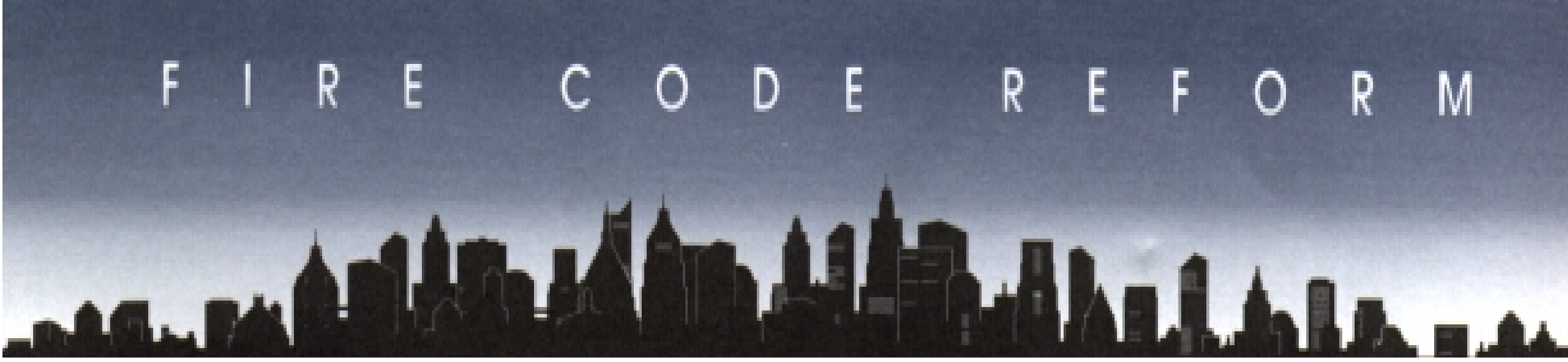

Project Report
FCRC-PR 99-01

Room and Furnace Tests of Fire Rated Construction

FCRC Project 3 Part 3
Fire Resistance and Non-Combustibility

Fire Code Research Reform Program
July 1999

Important Notice

Background

The Fire Code Reform Research Program is funded by voluntary contributions from regulatory authorities, research organisations and industry participants.

Project 3 of the Program involved investigation into aspects of, and the need for, regulatory control of Fire Resistance Levels and specification of Non-Combustibility in certain applications.

This Report of Part 3 of the Project presents results of a series of experimental tests on fire-rated construction exposed to furnace tests and room-fire tests. The test program included investigation of the effect of different levels of workmanship in the construction of the tested walls.

This Report has been assembled at completion of this work by CSIRO - Division of Building, Construction and Engineering at its establishment at Riverside Corporate Park, Delhi Road (P O Box 310), NORTH RYDE, New South Wales 1670 However, it fully recognises the very significant contributions made to the work by BHP Research, Melbourne Laboratories, whilst located at 245 Wellington Raod, Mulgrave, Victoria 3170 and by the Centre for Environmental Safety at Victoria University of Technology, Werribee Campus, Hoppers Lane, Werribee, Victoria, 3030

Acknowledgements

Since inception of the Fire Code Reform Research Program in 1994 the Australian Building Codes Board has been its principal financial contributor. Substantial funds have also been provided by Forest and Wood Products Research and Development Corporation and generous contributions have been received from a number of industrial and financial entities and individual donors.

The Board and management of Fire Code Reform Centre Limited acknowledge with sincere thanks receipt of all these financial contributions. The company also acknowledges the kind permission of the three major research organisations involved in this work for permission to re-produce and publish this document.

Comments

Comments on the content or other aspects of this document are always welcome and should be addressed to:- Fire Code Reform Centre Ltd, Suite 1201, 12th Floor, 66 King St, Sydney, NSW 2000, Australia. Tel. No: +61 (2) 9262 4358. Fax No: +61 (2) 9260 4255.

Project 3

FIRE RESISTANCE and NON-COMBUSTIBILITY

PART 3
Room and Furnace Tests of Fire Rated Construction

July 1999

CSIRO

Fire Code Reform Centre
Project 3
Fire Resistance and Non-Combustibility

ROOM AND FURNACE TESTS

J. Blackmore, C. Brescianini, G. Collins, M.A. Delichatsios,
G. Everingham, and J. Hooke
CSIRO Division of Building, Construction and Engineering
North Ryde

R. Ralph and I. Thomas
BHP Research – Melbourne Laboratories
Mulgrave

P. Beever
VUT Centre for Environmental Safety and Risk Engineering
Melbourne

July 1999

ABSTRACT

A series of five fire tests were conducted in *real* rooms that were constructed from fire-rated walls and furnished with combustible items and floor linings. The fire load was nominally identical in each of these room tests. In each room one of the walls was a *test wall* and was constructed either from common bricks or from plasterboard on steel studs. The air temperature near the exposed surface of the test wall and the unexposed-surface wall temperature were measured. In addition, fire-resistance tests on similar walls were performed in furnaces according to AS 1530.4-1990. This study compares the results from the room tests with the results from the furnace tests. It also examines the effects of differing levels of workmanship in the construction of the test walls, the within-laboratory repeatability, and the inter-laboratory reproducibility of the results.

1 INTRODUCTION

Fire-resistance levels have been established within the Building Code of Australia (BCA) on a mainly historical basis incorporating early research, but relying also on generally accepted practice. A review of the current BCA requirements for fire resistance undertaken as an earlier part of this project (Ref. 1) has revealed some inconsistencies and areas of conservatism which suggested that there were grounds for reviewing the basis for fire resistance. The earlier report set out a methodology for a rational basis to the calculation of fire resistance, which has since been implemented (Ref. 2).

The methodology selected relies on the development of a fire severity for each occupancy under consideration, followed by the calculation of the response to the fire of particular elements of construction. The calculation procedure adopted is based on estimations of heat transfer through construction materials, the corresponding temperature rises, and the thermal degradation of the materials to the point where the element may fail to perform as intended. By varying the dimensions and type of material under consideration it is possible to propose elements of construction which can survive the imposed fire severity. By repeating the analysis, but replacing the fire severity curve by the standard fire-resistance time-temperature curve, it is possible to deduce what fire resistance the proposed elements would have if tested in a fire resistance furnace. On the basis of these calculations recommendations for change in fire resistance levels will be proposed. These recommendations take into account the probabilistic effects relating to the likelihood of operation of sprinklers, or other fire safety systems.

It is the purpose of this experimental programme to provide support for the calculation procedures used to assess the response of construction elements to fire and furnace conditions. Emphasis has been placed on the repeatability of test results on nominally similar samples. The effect that construction quality has on the performance of elements in the standard furnace test and realistic fires was also investigated.

2 EXPERIMENTS UNDERTAKEN

2.1 Philosophy

The experiments are designed to show whether the calculation procedures used to estimate fire-resistance levels are reasonably well validated by comparison with experimental results. Clearly only a limited number of experiments can be carried out, in what is potentially a very large field. A decision was therefore taken at the outset to concentrate the effort on establishing the repeatability of results for common forms of construction rather than to assess the calculation procedure against numbers of different types of construction. The reason behind this decision was that it was felt that repeatability was an area which had been poorly addressed in earlier work, and is also one which is particularly relevant to building code changes that could result in a reduction of fire-resistance levels, thus reducing the cushion which might otherwise absorb variations in construction.

2.2 Materials

The number of materials studied had to be limited to two to keep the number of experiments to manageable proportions. On the basis of a literature search it was apparent that there is more information available on the protection of structural elements than on walls. It was decided therefore to study a masonry wall and a steel-stud-framed wall lined with plasterboard. In order to simulate the effects of poor workmanship, some of the test samples were deliberately constructed to represent a level of poor workmanship that might be encountered in practice.

2.3 Test Programme

Three test series were conducted as indicated in Table 1. The first series of 6 tests used test walls installed in *real* rooms that were subjected to a fire load. The test rooms were set up in an effort to replicated real fire conditions in a repeatable manner.

The other two series made use of a vertical furnace. Series #2 used the standard fire-resistance test specified by AS1530.4-1990. Series #3 was similar to the second except that the time-temperature curve attempted to match that measured in the room tests.

In most of these cases several tests were conducted in order to gain some view on the repeatability of results. In addition, some of the tests were repeated at two laboratories to gain some view of the interlaboratory reproducibility. The first and second test series also tested some walls that were deliberately constructed badly, so that the effects of construction variability could be gauged.

The second room test conducted by CSIRO (i.e. the test designation "CSIRO *#2"* which involved the standard-workmanship plasterboard wall as indicated in Table 1) suffered a failure in the data logging equipment during the test. The FCRC Project 3 Working Group decided that the measurements taken during this test were not meaningful, and hence the results from this test have been excluded from this report.

Table 1. Test Programme.

Test Series	Type of Test	Test Wall	Construction Workmanship	Number of Tests at CSIRO	Lab. Test ID	Number of Tests at BHP/WFRA	Lab. Test ID
1	Room	Masonry	Standard	1	CSIRO #1	1	BFT747
			Bad	-	-	1	BFT748
		Plasterboard[3]	Standard	1	CSIRO #2	2	BFT745, BFT746
			Bad	-	-	-	-
2	Standard Furnace[1]	Masonry	Standard	3	VR0030/0001, VR0031/0002, VR0035/0006	-	-
			Bad	3	VR0032/0003, VR0033/0004, VR0034/0005	-	-
		Plasterboard	Standard	1	VR0039/0010	2	BFT750, BFT752
			Bad	1	VR0036/0007	2	BFT751, BFT753
3	Modified Furnace[2]	Masonry	Standard	1	VR0041/0012	-	-
			Bad	-	-	-	-
		Plasterboard	Standard	1	VR0040/0011	-	-
			Bad	-	-	-	-

Notes:

[1] Standard furnace tests used the standard time-temperature curve from AS1530.4-1990.

[2] Modified furnace tests followed the time-temperature curve measured during the Room Tests.

[3] A failure of the data-logging equipment occurred for the plasterboard room test designated "CSIRO *#2"*.

3 PROCEDURES ADOPTED

The type of construction, the materials, the test elements, and the fire loads, are all specified in detail in Ref. 3 (which has been attached to this report as Appendix A). Some of the more-important points are summarised here.

3.1 Test Room

The test room was constructed of fire-grade plasterboard and had dimensions 3600 mm long x 3000 mm wide x 3000 mm high, as indicated in Figure 3-1. There was an 800 mm wide x 2000 mm high doorway in one of the 3000 mm x 3000 mm walls. A 2000 mm wide x 1800 mm high window was located in a 3600 mm x 3000 mm wall at right angles to the doorway. The 3000 mm x 3000 mm wall directly opposite the doorway was used as the test wall. The test wall was constructed either from steel studs lined with plasterboard, or from masonry.

An internal suspended ceiling was constructed in the test room at a height 2400 mm above the floor. The suspended ceiling was assembled from 1200 mm x 600 mm Fissured Board panels and a galvanised-steel suspended grid system. The height of the suspended ceiling matched the top of the window.

The floor of the test room was made of concrete and was lined with 50/50 acrylic/wool carpet and a rubber underlay. The room was fitted with furniture as indicated in Figure 3-2. The furniture was constructed predominantly of steel frames lined with particle board, plywood, and polyurethane-foam seat cushions. A desktop computer, telephone, wastepaper bin, and office in/out trays were added. Additional material, predominantly in the form of paper books and magazines, were then added to the bookcases and distributed around the room to increase the fire load. The theoretical total fire load of the room was 8730 MJ, or an average of 808 MJ/m2 of floor area. The room was ignited using a wooden crib located in the centre of the sofa.

3.2 Test Room Instrumentation

The principle instrumentation of the test room consisted of an array of nine symmetrically arranged *MIMS* (Mineral *Insulated Metal Sheath)* thermocouples located in a plane 200 mm from the test wall that were used to measure the exposed-wall air temperatures (see Figure 3-1), and an array of five thermocouples (copper *disk/QQ)* that were attached to the unexposed face of the test wall and located at the mid-point and four quarter points of the wall.

In addition, two thermocouples were attached to the unexposed face over the mortar joints of the masonry wall, and twenty thermocouples (see Figure 3-3) were placed in the test room to measure air temperatures at several locations. BHP used hot-junction *MIMS* to measure these air temperatures, while CSIRO used *24 AWG type K ½ (special) tolerance, duplex, glass-fibre types, with crimped ends* thermocouples. The BHP tests also used four *MIMS* thermocouples to measure outside air temperatures 1270 mm from the window, and three linear pots to measure the test-wall deflection. The location of all the thermocouples and the naming convention is described Table 2.

Table 2. Location of Thermocouples During Room Tests

Thermocouple Name	Description	Elevation	Location
T1	Exposed face air temp.	Top	200 mm from test wall. Side away from window
T2	Exposed face air temp.	Top	200 mm from test wall. Centre
T3	Exposed face air temp.	Top	200 mm from test wall. Side towards window
T4	Exposed face air temp.	Middle	200 mm from test wall. Side away from window
T5	Exposed face air temp.	Middle	200 mm from test wall. Centre
T6	Exposed face air temp.	Middle	200 mm from test wall. Side towards window
T7	Exposed face air temp.	Bottom	200 mm from test wall. Side away from window
T8	Exposed face air temp.	Bottom	200 mm from test wall. Centre
T9	Exposed face air temp.	Bottom	200 mm from test wall. Side towards window
U1	Unexposed face wall temp.	Top	Side away from window
U2	Unexposed face wall temp.	Top	Side towards window
U3	Unexposed face wall temp.	Mid	Centre
U4	Unexposed face wall temp.	Bottom	Side away from window
U5	Unexposed face wall temp.	Bottom	Side towards window
U6	Unexposed face wall temp.	Top	Centre
U7	Unexposed face wall temp.	Bottom	Centre
A1	Room air temperature	Above ceiling	Rear of room. Away from window.
A2	Room air temperature	Below ceiling	Rear of room. Away from window.
A3	Room air temperature	Mid	Rear of room. Away from window.
A4	Room air temperature	Bottom	Rear of room. Away from window.
A5	Room air temperature	Above ceiling	Rear of room. Towards window.
A6	Room air temperature	Below ceiling	Rear of room. Towards window.
A7	Room air temperature	Mid	Rear of room. Towards window.
A8	Room air temperature	Bottom	Rear of room. Towards window.
A9	Room air temperature	Above ceiling	Centre of room.
A10	Room air temperature	Below ceiling	Centre of room.
A11	Room air temperature	Mid	Centre of room.
A12	Room air temperature	Bottom	Centre of room.
A13	Room air temperature	Above ceiling	Front of room. Away from window.
A14	Room air temperature	Below ceiling	Front of room. Away from window.
A15	Room air temperature	Mid	Front of room. Away from window.
A16	Room air temperature	Bottom	Front of room. Away from window.
A17	Room air temperature	Above ceiling	Front of room. Towards window.
A18	Room air temperature	Below ceiling	Front of room. Towards window.
A19	Room air temperature	Mid	Front of room. Towards window.
A20	Room air temperature	Bottom	Front of room. Towards window.
AW1	Outside air temperature	2700 mm	1270 mm from window.
AW2	Outside air temperature	2100 mm	1270 mm from window.
AW3	Outside air temperature	1200 mm	1270 mm from window.
AW4	Outside air temperature	300 mm	1270 mm from window.

3.3 Plasterboard Test Walls

All the plasterboard test walls were constructed to a specified standard designed to represent walls of one-hour nominal fire resistance. The walls were constructed by experienced tradespeople, although they were not necessarily constructed by the same individual (different tradespeople were used at the different laboratories). The plasterboard walls were built using single layers of 16 mm fire-grade plasterboard located on both sides of 64 mm steel studs. For the room tests the walls were free standing at the sides, but fixed to the room at the top and bottom. None of the test walls were load bearing.

The bad-workmanship test walls were also built to a specification and were constructed using similar materials as the standard-workmanship wall. The details of the assembly, however, were modified to include gaps between the sheets, larger screw spacing, broken edges, and a non-staggered sheet arrangement.

Furnace tests on the plasterboard walls were conducted at two laboratories, namely, CSIRO DBCE and Warrington Fire Research (WFR). The WFR tests were co-ordinated by BHP. The tests conducted at CSIRO used a full-size test wall of dimensions 3000 mm x 3000 mm. The tests conducted at WFR used a 1600 mm (wide) x 3000 mm (high) plasterboard test wall, since their furnace could not accommodate a full-size test wall. Full details of the results of the furnace tests conducted by WFR are available in WFR reports prepared for BHP (Ref. 4).

3.4 Masonry Test Walls

The masonry test walls were constructed from 230 mm (long) x 110 mm (thick) x 75 mm (high) ordinary dry pressed common bricks. All bricks were purchased from the same supplier and distributed to both testing laboratories. A mortar mix of one part type A Portland cement, one part lime, and six parts bush sand was used. For the room tests the walls were free standing with the top slotting into a 125 mm x 65 mm steel channel. All walls at both testing laboratories were constructed by the same experienced tradesperson. None of the masonry test walls were load-bearing.

For the standard-workmanship walls, the walls were constructed using full beds and perpends. For the bad-workmanship walls less mortar was used in the perpends and bed joints. Although the quantity of mortar varied, it was estimated that on average 40-50% if the perimeter of the bricks were affected by an incomplete application of mortar to a depth of approximately 5-15 mm.

