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THE USE OF THERMOGRAPHY IN THE THERMAL PERFORMANCE TESTING OF BUILDINGS

by J M Hart

Summary

This paper reports on the use of infrared thermography as a means to investigate the many facets of building energy consumption and conservation.

Examples are shown of the qualitative and quantitative infrared technique used to study insulation defects, air infiltration and the heat loss from windows.

In addtion, case studies illustrate the general applications of the technique; eg the examination of heating system efficiency and electrical planned maintenance.

For lightweight responsive components such as windows, U-values have been calculated from quantified thermograms to enable comparisons to be made between forms of window insulation. In heavyweight non-responsive components, the technique has been extended to combine the visual thermal image with that of U-value measurement using a heat flux meter.

Also given, is a brief discussion on the derivation of emissivity and its importance in the infrared technique.

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THE USE OF THERMOGRAPHY IN THE THERMAL PERFORMANCE TESTING OF BUILDINGS

J Hart, Building Research Establihsment

1 THERMAL LOSSES FROM BUILDINGS

Heat is lost from a building in many ways, losses through the fabric constitute conductive losses which are quantified by the thermal transmittance or U-value. The greater the U-value, the greater the heat loss through the building envelope. In practice a building will consist of many areas of varying U-value, the total heat loss through the building fabric is found by multiplying U-values and areas of the externally exposed parts of the building, and multiplying the result by the temperature difference between inside and outside.

In addition to conductive heat loss, a building will also lose heat by the ingress of cold external air combined with the associated loss of warm internal air, quantified as ventilation losses. Ventilation, expressed in air changes per hour, is a design factor varied to maintain indoor air quality depending on the activity carried out within the building or part of a building. Building ventilation can either be provided naturally or mechanically.

Modern insulation techniques and standards have reduced the U-value and hence heat requirements of many modern buildings. Although the theoretical performance of most insulation materials is well documented, the performance of a completed building is less certain. The effects of transport, handling and site storage together with that of workmanship, cannot readily be estimated. Thermal testing of the completed building using thermography can help verify that the intended performance standard has been achieved.

In addition to improvements in U-value, modern construction practice and refurbishment work has tended to reduced air infiltration and hence ventilation heat loss in both the new and existing building stock. Again, although the theoretical performance of ventilation design is well documented the air quality in a completed building is less certain. Over-ventilation wastes energy, underventilation may lead to an unacceptable level of contaminants and condensation. Ventilation pressure testing of the completed building combined with infrared thermography can provide a means to monitor whole building air leakage characteristics. The results can then be compared to the design requirements and points of air leakage may be quickly identified.

In general, an infrared thermographic survey cannot be carried out on a building until it has been completed and the heating system commissioned. Thermal or air leakage problems discovered at this stage may then be rectified where necessary by retrofit measures. Equally, thermography can be used on existing building stock, eg housing rehabilitation projects which have included improved energy efficiency, to monitor the workmanship and appraise the efficiency of different conservation options. Thermography provides a rapid means to investigate the many facets of building energy consumption and conservation. When combined with other techniques and equipment the technique can be extended beyond a qualitative site investigation to encompass energy auditing, design appraisal and structural surveying.

2 INSULATION DEFECT DETECTION

Within the building industry, the use of infrared thermography has gained in usefulness as a means to monitor and evaluate modern insulation techniques and standards. Qualitative thermography can provide a rapid method of assessing the in-situ quality and performance of insulation.

Before such a survey is carried out, however, certain parameters must be considered. The building under investigation must be at least 10°C warmer than outdoors, the object surface must have a high, non-varying emissivity, and there must be no unusual thermal influences; when these requirements are met, insulation performance can be deduced by observing variations in surface temperature, Figure 1. Areas of reduced insulation will be cooler in comparison to the surrounding internal surfaces, so variations in grey tone (or colour) over the thermal image can be taken as variations in the thermal properties of the object. When used by a skilled operator, defects may be quickly identified and, where need be, remedial treatment applied. Figure 2 shows a very distinctive cold area on the ceiling of a house, where the painted surface has a uniform emissivity. In this case, however, the variation in surface temperature aligns with an area which has been left clear of insulation to prevent freezing of the cold water storage tank in the loft.

As shown, the analysis of most qualitative thermograms involves comparison to determine areas of reduced insulation. In most cases this approach is satisfactory, but occasionally, due to unusual circumstances, comparison can be misleading, this is particularly relevant when carrying out an external thermography. In addition to the normal thermographic precautions, allowance must be made for the influence of the external environment and its effect on surface features. Solar radiation, rain and wind will all affect the external structure of buildings to some extent. On facades of uniform material and construction exposed evenly to the prevailing climatic conditions, comparative analysis of thermograms should be satisfactory. However, if for example, a facade has surface features of differing colours, then surface temperature may be influenced by the materials differing absorptivity to solar radiation. In heavyweight constructions, a temperature variation generated by solar radiation may be retained for many hours after sunset, Figure 3. It follows, therefore, that 'historic' differences in external surface temperature must be expected, particularly for facades of different materials or orientation, and must be taken into consideration when interpreting external thermography measurements.

For a more detailed analysis, perhaps linked to an energy audit, a quantitative survey may be carried out, but for this, the prevailing conditions both indoors and outdoors must be carefully monitored. Consideration must be given to the thermal mass of the building construction, and all the parameters necessary for the subsequent analysis carefully measured and logged. In the UK, the absence of a British Standard for thermography means that ISO/DIS 6781 is the best source of guidance, supplemented by factors related to British building and climatic conditions. Figure 4 shows a quantified thermogram, the internal leaf of this cavity filled wall shows clearly an area of reduced insulation. By analysing the image, surface temperature can be calculated for the two defined areas. In this case, area 1 has an average surface temperature close to the internal air temperature indicating a high degree of insulation, whilst area 2, the adjacent area has an average surface temperature 1.6°C lower, indicating a substantial reduction in insulation.

Quantitative analysis of a thermogram may be taken one stage further by combining the infrared technique with that of U-value measurement using a heat flux meter. Using the quantified thermogram as a guide, the heat flux sensor plate is located on a representative area of a wall. The U-value obtained over a long averaging period is then representative for the area indicated by the thermogram. In this way, comparison with design value can be made, (see section 6).

Before remedial insulation treatment is applied to any building based on the findings of thermography, it may be desirable to carry out a structural survey to investigate the cause or reason for the deficiency, In such cases the thermogram may be used as a guide to the accurate positioning of inspection equipment such as industrial borescopes. An internal inspection will then verify absolutely the absence of insulation and also identify any structural defect which may be the underlying cause of the problem.

3 AIR LEAKAGE DETECTION USING THERMOGRAPHY

In nearly all buildings, a continuous exchange of air takes place between the inside and the outside. Naturally occurring pressure differentials across the construction provide the driving force for this air exchange and its occurrence provides natural ventilation to the typical UK building. Modern construction techniques and practices have, however, attempted to reduce natural ventilation to a minimum and in some cases mechanical ventilation coupled with heat recovery has replaced the need for natural ventilation. In such constructions, uncontrolled infiltration of cold external air is both undesirable and a waste of energy.

Detecting air leakage within a building by thermography relies on observing the lowering of the surface temperature on parts of the wall adjacent to the leakage point. The magnitude of this change in temperature depends upon:

1 The nature and size of the point of leakage.
2 The pressure differential across the construction.
3 The temperature difference between indoors and outdoors.

Due to the irregular effects of wind on a building, the most difficult parameter to establish is the naturally occurring pressure differential. Pressure conditions in practice are relatively varied and complex, and airflow into a building through leakage paths cannot be guaranteed. The temperature difference between indoors and outdoors is, however, more easily established and should be at least 5°C.

When a detailed study of air infiltration is to be undertaken, it is preferable to stabilize the pressure differential by the use of mechanical extract fans. Such equipment is already used to measure whole building air leakage charactetistics; when combined with the qualitative thermographic technique points of air leakage may be quickly identified and, where need be, remedial treatment applied.

The effect of mechanical air extraction is to reduce, in a controlled way, the pressure within a building to below that of the external air and hence to increase the rate of airflow through any air flow paths through the building envelope. Under such circumstances the direction of the flow is inwards and the cold air cools the surfaces close to the point at which it enters the building. If thermograms are taken before and at intervals after the building is depressurised the colder area is seen to become larger as the incoming air progressively cools a larger surface area. This technique enables cooling due to airflow to be distinguished from heat loss due to conduction through the fabric.

Figure 5 is a typical thermogram of an air leakage path at a wall to ceiling joint under naturally occurring pressure differences. Figure 6 is the same view taken 10 minutes later with a mechanical pressure difference of 45Pa applied across the building envelope. It is clear that the cold area of this joint has increased substantially as more of the internal surface becomes cooled by the induced inflow of cold air.

