The use of thermography in the building industry

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1. Introduction

Techniques and procedures which make a useful contribution to energy savings have understandably received increasing attention during recent years uses. One such technique known as thermography, uses thermal imaging cameras to examine the thermal integrity of buildings giving valuable information relating to building design and quality of assembly.

2. Thermal imaging camera

Thermal imaging cameras are similar in operation to television cameras, except that they detect the infra-red radiation rather than the visible light from an object. They consist essentially of a compact, portable camera unit and display monitor (figure 1).

Thermal imaging cameras were originally developed for military purposes, but for the last decade they have been used extensively for civilian applications, in particular in industrial[1] and medical fields[2].

In a typical system the camera rapidly scans the surface of an object making between 10^5 to 10^6 measurements per second; the infra-red detector's response being proportional to the energy of the incident radiation. The heat picture is constructed from the resulting detector signals and displayed in real-time on a television-type monitor. Variations in energy levels, and hence, temperature changes, are displayed as shades of grey. The usual mode is as shown in figure 2(a) with lighter shades representing warmer temperatures. This image which can be recorded on photographic film or video tape can be presented as discrete quantified levels of energy or temperature, known as isotherms, with each level being highlighted as a brilliant white shade. This facility, examples of which are given in figure 2, allows a temperature profile of the image to be recorded. If necessary a colour picture can be taken where each colour represents a discrete temperature band.

Fig 1 Thermal imaging camera and display monitor

The conversion of the camera recordings into temperature values involves calibration curves for the gain and aperture settings, the position and width of the relevant isotherm marker and a knowledge of the emissivity and transmittance of the object being studied. This paper is only concerned with the inspection of opaque surfaces, and hence only the emissivity factor is required.

Modern thermal imaging cameras are expensive temperature-measuring devices (about £30 000 each), but they do have several unique features which offset this financial disadvantage for certain applications. Because of the "visual" quality of the image, rapid scanning can be made of large areas from remote positions, giving high thermal and spatial resolution (typically 0.2°C at 20°C and 1m rad respectively). A large quantity of thermal data is displayed in real time in a form that can be readily appreciated and, if necessary, easily recorded.

3. Thermographic inspection

The camera has proved a useful tool to engineers and architects, giving detailed thermal information relating to building insulation faults, structural design, heat distribution, etc. A major application is the detection of insulation faults and voids in walls, floors and ceilings. Techniques of this nature have been well established in industry for several years. Thermography has been used on a routine basis to monitor refractory and insulation losses in blast furnace complexes, catalytic cracker units, etc. The work has developed around industrial plant with high capital and process costs, where expensive inspection techniques can readily be justified.

A factor that affects thermographic inspection work in the building industry to a greater extent than work on industrial plant, is that in general smaller surface temperature differentials are required to be measured. Generally, temperature differences of the order of 0.2°C have significance with regard to the insulation condition in buildings.

4. Measurements limitations

The small temperature differentials associated with building inspection work often require the use of the camera to its maximum sensitivity and, more important, a careful choice of monitoring procedure.

Modern thermal imaging cameras will accurately and reliably monitor the energy distribution coming from a surface. The problems stem sometimes from the conversion of these energy levels to temperature, but, more often, from the analysis of the temperature profiles in terms of, for example, thermal insulation condition.

All opaque objects will emit energy proportional to the fourth power of their absolute temperature and their surface emissivity. A camera looking at the object will record this energy plus additional quantities reflected from the surface. The proportion of reflected

Fig 2(a) Greytone thermogram showing qualitative variations of temperature over a face

Fig 2(b) Cool background highlighted as white to improve visual appearance of recording

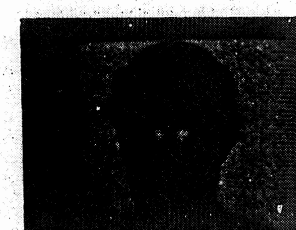

Fig 2(c) Highest temperatures on face are highlighted as white. Marker position on slide scale and its width can be used to calibrate this highlighted area in terms of a temperature band

Fig 2(d) Two temperature levels are highlighted on the face corresponding to the two marker positions