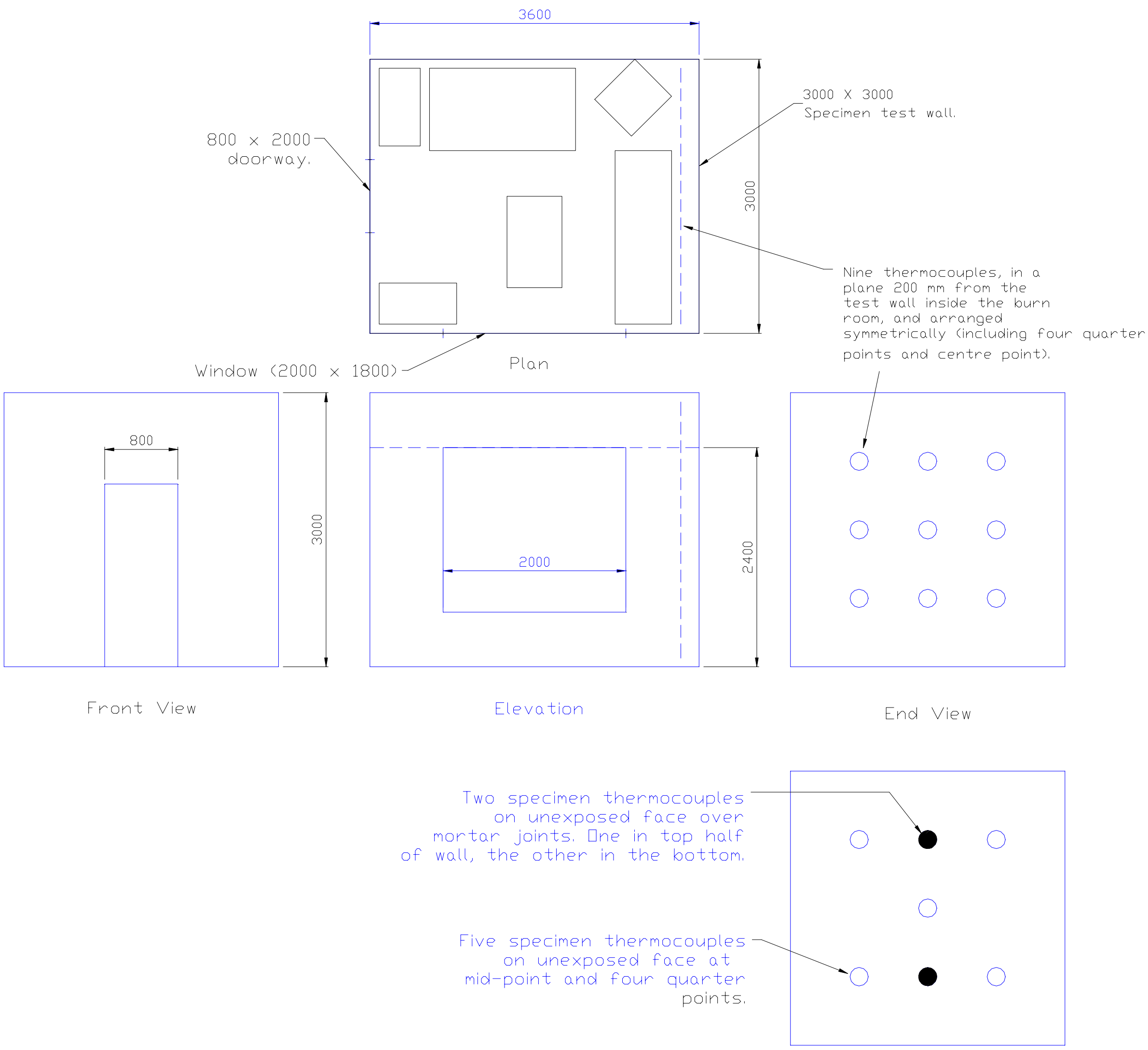

Figure 3-1. Burn room dimensions.

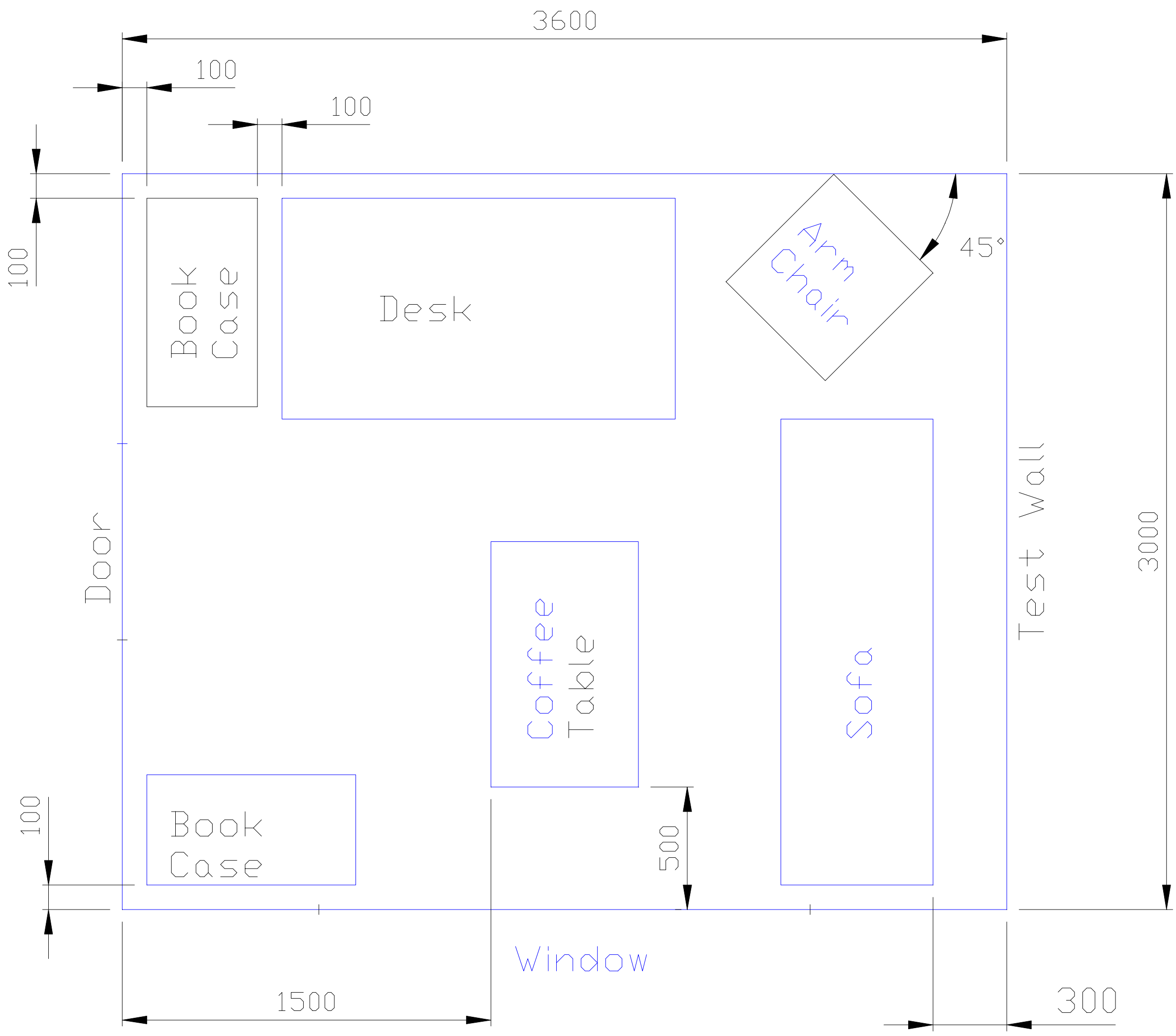

Figure 3-2. Burn room furniture layout.

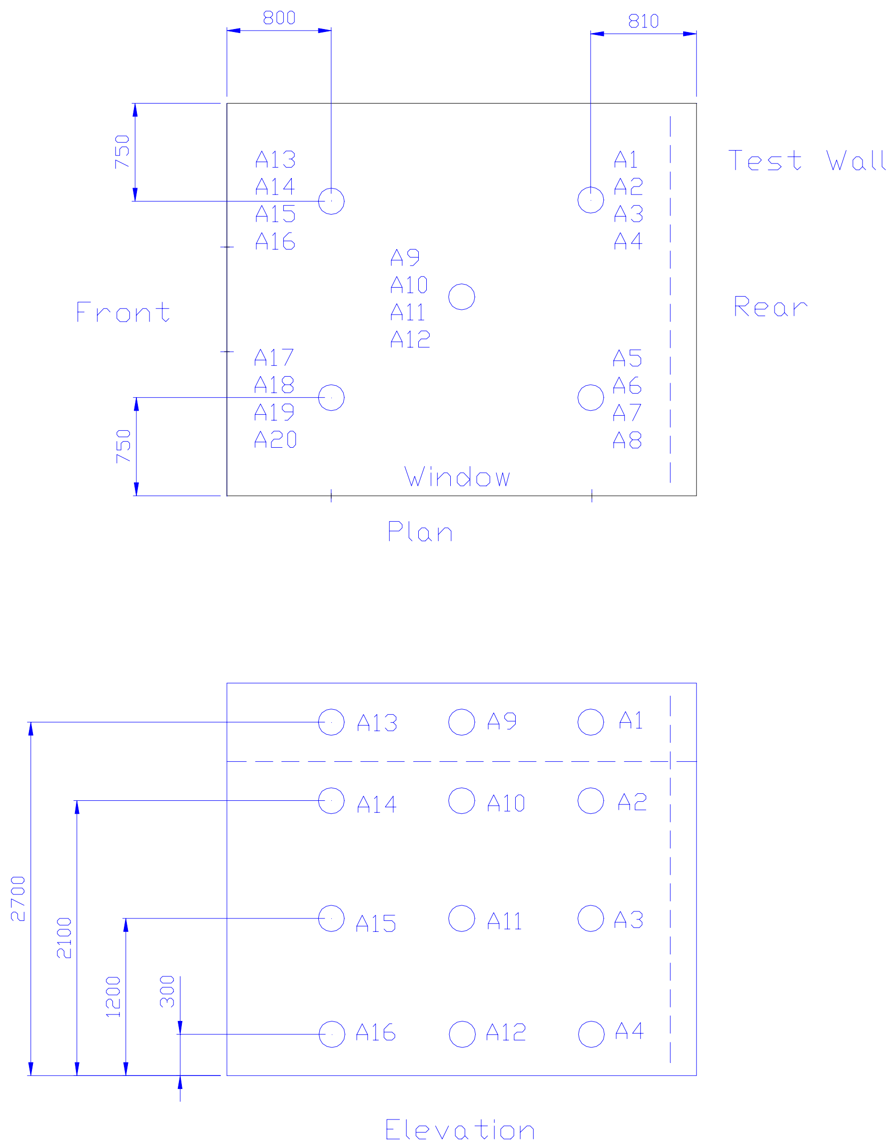

Figure 3-3. Location of air-temperature thermocouples.

4 TEST SERIES #1- ROOM TESTS RESULTS

4.1 Masonry Test Walls

Room tests involving a *standard-workmanship* masonry test wall were conducted by BHP (Test *BFT 747*) and by CSIRO North Ryde (*CSIRO Test #1*). Figure 4-1 shows the average air temperature recorded near the exposed face of the test wall for test *BFT 747* (see temperature scale on the left axis). This temperature was measured by the array of nine thermocouples (*T1-T9*) located in a plane 200 mm from the test wall. Figure 4-1 also shows the average temperature measured by the five thermocouples located at the mid-point and four quarter points (*U1-U5*) and the two additional thermocouples (*U6* and *U7*) on the unexposed face of the test wall (see temperature scale on the right axis). The layout of the thermocouples was similar to that used in the standard furnace test.

The air temperatures show a very rapid rise during the initial stages of the fire. Average temperatures exceed 100˚C in less than 1.5 minutes, and reach a peak of 992˚C within 3.2 minutes. For a period of approximately 10 minutes the temperatures are relatively steady at around 600°C, and then they begin to fall slowly. At a time of 40 minutes the temperatures are still above 200˚C. The fire is finally suppressed by using manually-activated sprinklers at around 43 minutes.

Figure 4-2 shows the average air temperature measured by the top-level thermocouple tree (thermocouples *T1-T3*), the middle-level thermocouple tree (*T4-T6*), and the bottom-level thermocouple tree (*T7-T9*), over the first 30 minutes of the fire. A distinct variation in temperature with height in the room is observable.

The fire in the test room was ignited on the three-seat sofa chair located towards the rear of the room, closest to the test wall. As a result, the intensity of the fire was highest

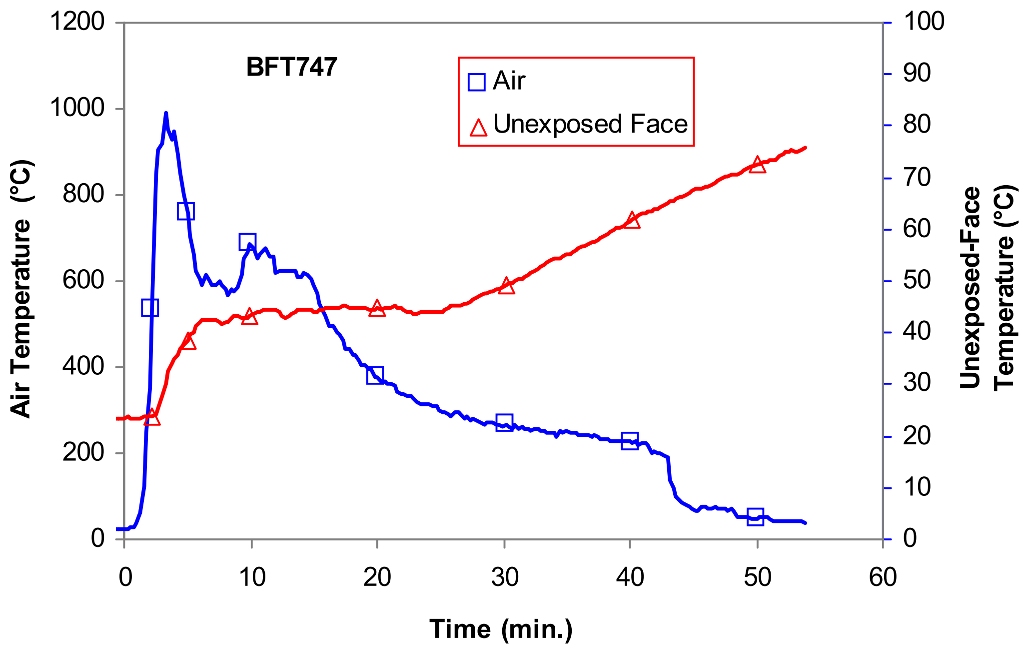

Figure 4-1. Masonry wall room test *BFT 747*.

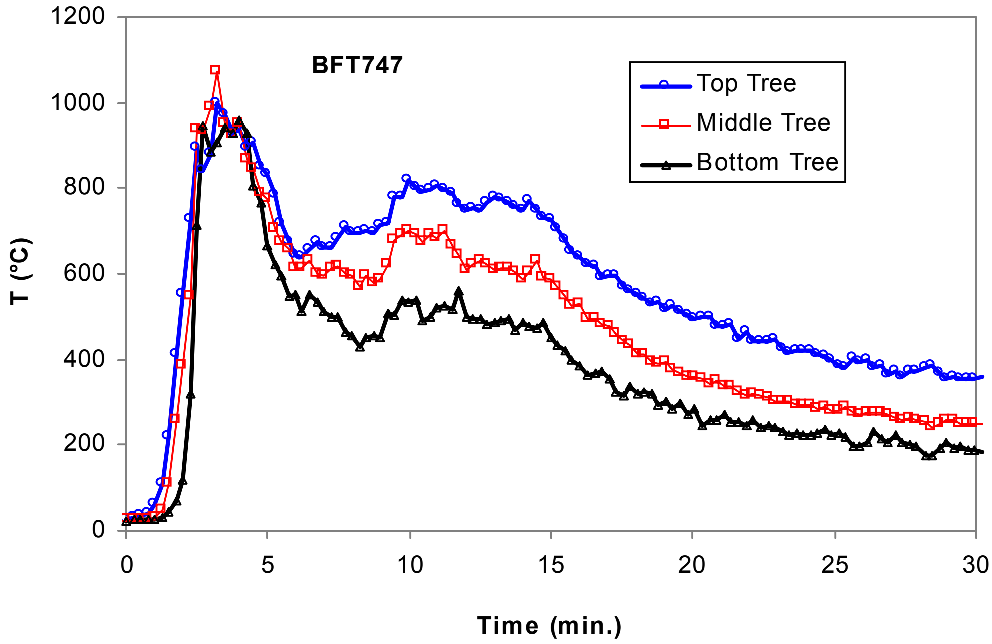

Figure 4-2. Air-temperature variations on exposed face *BFT 747*.

towards the rear of the room during the early stages of the fire. However, the total fire load was concentrated more highly at the front of the room (closest to the doorway) due to the location of the two book cases filled with books and magazines, and hence the fire continued to burn with greater intensity at the front of the room as time progressed. Evidence for this can be seen if Figure 4-3 which compares the average temperatures measured at the front (thermocouples *A13-A20*), centre (*A9-A12*), and rear of the test room (*A1-A8*), and near the test wall (*T1-T9*). Clearly the temperatures at the front of the room are noticeably higher than at the rear of the room after a time of approximately 5 minutes.

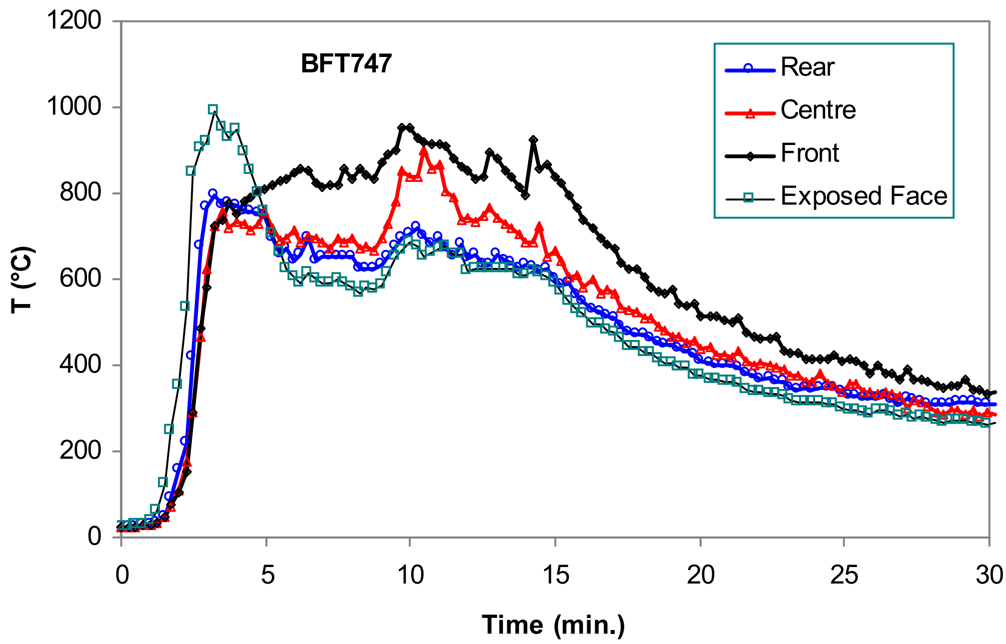

Figure 4-3. Temperature variations between front and rear of room.