Points of air leakage which may have remained undetected under naturally occurring pressure differentials because of low or positive internal pressures may also be found by this means. Under depressurisation Figure 7 shows a large area of cooled surface on an open plan pitched roof, this would indicate possibly an incomplete or damaged vapour barrier. Under natural pressure differentials, however, the area at the wall to ceiling joint was just visible but the extent of the damage was impossible to assess, and could easily have been missed.

4 THERMOGRAPHY AND HEAT LOSS THROUGH WINDOWS

So far, consideration has been given to the potential use of thermography in detecting heat loss from a buildings structural fabric and from paths of air leakage. The infrared technique may also be used to examine heat loss from windows, and to examine the benefits of window 'insulation'.

Windows, although apparently simple in construction, are in fact thermally quite complex; and there are many ways in which their thermal performance can be improved. Heat is lost from a window by conduction and through paths of air leakage. Heat loss from draughts around the frame, through hinges and ill-fitting openable windows can be detected using the air leakage infrared technique. Fabric losses can also be examined by thermography provided the short wavelength transmitted energy path through the glass is eliminated by the use of a suitable spectral filter.

The traditional UK window is a single glazed unit with either a wooden or metal frame. Its thermal performance is often upgraded to a double glazed unit by replacement or the addition of secondary glazing. Using thermography, a useful comparison can be made between the various forms of window insulation, and given the rapid thermal response of window constructions, the technique can be extended to quantify heat loss in terms of a U-value.

Figure 8 is a thermogram of a typical single glazed, metal framed window. By using a glass spectral filter (Cut-On wavelength 4.8 μm) and detailed analysis, (see section 6), a mean surface temperature of 13.5°C is obtained. Given that the heat transfer is close to steady state and assuming an internal heat transfer coefficient of 0.123 $W/m^2 {}^\circ C$, an estimated U-value for the window of 5.0 $W/m^2 {}^\circ C$ is obtained from the internal and external air temperatures and the calculated surface temperature ie close to the expected value.

For comparison, Figures 9a and 9b show a good quality wooden framed double glazed window. The surface temperature of the glazed surface was calculated to be 11.3°C. This yeilds an estimated U-value of 3.5 $W/m^2 {}^\circ C$, which is in the range expected for double glazing with a small air gap (6 mm). The frame temperature of 18.3°C indicates an approximate U-value of 0.5 W/m²°C. This gives an average U-value for the window, including frames, of 2.4 W/m²°C. Close to the design value of 2.5 W/m²°C.

At night in housing, thermal performance is improved when the curtains are closed. Figures 10 and 11 are thermograms of two adjacent windows of the type shown in thermogram 8, but with curtains hung within the window reveal. Figure 10 is an unlined cotton curtain, Figure 11 is an identicial curtain with a looose lining. By examining the two pairs of curtains, hanging under identical conditions, direct comparison can be made about their thermal performance. Clearly the lined curtain provides better insulation as indicated by the warmer internal surface; translated to an estimated U-value gives an improvement of 0.5 W/m²°C compared to the unlined equivalent.

In addition to the use of thermography to examine the thermal performance of windows, the technique can also be used to investigate the thermal environment around windows. Traditionally, central heating radiators are placed beneath windows to help reduce the effect of cold convection currents on room occupants. This practice, however, can have a dramatic effect on the thermal environment around the window.

Figure 12 is an internal thermogram of a single glazed window with closed curtains, with no radiator under the window, the curtains have an average surface temperature 3.5°C below the room air temperature. Figure 13, however, shows the adjacent window, which has a radiator beneath, to have an average surface temperature 0.5°C below air temperature. Thus, thermography may be used to demonstrate how the difference in the local micro-climate can affect the heat loss through a component. Clearly this rise in curtain temperature will lead to an increase in heat loss possibly by about 30% in this particular case.

5 GENERAL BUILDING APPLICATIONS FOR THERMOGRAPHY

In addition to testing the thermal performance and airtightness of buildings, thermography is principally a diagnostic tool when used within the building and building services industry. The range of application is extensive, provided an object exhibits variations in surface temperature which can be related to its physical state or position, then thermography can be used to locate or diagnose the underlying problem.

Objects for investigation by thermography may be grouped into two categories, passive objects and active objects. Generally most building components are passive; heat is not generated within the structure but conducted through from one side to the other. By this method, variations in surface temperature are then related to the thermal resistance of the materals and the temperature difference across the material, ie variations in insulation. The technique may also be used, however, to 'visualise' hidden structural detail and locate sub-surface objects. The main criterion for such work is a high emissivity surface and a temperature difference sufficient to cause surface temperature variations. Figure 14 for example clearly shows the position of the mortar joints and perpends between the internal block construction of this plastered wall.

Active components within a building structure, include the heating system and thermography may be used to examine the efficiency and condition of a system in situ. The thermogram in Figure 15a shows the distribution of underfloor heating pipes, an application useful for position location, identifying blockages and leaks and for assessing overall temperature distribution. In this example of a ground floor heating installation, the plastic pipes are situated beneath a 50 mm concrete floor screed. Initially, however, the surface temperature distribution was so even that a step change in the cirulated water temperature was necessary to highlight the pipes. Figure 15b shows the first floor pipes of the same installation located beneath 25 mm of chipboard, where not only are the pipes very clearly defined but so also are the metal heat spreader plates located at intervals over the pipes.

Figure 16a shows the heat distribution from a convector/blower heater. Although the IR camera cannot 'see' warm air, the distribution of heat from this low level fan assisted warm air system can be clearly seen as it warms the floor area in front of the heater. The thermogram Figure 16b, however, shows a similar heater with an uneven temperature distribution, clearly indicating a blockage in the air duct at the centre.

Thermography may also be used to diagnose and locate faults in electrical installations. An example is the detection of overheating connector blocks in the trunking of a high level lighting circuit. Using the infrared camera from the ground, an affected joint section may be located for closer inspection Figure 17a. With the connector removed from the trunking, Figure 17b clearly shows heat generated within the connector block indicating a high resistance joint. By using thermography in this way, planned preventative maintenance can take place to eliminate a possible hazard.

The examples shown give an indication of the variety of naturally occurring applications for thermography within the building industry, but they are by no means exhaustive. There are also a number of ways in which object surfaces may be artificially heated in order to visualise defects, (Reynolds), and (Hillemeier), including radiant heating of surfaces and induction heating of reinforcing bars.

6 QUANTITATIVE HEAT LOSS MEASUREMENT

The apparent simplicity of use of infrared thermography applied to buildings may result in large errors in the final interpretation of results when problems associated with the technique are not properly evaluated and accounted for. Although possible misinterpretation can occur in all thermographic surveys, particular care should be taken when the results are to be quantified for use in further heat loss calculations.

A thermogram may be quantified in terms of absolute surface temperature provided the following parameters can be determined:

1 The ambient air temperature.

2 The temperature and emissivity of a point reference in the field of view.

3 The camera to object distance, and hence atmospheric correction.

4 The camera and display settings for the equipment in use.

5 The object emissivity.

The accuracy of the calculated surface temperature will depend upon the reliability with which these parameters can be established and the quality of the infrared image. It should also be noted that:

1 For non-uniform surfaces, areas in the same field of view with differeng parameters will each require a separate calculation.

2 The overall reliability of a thermographic survey depends on a full understanding of the prevailing thermal conditions inside and outside the building both prior to, and for the duration of the survey.

For lightweight responsive components where undirectional and stationary heat flow can be established, thermography may be used directly to establish surface temperature. The results may then be extended to estimate U-value and determine heat loss in terms of W/m². At all times in this process, careful consideration must be given to the accuracy of the thermal image and the additional parameters needed to carry through such a calculation. Figures 9a and 9b illustrate the estimation of U-value applied to a wooden double glazed window.

For the calculation of U-value, the numeric value for the internal surface resistance, Rsi, may be taken from guide values, (CIBSE) or calculated to suit individual applications, (Petterson), and (McAdams).

In heavy weight non-responsive building components steady state thermal conditions rarely occur. The effect of diurnal variation coupled with cyclic heating patterns combine to ensure a continually changing thermal environment. For building with a large thermal mass, the heat flow through the structure (the thermal conductance) is not in step with the temperature difference across the structure. Under such conditions, an estimation of U-value based on an infrared image captured at one instant in time, may be very misleading.

One way to overcome this problem is to combine quantitative analysis of a thermogram with that of U-value measurement using a heat flux meter. Using the quantified thermogram as a guide, the heat flux sensor plate is located on a representative area of a wall. The U-value may then be derived from time dependent data from the average heat flux divided by the average air temperature difference between inside and outside. Provided this cumulative process is continued for long enough for thermal mass to have a negligible influence then this ratio ultimately converges to the U-value (Anderson 1985), which is then representative for the area indicated by the thermogram. In this way, comparison with deisgn value can be made. Figure 17 shows a graph of U-value against time for a typical uninsulated brick/block cavity wall. The rapidly changing instantaneous U-value can be clearly seen compared to the long term running average. At least five days are necessary in this particular case before a stable U-value is obtained.