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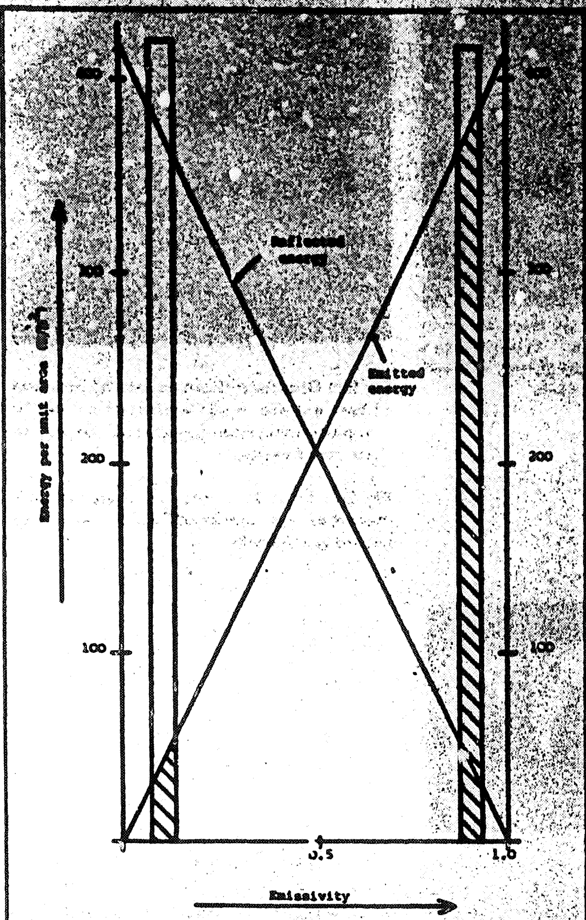

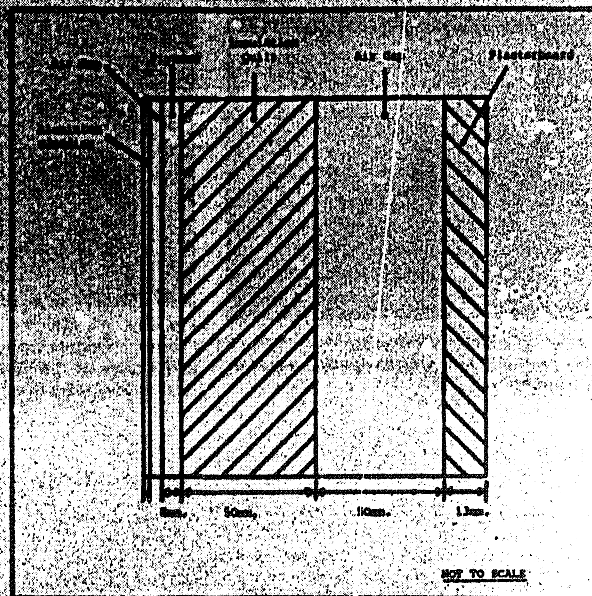

Fig 4 (above) Typical cross section of wall of wooden framed domestic dwelling giving details of those components contributing to the overall thermal resistance

Fig 3 (left) Total energy against emissivity for an object at 19°C surrounded by a uniform ambient at 20°C. Examples of the total energy at two discrete emissivities 0.1 and 0.9 are given by the two histograms. The shaded areas show that proportion of the total that is emitted energy

energy will be dependent on the emissivity of the object's surface and the energy from the source of reflections. A high emissivity is the same as a low reflectivity.

To obtain an accurate temperature profile, it is important to know what quantity of the recorded total energy has been emitted from the surface. If the survey is of a high emissivity surface, such as brickwork, wallpaper, emulsion paint, etc, then most of the energy will be emitted and the temperature profile can be accurately obtained. However, for lower emissivity surfaces, such as aluminium or galvanised sheeting, the emitted proportion becomes less significant and the temperature profile errors greater. Sources of reflection, especially from non-uniform backgrounds, will have a greater effect on such surfaces. Ideally, it is best to inspect high emissivity surfaces which are surrounded by a uniform ambient temperature. The significance of the emissivity factor is illustrated in figure 3.

The thermal imaging camera is essentially a device for comparing temperature differences. If used to compare temperature variations across a surface of uniform emissivity, then a surface temperature difference accurate to 0.2°C can be recorded. However, if absolute temperature values are to be quoted, then the errors of the reference source required for a temperature base level, will increase the overall error to 0.5°C or higher. Absolute temperatures are required when quoting surface temperatures relative to their surroundings to obtain for example, absolute U values or energy losses. Measurement of the effective ambient temperature will incur added error and, although with the errors may only be of the order of ½°C, they can be relatively large because of the significance of small temperature changes.