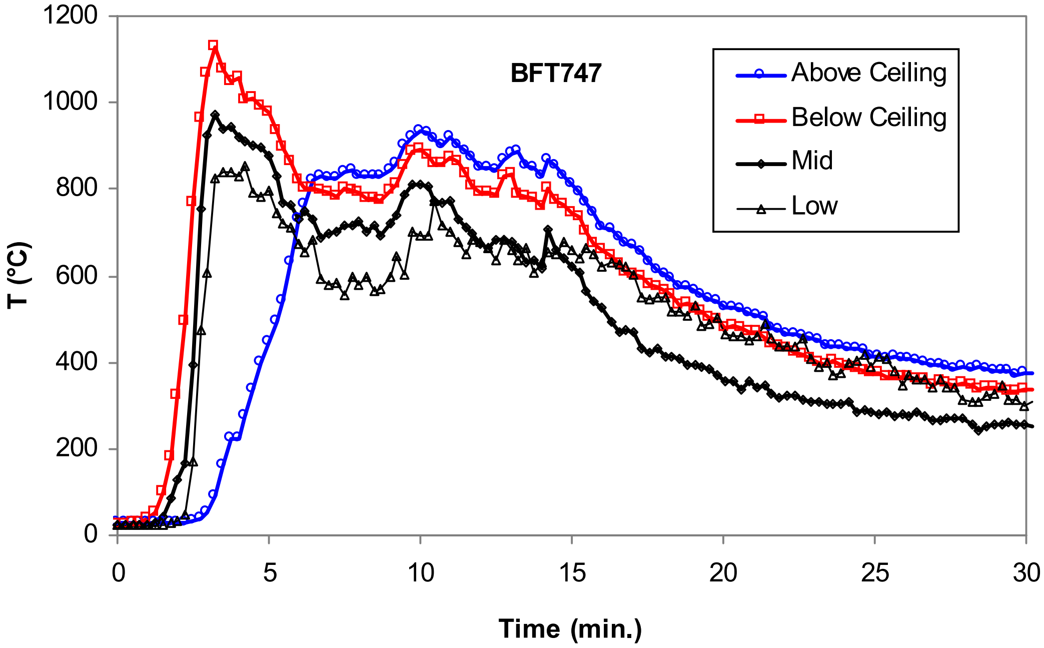

Figure 4-4. Room air temperatures at different levels.

It should be noted that the thermocouples measuring the exposed-wall air temperatures (thermocouples *T1-T9*) are not at exactly the same elevations as the other room air-temperature thermocouple trees (thermocouples *A1-A20*). In addition, the room air-temperature thermocouple trees also contain thermocouples located above the suspended ceiling. The temperatures measured in this cavity can be expected to be initially insulated from the hot gases just below the ceiling until the time the ceiling structure breaks down. Figure 4-4 shows the average room air temperatures measured at different levels within the test room. A strong temperature increase with distance from the floor is generally present. The early temperatures recorded above the suspended ceiling are lower than the other temperatures as expected, while at later times the highest temperatures are recorded at this level. The temperatures at the lowest level actually rise above those recorded at the mid level after a time of approximately 14 minutes, possibly due to the large amount of material/debris burning at the floor level.

Figure 4-5 is similar to Figure 4-3 except that the average temperatures have ignored the thermocouples located above the suspended ceiling (*A1, A5, A9, A13* and *A17*) for the first 6 minutes of the fire. After a time of 6 minutes the thermocouples above the ceiling have been included. Six minutes was chosen to give an estimate of the time for ceiling break down, as determined from Figure 4-4.

The average temperature measured by all the room-air thermocouples (i.e. thermocouples *A1-A20*) is plotted on Figure 4-6, along with the maximum temperature recorded by any of the thermocouples outside the window i.e. Max (*AW1, AW2, AW3, AW4*). The maximum outside air temperatures have been smoothed slightly by time-averaging over a period of one second (5 data points). Very hot gases can be seen to be escaping the room quite early in the fire. The variations in the recorded temperature outside the window could be due to a reduction of the flaming out of the window, or due to varying air patterns and/or turbulence out side of the room

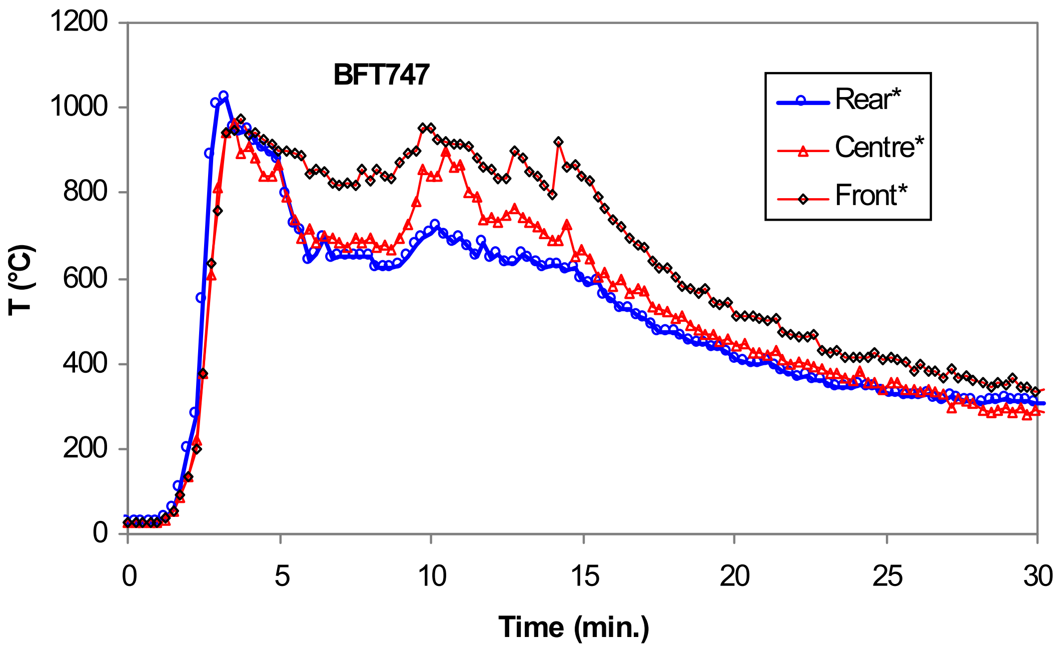

Figure 4-5. Adjusted temperature variations between the front and rear of room.

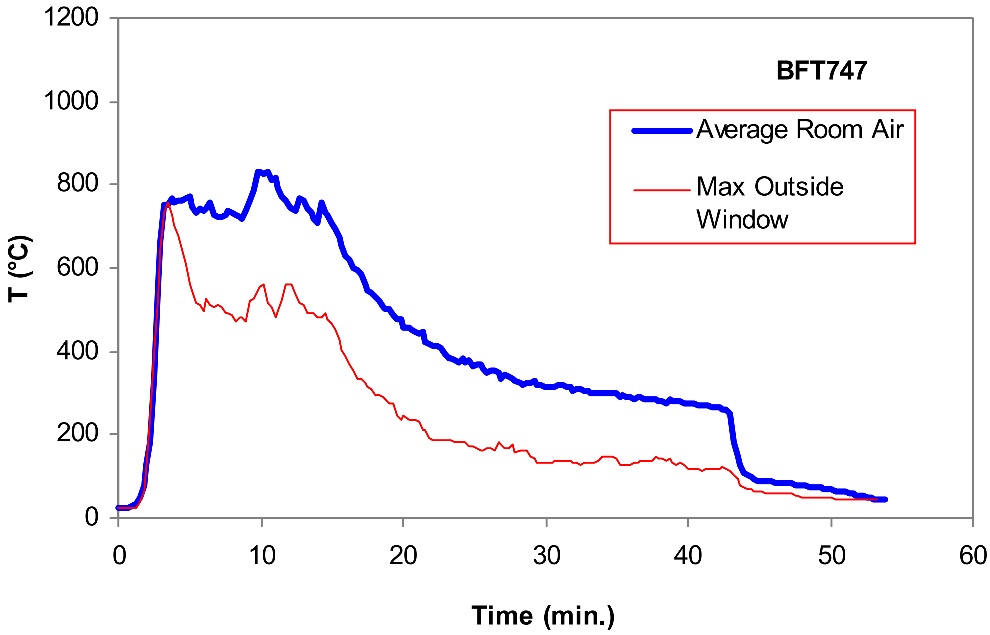

Figure 4-6. Air temperature in room compared to temperature outside window.

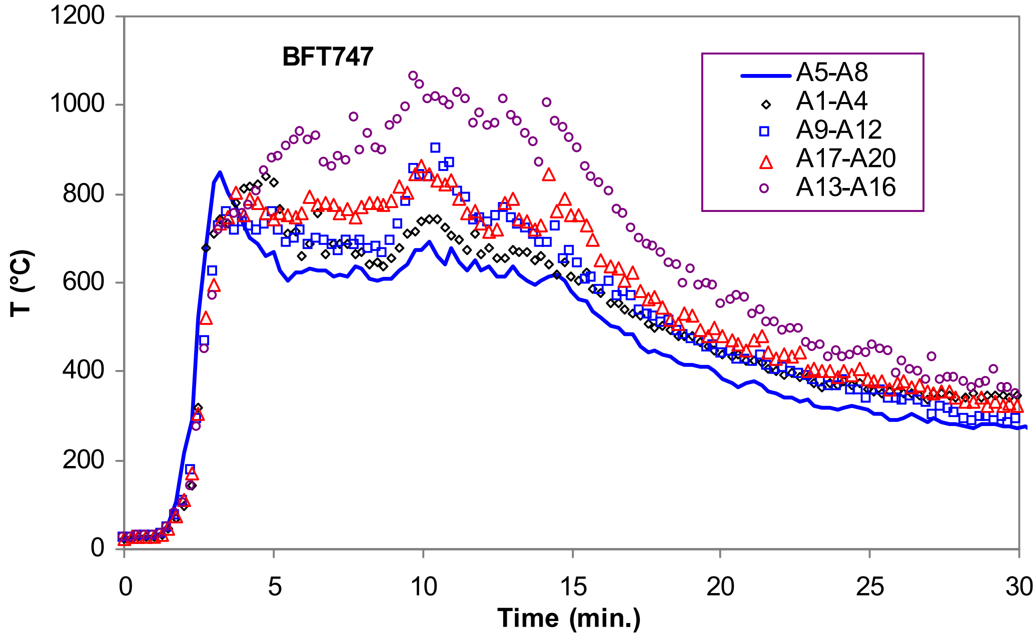

Figure 4-7. Room-air temperatures in different corners of room.

Figure 4-7 shows that the air-temperature varies at different corners of the test room. The highest temperatures are recorded at the thermocouple trees located towards the front of the room after a time of approximately 5 minutes. A temperature variation across the width of the room is also noticeable, with temperatures being slightly cooler towards the window side.

4.2 Repeatability and Reproducibility

Figure 4-8 compares the exposed-wall air temperatures (averages of thermocouples *T1-T9*) recorded during the five room tests. The repeatability and reproducibility are good given the nature of the tests. The curves for all four BHP tests are very similar, while the curve for the CSIRO test is slightly different in appearance. The CSIRO test does not reach the same initial peak temperatures obtained by the BHP tests (see Table 3), yet the CSIRO temperatures are generally higher between times of 5 and 8 minutes, and then suddenly fall below the other curves. The results indicated in Table 3 show larger peak temperatures at the exposed face for the plasterboard test walls than for the masonry walls.

Table 3. Peak average-air temperatures for room tests.

Test	Material	Peak average air temperature Thermocouples T1-T9 (˚C)	Peak average air temperature Thermocouples A1-A20 (˚C)
BFT745	Plasterboard	1116	864
BFT746	Plasterboard	1095	960
BFT747	Masonry	992	832
BFT748	Masonry	964	871
CSIRO #1	Masonry	889	613

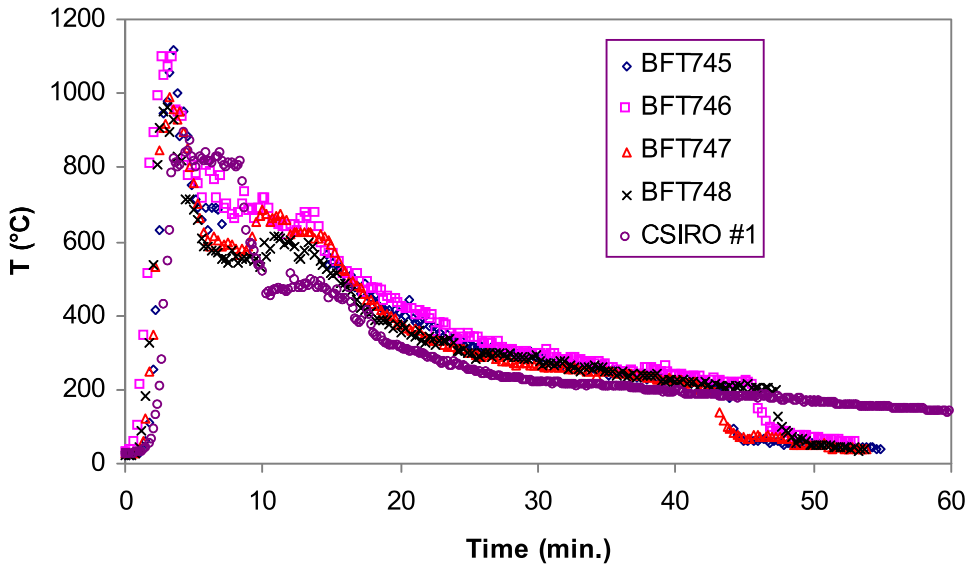

Figure 4-8. Exposed-wall air temperatures (average of thermocouples *T1-T9*): A comparison of five room tests.

Figure 4-9 shows the average air temperatures measured by all the room air thermocouples. The four BHP tests show good repeatability, however, the CSIRO test is noticeably lower in temperature. A possible explanation is the different types of thermocouples used to measure the air temperatures at CSIRO and at BHP (see Section 3.2). In addition, two of the CSIRO air thermocouples recorded physically unrealistic

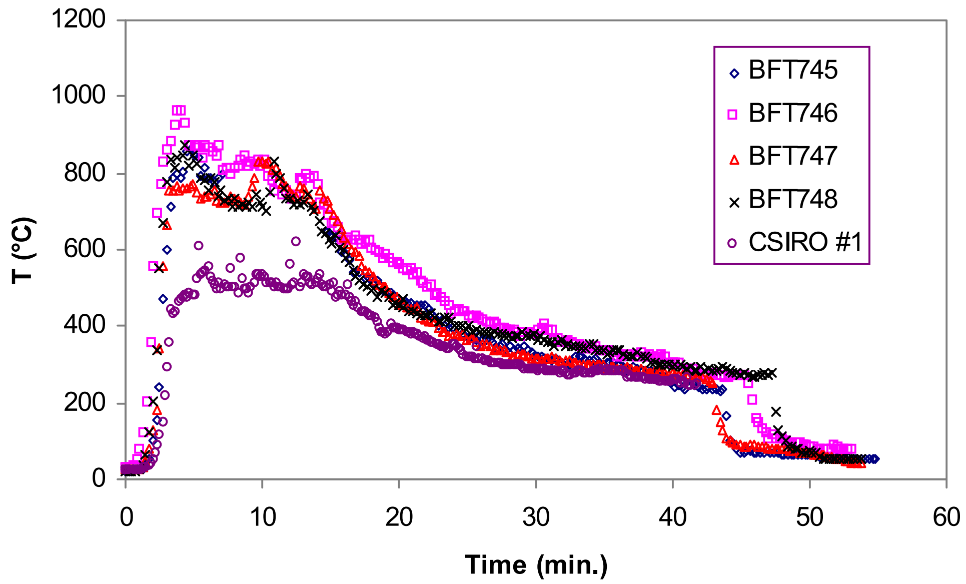

Figure 4-9. Room air temperatures (average of thermocouples *A1-A20*): A comparison of five room tests.

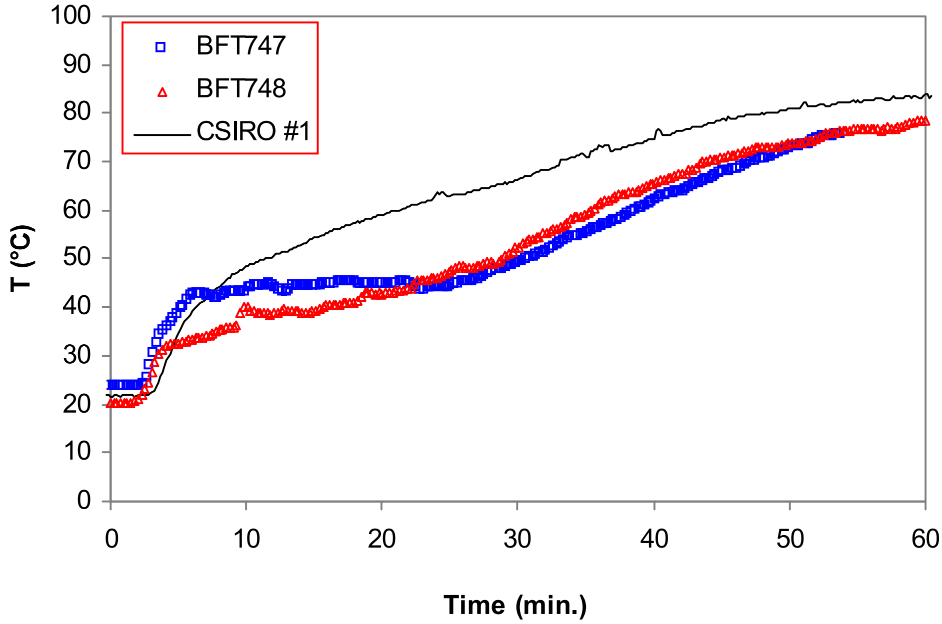

Figure 4-10. Masonry test walls: Unexposed-face average temperatures (thermocouples *U1-U7*) recorded during room tests.

temperatures during the CSIRO test and have been eliminated from the average during the data analysis.

Figure 4-10 shows the average temperatures (thermocouples *U1-U7*) recorded on the unexposed face of the masonry test walls during the three room tests, while Figure 4-11 shows the maximum temperatures. Tests *BFT747* and *CSIRO #1* involved a standard-workmanship wall, while test *BFT748* involved a bad-workmanship wall. The two BHP tests are similar, even though two different methods of construction have been used. One possible explanation as to why the CSIRO results differ to the BHP results is that the CSIRO test room was contained within a slightly larger structure. Although this outer structure was reasonably well ventilated to the outside surroundings, it is possible that some hot gases escaping the test room were trapped in this outer room, which in turn may have affected the thermocouple readings on the unexposed face of the test wall.

4.3 Plasterboard Test Walls

Figure 4-12 shows the average air temperature measured at the exposed face of a *standard-workmanship* plasterboard test wall (thermocouples *T1-T9*), and the corresponding unexposed average wall temperature (thermocouples *U1-U7*). In comparison to the masonry walls, the plasterboard wall temperature rises more quickly, and then reaches a plateau between 70˚C and 80˚C after approximately 14 minutes.

Figure 4-13 compares the average unexposed wall temperatures measured during the two nominally-identical room tests. The agreement is very good (note that there is no recorded data for test *BFT745* between time t = 7 and 14 minutes). The maximum temperatures are shown in Figure 4-14.

