DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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TEMPERATURES WITHIN THE WALLS OF A COMPARTMENT CONTAINING A FIRE

by

P. H. THOMAS, the late C. T. WEBSTER
AND P. G. SMITH

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December, 1963.

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F. R. Note No. 524

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SUMMARY

The temperatures measured near the ceiling of a compartment containing a fire, and the radiation from the opening, have been used to calculate the temperatures within its walls. The comparison, between these calculated temperatures and those measured, suggests that one measurement of radiation from the opening is at least as accurate for determining temperatures within the brick structures tested, as are conventional measurements near the ceiling, although neither method is satisfactory once the flaming subsides. However, for the purpose of estimating the onset of structural damage the period after the flames begin to subside is of lesser importance than the earlier period and it may prove possible to disregard this deficiency in any practical application of these methods of estimating structural temperatures.

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Introduction

The damage sustained by a structure in a fire depends primarily on the rise in temperature at different depths within the structure, and this in turn depends on the thermal transport properties of the structure and the heat transfer to it from the fire. In calculating the temperatures within structures it has sometimes been assumed that the heated surface of the structure immediately reaches the same temperature as that measured in or near the flames. It is only on this basis that the temperature rise in structures can be computed directly from the British Standard temperature-time curve(1) since the actual rate of heat transfer is unknown. The assumption is not always justifiable, even with real fires, since the temperature actually recorded by the measuring device at any position depends on several factors; these include differences in temperature between the radiating walls and the flames, their height and thickness, and the size and construction of the enclosure.

Recent experiments have shown that the rate of burning of fully developed fires in compartments in still air is strongly correlated with the intensity of radiation from the compartment opening(2), and that the radiative transfer is likely to be by far the most important component of heat transfer within the compartment(3). These results suggest that the radiant intensity from the opening might serve as a method of predicting the temperature rise within the structure. This, in addition to having the advantage of experimental simplicity, would increase the value of measurements made at an actual fire. If, for example, the damage to exposed surfaces, such as charring or discoloration can be related to intensity, it might prove possible to relate internal structural damage to external damage.

So far three experiments have been carried out in two brick compartments, and measurements of the temperatures within the walls have been compared with those calculated from measurements of the temperatures near the ceiling (this is a similar method to that used in the fire resistance tests(1)) and from measurements of the radiation received outside the opening.

Experimental method and results

A compartment 2.44 m (8 ft) cube was used for two of the fires(4). It consisted of three 23 cm (9in) brick walls with a concrete ceiling, 10.2 cm (4 in) thick and a 7.6 cm (3 in) burnt aggregate and fire brick floor. The combustible material used was 203 cm (80 in) x 2.5 cm (1 in) sq. sticks of wood, arranged to form cribs, producing fire loads of 2.4 g/cm^2 (5 lb/ft^2) and 3.4 g/cm^2 (7 lb/ft^2). Ignition was by means of fibre insulating board soaked in paraffin.

Temperatures were measured with 5 chromel/alumel thermocouples inserted through holes in the roof slabs so that their junctions were 7.5 cm (3 in) below the ceiling - one being in the centre, and the remainder symmetrically placed equidistant from the centre and each corner of the ceiling. Four other thermocouples were centrally placed in the mortar in each wall two each at 5.7 cm ($2\frac{1}{4}$ in) and 11.4 cm ($4\frac{1}{2}$ in) from the inner face. The intensity of radiation from the open side of the compartment was measured with an enclosed gold-disc type radiometer(5) centrally placed 2.4 m (8 ft) from the plane of the opening.

A further experiment, with a fire of higher temperature and longer duration was carried out in the ground floor room of a four storey brick tower. The inside dimensions of the compartment were 2.84 m x 3.05 m x 2.46 m (9 ft 4 in x 10 ft x 8 ft 2 in high) with walls 23 cm (9 in) thick. One wall had an opening 71 cm (2 ft 4 in) wide extending from the floor to the ceiling (Fig. 1).

In order to measure the temperatures within the walls, a brick panel 61 cm square x 23 cm thick (2 ft square x 9 in thick) containing four thermocouples was placed in a hole halfway up the wall opposite the opening. The thermocouples were laid in pairs in the mortar at 5.7 cm (2¼ in) and 10.4 cm (4.1 in) from the inner (heated) face.