5. Detection of insulation faults

Details of past thermographic surveys are used to illustrate some of the difficulties of measurement and analysis, emphasising the importance of the correct inspection procedures for a particular situation.

A survey of about eighty wooden-framed domestic dwellings was carried out with the aim of locating voids in the fibre insulation of the walls. Relevant details of the wall structure are given in figure 4.

The major portion of the thermal resistance of the wall (70%) was due to the 50mm fibre glass insulation blanket suspended between the inner and outer skins of the wall.

Generally, the insulation faults noted were:-

i complete insulation panels missing
ii panels cut short leaving a void at the skirting board level
iii badly fitted insulation around window frames and electric fittings.

The results given in figure 5 are typical of the faults noted and illustrate the first two types of defects mentioned above. During the recording of these results, the external ambient temperature was 5°C and the internal ambient temperature was 15°C. The graph in figure 6 shows the expected theoretical temperature differentials between the surface and the adjacent ambient temperatures for the inside and outside surfaces of the exterior walls. The U value for the wall structure with the insulation intact was 0.5W/m²°C, and for a complete insulation void 1.5W/m²°C.

A localised insulation void would theoretically result in a temperature variation on the inside surface of the wall of 1.5°C, but only 0.5°C on the outside. This change of 1.5°C on the inside wall was consistent with the results obtained, as shown in figure 5. However, these defects could not be identified on the outside surface because of the correspondingly lower differential temperature and the complicating effects of the external environment. Reflection effects from adjacent warm structures were a particular problem due to the lower emissivity (0.6) of the outside surface.

The insulation defects at the skirting board level were readily identified, but again only from an inspection of the

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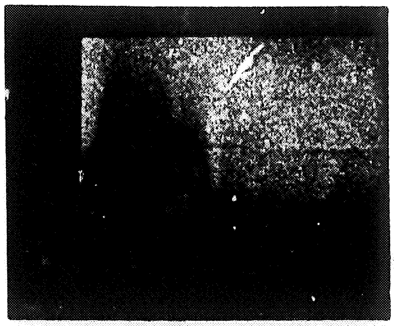

Fig 5(a) Greytone thermogram of wall to floor junction, showing insulation voids at skirting board level

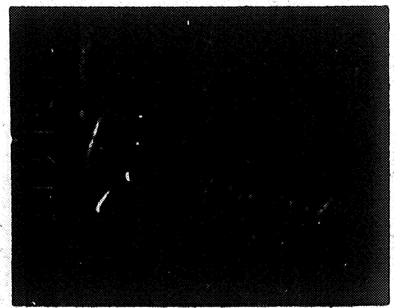

Fig 5(b). As 5(a) but with two isotherm levels respecting a temperature difference of 1.6°C highlighting general background and area of voids

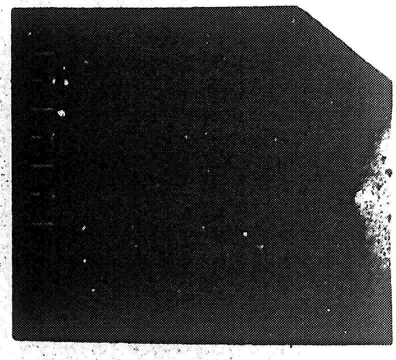

Fig 5(c) Greytone thermogram of junction of two exterior walls with roof ceiling. A complete insulation panel from ceiling to floor was missing