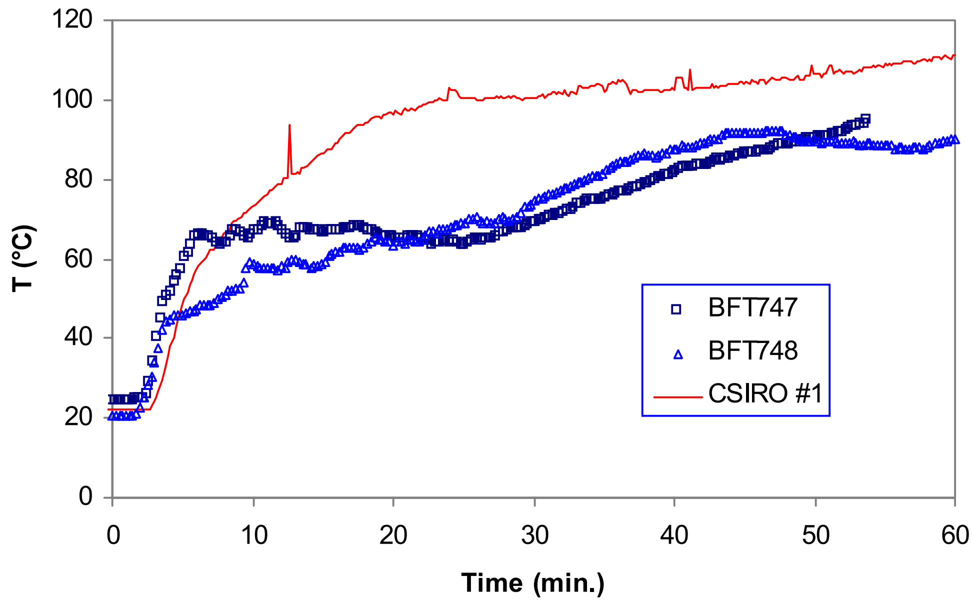

Figure 4-11. Masonry test walls: Unexposed-face maximum temperatures (thermocouples *U1-U7*) recorded during room tests.

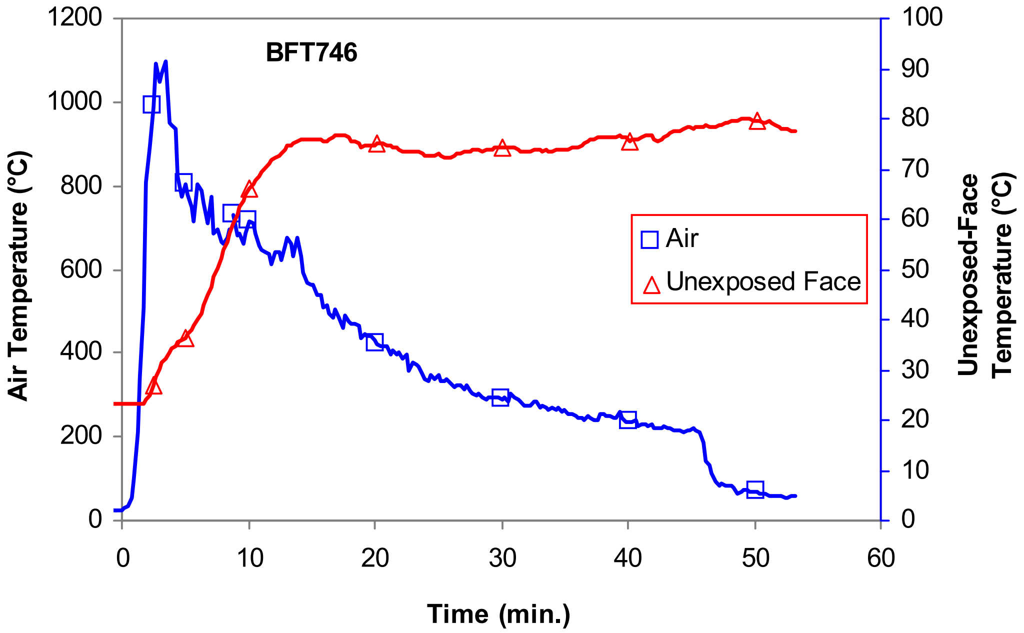

Figure 4-12. Plasterboard wall room test *BFT 746.*

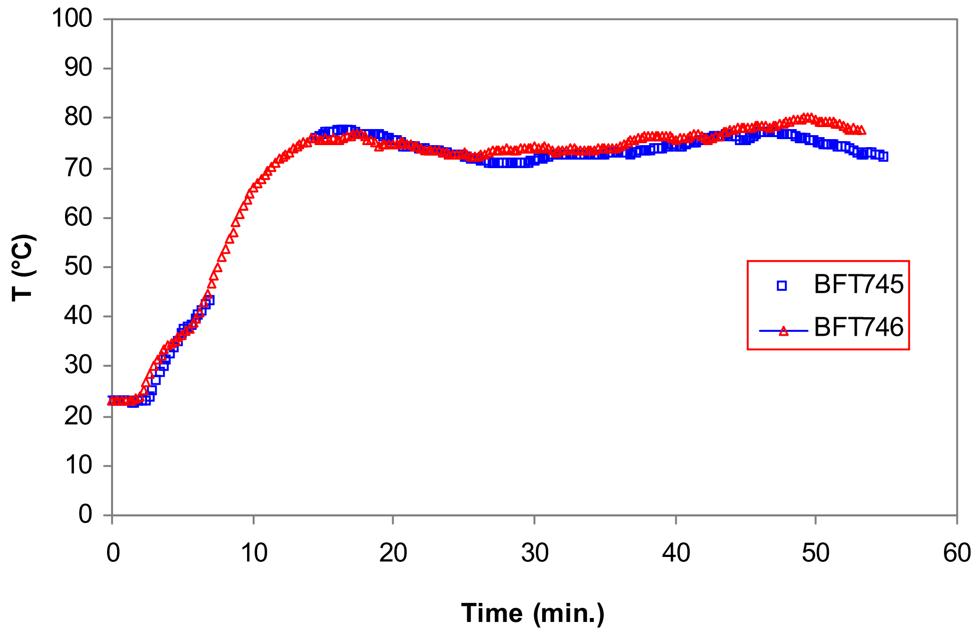

Figure 4-13. Plasterboard test walls: Unexposed-face average temperatures (thermocouples *U1-U7*) recorded during room tests.

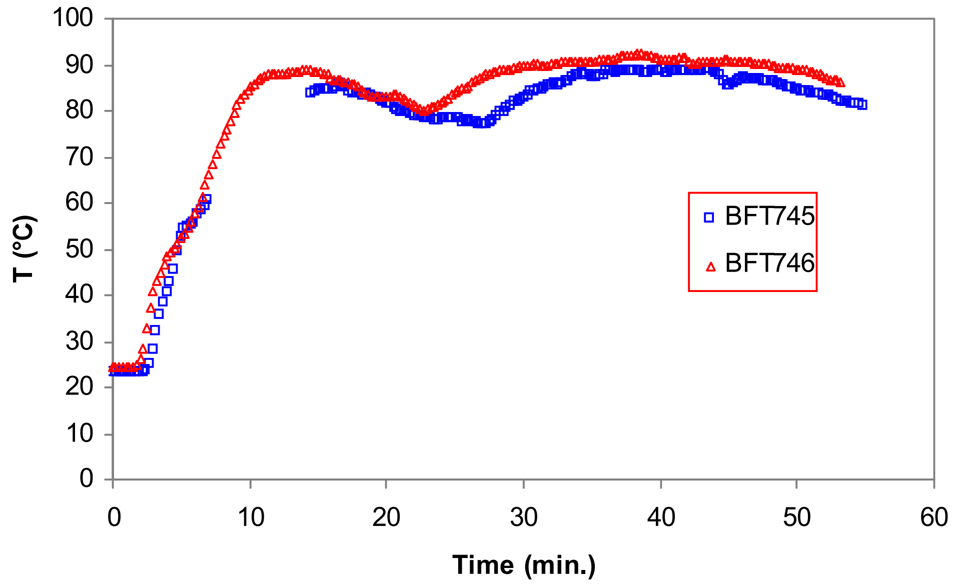

Figure 4-14. Plasterboard test walls: Unexposed-face maximum temperatures recorded during room tests.

5 TEST SERIES #2- STANDARD-FURNACE TEST RESULTS

5.1 Standard-Workmanship Masonry Walls

The results for the furnace tests on the masonry walls are shown in Table 4 and Table 5. In the case of the three *standard-workmanship* walls that were tested, insulation failure was very repeatable. Using the *average-temperature* criteria failure occurred at 105 ± 2 minutes, while using the *maximum-temperature* criteria failure occurred at 120 ± 3 minutes.

Integrity failure did not occur for two test samples over the duration of the test (241 minutes), while the third sample (VR0035) reached integrity failure at 220 minutes. This integrity failure was in the form of a vertical crack through the centre of the wall. This crack first appeared at 31 minutes, and then began to widen at 210 minutes. By 220 minutes the crack was wide enough to see features of the furnace through the crack.

None of the standard-workmanship test walls suffered from structural failure over the duration of the test. An example of the average temperature (for the *unexposed face* this temperature is the average of the temperatures measured at the four quarter points and the centre point of the wall) versus time can be seen in Figure 5-1.

5.2 Bad-Workmanship Masonry Walls

The *bad-workmanship* masonry walls displayed a different behaviour to the *standard-workmanship* walls when subjected to the standard furnace test. Three bad-workmanship walls were tested as indicated in Table 4, however, one of these walls was of better construction than the other two. All three walls collapsed suddenly before the test was completed with little or no warning that a major failure was imminent from casual observations of the wall.

Only one of the walls (VR0032) reached integrity failure before the wall collapsed. During the test of wall VR0032 a vertical crack first appeared in the wall at 44 minutes. By 46 minutes six places where integrity failure had occurred at the top of the wall in the joints had been identified. Further cracks near the four corners of the wall appeared at 47 minutes, and by 59 minutes integrity failure had become apparent in the central area of the specimen in the mortar joints. The wall collapsed suddenly at 95 minutes.

The time until collapse of the two walls of similar construction (VR0032 and VR0034) was 88 ± 7 minutes. The average temperature of the unexposed face when the two walls collapsed were similar (130 ± 4 °C), as were the maximum temperatures (153 ± 2 °C), despite the 14 minutes difference in time to collapse. Both walls collapsed before insulation failure had been reached. Figure 5-2 shows the average temperatures recorded for test VR0034. The unexposed face temperatures are compared to those measured on a standard-workmanship masonry wall in Figure 5-3**.**

The third bad-workmanship wall (VR0033) was of better construction than the other two. A crack first appeared at the centre of the wall at 18 minutes, and at 49 minutes cracks appeared at both of the bottom corners. The wall reached insulation failure at

98 minutes (based on the average-temperature criteria) before the wall subsequently collapsed at 147 minutes.

The average deflection measured at the centre point of all three bad-workmanship walls just prior to collapse was 99 ± 2 mm. In comparison, at least one of the good-workmanship walls (VR0035) was able to withstand a deflection of 156 mm without suffering a structural failure. Figure 5-4 shows the deflection versus time for the standard-workmanship and the bad-workmanship walls.

5.3 Standard-Workmanship Plasterboard Walls

The results for the plasterboard test walls are show in Table 6 and Table 7. The three standard-construction walls reached insulation failure at 78 ± 1 minutes based on the average-temperature criteria. This shows excellent within-laboratory repeatability and inter-laboratory reproducibility. The insulation failure based on the maximum-temperature criteria varied slightly more at 78 ± 5 minutes, although the result would be 76 ± 1 minutes if the joint temperature was used to determine the insulation failure for CSIRO test VR0039.

Both laboratories found that sustained flaming occurred on the unexposed faces of the plasterboard test wall during the test, and when this occurred it was recorded as an integrity failure. Plasterboard sheeting was found to fall away soon after the initiation of flaming and the tests where subsequently discontinued. The average time to integrity failure based on the flaming criteria was 107 ± 2 minutes.

The average-temperature versus time recorded for test VR0039 can be seen in Figure 5-5.

5.4 Bad-Workmanship Plasterboard Walls

The three *bad-workmanship* walls reached insulation failure at 76 ± 3 minutes based on the average-temperature criteria, and 73 ± 3 minutes based on the maximum-temperature criteria. Thus, the bad-workmanship walls reached insulation failure approximately 5 minutes earlier than the good-workmanship walls (the best performance by a standard-workmanship wall was 83 minutes, while the worst performance by a bad-workmanship wall was 70 minutes).

The average time to integrity failure based on the flaming criteria was 108 ± 4 minutes, almost the same result as for the standard-construction wall although the variability was higher.

The average-temperature versus time recorded for test VR0036 can be seen in Figure 5-6. The average temperature recorded on the unexposed face is compared to the same measurements on a standard-workmanship wall in Figure 5-7.

Table 4. Furnace Test Results – Masonry Walls.

Type of Furnace Test	Construction/ Workmanship	Testing Lab.	Lab. Test Ident.	Insulation Failure – Average [1] (minutes)	Insulation Failure – Maximum [2] (minutes)	Integrity Failure (minutes)	Structural Failure (minutes)	Final Temp. Average [3] (˚C)	Final Temp. Maximum [4] (˚C)	Final Deflection5 (mm)	Min. Failure Time any Reason (minutes)
Standard	Standard	CSIRO	VR0030	103	122	No failure at 241 min.	No failure at 241 min.	294	307	Not measured.	103
Standard	Standard	CSIRO	VR0031	104	117	No failure at 241 min.	No failure at 241 min.	304	318	87	104
Standard	Bad	CSIRO	VR0032	No failure at 95 min.	No failure at 95 min.	46	95	126	155	101	46
Standard	Bad6	CSIRO	VR0033	98	114	147	147	222	237	98	98
Standard	Bad	CSIRO	VR0034	No failure at 81 min.	No failure at 81 min.	81	81	133	151	98	81
Standard	Standard	CSIRO	VR0035	107	122	220	No failure at 240 min.	303	315	156	107
Modified	Standard	CSIRO	VR0041	No failure at 60 min.	No failure at 60 min.	No failure at 60 min.	No failure at 60 min.	69	73	7	-

Notes:
[1] The average temperature of the relevant thermocouples attached to the unexposed face rises by more than 140 K above the initial temperature.
[2] The temperature of any of the relevant thermocouples attached to the unexposed face rises by more than 180 K above the initial temperature.
[3] Average temperature of the thermocouples attached to the unexposed face (excluding those over the mortar joints) when structural failure occurred or when the test was terminated, which ever occurred first.
[4] The maximum temperature recorded by any thermocouple attached to the unexposed face (excluding those over the mortar joints) when structural failure occurred or when the test was terminated, which ever occurred first.
[5] The final deflection recorded at the centre point of the wall when structural failure occurred or when the test was terminated, which ever occurred first.
[6] The wall used in CSIRO test VR0033 was nominally of *bad-construction,* however, it was judged to be of better constructed than the other *bad-construction* masonry walls.

Table 5. Average Time To Failure For Masonry Walls In Furnace.

Construction/ Workmanship	No. of Tests	Insulation Failure-Average (minutes)	Insulation Failure-Maximum (minutes)	Integrity Failure (minutes)	Structural Failure (minutes)	Minimum Failure Time due to any Criteria (minutes)
Standard	3	105 ± 2	120 ± 3	N.D.	> 240	105 ± 2
(Less) Bad	1	98	114	147	147	98
Bad	2	N.D.	N.D.	63 ± 17	88 ± 7	63 ± 17

[1] N.D. = *not determined.*

Table 6. Furnace Test Results - Plasterboard Walls.

Type of Furnace Test	Construction/ Workmanship	Testing Laboratory	Lab. Test Ident.	Insulation Failure – Average [1] (minutes)	Insulation Failure – Maximum [2] (minutes)	Integrity Failure [3]	Min. Failure Time any Reason (minutes)	Notes
Standard	Standard	WFRA/BHP	BFT 750	78	75	108 min 50s	75	
Standard	Bad	WFRA/BHP	BFT 751	79	75	112 min	75	
Standard	Standard	WFRA/BHP	BFT 752	78	76	109 min 30 s	76	
Standard	Bad	WFRA/BHP	BFT 753	75	70	106 min.	70	
Standard	Bad	CSIRO	VR0036	75 wall	75 wall	107 min.	75	Sheet fell off at 110 min and test terminated.
Standard	Standard	CSIRO	VR0039	79 wall (73 joint)	83 wall (77 joint)	105 min.	79	Test terminated at 109 min.
Modified	Standard	CSIRO	VR0040	No failure at 61 min.	No failure at 61 min.	No failure at 61 min.	-	Test terminated at 61 min.

Notes:

[1] The average temperature of the relevant thermocouples attached to the unexposed face rises by more than 140 K above the initial temperature.

[2] The temperature of any of the relevant thermocouples attached to the unexposed face rises by more than 180 K above the initial temperature.

[3] Sustained flaming occurred on the unexposed faces of all the plasterboard wall specimens. When this occurred it was considered to be an integrity failure. Plasterboard sheeting on the unexposed face fell away soon after initiation of flaming, and the tests were discontinued thereafter.

Table 7. Average Time To Failure For Plasterboard Walls In Furnace.

Construction/ Workmanship	**No. of Tests**	**Insulation Failure-Average (minutes)**	**Insulation Failure-Maximum (minutes)**	**Integrity Failure (minutes)**	**Structural Failure (minutes)**	**Minimum Failure Time due to any Criteria (minutes)**
Standard	3	78 ± 1	78 ± 5	107 ± 2	N.D.	77 ± 2
Bad	3	76 ± 3	73 ± 3	108 ± 4	N.D.	73 ± 2

[1] N.D. = *not determined.*

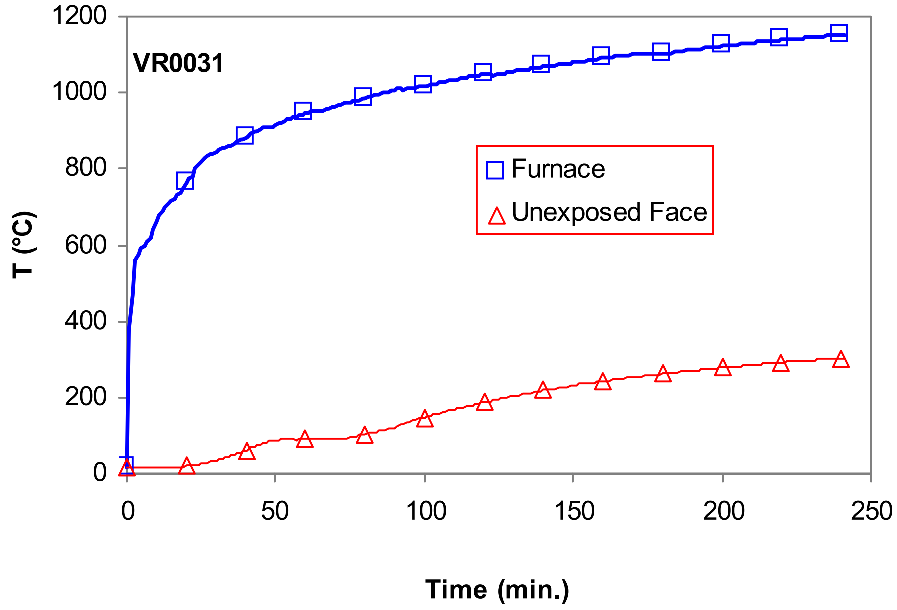

Figure 5-1. Average temperature versus time for *standard-workmanship* masonry wall. Standard furnace test.