To ensure that insufficient moisture was present to affect the conduction of heat through the panel, it was first dried out by heating one face with a bunsen burner, and then a strip of polythene sheet was used to cover the sides of the panel so that, when mortared into the wall, it would not absorb moisture from the brickwork.

Three chromel/alumel thermocouples were placed along a diagonal of the ceiling with their junctions 7.5 cm (3 in) below the ceiling. One thermocouple was in the centre with each of the others equidistant from the centre and a corner of the ceiling (Fig 1). The radiation from the opening was measured with a gold disc type radiometer placed 2.44 m (8 ft) from the plane of the opening. The configuration factor was therefore 0.07. The flame heights were measured from photographs of the flames against a scale and the results will be used to improve correlations between flame height and burning rate in another report.

The crib used for this fire was made with two thicknesses of wood. The thinner wood was at the bottom and burned rapidly to provide a source of ignition for the thicker wood above. The three lower layers of the crib consisted of 2.54 m (100 in) long, 2.5 cm (1 in) square sticks with a packing density of 33⅓ per cent; i.e. the space between sticks was twice the thickness of the sticks; the three upper layers consisted of 2.54 m (100 in) long, 7.5 cm (3 in) square sticks with a packing density of 50 per cent i.e. the space between the sticks was equal to the thickness of the sticks. The total fire load was 480 kg (1060 lb). The crib was ignited with strips of fibre insulating board in the same way as in the 2.44 m (8 ft) cube compartment.

The mean ceiling temperatures obtained in each fire are given in Fig. 2 together with the radiation measurements from the opening converted to equivalent black body temperatures.

Calculations

The temperature-time curves at depths of 5.7 cm (2¼ in) and 11.4 cm : (4½ in) (10.4 cm (4.1 in) for Test 228) from the heated surface inside the brickwork have been calculated (Figs. 3-5) by a version of the Schmidt method(6) by assuming that the temperature-time curve on the heated face of the wall was given by

(a) the ceiling temperatures,

or (b) the radiation temperatures.

Either assumption would be permissible in these calculations because, at the depths considered within the walls, the temperatures are not very sensitive to changes in temperature at the heated face(7). Conversely, a small error in the temperature measured at a depth would lead to a greater uncertainty in an estimate of the surface temperature based on it. No direct measurements were made of the surface temperature.

An appropriate value of thermal diffusivity (k) was found by calculating the temperatures at 11.4 cm ($4\frac{1}{2}$ in) from the heated face in the brickwork from the temperatures measured at 5.7 cm ($2\frac{1}{4}$ in) using a range of values of k. The value giving the closest temperature-time relation to that measured at 11.4 cm ($4\frac{1}{2}$ in) was 7×10^{-3} cm^2/s. This value, about 30 per cent above the room temperature value for dry brickwork, was used to calculate the temperatures at these depths from the estimates of the surface temperatures obtained from the ceiling temperatures and the radiation.

Discussion

Three observations follow from a comparison of temperatures measured at certain depths within the walls of brick compartments, with those calculated from measurements of radiation from the openings and temperature measurements near the ceilings.

(i) At the point further from the exposed surface (10.4 cm or 11.4 cm), both methods of calculation give values in good agreement with the measured values.

(ii) At the point nearer the exposed surface (5.7 cm) both methods give values in good agreement with the measured values until flaming subsides (Fig. 5) and then both sets of calculated values fall well below the measured values. This divergency is to be expected, since when the tops of the flames do not reach the ceiling the thermocouples there cool down. The residual flames are still in contact with the wall so that the heat transfer there does not diminish so rapidly.

(iii) The radiation calculations are in better agreement with the measured values than those calculated from the temperatures at the lower fire loads, but at the highest fire load the difference is not significant. This is probably because the flames are thicker and more emissive at the highest fire load, i.e., the flame and radiation temperatures are more nearly equal.