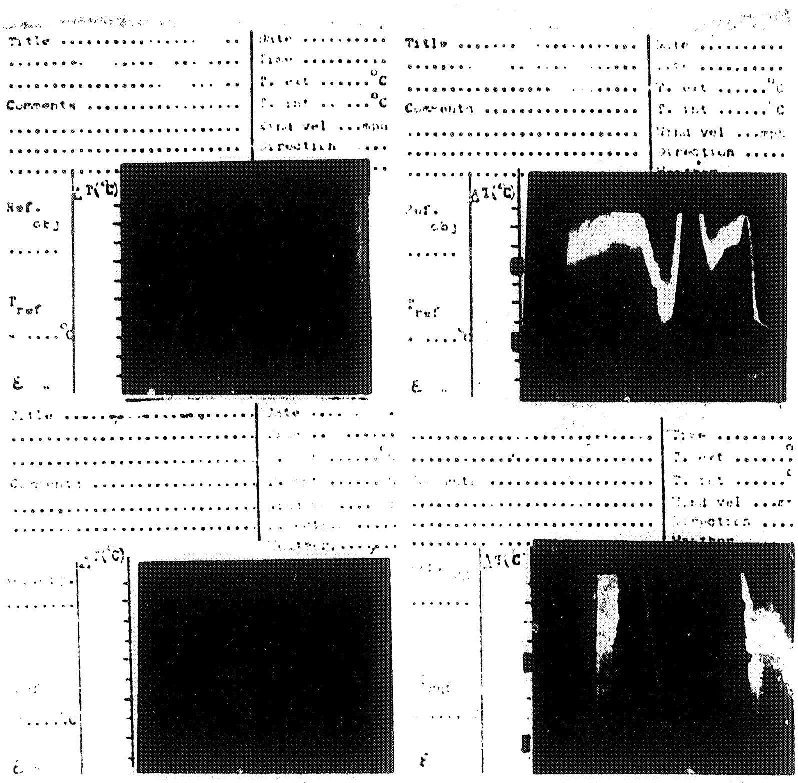

Fig 5(d) (left) Two sets of thermograms mounted on standard cards used to record site details

internal surfaces. A cool band would be expected at the junction of an external wall and floor due:-

i to the surface area of the external wall being greater than that of the internal wall, and

ii a reduction in radiation and convection surface heat exchanges.

This effect could be readily differentiated from that due to any insulation voids by accurate temperature measurement and an inspection of the temperature profile variation at a fixed horizontal level; ie comparisons were made between adjacent areas where changes in insulation properties had occurred but which where subject to the same environmental conditions.

The analysis of the data is more accurate when relative changes of insulation standards are required, such as those that occur with localised defects. Surface heat transfer parameters are major uncertainties, wind variation being the main factor. Effective ambient temperatures are also difficult to establish for example, air temperature changes are more rapid than wall surface temperature changes and the air temperature varies within a room, especially from the floor to the ceiling. These and other factors are generally common to adjacent areas of, for example, a wall, and hence the effect is minimised using a comparative technique.

The question usually arises whether to survey a building externally or internally. It is important to identify the aim of the survey as there are many conflicting factors which affect the choice of inspection procedures. Gross defects, for example complete voids in insulation, can sometimes be detected by an inspection of the outside walls and roof of a building. Generally it is necessary to inspect the internal surfaces of a building, especially if lesser defects are to be located and quantified. There are two main reasons for this.

i The heat transfer on internal surfaces is generally three-fold lower than that for the external surface due to the greater surface air movements on an external surface. Hence, temperature differentials on the inside surface are correspondingly three-fold greater than that of the outside surface.

ii The environmental conditions of the interior surfaces of buildings are relatively controlled, eg still air conditions and hence in the analysis of the results, the parameters used are constant and known[3].

Local variations in wind due to the building shape and superstructure, will affect the outside surface temperature profile and can give misleading results. However, the wind will have little effect on the inside surface of an insulated wall or roof due to the relatively large thermal resistance of the insulation, less than

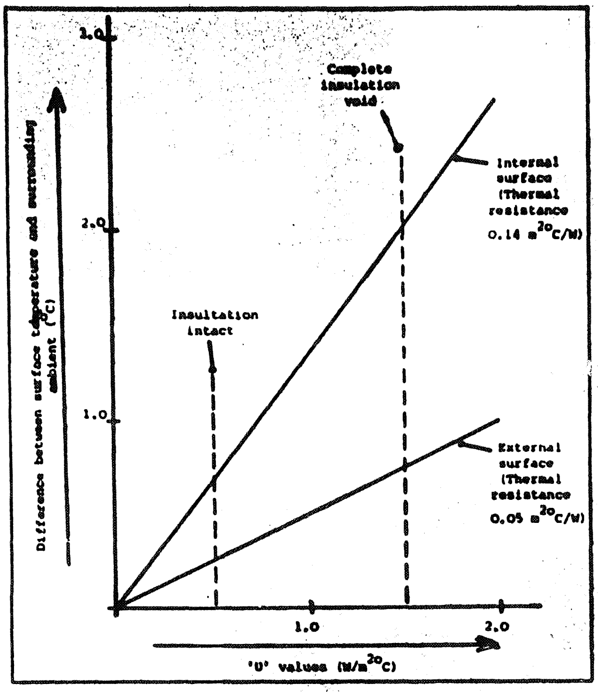

Fig 6 (left) Expected temperature differences between internal and external surfaces and their surrounding ambient against U value variations for wall described in Fig 4

Figure 7 Practical conditions required for a thermographic survey of occupied dwellings.