By using this combined approach, a method can be provided to investigate the thermal performance of a structure and derive a U-value in situ.

7 EMISSIVITY

Emissivity is a very important parameter which must be taken into consideration for all surfaces viewed by an infrared camera. The term emissivity describes the ability of any given surface to emit radiation. Its dimensionless numeric value is temperature and wavelength dependant and its theoretical limits lie between 0 and 1.

The name given to a perfect emitter is a blackbody and it may be defined as an object which absorbs all incident radiation striking it regardless of wavelength. From Kirchoff's Law it can also be shown that a blackbody is equally capable of emitting radiation at all wavelengths.

Unfortunately, 'real' objects never respond as perfect blackbodies over an extended wavelength band, although a surface may approach blackbody behaviour within a given spectral region. For example, white paint appears perfectly 'white' in the visible light spectrum, but beyond 3 μm it is almost black.

There are three processes which can occur which prevent a 'real' object from acting as a blackbody. A fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted.

These three fractions are all more orless wavelength dependent, but for any given wavelength must add up to unity. So we have the relation

$$\alpha\lambda + \rho\lambda + \tau\lambda = 1$$

Where the spectral absorptance $\alpha\lambda$ = the ratio of the spectral radiant power absorbed by an object to that incident upon it.

The spectral reflectance $\rho\lambda$ = the ratio of the spectral radient power reflected by an object to that incident upon it.

The spectral transmittance $\tau\lambda$ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

For a blackbody $\alpha\lambda = 1 \quad \tau\lambda = \rho\lambda = 0$

In building thermography all surfaces of interest are non-blackbody emitters and most (with the exception of glass and some plastics) are opaque to infrared radiation over the wavelength range 3.0 to 5.6 μm, so the above relation simplifies to:

$$\alpha\lambda + \rho\lambda = 1$$

The factor emissivity, ε is required, however, to describe the fraction of the radiant power of a blackbody produced by a non-blackbody object at a specific temperature.

The spectral emissivity $\varepsilon\lambda$ = the ratio of the spectral power from an object to that from a blackbody at the same temperature and wavelength.

According to Kirchoff's Law, for any material, the spectral emissivity and spectral absorptance of a surface are equal at any given temperature and wavelength. That is $\varepsilon\lambda = \alpha\lambda$. For an opaque surface:

$$\varepsilon\lambda + \rho\lambda = 1$$

As the wavelength range of the camera has now been specified (3.0 to 5.6 μm), we can now write:

$$\varepsilon + \rho = 1 \quad \text{for an opaque surface.}$$

When carrying out a qualitative infrared survey, the most important surface characteristic is a high uniform emissivity and fortunately, most building materials have emissivities generally in the region 0.8 to 0.95 at ambient temperatures. When direct comparison between adjacent areas are to be examined an abslute value for emissivity is not as important as uniformity. However, it must be remembered that for a surface emissivity of 0.9, 10% of the received radiation will be reflected, so consideration must be given to the temperarture of the local surroundings and objects.

When a quantitative infrared survey is carried out or when adjacent surfaces for comparison are not uniform, then the absolute value for emissivity becomes of paramount importance. If the true value is unknown and tabulated emissivity values provide insufficient data, then consideration must be given to a specific 'on-site', or laboratory determination of emissivity rather than relying on general guide values.

Finally, although most objects found in buildings are opaque to infrared radiation, there are some which are not or at least are wavelength dependant. The main example being glass. The transparency of glass extends beyond the visible range of the spectrum to about 4.8 μm inside the infrared region. For cameras operating in the 3 to 5.6 μm region, this means they can 'see' the thermal environment on the other side of the glass. This unwanted radiation path can be prevented from reaching the infrared detector by the use of a suitable spectral filter with a cut-on wavelength of 4.8 μm. Using such a filter, only radiation above 4.8 μm is used to form the thermal image so glass can be treated as an opaque surface with only an emitted and reflected radiation path, (see section 4).

ACKNOWLEDGEMENT

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Building Thermography - Thermogram Captions

Figure 1 A qualitative thermogram, where the black areas indicate reduced insulation in this stairwell cavity wall.

Figure 2 The deliberate omission of loft insulation under cold water storage tank can be clearly seen on this first floor ceiling.

Figure 3 The south facade of an office block where the base plinth clearly shows the effect of a 'historic' temperature difference caused by dissimilar materials and solar radiation.

Figure 4 A quantified thermogram. Area 2 on the left hand side has a surface temperature 1.6°C lower than the rest of the insulated wall. Peak white defines the analysis areas.

Analytical parameters

Reference temperature	22.0°C
Reference emissivity	1.0
Object emissivity	0.92
Camera to object distance	2.0m
External air temperature	4.0°C
Camera aperture setting	f1.8
Camera thermal range	5.0

Calculated surface temperature:-

For defined area 1 = 20.7°C
For defined area 2 = 19.1°C

Figure 5 Air leakage at a wall to ceiling joint of this open plan pitched roof at naturally occurring pressure differences.

Figure 6 The same view as Figure 5 with a pressure difference of 45Pa.

Figure 7 The black area indicates the extent of surface cooling caused by enhancing the air leakage path at this wall to ceiling joint using the depressurised infrared technique. The horizontal white areas are fluorescent lights.

Figure 8 A single glazed metal framed window. Peak white defines the analysed area and the temperature reference can be seen in the lower left hand corner.

Figure 9a The isotherm function and spectal filter is used to analyse the glass temperature of this double glazed unit.

Figure 9b The isotherm function is used to analyse the wooden frame temperature of this window unit.

Figure 10 A single glazed metal framed window with unlined curtains hung within the window reveal. Peak white defines the analysed area.

Figure 11 As Figure 10 but with the addition of a loose curtain linning.

Figure 12 The thermal environment surrounding a window with closed curtains and no radiator beneath. Peak white defines the analysed area.

Figure 13 An adjacent window to Figure 12 with closed curtains and a radiator beneath.

Figure 14 The black lines clearly indicate the block structure of this wall although 'hidden' behind 15 mm of plaster.

Figure 15a The layout and performance of this underfloor heating system can be visualized by thermography. The black vertical line is the leg of a table standing on the floor.

Figure 15b The additional feature of heat spreader plates can be seen under the first floor chipboard.

Figure 16a The low level heat distribution from this fan assisted heater is seen as it spreads over the floor surface.

Figure 16b An identical heater to Figure 16a but clearly showing an air blockage at the centre of the slotted output.

Figure 17 Variation with time of the instantaneous and average U-value for a cavity constructed brick/block wall.

BIBLIOGRAPHY

Pettersson, Bertil, and Axen, Bengt. Thermography - testing of the thermal insulation and airtightness of buildings. Swedish Council for Building Research 1980.

Hart, J M. BRE experience in building thermography: selected case studies. Presented at International Congress of Thermography, Lucerne Switzerland, 1984.

Anderson, B R. The measurement of U-values on site. Presented at Thermal performance of the exterior envelopes of buildings III. 1985.

Building Research Establishment Digest 306. Domestic Draughtproofing: Ventilation considerations, 1986.

Reynolds, W N. Thermal pulse video thermography. NDT Centre, AERE Harwell.

Hillemeier, Bernd. Qualitatssicherung im hoch- und tiefbau mit hilfe der therographie. Hochtief AG, Abteilung Qualitatssicherung, Frankfert/m.

CIBSE Guide.

McAdams, William H. Heat Transmition. McGraw-Hill.