Conclusion

The results from these three large scale experiments suggest that the intensity of radiation can be used to provide temperatures at certain depths within brick structures at least until the flames begin to subside. Furthermore, the longer the duration of the fire, the longer the period over which the agreement will remain, and the better the guide the radiation intensity will be to the damage likely to be sustained by the structure.

This conclusion is based on only three tests in two compartments. Before it can be considered as a general rule, further confirmation by tests over a wide range of conditions is necessary. If the burning is known to be uneven, as with a side-wind, it is doubtful if either of these substitutes for a direct measurement is satisfactory.

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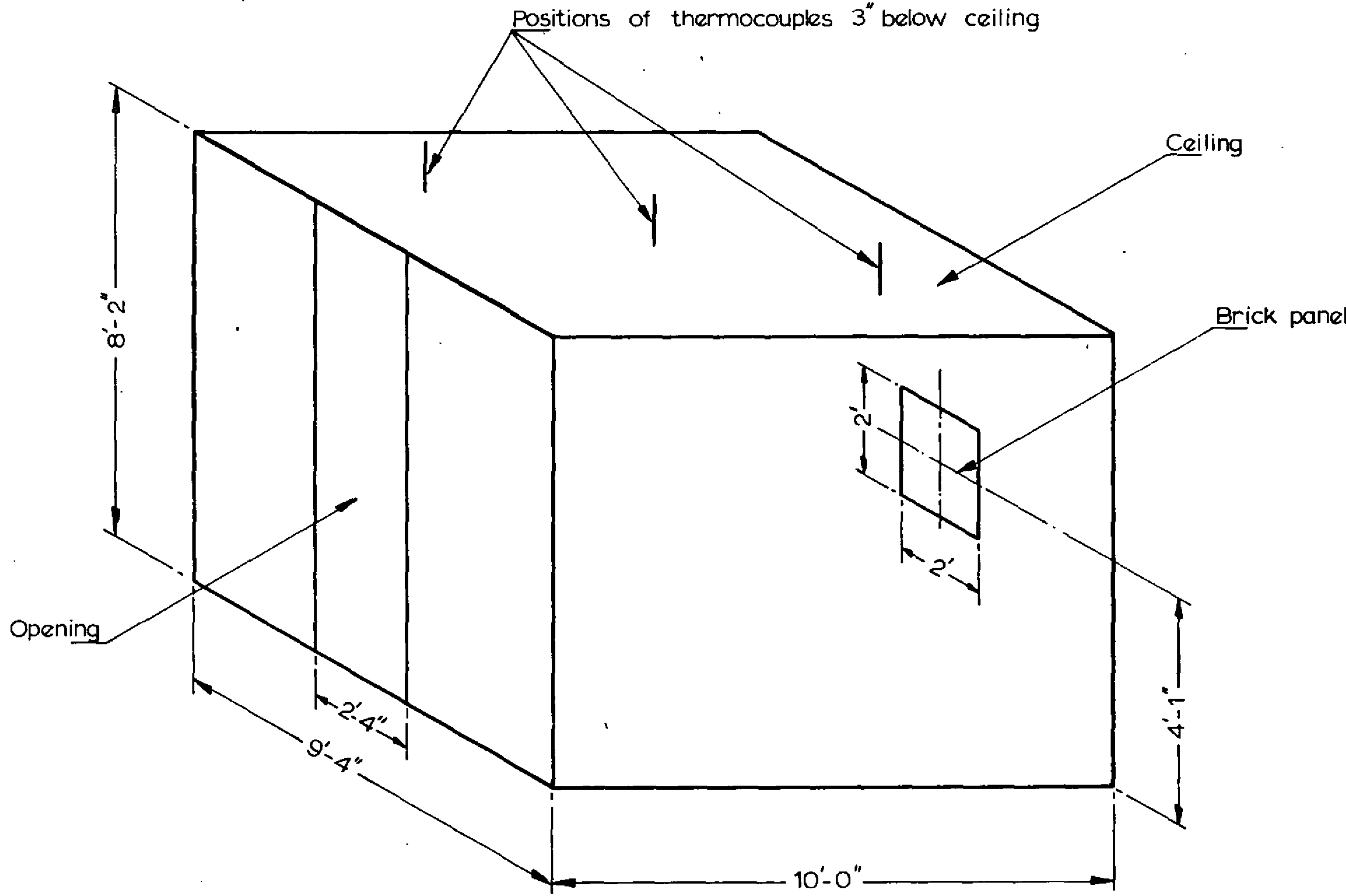
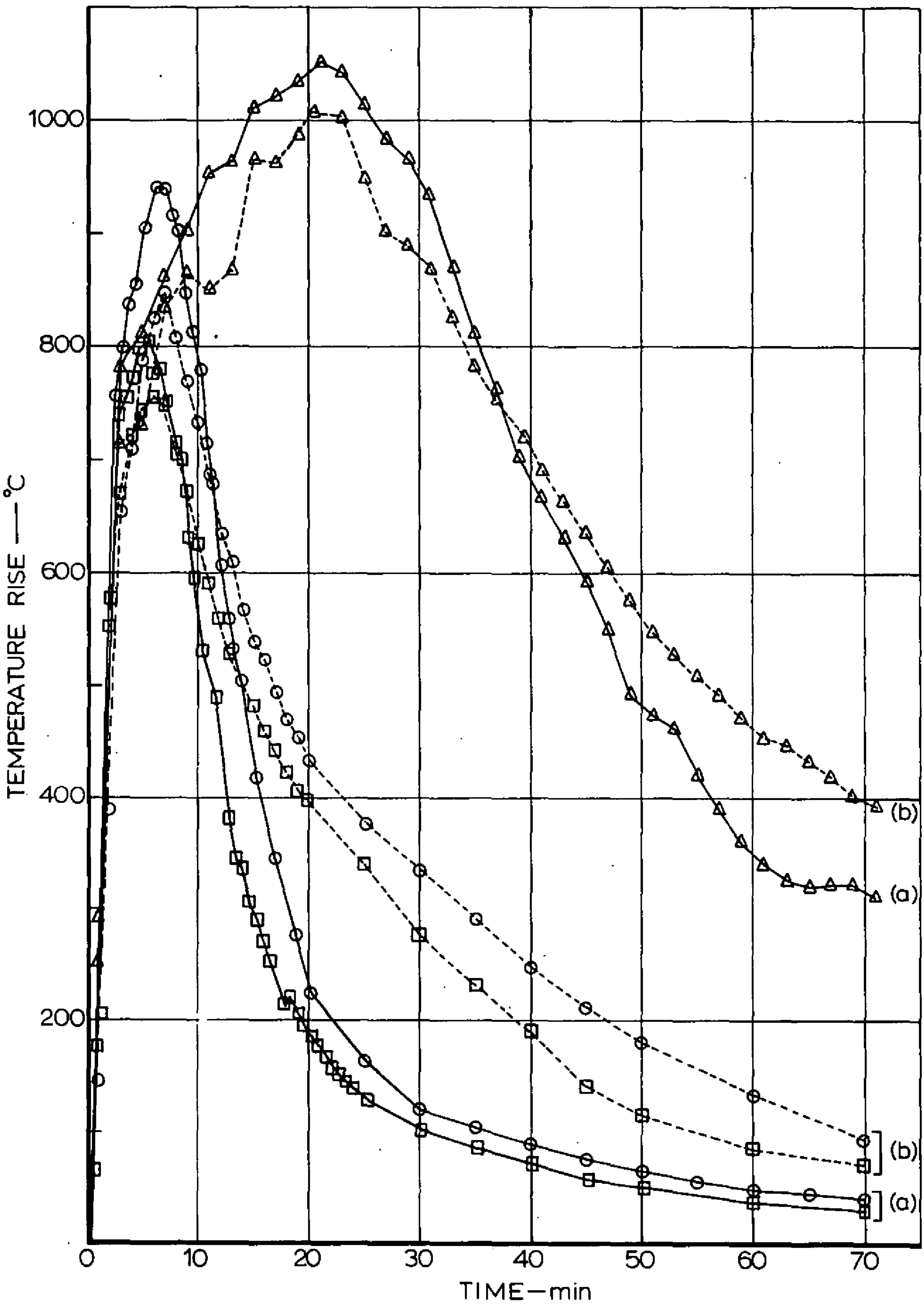