1. Thermal Conditions
A minimum temperature differential of 10°C is required between outside ambient and the inside ambient air. This should be maintained for at least twelve hours prior to the inspection to attain steady state conditions. Convective heat sources should be used as radiant heating will give localised heating effects.

2. View and Access
Wherever possible wall furniture, pictures, curtains, cupboards, etc, should be moved from those walls to be inspected at least twelve hours prior to the survey.

3. Environmental Conditions
Surveys generally need to be conducted during overcast, day-time conditions or in the evening to avoid complications due to solar heating and reflection.

10% change in surface temperature difference with respect to ambient for a wall with a U value of 1.0 W/m²°C.

The points mentioned above are normally the overriding considerations, although there are other factors. One of the main benefits of surveying external surfaces is the opportunity to scan large areas quickly and without disturbance to occupants. Internal surveys can be disruptive as cupboards, curtains, pictures, etc, have to be removed from walls several hours prior to the inspection. If a building can be surveyed when empty, then of course this problem does exist.

In the case of the survey discussed previously, inspection from the inside of the buildings enabled the technique positively to identify and measure localised changes in U values of the wall structure of 0.2 W/m² °C. This corresponded to a 30% thinning of the insulation blanket. The presence of complete voids was readily located.

If the technique had been required to measure the U value of the wall insulation, it would have been necessary to measure the wall surface temperature with respect to internal ambient temperature. The internal surface could have been measured to 0.5°C with a reference, but then there would have been an error in determining the effective room temperature, especially as this varied within each room. It was considered that in practice an absolute U value measurement would have had an uncertainty of at least 0.5W/m²°C. Hence, the technique would not have been particularly useful in checking the standard of the material, although, it would readily have detected a complete absence of insulation over a whole wall, even if no intact area had existed to allow the comparative technique.

Prior to the inspection, certain practical conditions, which are outlined in figure 7, had to be obtained. The main difficulties were in obtaining full coverage of the inside walls and an adequate temperature differential between internal and external ambient temperatures.

6. Building design problems

This paper has concentrated on the application of the detection of insulation voids. However, the thermal imaging camera has been valuable in providing additional information for a variety of building problems and many of the requirements mentioned previously apply equally to this type of work.

Inspection of internal surfaces of buildings will readily show a range of features that can be related to structural or environmental problems, such as cold bridging and condensation.

The technique will identify areas of air ingress into cavities often due to poor assembly work and draughts under doors and window frames. The effectiveness of thermal insulation at wall or roof junctions, often a suspect area, can be studied. An advantage of the camera is that besides quickly locating these areas of weakness and presenting a detailed thermal picture, it presents the information in a visual form that can readily be appreciated.

Thermal imaging cameras have been used in connection with heat balance problems in large buildings. For example, the temperature profile of the side of a multi-storey building has shown the temperature differences between each floor level.

Thermograms have very effectively illustrated the benefits of low emissivity aluminium foil barriers placed behind domestic radiators (see figure 8). The camera was used to quantify the resulting reductions in heat flow, which were approximately 50% immediately behind the radiators, to confirm the theoretical analysis. The cameras have also been used to identify leaks in underground district heating lines. The result in figure 9 shows a warm area above a buried pipeline that was due to a local absence of insulation.

7. Future trends

Thermography is a technique that can be widely applied throughout the building industry. The detection of insulation voids in buildings is an area where inspection procedures can be relatively simple. Although at present inspection costs are expensive and an inhibiting factor, a thermographic survey for insulation defects in a typical three-bedroom semi-detached house, would only take one to two hours and cost about £50. The inspection would be from the inside of the building and cover the exterior walls and, for no extra time, the ceilings. An inspection of a ceiling would be difficult to justify on its own merit as the insulation condition can often be visually inspected from inside the loft.

Thermography can readily perform a quality assurance inspection role. However, one of its major assets is the use of the detailed thermal profiles to design out potential problem areas. New building designs and methods of insulation should initially be assessed and subsequently monitored using thermal imaging cameras. This approach would be particularly cost-effective when considering an estate of houses composed of few basic building designs or large prefabricated building complexes.