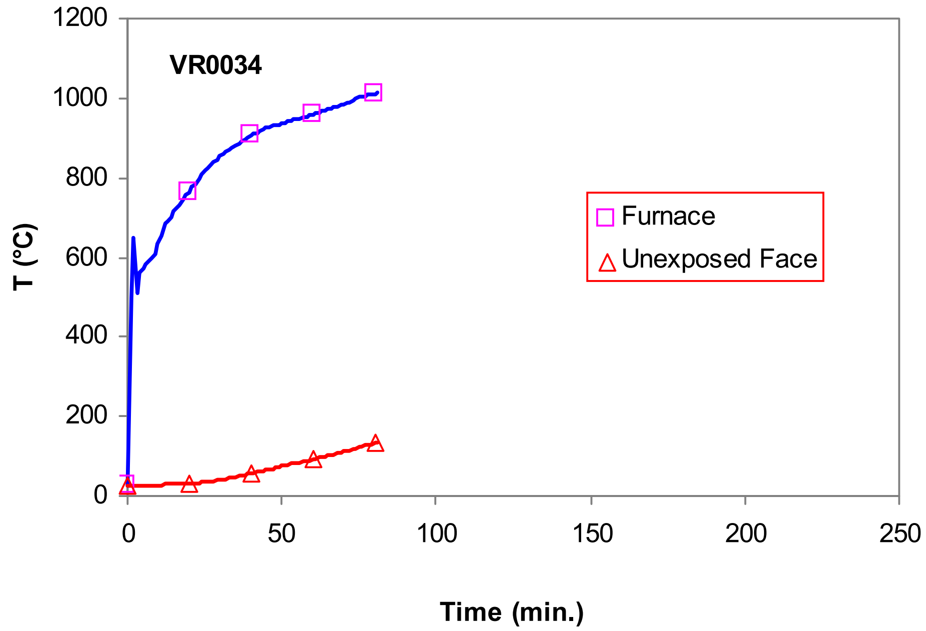

Figure 5-2. Average temperature versus time for *bad-workmanship* masonry wall. Standard furnace test.

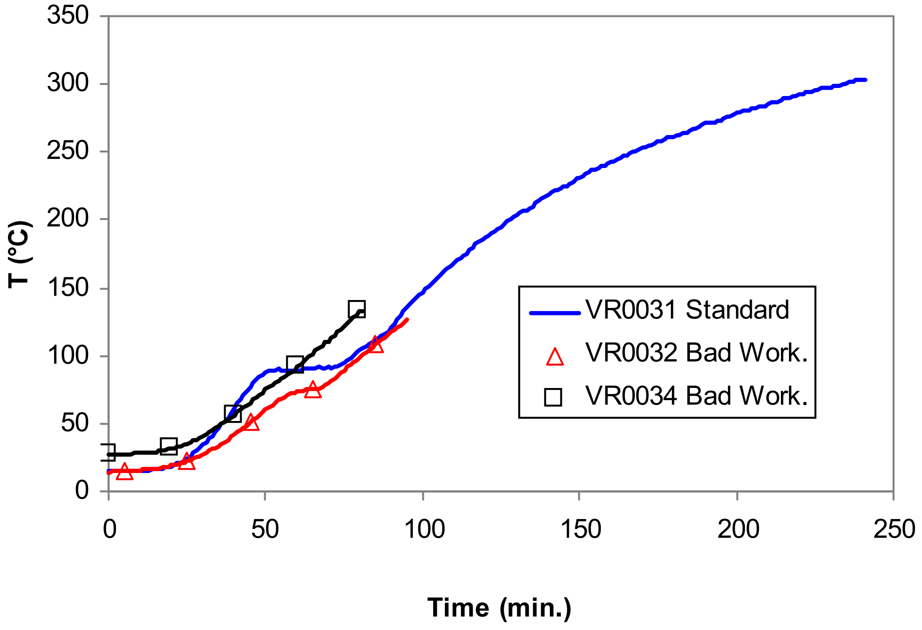

Figure 5-3. Average temperature on unexposed faces of masonry test walls. Standard furnace test.

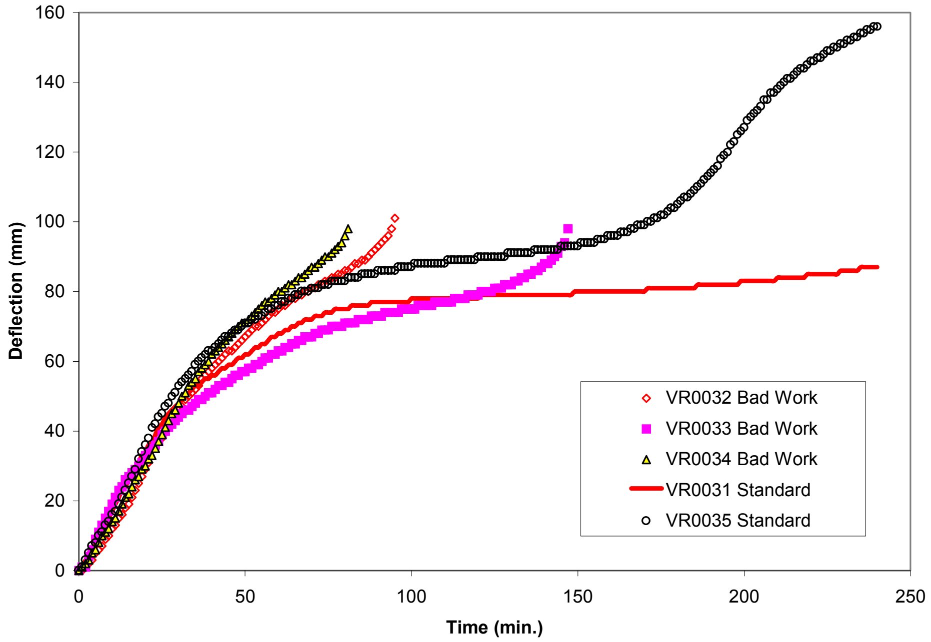

Figure 5-4. Deflection measured at midpoint of standard and bad-workmanship masonry walls. Standard furnace test.

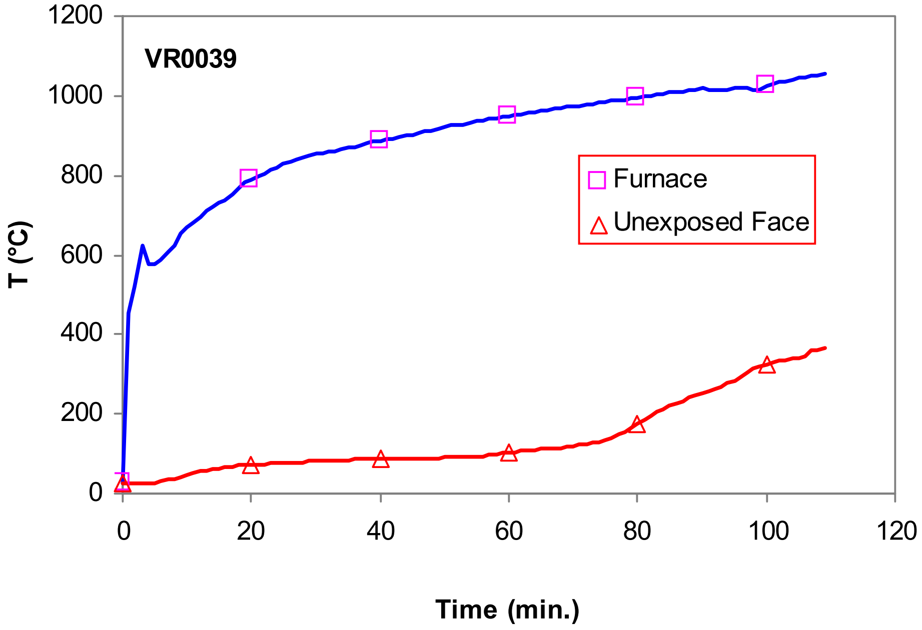

Figure 5-5. Average temperature versus time for standard-workmanship plasterboard wall. Standard furnace test.

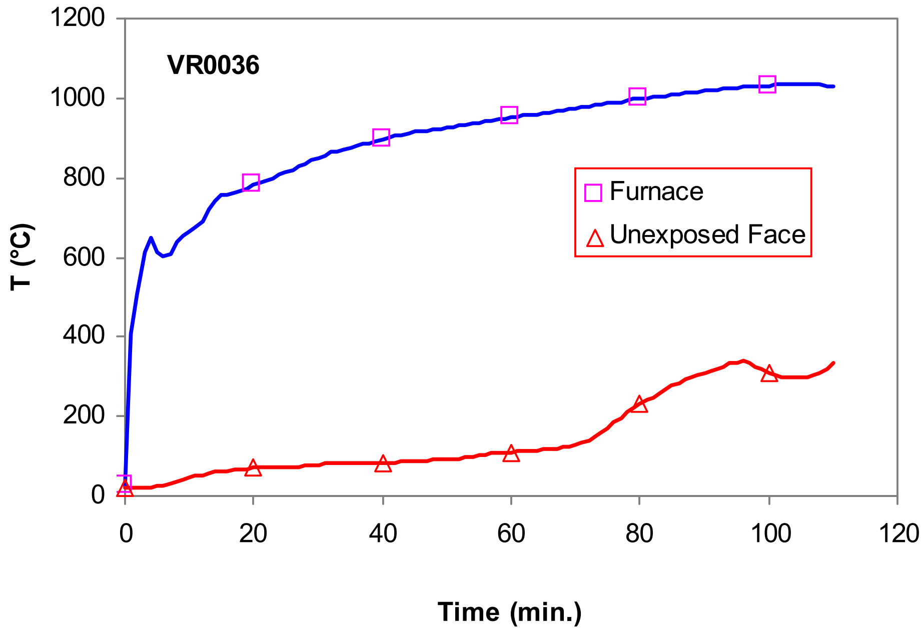

Figure 5-6. Average temperature versus time for bad-workmanship plasterboard wall. Standard furnace test.

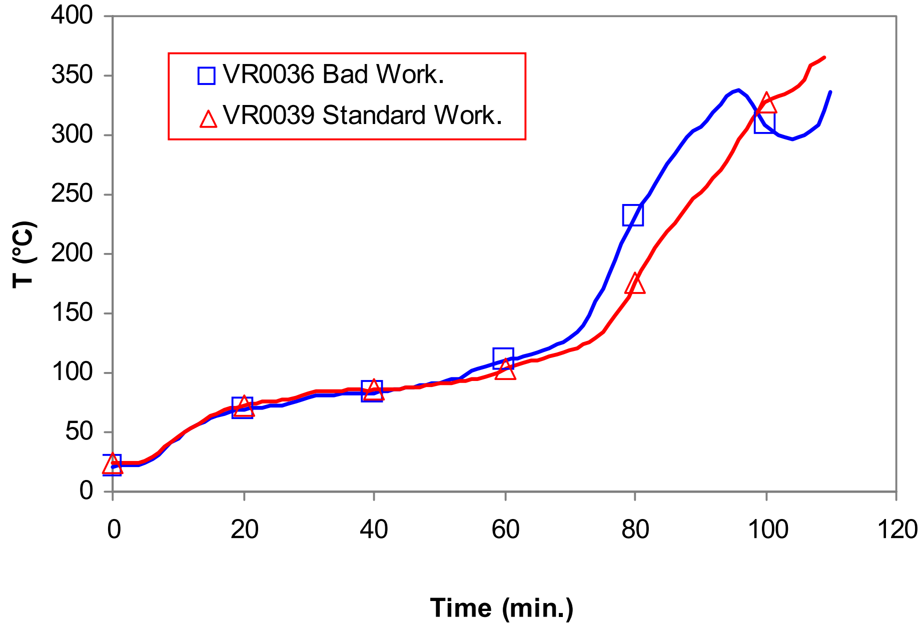

Figure 5-7. Average temperature on unexposed faces of plasterboard walls. Standard furnace test.

6 TEST SERIES #3- MODIFIED FURNACE TESTS

6.1 Masonry Walls

A modified furnace test was conducted (test *VR0041*) where the time-temperature curve for the furnace approximated the time-temperature curve recorded by the average of thermocouples *T1-T9* taken during the masonry room test *CSIRO #1*. A comparison of these two time-temperature curves can be seen in Figure 6-1.

Figure 6-2 compares the average unexposed-face wall temperatures recorded during this modified-furnace test (VR0041) with those measured during the actual room test (*CSIRO #1).* For comparison, the results from the two other masonry wall tests (*BFT747* and *BFT748)* are also shown, although the furnace time-temperature curve did not try to match the air temperatures obtained during these tests. The figure also shows the results from a standard furnace test on a masonry wall (*VR0031*). Each curve represents the average of five thermocouples, namely *U1-U5* (compared with Figure 4-10 and Figure 4-11 which are averages of seven thermocouples, *U1-U7).* One observation from this figure is that all three room tests (conducted at two laboratories) indicate quite an early rise in temperature on the unexposed face, while both the furnace tests indicate quite a long time lag due to the thermal inertia of the wall. This rapid rate of heat transfer through the masonry wall in the room tests is discussed further in Section 8.2.

The recorded deflection at the mid-point of the test walls is shown in Figure 6-3. Note that *BFT747* involves a *standard-workmanship* wall, while *BFT748* involves a *bad-workmanship* wall. The test-room walls show a rapid increase in the deflection around the time of 2-3 minutes that corresponds to the initial rise in temperature at the exposed face (see Figure 4-1.) and also coincides closely the first rise in temperature experience at the unexposed surface in Figure 6-2.

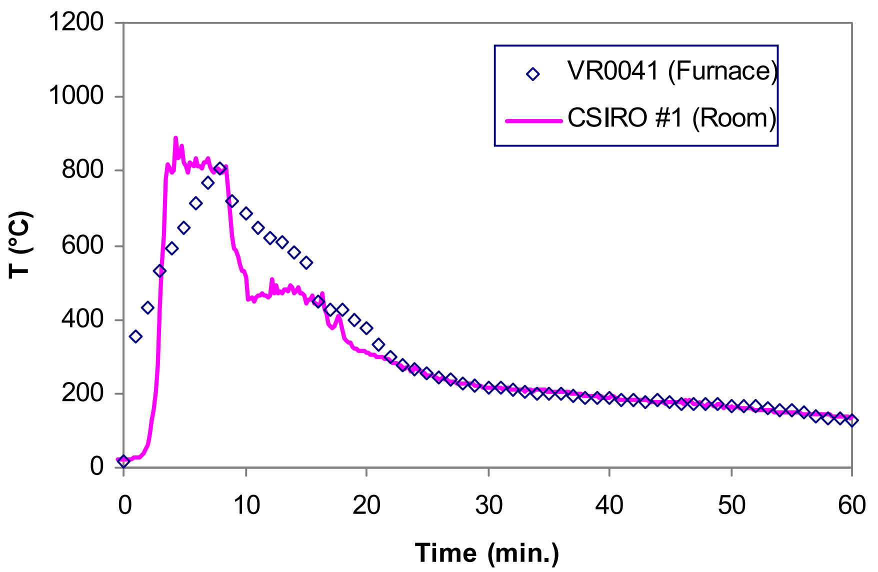

Figure 6-1. Modified furnace test on masonry wall: Comparison of average furnace temperatures with average room-test air temperatures.

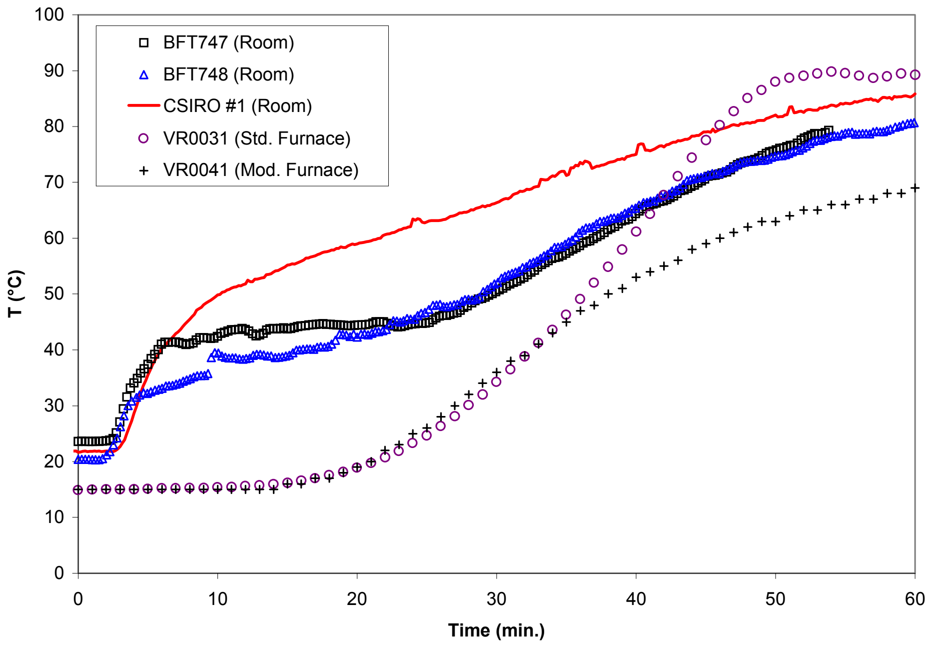

Figure 6-2. Modified furnace test on masonry wall: Comparison of average unexposed-face wall temperatures (thermocouples *U1-U5)* obtained during the furnace and room tests.