FIG. 1. BRICK COMPARTMENT USED FOR THE HIGHEST FIRE LOAD



○ J.F.R.O. Test No. 225

□ J.F.R.O. Test No. 226

△ J.F.R.O. Test No. 228

(a) —— Mean ceiling temperature rise

(b) ----- Equivalent black body temperature rise calculated from radiation from opening measurements

FIG. 2. ESTIMATED WALL SURFACE TEMPERATURES

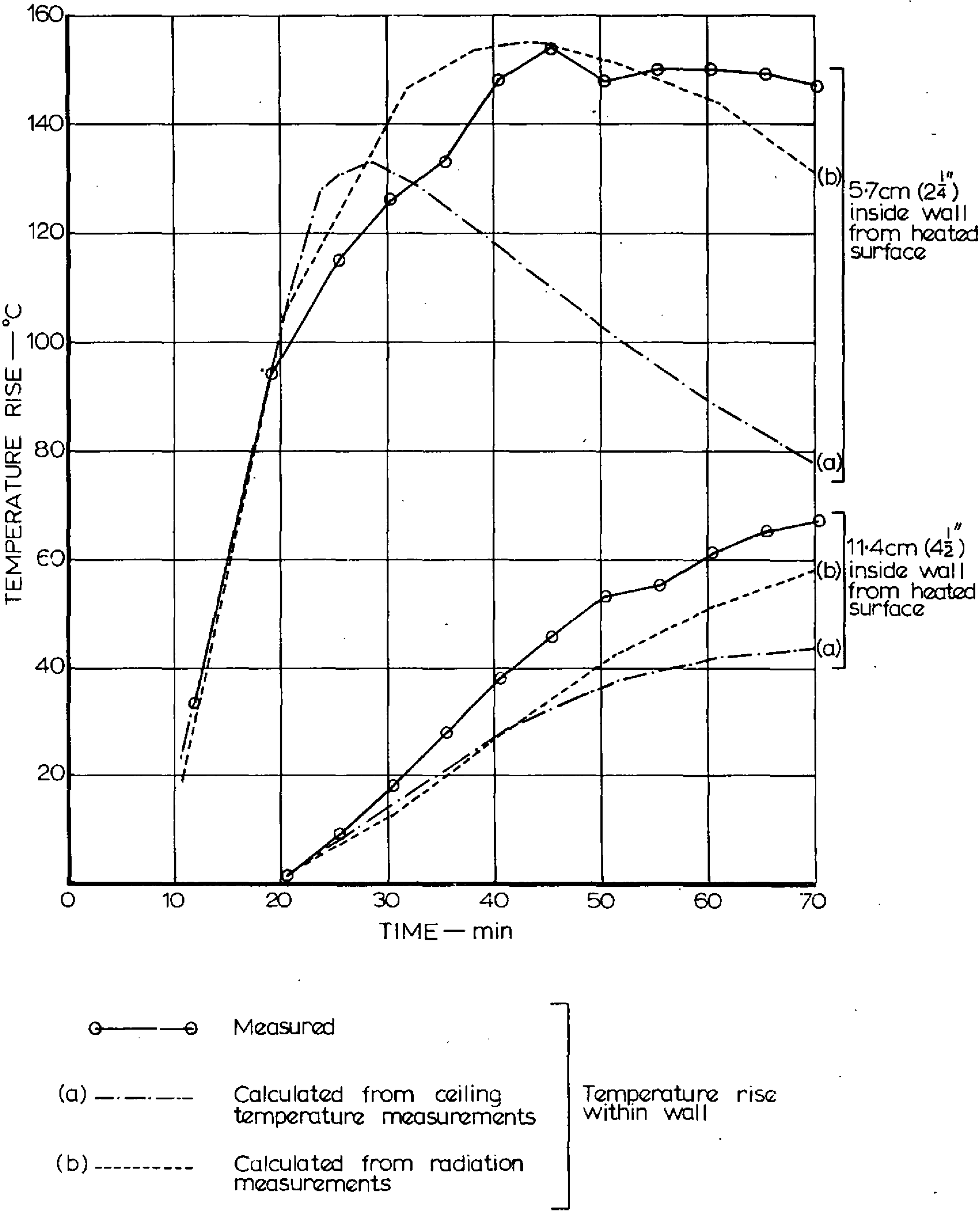


FIG. 3. TEMPERATURE RISE WITHIN WALL
(TEST No. 225)