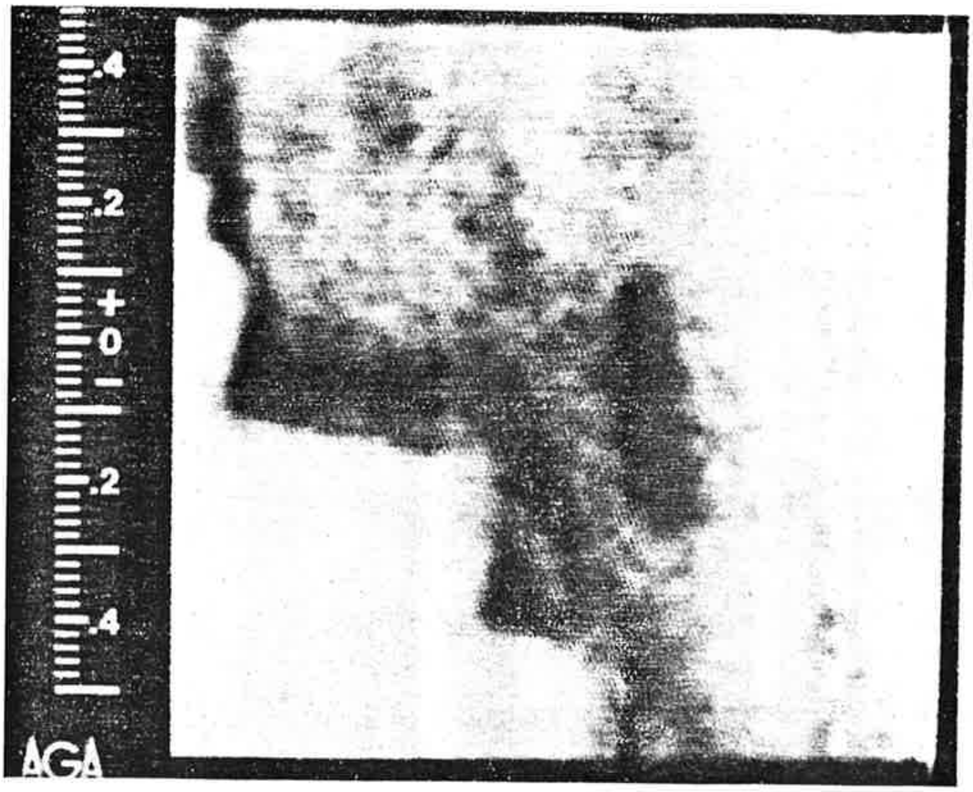


Figure 1 A qualitative thermogram, where the black areas indicate reduced insulation in this stairwell cavity wall.

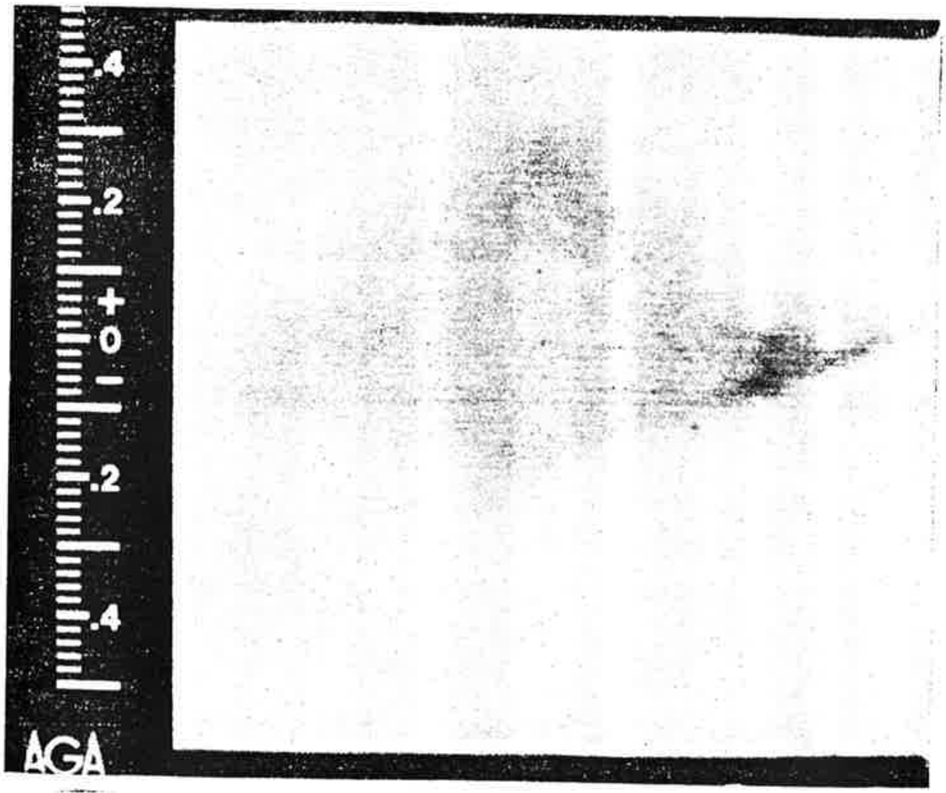


Figure 2 The deliberate omission of loft insulation under a cold water storage tank can be clearly seen on this first floor ceiling.

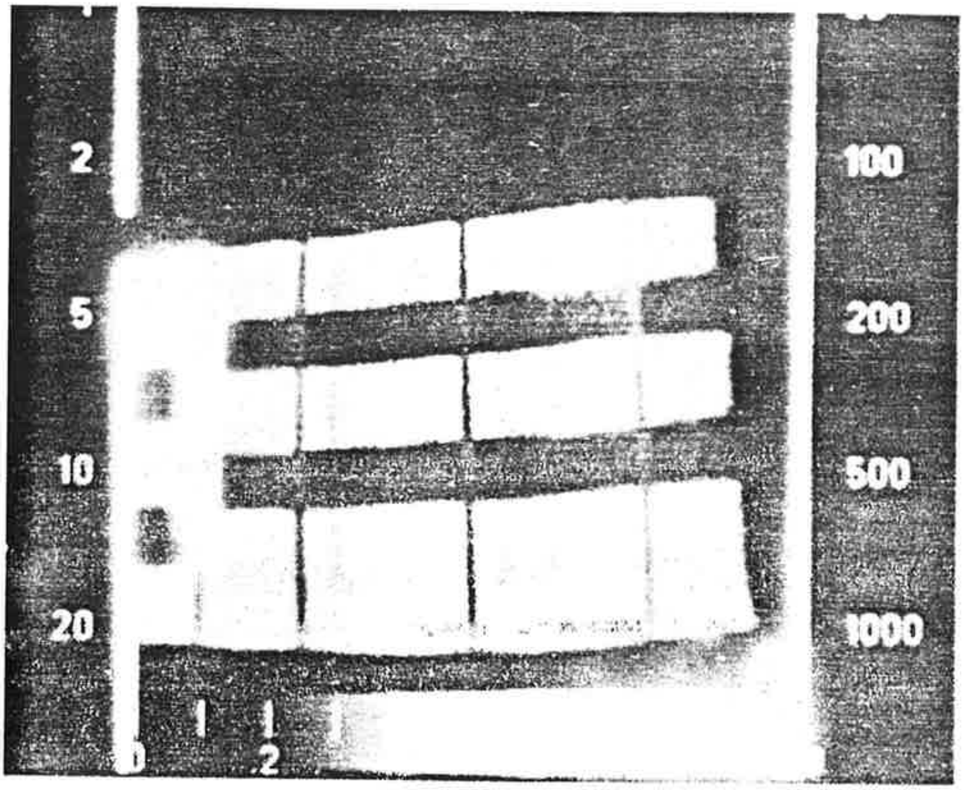
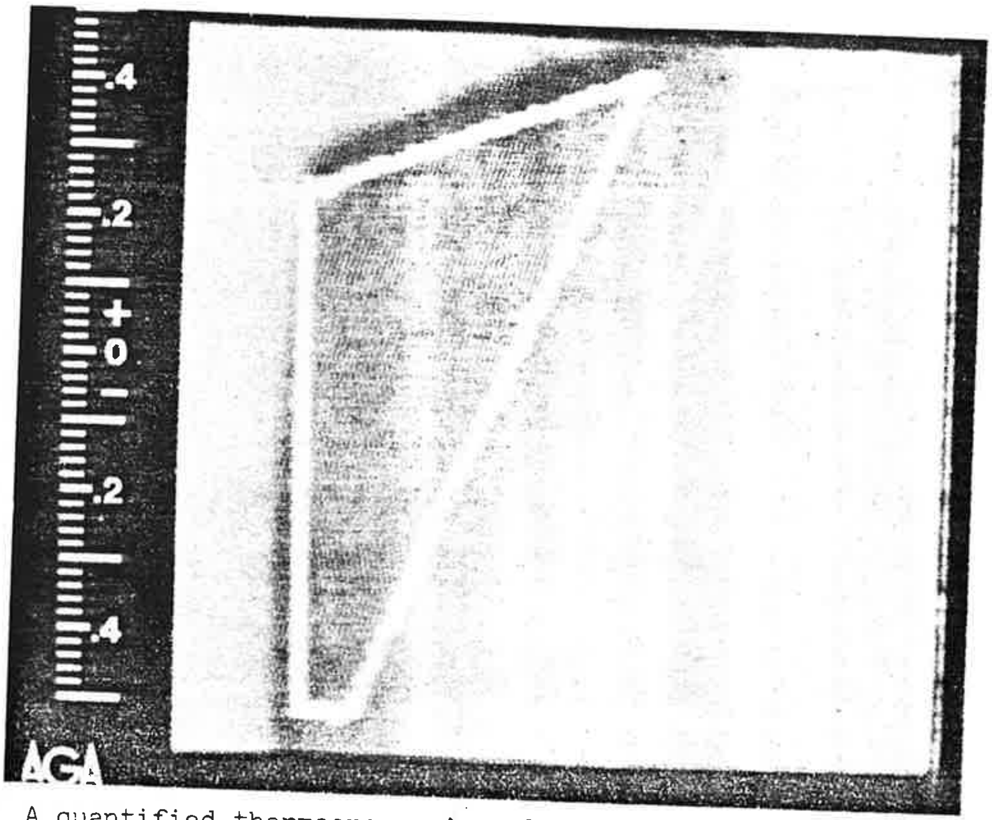


Figure 3 The south facade of an office block where the base plinth clearly shows the effect of a 'historic' temperature difference caused by dissimilar materials and solar radiation.