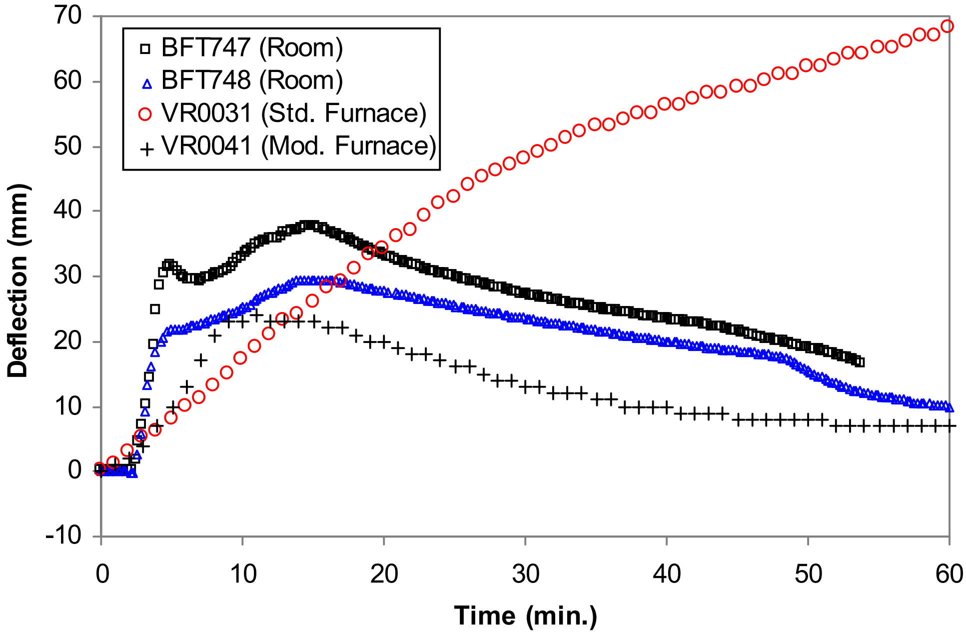

Figure 6-3. Modified furnace test on masonry wall: Comparison of deflection at mid-point of wall obtained during the furnace and room tests.

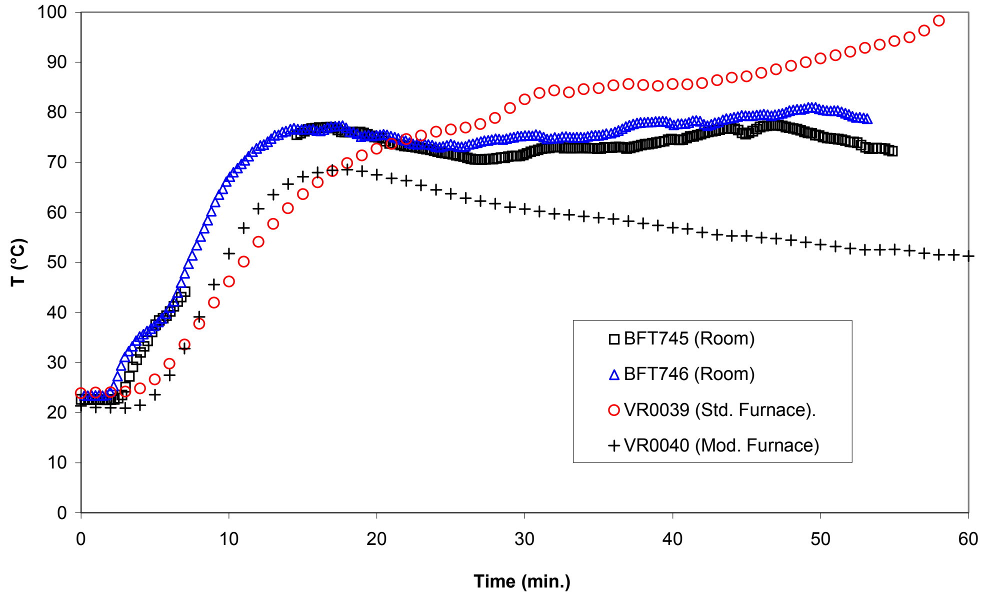

Figure 6-5. Modified furnace test on plasterboard wall: Comparison of average unexposed-face wall temperatures (thermocouples *U1-U5)* obtained during the furnace and room tests.

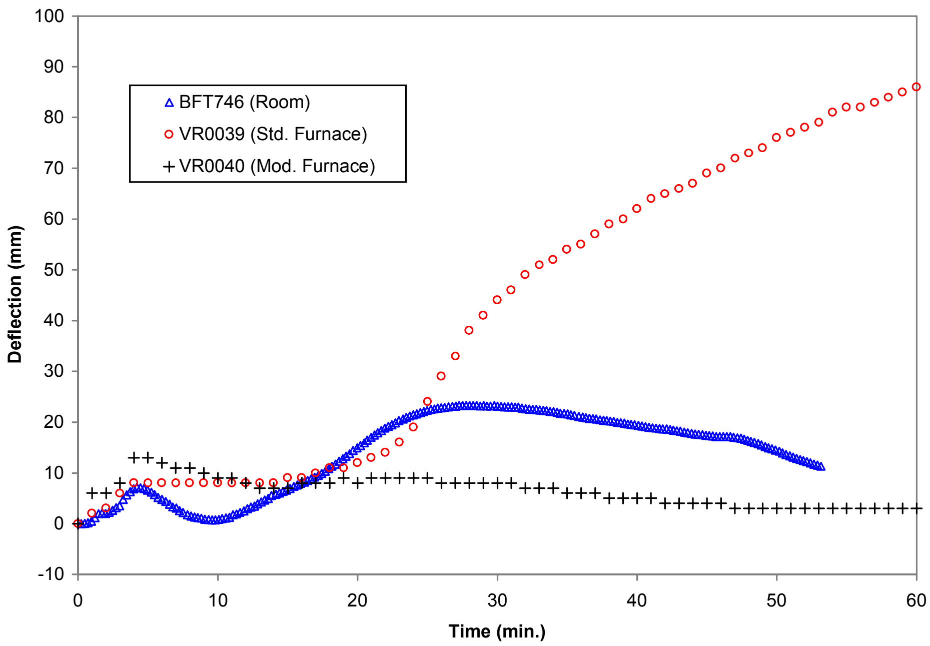

Figure 6-6. Modified furnace test on plasterboard wall: Comparison of deflection at mid-point of wall obtained during the furnace and room tests.

7 COMPARISON OF ROOM AND FURNACE TESTS

Figure 7-1 shows the average air temperatures measured at the exposed face (average of thermocouples *T1-T9*) averaged over all four BHP room tests, including masonry and plasterboard walls. For comparison, the standard time-temperature variation prescribed for the furnace test in AS 1530.4-1990, namely,

$$T - T_i = 345\log_{10}(8t+1) \qquad \textbf{(Equation 7-1)}$$

where

T = furnace temperature at time t in degrees Celsius
T_i = initial furnace temperature in degrees Celsius
t = time in minutes

is also shown.

The two curves from Figure 7-1 are integrated and plotted on Figure 7-3, where

$$Q_C \equiv \int (T-T_i)\, dt \qquad \textbf{(Equation 7-2)}$$

and T_i is the initial temperature. The resulting two curves are similar up until a time of approximately 15 minutes. This would indicate that the total heat absorbed by the test walls due to conduction should be similar up until this time.

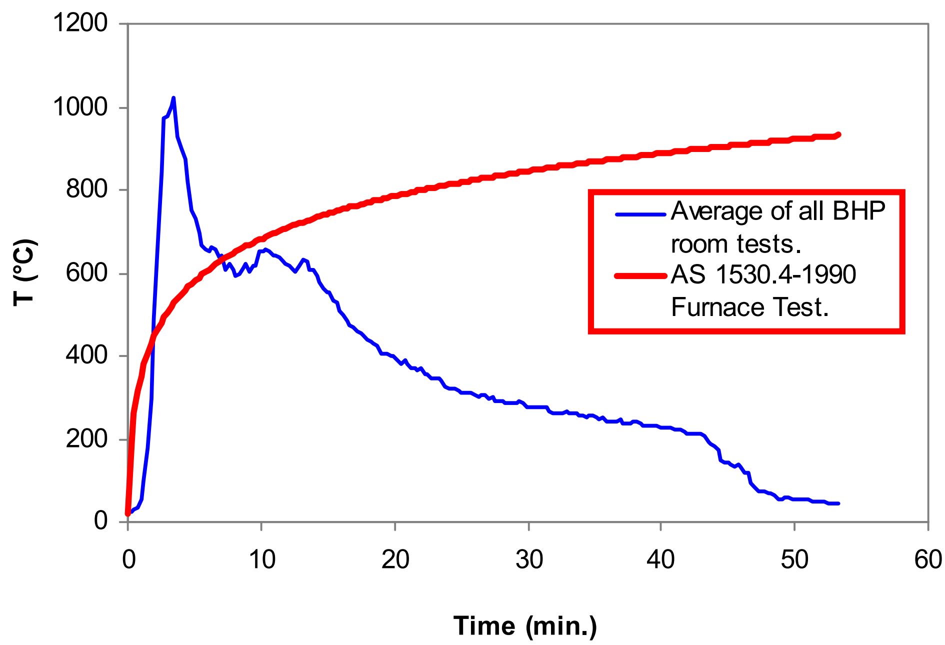

Figure 7-1. Exposed-face air temperatures measured during BHP room tests compared with the standard furnace test from AS1530.4-1990.

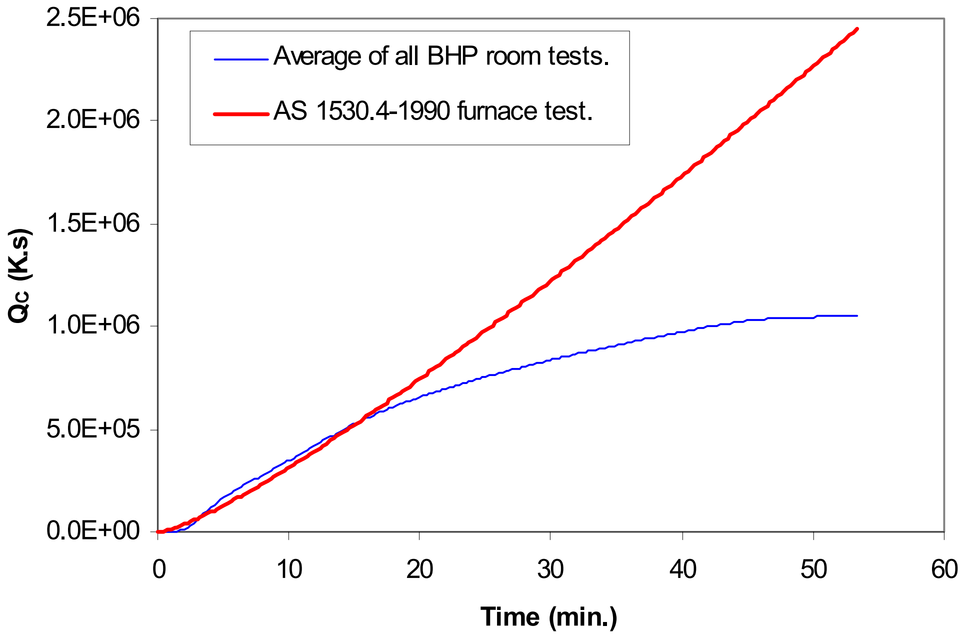

Figure 7-3. Integrated values of the time-temperature curves recorded near the exposed faces of the test walls.

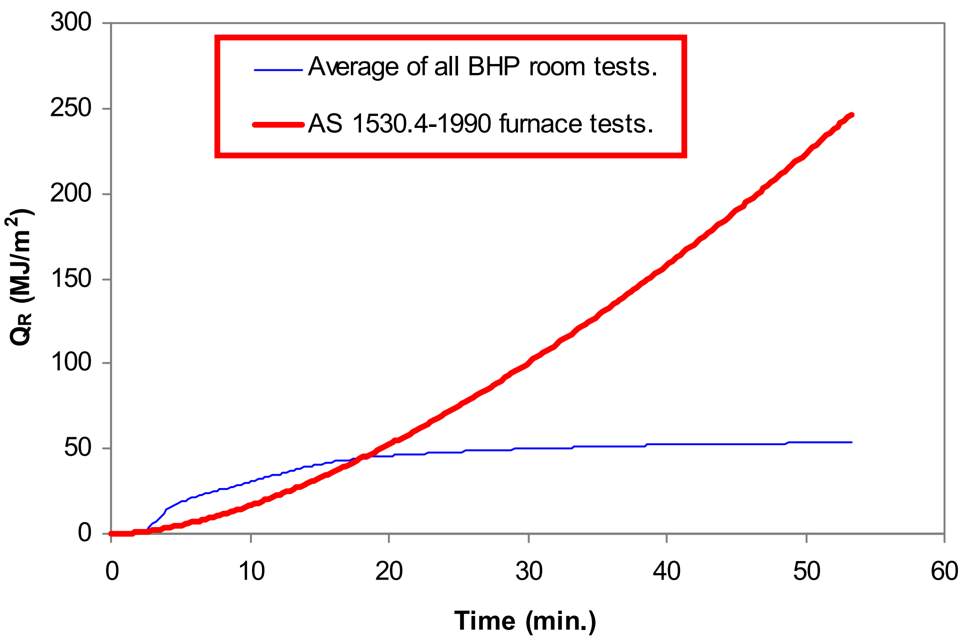

Figure 7-2. Values of Q_R evaluated near the exposed faces of the test walls.

Figure 7-2 is similar to Figure 7-3 except that values of Q_R versus time have been plotted, where

$$Q_R \equiv \int \sigma(T^4 - T^4_i)\, dt \qquad \textbf{(Equation 7-3)}$$

and where σ is the Stefan-Boltzmann constant and T is the absolute temperature. This curve may give an indication of the different levels of radiative heating to the test wall, although in reality variations in the exposed-wall temperatures, different emissivities of the participating gases, and different levels of background radiation, would have an influence on the radiative heating rates.

Figure 7-4 compares the time required to increase the average temperature of the unexposed face of the test wall (relative to the initial temperature) in the standard furnace test, with the time taken for the same increase in temperature in the room tests. The relationship for the plasterboard wall is fairly linear between furnace times of approximately 9 and 26 minutes. The curve cannot be extended beyond this point since the temperatures measured in the room test plateau, while the temperatures in the furnace test continue to rise (see Figure 6-5). The curve for the masonry wall is almost flat up until furnace times of approximately 29 minutes due to the long thermal lag that is present in the furnace test but absent from the room test (see Figure 6-2). The curve is fairly linear between furnace time of 31 minutes and 39 minutes. The curve for the masonry wall cannot be extended beyond this point due to lack of data.

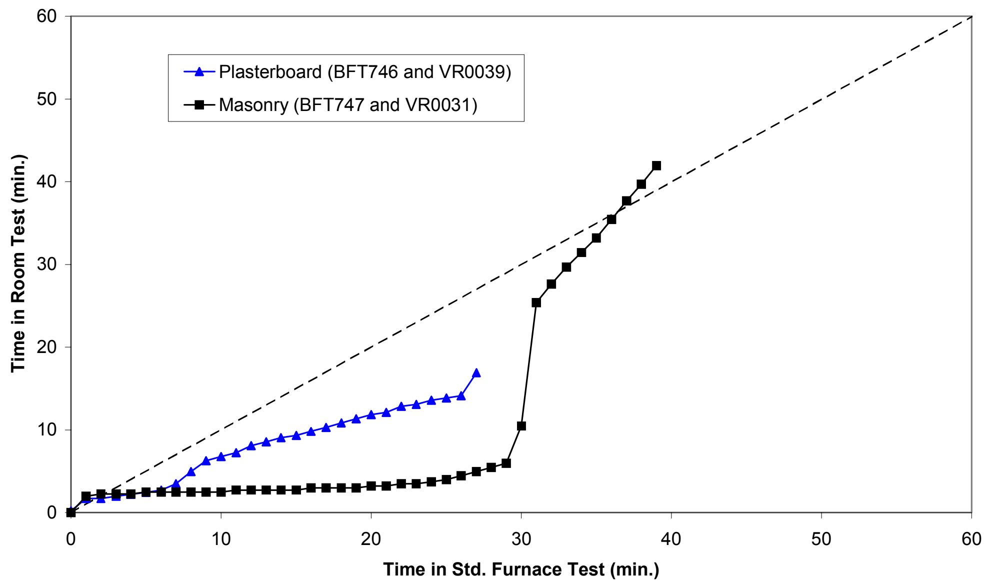

Figure 7-4. Time to reach the same change in unexposed-face temperature in standard furnace test and room test (using thermocouples *U1-U5)*.

8 DISCUSSION

8.1 Burn-Out Time

Observations of ventilation-controlled, post-flash-over, wood fires in the literature has lead to the follow empirical relation[6]

$$\dot{m}_f = 0.09 A_o \sqrt{H_o} \qquad \textbf{(Equation 8-1)}$$

where

$\dot{m}_f$ = mass burning rate of fuel (kg/s)

A_o = area of opening (m^2)

H_o = height of opening (m).

If we assume that the equation can be modified for two openings as follows

$$\dot{m}_f = 0.09\left(A_{o,d}\sqrt{H_{o,d}} + A_{o,w}\sqrt{H_{o,w}}\right) \qquad \textbf{(Equation 8-2)}$$

where the subscript *d* represents the door, and *w* the window, then we can determine that the theoretical consumption rate of wood within the current test room, based on the dimensions shown in Figure 3-1, would be 0.638 kg/s.

Now, the total fire load of the test room is 8730 MJ (consisting of 88% materials of wood origin, and 12% of other origin.). Assuming we can convert the total fire load to an *equivalent* mass of wood by dividing by the heat of combustion of wood (using ΔH_c = 18 MJ/kg) then the total fire load of the room is equivalent to 485 kg of wood. Hence the theoretical time for consumption of the fuel in the room is approximately

$$\tau = 485/0.638 = 760 \text{ s} = 12 \text{ min } 40 \text{ s}.$$

From the room-test data shown in Figure 7-1, if we take the time of ventilation-controlled flashover to be from the first peak in temperature (at time $t \approx 2.7$ minutes), until the end of the constant-temperature period (at time $t \approx 13.9$ minutes), then the experimental ventilation-controlled burn-out time for the room is approximately 11 minutes, which is in quite good agreement with the theory presented above.

