSi semiconductor detectors and is able to detect radiation from the surface of the specimen in a wavelength range of 3 - 5 mm. The measured radiation intensity values can be converted into temperature values using look-up tables and can be presented as a grey or colour scaled picture (thermogram). During data acquisition the thermal image data are transferred to the computer at a maximum frame rate of 50 Hz and a storage depth of 12 bits per pixel. After receiving the thermal images the computer is used to analyse the data with dedicated software programs.

Typical testing problems in civil engineering are voids and honeycombing in concrete elements. Therefore a test specimen with a size of 150×150×50 cm3 was built containing voids of different sizes (10×10×10 cm3 and 20×20×10 cm3) and different amounts of concrete coverage, Figure 2. Measurements were performed by heating the surface of the specimen with varied heating times up to 60 min at a fixed heating power of 1250 Wm-2. After switching off the heating source the cooling-down process was monitored with the infrared camera and thermal images were recorded with a frame rate of 2 Hz up to 120 min. To improve the signal to noise ratio the average of 10 images was determined. Thus a film of 1440 images with a time step of 5 s between single images is received.

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| [Fig 2:](http://www.ndt.net/article/ndtce03/papers/p024/fig2.jpg)Sketch of the concrete test specimen including 8 polystyrene cuboids (units in cm). |



Figure 3a shows a thermogram selected from a series of measurements with 15 min heating up time. The image was taken 8 min after switching off the external heating unit. Shallow voids (up to 6 cm coverage) are clearly distinguishable with a good thermal contrast. Deeper voids cannot be detected so far but appear clearly after waiting for longer times (e.g. 50 min).



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|  | [Fig 3:](http://www.ndt.net/article/ndtce03/papers/p024/fig3.jpg) (a) Thermogram recorded 8 min after switching off the heating source. The heating up time was 15 min. (b) Temperature and temperature difference curves versus time for the selected surface points in a (above a defect (D) and reference position (O)). Also shown is the dedicated temperature difference curve, comprising a maximum temperature DTmax at a distinct time tmax. |

The main approach in analysing the thermal data was to interpret the function of surface temperature versus cooling time for selected areas with and without inhomogeneities. These selected transient curves were compared and difference curves (between transient above a void and transient above a sound area) were calculated. In Figure 3b the results of a defect with an approximate concrete coverage of 3.5 cm are shown. The temperature difference curve usually has a maximum DTmax at a distinct time tmax, indicating the point of maximum temperature contrast. The values of DTmaxtmax depend mainly on the depth of the void and the amount of heating up time.

 **ADVANTAGES:-**

* The major advantage of this technique is that the area under test need not be destroyed during testing.
* This results in major saving in time,labour,equipment and scheduling problem.
* In addition when aesthetic is concerned, no disfiguring occurs in the concrete to be tested.
* As no dust or debris is generated it is pollution free.
* The infrared equipment used is safe as it does not generate any harmful radiations.
* The main advantage is that it is a area testing technique unlike other NDT methods that are line testing or point testing.
* The device is easy to handle (barely 10N weight)
* It does not obstruct construction or use of the structure under investigation.
* The images can be obtained instantly as in digital camera and can be stored, retrieved or processed further for details later.
* The process is easy to comprehend and not highly complex.

**CONCLUSION**

Thermal images provide an excellent tool for rapid assessment of structure. Being a non-contact and non-destructive method, it is useful in survey of structures without requiring any access. The method has immense potential in quality control during construction as well as investigations of deteriorated structures without interrupting utility or construction of the structure.

As concrete is used in newer areas and evidence is coming in type of premature deterioration in concrete structures there is a need to develop new methods for quality control at the time of concrete construction and for the evaluation of deteriorated structures. From the study it emerges that infrared thermography is an effective tool for concrete placement and identifying location of voids and cracks in fresh and hardened concrete or in areas that needed closer attention during an in-service inspection of concrete structures.

Infrared thermography is very useful as it is a non-contact technique, it saves time and labour and the exact location of the fault can be found easily. Though the cameras used in this technique are expensive but this technique saves other expenses like labour cost , cost of other equipments ( needed for a destructive test ) etc and more importantly it does not cause any pollution.

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