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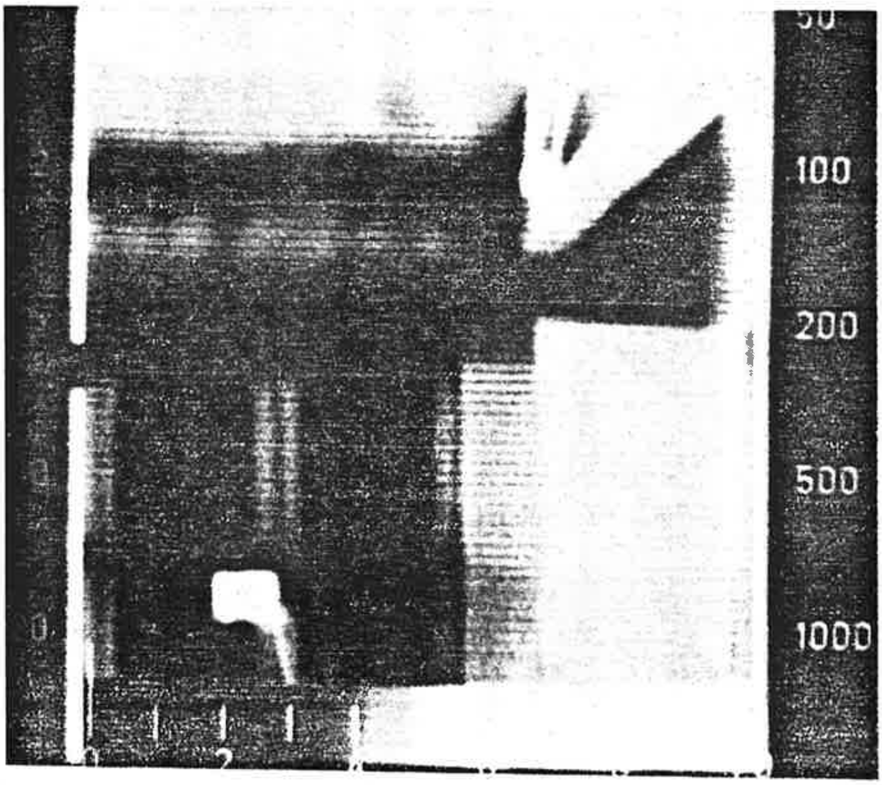

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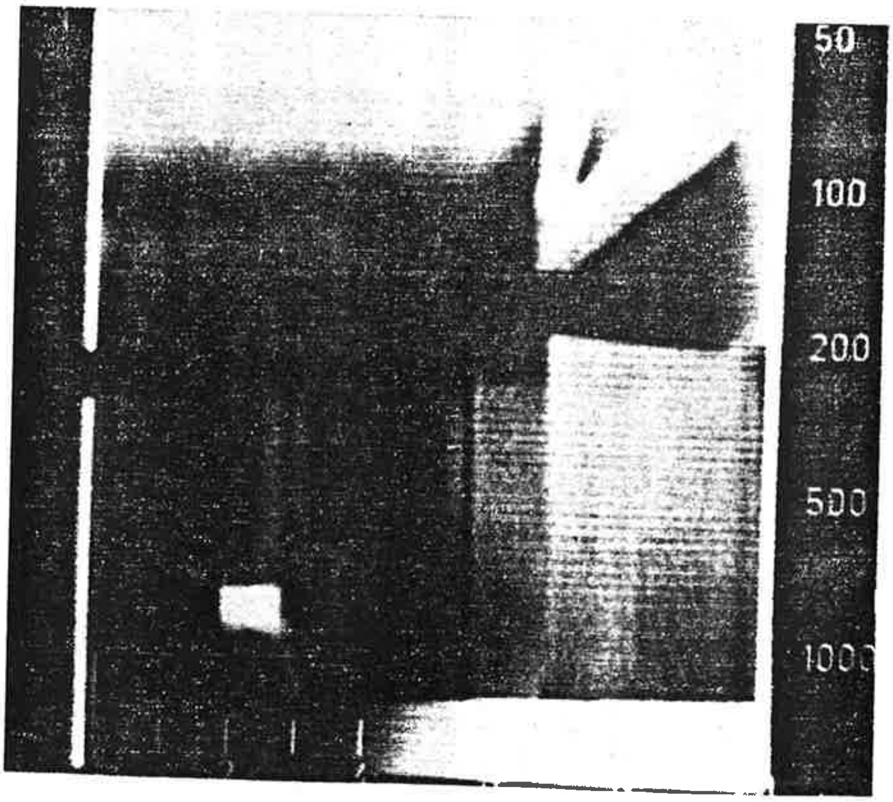

Figure 6 The same view as Figure 5 with a pressure difference of 45Pa.

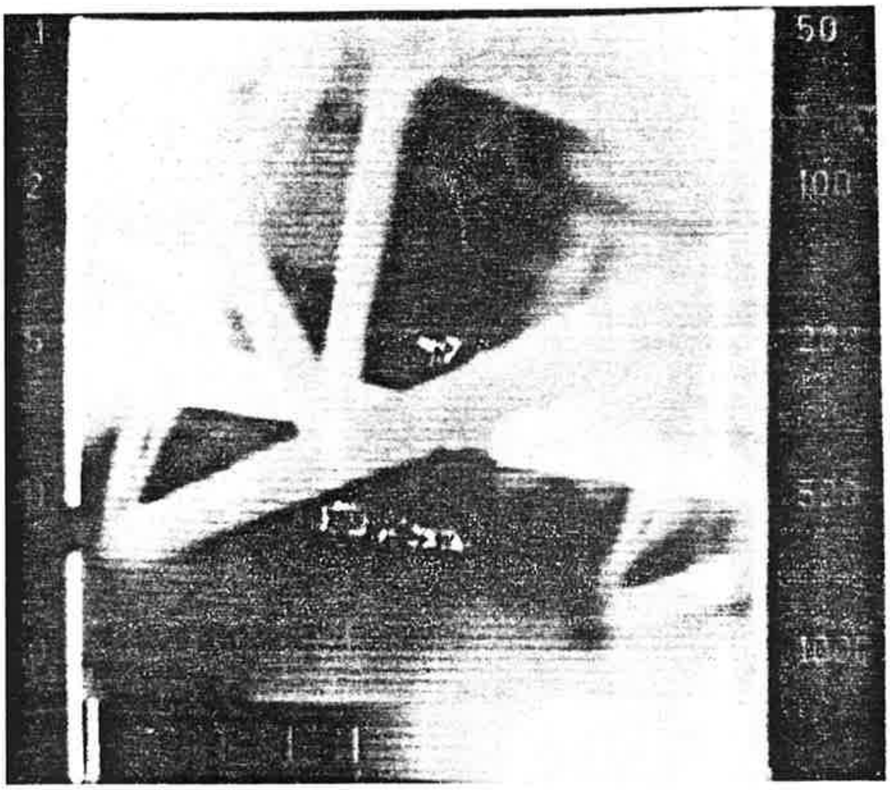

Figure 7 The black area indicates the extent of surface cooling caused by enhancing the air leakage path at this wall to ceiling joint using the depressurised infrared technique. The horizontal white areas are fluorescent lights.

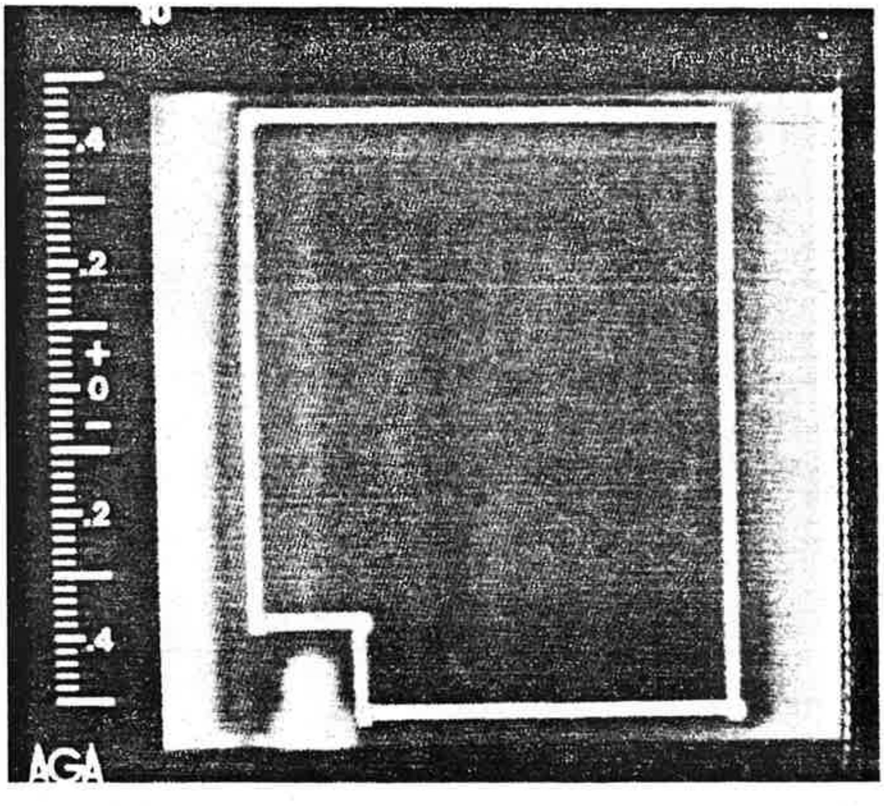

Figure 8 A single glazed metal framed window. Peak white defines the analysed area and the temperature reference can be seen in the lower left hand corner.