8.2 Heat-Transfer in Masonry-Wall Room Tests

8.2.1 Thermocouple Location

The masonry-wall results from Figure 6-2 indicate significantly earlier temperature rises on the unexposed faces during the room tests, than for the furnace tests. In Figure 8-1 the individual temperature traces from all the thermocouples attached to the unexposed face during room test *BFT 747* are displayed. All thermocouples show

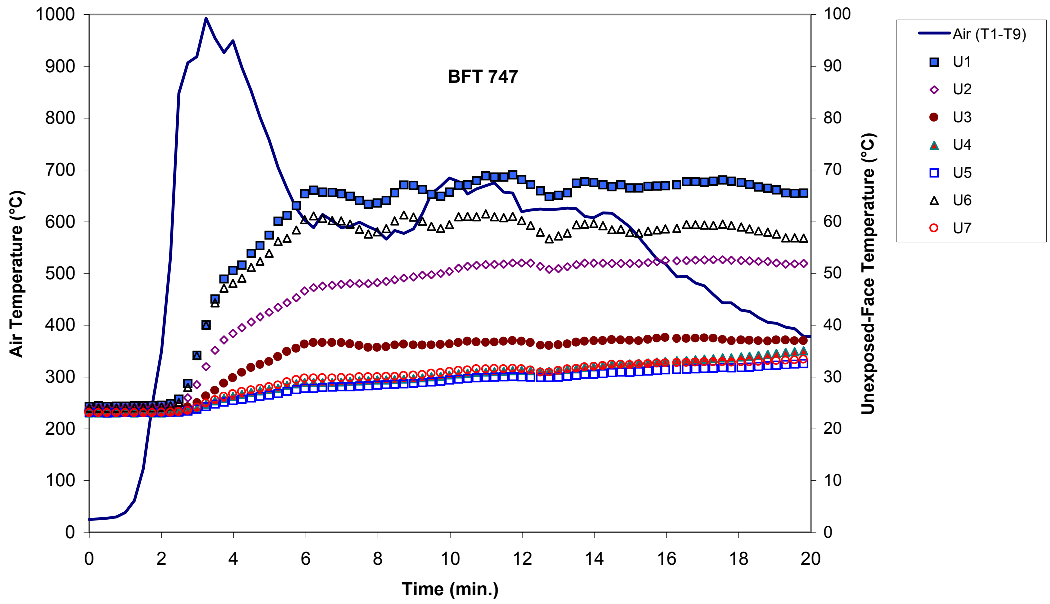

Figure 8-1. Temperatures recorded during room test on masonry wall.

a rise in temperature from around time t = 3 minutes. The temperature rises occur both on thermocouples attached to the brick faces (thermocouples *U1-U5)* as well as those attached to the mortar joints (*U6* and *U7).* There appears to be, however, a correlation in temperature with height on the wall. Thermocouples *U1, U2,* and *U6* are located towards the top of the wall, *U3* is located at the centre of the wall, and *U4, U5,* and *U7* are towards the bottom. The higher thermocouples show larger temperature rises.

8.2.2 Theoretical One-Dimensional Heat Transfer

Solving the one-dimensional heat-transfer equation, assuming heat transfer within the solid is due only to conduction, assuming the following properties for common bricks from the literature (Ref. **Error! Reference source not found.**)

Density	ρ	1920	kg/m3
Specific heat	C	835	J/kg·K
Thermal conductivity	k	0.72	W/m·K

and assuming the exposed-face boundary conditions is either

(a) a constant temperature of 1000°C , or
(b) a constant heat flux of 50 kW/m2

produces the results indicated in Figure 8-2. It can bee seen that according to this theory, at a time of three minutes, the region of high temperature should only have penetrated to a depth of approximately 30 mm. In comparison, the masonry wall thickness used in the tests was 110 mm. This would indicate that the unexposed-face temperature rises at time t = 3 minutes measured in the room tests must be due to a

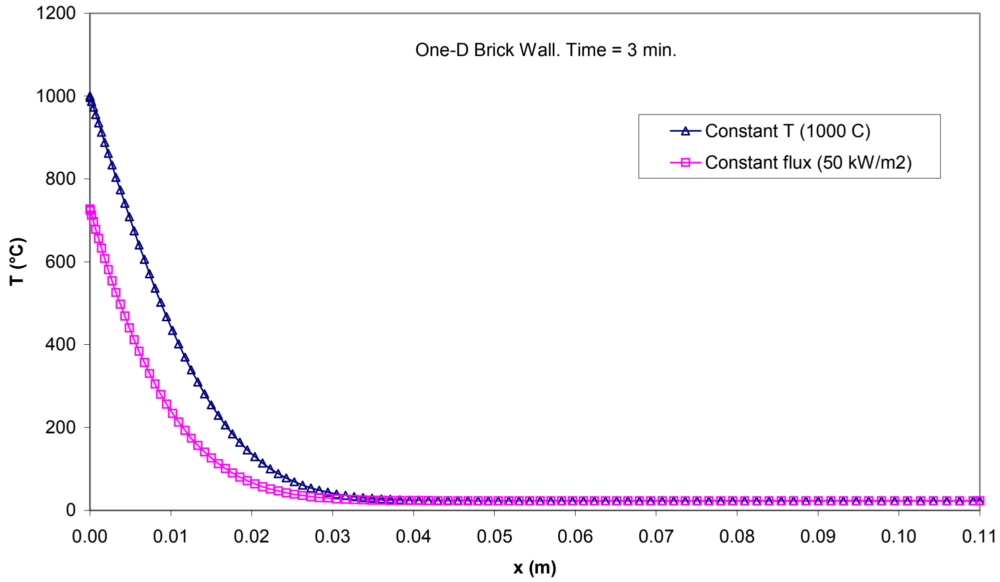

Figure 8-2. Theoretical temperature profile through thickness of brick wall at time 3 minutes.

different mechanism that simple conduction and/or due to a significant variation in the thermal properties.

8.3 Thermocouple Temperature Errors

It is well known that large systematic errors can exist in the instantaneous and time-averaged local-gas-temperature measurements made with thermocouples in a fire environment (see e.g. Refs. 8 and 9). These errors are primarily due to the radiative heat transfer to/from the thermocouples, as well as the finite time of response.

8.3.1 Radiation

In the study of bare-bead and shielded-aspirated thermocouples presented in Ref. 9, it was found that in the *upper layer* the relative error in local gas-temperature (T_g) measurements were fairly insensitive to the effects of background temperature (T_∞). The relative error approached zero as T_∞ approached T_g. However, at the *lower* levels of the room, the relative error was a strong function of both T_g and T_∞. The most extreme errors occurred when T_g was at very low values, and T_∞ was at very high values.

If we assume that T_∞ is approximately 1200 K for the fully-developed room fire, the results given in Ref. 9 (which were for 1 mm bare-bead thermocouples) would indicate an approximate error of 225% in the local gas temperature (expressed as a percentage of the true gas temperature) when T_g = 300 K. The percentage error reduces to zero as T_g approaches 1200 K.

We would expect the local-gas-temperature-measurement errors associated with the present room tests and measured with the *crimped-end* thermocouples (CSIRO thermocouples *A1-A20)* to approximate the performance of bare-bead thermocouples, while the errors associated with *MIMS* thermocouples to be less than those recorded with bare-bead thermocouples, however, the actual values are difficult to quantify. As a result of these measurement errors, it is likely that the true local gas temperature at the lower levels of the test room is less than that indicated by the thermocouples, and hence the variation in local gas temperature with height may be more significant.

It should be noted that although the thermocouples may not measure the local *gas* temperature accurately because of the radiation effects, they do help to quantify the temperatures that objects (which would also be exposed to similar radiation effects) would experience if placed in the same location of the test room.

8.3.2 Response Time

Still-air furnace data presented in Ref. 10 indicate that 3.2 mm *MIMS* thermocouples[*] have a response time of approximately 50 second at 500°C, and 25 seconds at 900°C.

A comparison of gas-temperature measurements made in a furnace that followed the AS1530.4-1990 time-temperature curve with three different types of thermocouples[11] found that *MIMS* thermocouples gave temperature measurements that were very similar to bare thermocouples. It was found that the response time of the *MIMS* and bare thermocouples was significantly faster than for substantially-enclosed thermocouples.

[*] These are the only size *MIMS* thermocouples given in Ref. 10.

9 CONCLUSIONS

9.1 Room Tests

The temperatures recorded inside the room during the room tests showed a small time delay after ignition, followed by a rapid rise in temperature to high levels, then a period of constant temperature, followed in turn by a gradual decline in temperature. In comparison, the standard time-temperature curve specified for the furnace tests rose rapidly from the start, however, the slope of the curve decreased with time, while the actual temperatures always increased. Integrating the time-temperature curves from the room tests and the standard furnace tests produced similar results for approximately the first 15 minutes, after which time the standard furnace test was more severe.

Within-laboratory repeatability of the room tests conducted by BHP were excellent. The peak average air temperatures recorded at the exposed face (average of thermocouples *T1-T9)* was 1106 ± 11 °C for the masonry walls, and 978 ± 14 °C for the plasterboard walls. The interlaboratory reproducibility was not as good, despite quite a detailed test specification. The results obtained from the *CSIRO #1* test, however, were in reasonable agreement with the BHP test results.

9.2 Furnace Tests

In general, good repeatability of results were obtained from both plasterboard and masonry furnace tests. Badly constructed plasterboard walls were found to fail on average 5 minutes earlier than standard-construction walls based on insulation criteria. In other respects the performance of the plasterboard walls in the furnace tests were similar, and all walls achieved a higher FRL than the nominal one-hour resistance they were designed for.

Standard-construction masonry walls were found to fail due to insulation failure. Badly-constructed masonry walls were found to collapse suddenly before they reached insulation failure, and hence before the design fire rating (which would be typically-based on the insulation failure of a good wall) had been achieved. A single masonry wall that was constructed with less severe defects survived structurally for the duration of the fire rating (determined by insulation failure), although the wall still eventually collapsed.

It was noted that the average temperatures reached when structural failure occurred for the two similar *bad-workmanship* masonry walls were nearly identical (130 ± 4 °C), and the deflection for all three *bad-workmanship* masonry walls were also similar (99 ± 2 mm). More tests are required, however, to determine the significance of these values.

9.3 Plasterboard Walls

Comparison of the unexposed-face temperatures in the room tests and standard furnace test showed fairly similar results for the plasterboard walls. The room tests produced a more rapid rise in temperatures, and were more severe up until a time of approximately 20 minutes. After a time of 20 minutes the standard furnace test was producing higher temperatures on the unexposed face (although the temperatures recorded during the room test at this point in time were slightly lower than they had been 5 minutes earlier. See Figure 6-5).

Running the furnace test with a modified time-temperature curve produced unexposed-face temperatures that were similar to the standard furnace test up until a time of 20 minutes, with diverging results from this point onwards. Direct room test data were not available for comparison.

9.4 Masonry Walls

All three room tests on masonry walls indicated only a small time lag before the unexposed-face temperature began to rise. By examination of the unexposed-face temperature, it was concluded that the room tests were more severe than the furnace tests up until a time of approximately 40-45 minutes, after which time the furnace tests were more severe. In comparison to the room tests, the furnace tests had a long thermal lag period. This long thermal lag is typical of results from furnace tests on materials with a large thermal inertia, and it might have been expected that a long thermal lag period would also exist in the room tests. However, this was found not to be the case. The modified furnace test results were similar to the standard furnace tests, which indicated that the different time-temperature curves were not solely responsible for the differences in the heating rates observed.

The exact mechanism for this high heat-transfer rate through the masonry wall in the room tests is not certain. It was found, however, that the temperature rises on the unexposed-face were more significant towards the top of the wall, and were also associated with quite large deflections recorded at the centre of the wall. For the room test conducted here, the high heat-transfer rates appear to be mostly academic, as the masonry walls withstood the duration of the fire without structural or insulation failure. However, since the mechanism is not totally understood, it is not possible to determine whether this would always be the case, particularly if the burn-out times for the room were significantly longer.

The badly-constructed masonry wall used in the room test survived the duration of the test without collapse, although the total length of time for the test was less than that required to produce collapse as indicated by the furnace tests. In other respects the badly constructed wall performed in a similar fashion to the *standard-construction* wall in the room tests.

9.5 Overall Results

1. Furnace and room test results were repeatable and reasonably reproducible.
2. Different levels of workmanship had a measurable difference on the fire-resistance performance of plasterboard and masonry walls. In the case of the plasterboard walls the differences would not usually be considered significant. In the case of the masonry walls, very badly constructed walls could significantly affect the structural performance of a wall exposed to a fire, and special care may be required when constructing masonry walls that are used in areas where large fire resistance levels are required.

3. The real-room fire that was used in the series of experiments reported here was more severe on the test walls than the standard furnace test during the early stages of the fire. As time progressed, however, the standard furnace test became more severe. The relationship between time in the standard furnace test and time in the real fire was a complex one that also depended on the material under test.
4. Significantly higher heat-transfer rates through the masonry walls were experienced in the early stages of heating in the room-burn tests than in the furnace tests. The mechanism by which this occurs is not yet understood.

10 REFERENCES

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APPENDIX A

FIRE TEST SPECIFICATION

FIRE CODE REFORM PROJECT 3
FIRE TEST SPECIFICATION

J. Blackmore, C. Brescianini, G. Collins and N. L. Mulcahy
CSIRO Division of Building, Construction and Engineering
North Ryde

R. Ralph and I. Thomas
BHP Research – Melbourne Laboratories
Mulgrave

P. Beever
VUT Centre for Environmental Safety and Risk Engineering
Melbourne

February 1998

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1 BURN ROOM SPECIFICATION

1.1 The Room

The room shall consist of four walls at right angles, with the specimen wall forming one of the 3000 mm x 3000 mm boundaries, a floor and a ceiling, and shall have the following *internal* dimensions:

3600 mm(± 50 mm) long x 3000 mm (± 50 mm) wide x 3000 mm (± 50 mm) high.

The room shall be placed indoors in an essentially draught free environment. There shall be a doorway in the centre of the 3000 mm x 3000 mm wall opposite the specimen wall, and a window in one of the walls adjacent to the specimen wall. No other wall, floor or ceiling shall have openings that will permit ventilation.

The doorway shall be 800 mm (± 10 mm) wide x 2000 mm (± 10 mm) high. The window shall be 2000 mm (± 10 mm) wide x 1800 mm (± 10 mm) high. The top of the window will be at the same height as the internal suspended ceiling (i.e. 2400 mm above the floor). The window will be located midway between the front wall (which contains the door) and the rear specimen wall.

All walls (other than the specimen test wall) and the ceiling (excluding the suspended ceiling), shall be 'permanent' and of fire-rated construction, consisting of two layers of 16 mm fire-grade plasterboard (Boral Firestop or CSR Fyrchek). The floor of the test room will be concrete and lined with a carpet and underlay.

Standard "bull-nose" skirting board, 68 mm in height, will be added to the perimeter of the test room after laying carpet. The skirting board will be constructed from 18 mm Medium Density Fibreboard (MDF).

Sheet metal flashing should be applied to the window and door areas. Skirting board should also be fitted around the doorway and the window to finish off these edges.

The window of the test room is to be covered with two layers of clear, 100-micron thick, PVC film.

At least one manually-operated sprinkler head will be mounted to the ceiling of the test room as a safety precaution.

Notes:

The 'permanent' walls of the test room use two layers of plasterboard attached to a single side of the steel studs, whereas the specimen plasterboard wall (described in Section 3) will be constructed from single layers of plasterboard attached to two sides of the steel studs.

The test room is to be constructed with both a 'permanent' plasterboard ceiling 3000 mm above the floor, and an internal suspended ceiling 2400 mm above the floor.

It is not required that the suspended ceiling withstand the entire duration of the fire test.

1.2 Rationale

The dimensions of the wall are selected to be compatible with the dimensions of specimens tested in AS1530.4-1990 furnace tests. The other dimension of the test room (i.e. the 3600 mm length) is chosen to be consistent with the length of the ISO 9705-1993 Fire Test Room.

The dimensions of the door opening are the same as the door opening in the ISO 9705-1993 Fire Test Room, while the dimension of the window are chosen to provide adequate ventilation.

Plastic sheeting is to be used over the window based on experience obtained from room-fire tests conducted by the Centre for Experimental Safety and Risk Engineering (CESARE), Victorian University of Technology (VUT). These tests indicated that reduced ventilation in the early stages of the fire helped to achieve repeatable flashover conditions.

The fire-grade plasterboard construction materials are compatible with the ISO 9705-1993 requirement that the test room be constructed from a non-combustible material with a density of 500 kg/m^3 to 800 kg/m^3 and a minimum thickness of construction of 20 mm.

2 INSTRUMENTATION

Nine mineral insulated high temperature stainless steel sheathed thermocouples (MIMS) having a wire diameters less than 1.0 mm and measuring junction welded to the sheath shall be fixed 200 mm from the test wall, inside the burn room, and arranged symmetrically relative to the face of the test wall. (These thermocouples are of the same type to be used during the furnace tests conducted at CSIRO-DBCE, and are the same as those expected to be stipulated in the new edition of AS 1530.4 due for release shortly).

Five specimen thermocouples as specified in clause 2.2.3.2 of AS 1530.4-1990 shall be attached to the unexposed face of the test wall at the mid-point of the wall and the four quarter points. Additionally two specimen thermocouples as specified in clause 2.2.3.2 of AS 1530.4-1990 shall be attached to the unexposed face of the test wall over mortar joints, one in the top half of the wall and one in the bottom half of the wall.

The temperature shall be measured at one-minute intervals to an accuracy of ± 1 percent or ± 3°C, whichever is greater.

Deflection at the mid-point of the wall shall be measure throughout the test to an accuracy of ± 2 mm.

Note, a plan showing the location of all thermocouples should be recorded.

A comprehensive video record of all tests shall be made. A clock should appear in the video record, giving time to the nearest 1 s.

3 PLASTERBOARD SPECIMEN WALL SPECIFICATION

3.1 General

The plasterboard specimen wall represents a wall of one-hour nominal fire resistance.

3.2 Materials

3.2.1 Plasterboard

16 mm fire-grade plasterboard (Boral Firestop or CSR Fyrchek).

The Boral Firestop is described as fire-resistant grade plasterboard, consisting of gypsum based core. The Early Fire Hazard Indices for the Firestop, when tested according to AS1530.3-1989, are Ignitability 14, Spread of Flame 0, Heat Evolved 1, Smoke Developed 1. (Test Report No. NBTC E 5086). Density of the 16 mm plasterboard is approx. 13 kg/m^2.

3.2.2 Screws

Corrosion-Resistant, Bugle Head Type 1 & Type 2 Gypsum Screws:
8 x 25, 32 mm for single layer application

3.2.3 Joint Treatment

B300, Basebond 60 or 90 Jointing Cement Slotted paper tape,
50mm width F300 Plus, TX500 or TopCote Cement or similar

3.2.4 Caulking

Boral Plasterboard Cornice Adhesive, Boral Fyreflex Sealant or similar.

3.2.5 Steel Component Designations

64 mm (deep) CS Stud 0.55, 0.75 and 1.15 BMT

64 mm (deep) DT Deflection Head Track 0.75 BMT

3.2.6 Skirting Board

Standard "bull-nose" skirting board, 68 mm in height. Constructed from 18 mm Medium Density Fiberboard (MDF).

3.2.7 Flashing

The flashing material for around the door and window will be 0.8 mm thick steel sheet folded into a 125 x 40 channel section.

3.3 Installation

Partition layout for 3000 mm x 3000 mm x 96 mm (i.e. stud plus plasterboard) thick test wall should be marked accurately, checking individual measurements against overall dimensions.

Align top and bottom tracks accurately according to the layout, and attach at ceiling and floor to structural elements with suitable fasteners located 50 mm from each end and spaced at max. 600 mm centres.

Cut studs 16 mm short of the floor-to-ceiling height to allow 16 mm expansion gap at top, fit deflection heads as required. Studs in fire-rated partitions are not to be fastened to top and bottom tracks.

First Side
Screw fasten plasterboard vertically to studs at edges only, centering abutting edges on stud flanges. Sheets should be installed by advancing in the direction opposite to the stud flange direction.