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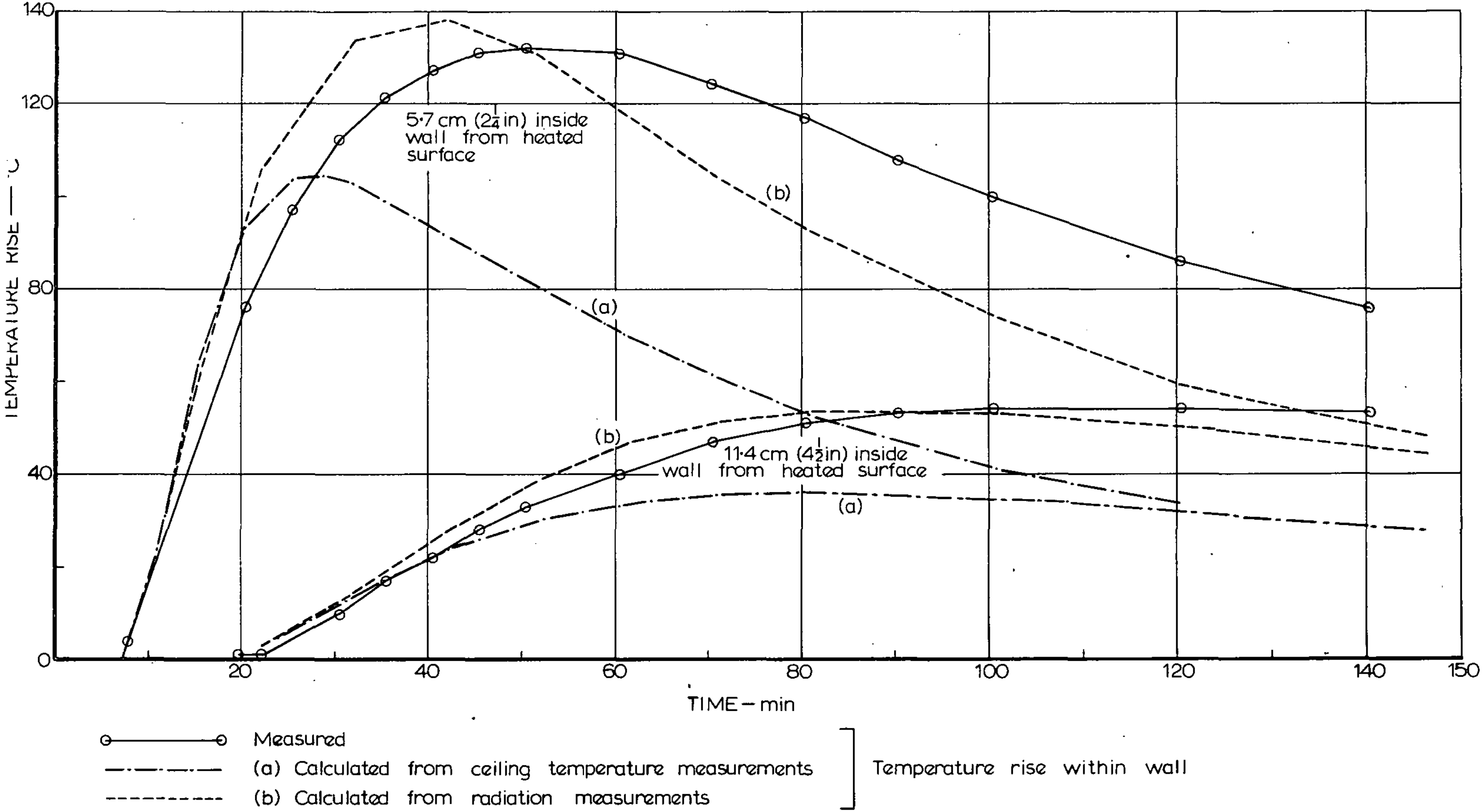