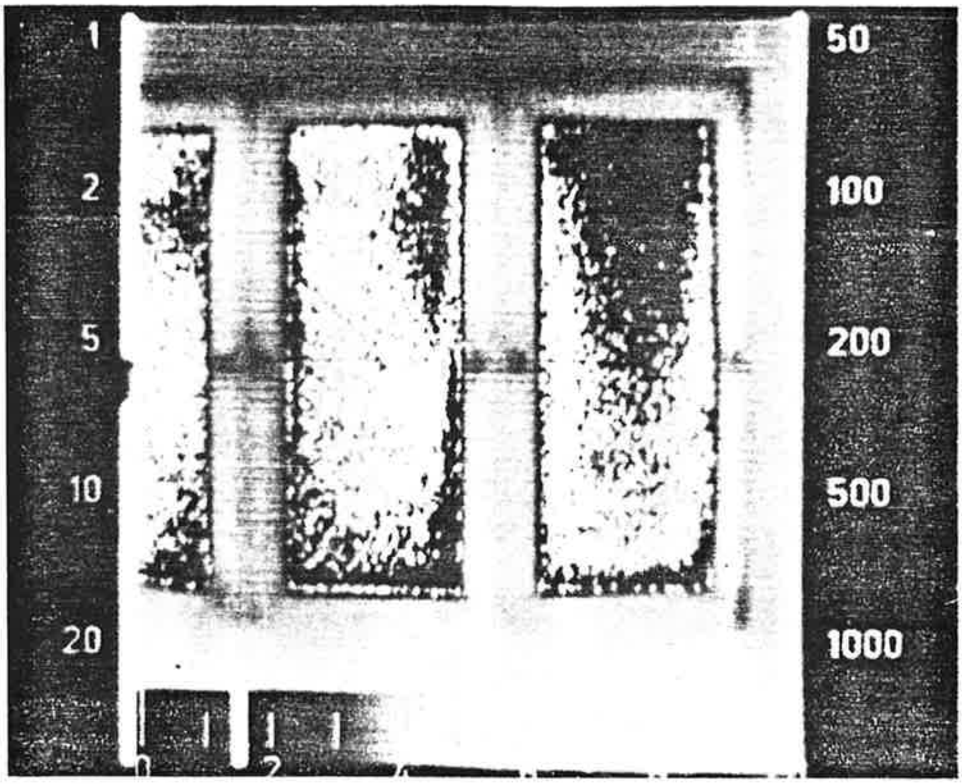

Figure 9a The isotherm function and spectal filter is used to analyse the glass temperature of this double glazed unit.

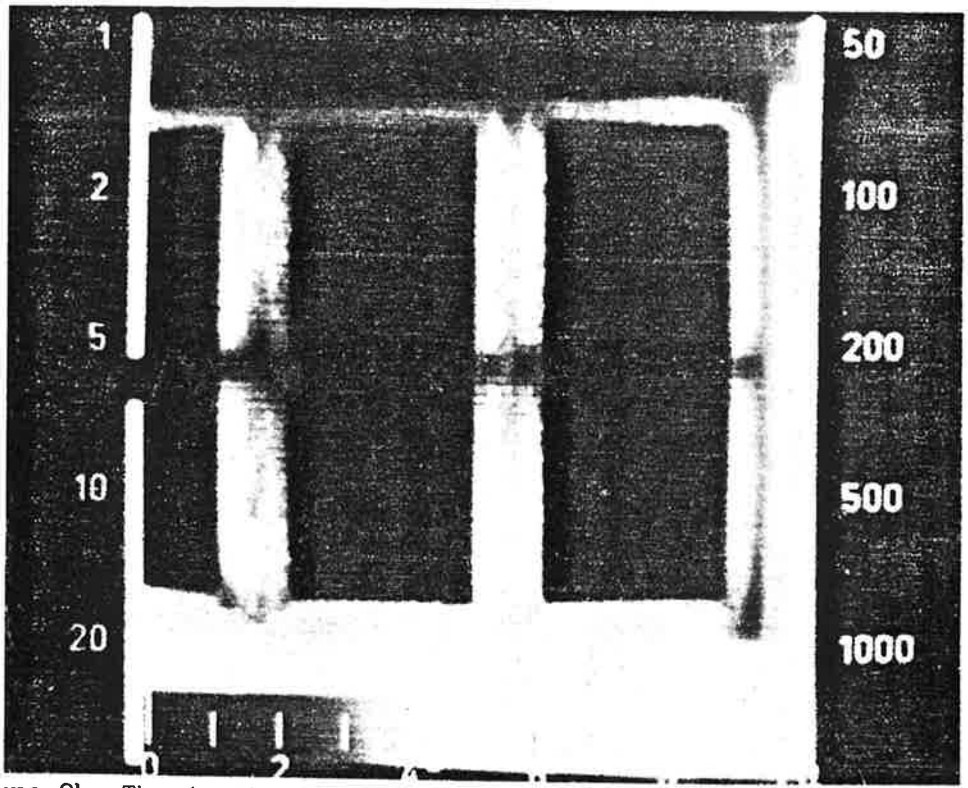

Figure 9b The isotherm function is used to analyse the wooden frame temperature of this window unit.

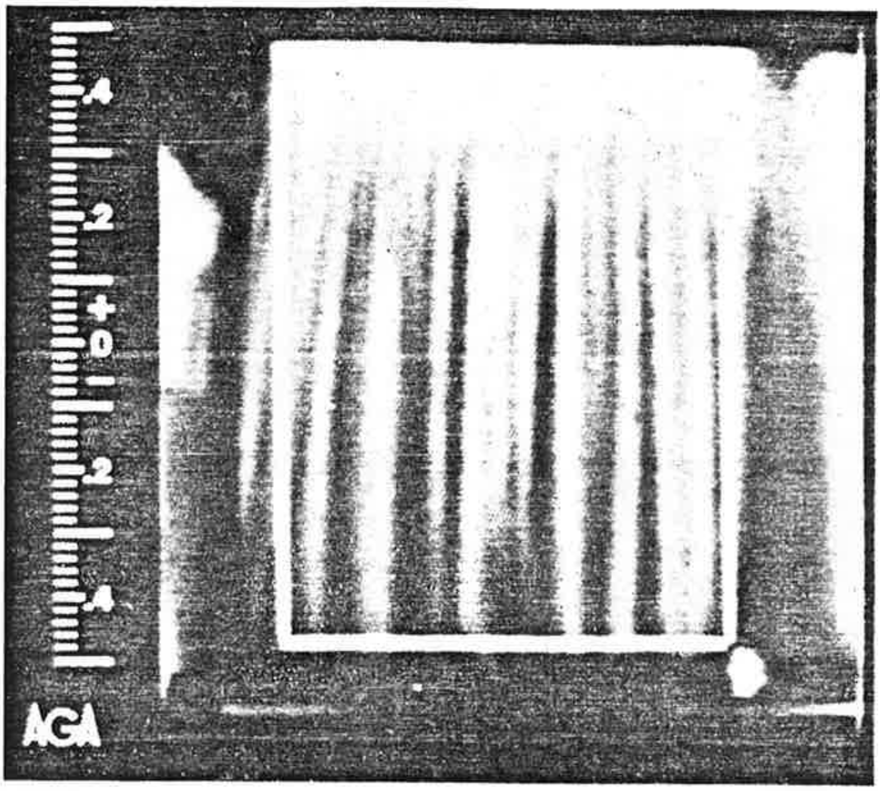

Figure 10 A single glazed metal framed window with unlined curtains hung within the window reveal. Peak white defines the analysed area.