Work involving the use of thermal imaging cameras has understandably developed further in the Scandinavian countries where climatic conditions are

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more severe. Thermographic inspections are often obligatory prior to mortgages being approved for new houses[4]. Future requirements to increase energy savings and a reduction in inspection instrument costs should generate similar activity in the UK. This could, for example, involve thermal imaging cameras in the statutory inspection of buildings prior to a certificate being granted confirming acceptability of thermal insulation standards.

Acknowledgement

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References

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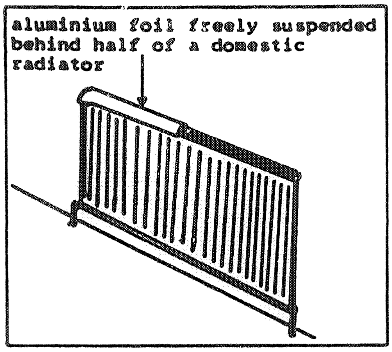

Fig 8(a) Radiator with aluminium foil suspended behind heat source

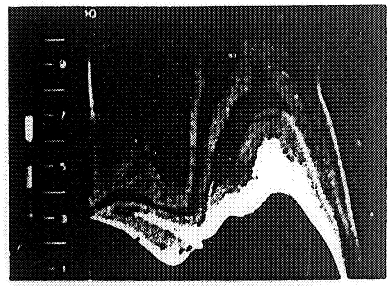

Fig 8(b) Thermal profile of inside of wall above radiator. Original thermogram was a quantified colour picture, hence discrete bands. Lip on the foil effectively directs hot convection currents into the room. Maximum temperature with respect to ambient on wall was 4°C above the foil and 15°C directly above radiator

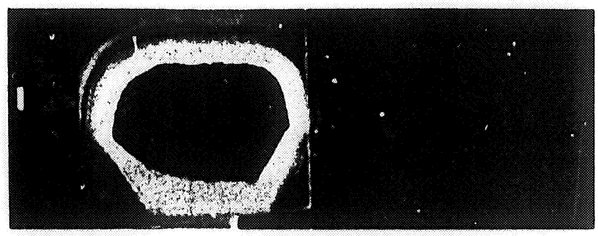

Fig 8(c) Thermal profile taken of outside surface of wall directly behind radiator. Cool area behind the foil on right side of picture was 5°C above ambient, whereas adjacent hot area was 10°C

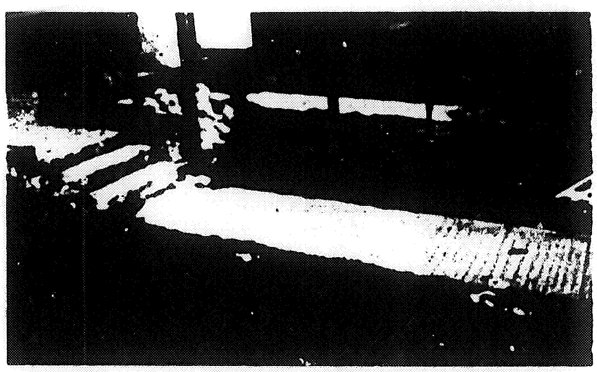

Fig 9a Path covering underground heating pipe buried approximately 4ft

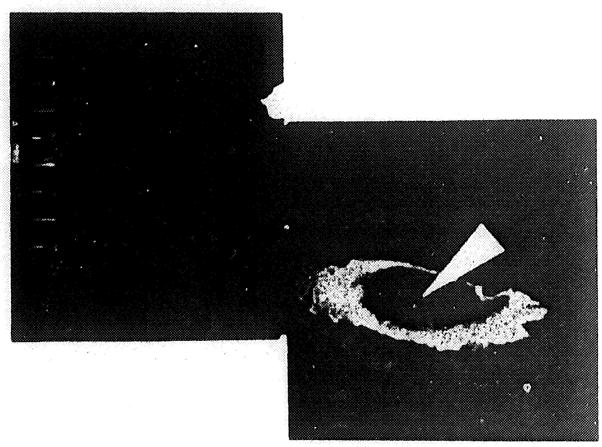

Fig 9b Thermogram of warm area arrowed. This point was 7°C above ambient temperature

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