FIG. 4. TEMPERATURE RISE WITHIN WALL (TEST No. 226)

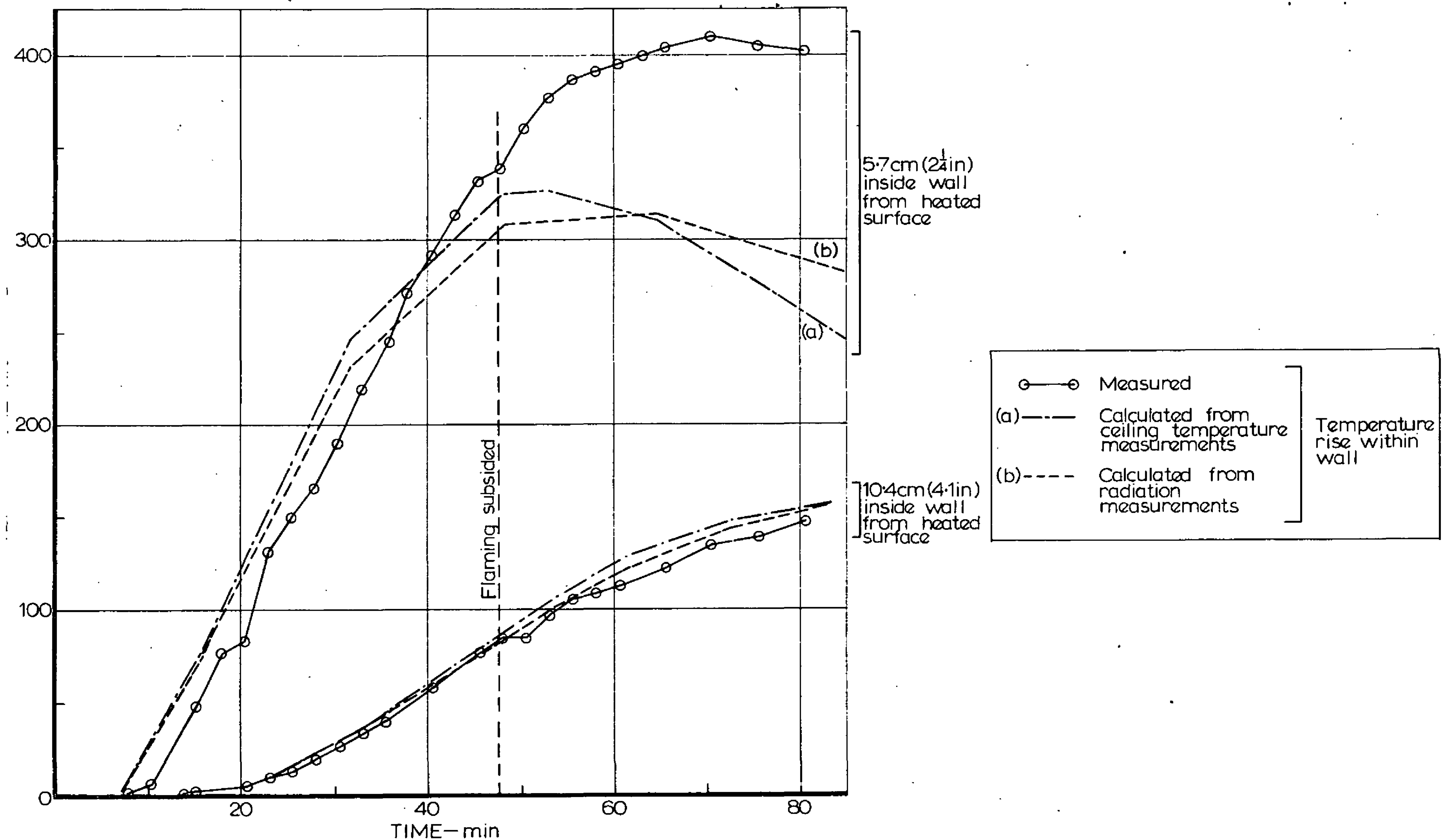

FIG. 5. . TEMPERATURE RISE WITHIN WALL (TEST No. 228)