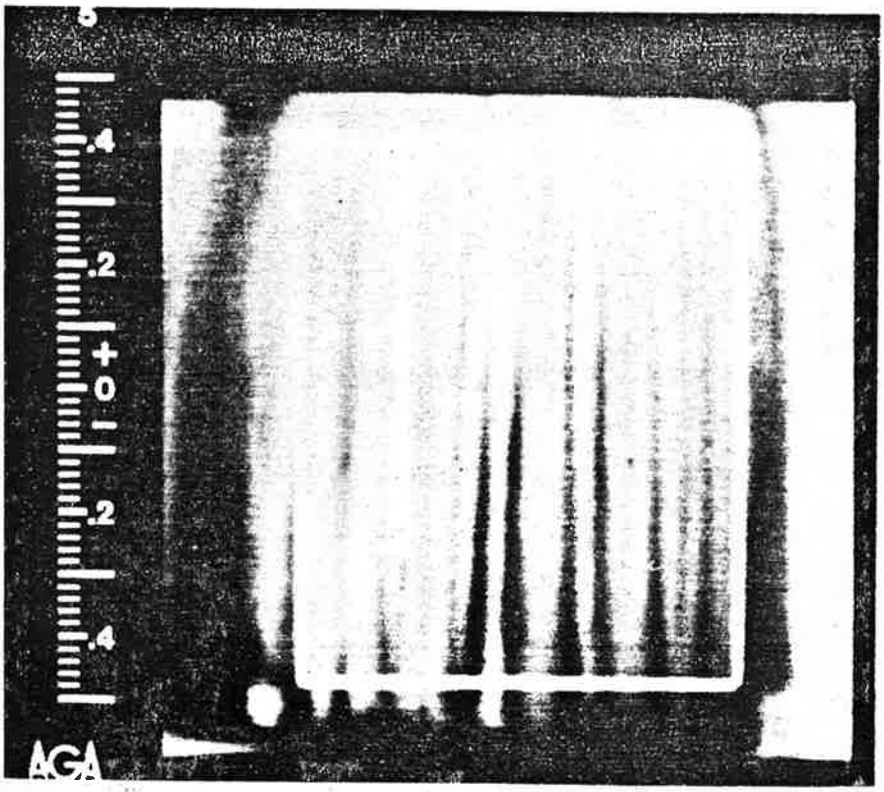

Figure 11 As Figure 10 but with the addition of a loose curtain lining.

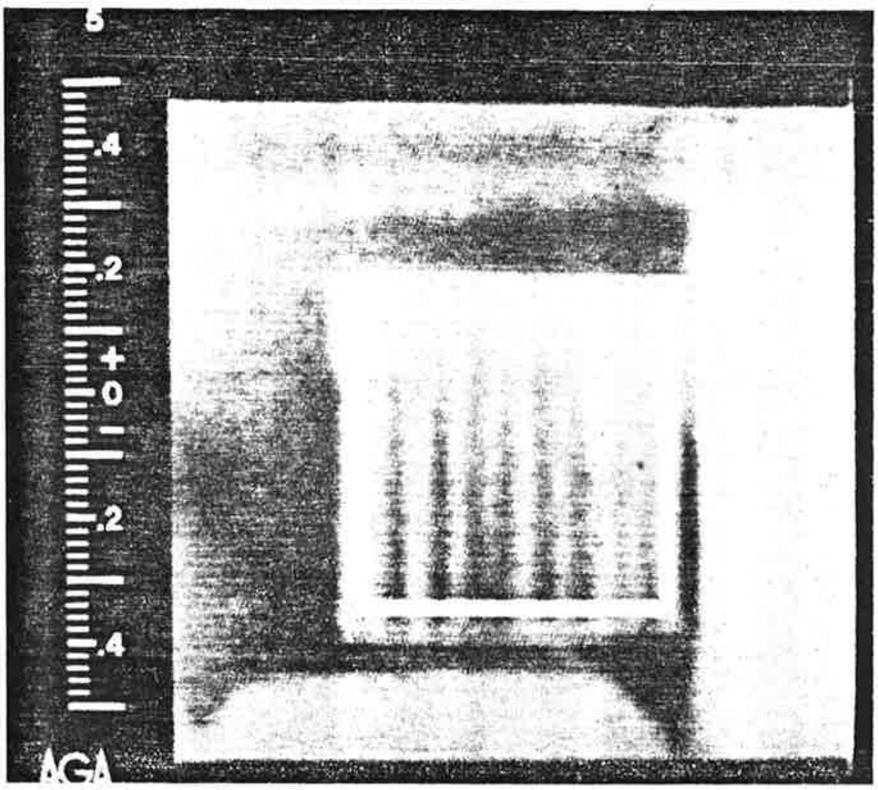

Figure 12 The thermal environment surrounding a window with closed curtains and no radiator beneath. Peak white defines the analysed area.

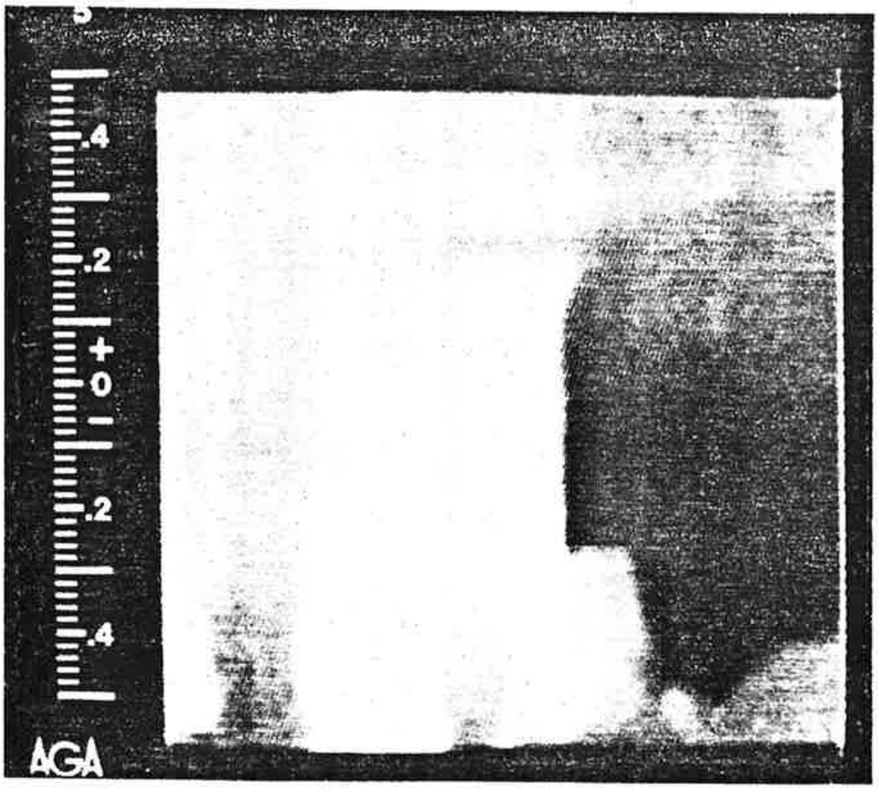

Figure 13 An adjacent window to Figure 12 with closed curtains and a radiator beneath.

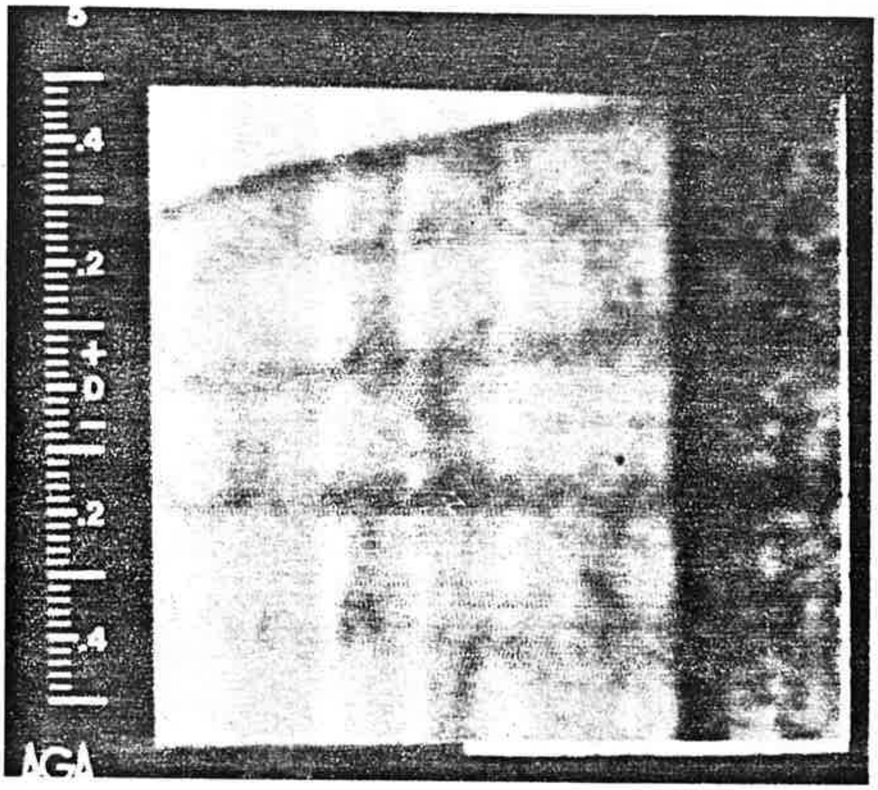

Figure 14 The black lines clearly indicate the block structure of this wall although 'hidden' behind 15mm of plaster.

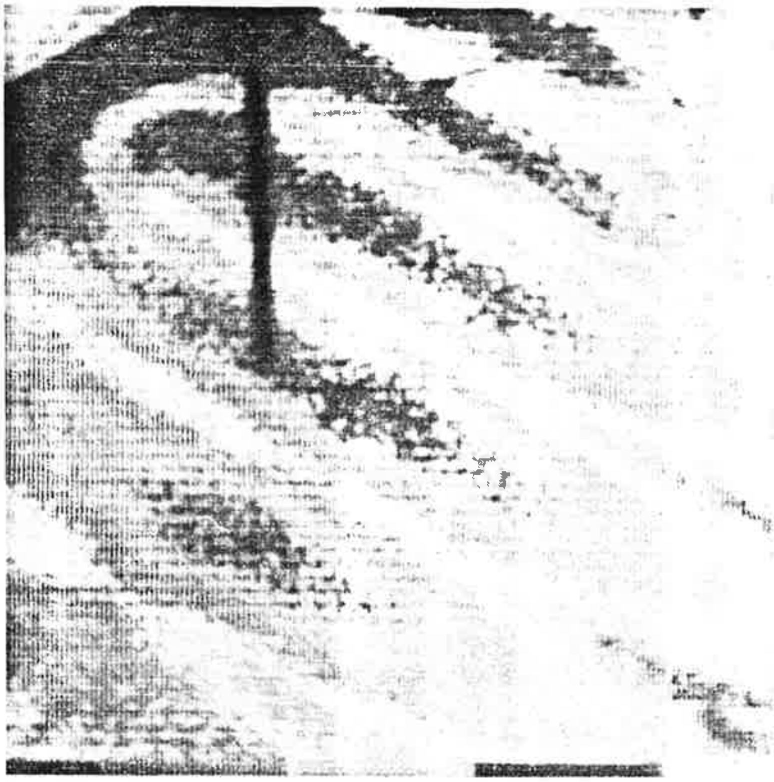

Figure 15a The layout and performance of this underfloor heating system can be visualised by thermography. The black vertical line is the leg of a table standing on the floor.

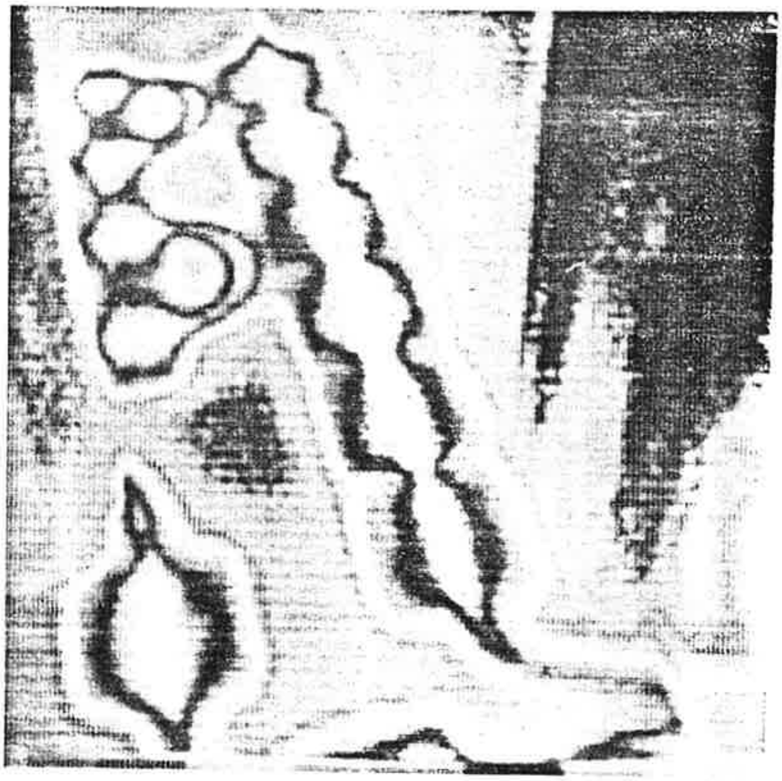

Figure 15b The additional feature of heat spreader plates can be seen under the first floor chipboard.

Figure 16a The low level heat distribution from this fan assisted heater is seen as it spreads over the floor surface.

Figure 16b An identical heater to Figure 16a but clearly showing an air blockage at the centre of the slotted output.

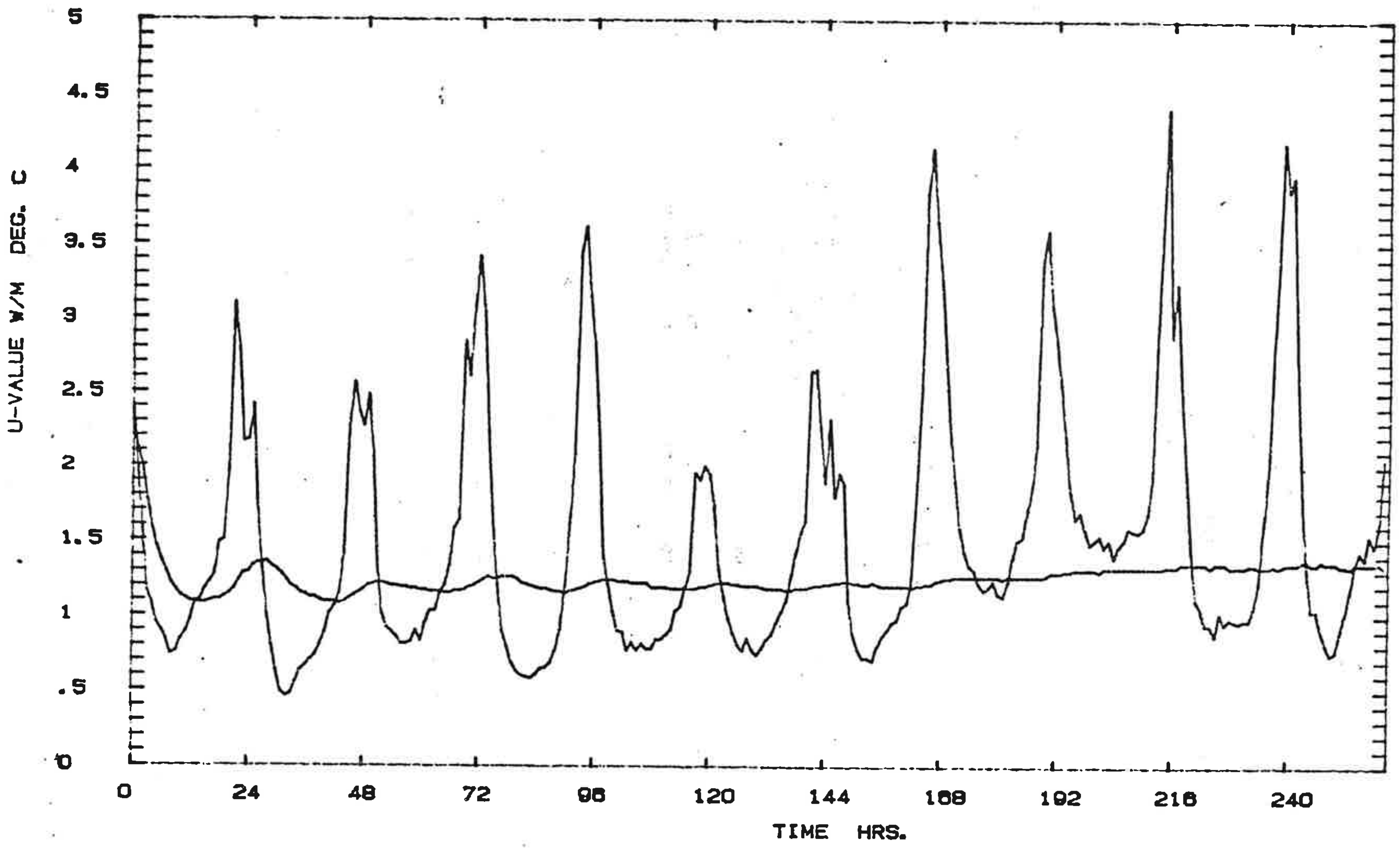

Figure 17 Variation with time of the instantaneous and average U-value for a cavity constructed brick/block wall.