Second Side
Cut first sheet of plasterboard 600mm wide to stagger joints to first side. Screw fasten this sheet and all subsequent full width sheets to all studs. Return to first side and screw fasten plasterboard sheets to previously unattached studs.

Note
When viewing the test wall from the doorway of the test room, the 600 mm wide plasterboard sheet should be on the right-hand size of the test wall.

Tape and finish joints and angles, and stop fastener heads with any of the range of tested jointing systems.

Caulk all perimeter gaps in fire-rated walls with Boral Plasterboard Cornice Adhesive, Boral Fyreflex Sealant or equivalent.

Fastener Spacing
Space screws at 200 mm centres at vertically abutting edges or ends, staggering screws in adjacent boards 100 mm. Locate screws no closer than 10 mm or more than 16 mm from board edges and ends. Space screws at 300 mm centres around openings and on intermediate studs in the field of the board.

Skirting and Flashing
Screw fix skirtings to bottom track.

3.4 Bad-Workmanship Plasterboard Wall Specification

The 3000 mm x 3000 mm x 96 mm “bad-workmanship” specimen test wall, representing a wall of “one-hour” nominal fire resistance with a reduced quality of workmanship, is to be constructed according to the following specifications:

The test wall is to be constructed from single layers of 16 mm fire-grade plasterboard installed vertically on each side of 64 mm studs. Studs are to be located at 600 mm centres. The type of plasterboard, studs, screws, and caulking material, will be identical to that used in the good-workmanship walls. The studs will be cut 16 mm short of the floor-to-ceiling height to allow 16 mm expansion gap at top, with fitted deflection heads as required. Studs in fire-rated partitions are not to be fastened to top and bottom tracks.

Each side of the wall will consist of three plasterboard sheets, "*A*", "*B*", and "*C*", as indicated on the diagram below. Note that the sheets on Side 1 are *not* to be staggered with respect to those on Side 2.

A 10 mm gap is to be left between sheets A and B, while no gap is to be left between sheets B and C. The 10 mm gap is to be filled with plaster.

All perimeter gaps at the top and bottom of the test wall are to be caulked.

Sheet "*A*"

Plasterboard sheet *A* is to be fastened using the same screw spacing as used on good-workmanship walls. i.e. 200 mm spacing for screws on the perimeter of the sheet, and 300 mm spacing for screws along the centre line of the sheet.

In general, the screws are to be located no closer than 10 mm or more than 16 mm from board edges and ends, as required on the good-workmanship walls. The screws along the side of sheet *A* closest to the 10 mm gap, however, may be located closer to this edge if required.

Every second screw along the centre line of sheet A (i.e. the screws with the 300 mm spacing) is to be driven so that the screw head penetrates the paper.

Every second screw along the side of sheet A that is closest to the 10 mm gap is to break the edge of the sheet.

Sheet "*B*" and Sheet "*C*"

All screws in sheets B and C are to have a spacing of 375 ± 15 mm.

In general, the screws are to be located no closer than 10 mm or more than 16 mm from board edges and ends. The screws along the side of sheet *B* closest to the 10 mm gap, however, may be located closer to this edge if required.

Every second screw along the side of sheet B that is closest to the 10 mm gap is to break the edge of the sheet.

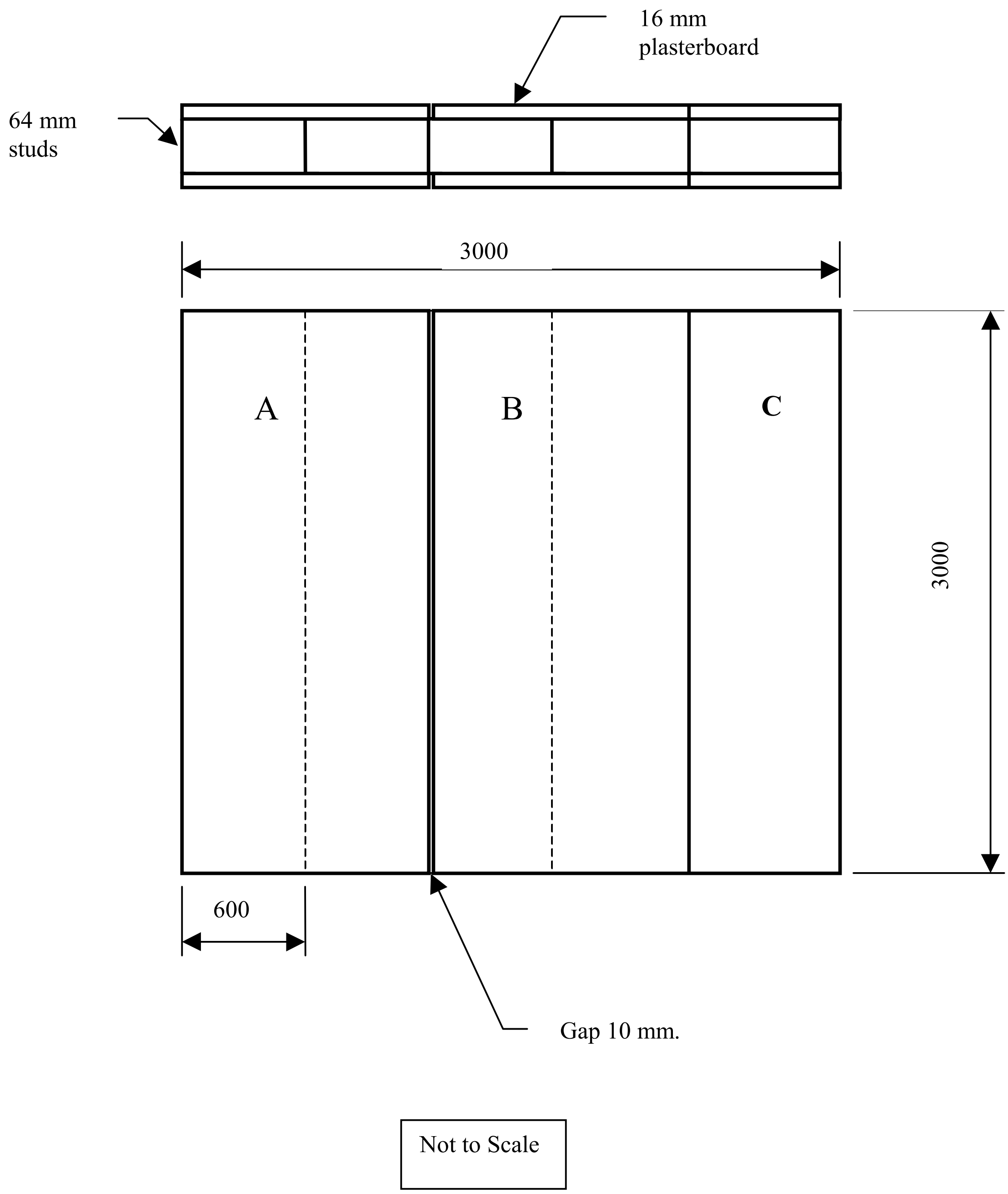


Figure 1 Bad-workmanship plasterboard specimen wall.

4 BRICK SPECIMEN WALL SPECIFICATION

4.1 General

Wall to be constructed using 230 mm long x 110 mm wide x 76 mm high ordinary dry pressed common bricks. To help achieve uniformity, all the bricks will be purchased by CSIRO-DBCE from the same supplier. All walls at both test sites shall also be constructed by the same brick layer.

Supplier: Austral Brick Co. Pty. Ltd. (Sydney)
Estimated cost: $650 per 1000 bricks.

Wall to be 3000 mm long x 3000 mm high x 110 mm thick laid up in stretcher bond using a mortar mixture that comprises one part type A Portland cement, one part lime and six parts bush sand. All brick walls are to be constructed at least 14 days before they are tested.

The “standard” (“good”) workmanship walls are to be constructed with full beds and perpends. “Bad” workmanship walls, representing a reduced quality of workmanship, are to be constructed with peripheral mortar application of defined depth, in accordance with the specification shown below. To achieve uniform workmanship across the laboratories, all the test walls at CSIRO and all the test walls at BHP will all be constructed by the same brick layer.

4.2 Specification for Bad-Workmanship Wall

- The wall shall be constructed from the same type and the same size bricks used to construct the standard-workmanship wall (i.e. 230 mm x 110 mm x 75 mm).

- The mortar shall be the same as that used to construct the standard-workmanship wall (i.e. a standard C:L:S 1:1:6 mix).

- The general alignment and level of the brick wall shall be of the same quality as used to construct the standard-workmanship wall.

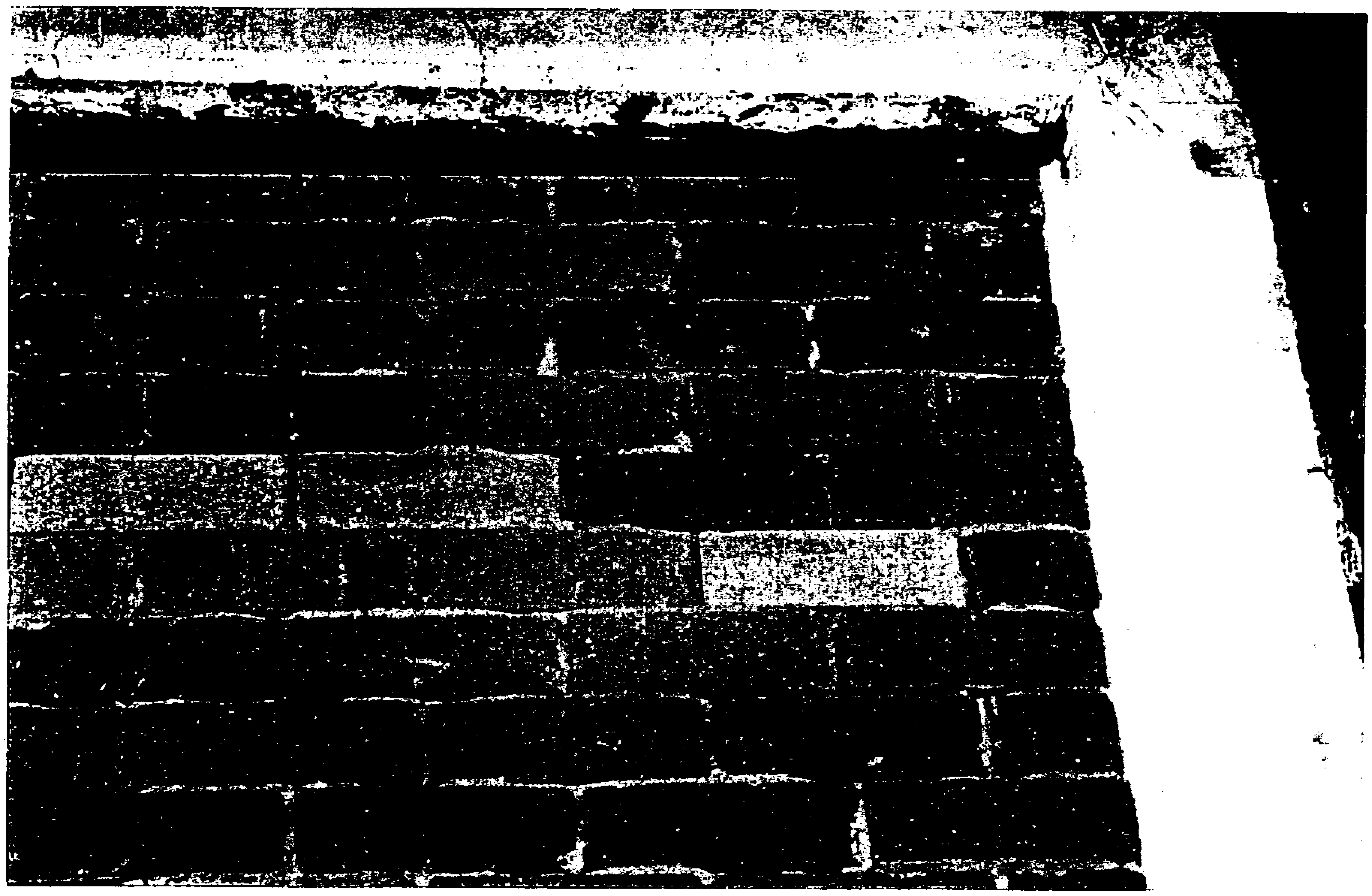
- Ceramic insulation will separate the edge of the brick wall from the frame. This insulation shall be approximately 27 mm thick.

- There shall be no major differences between the front and the rear of the wall.

- The principal difference between the standard-workmanship wall and the bad-workmanship wall will be the way in which the mortar is applied to the perpends and bed joints. Approximately 40-50 % of the perimeter of the brick will be affected by *incomplete application of mortar*.

- This *incomplete application of mortar* will be defined as a lack of mortar along the peripheral of the brick face to a depth of approximately 5-15 mm.

• An example of a bad-workmanship wall constructed at North Ryde in June 1997 is shown in the following photographs, and will also form part of the definition.



5 CORNER AND JOINT SPECIFICATIONS FOR TEST WALL IN BURN ROOM

5.1 Masonry Wall

The masonry test wall will sit on the floor under its own weight. The top of the wall will slot into a 125 mm x 65 mm steel channel with thickness of approximately 6 mm. At the sides of the test wall will be *Kao Wool* ceramic fibre insulation, approximately 25 mm thick, which will fit in between the masonry wall and the plasterboard side walls of the test room. Note that the *internal* dimensions of the test room are to be 3600 mm (length) x 3000 mm (width) x 3000 mm (height), and so the width of the test wall will need to be slightly less than 3000 mm to accommodate the ceramic fibre insulation. The steel channel will be fixed to the plasterboard ceiling of the test room using screws or bolts. The masonry wall will be free-standing within the steel channel (i.e. it will *not* be fixed in place using mortar). A diagram indicating the joint and corner specifications for the masonry test wall is shown below.

Cost of steel channel: approximately $ 140 for an 8 m length.
Supplier: BHP.

Note: Staff are advised to use facemasks and other personal protection equipment when working with insulation wool.

5.2 Plasterboard Wall

The plasterboard test wall will be fixed to the ceiling and to the floor of the Test Room in the same fashion as the other plasterboard walls of the Test Room. The test wall will be free standing at the sides. Located at the sides of the test wall will be *Kao Wool* ceramic fibre insulation, approximately 25 mm thick, which will fit in between the test wall and the plasterboard side walls of the test room. Note that the *internal* dimensions of the test room are to be 3600 mm (length) x 3000 mm (width) x 3000 mm (height), and so the width of the test wall will need to be slightly less than 3000 mm to accommodate the ceramic fibre insulation.

Note: Staff are advised to use facemasks and other personal protection equipment when working with insulation wool.

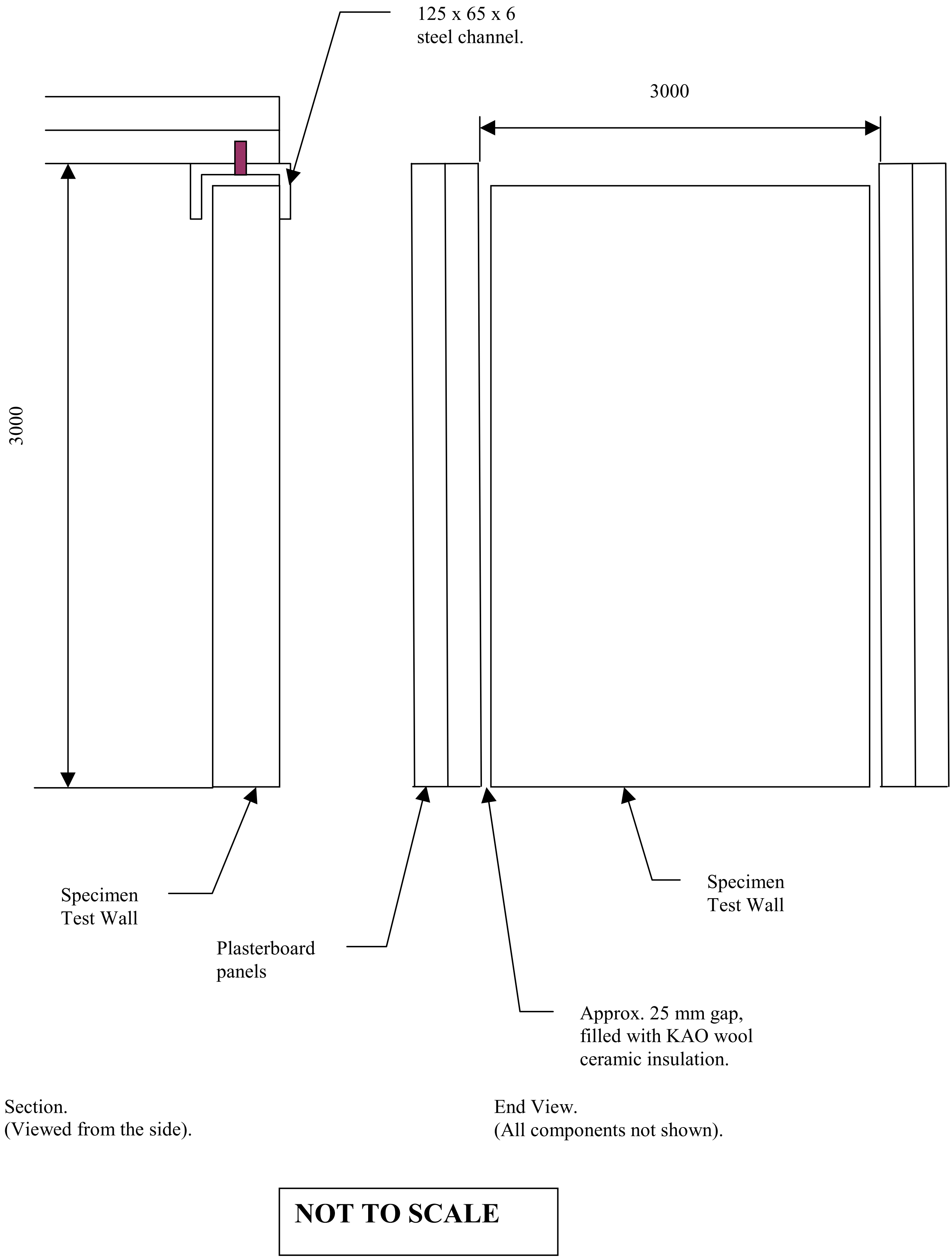


Figure 2 Corner and joint specification for masonry specimen wall.

6 IGNITION SOURCE

Ignition shall be accomplished using the three-seat sofa subjected to a 150 g wood crib ignition source. The crib is to be placed on the centre seat cushion, abutting the centre of the seat back, and ignited on three sides with a gas flame. All the ignition cribs will be supplied by CSIRO–DBCE (Highett). Details of the wooded crib are provided on the following page.

7 WEATHER CONDITIONS

The room burn tests shall be conducted on a day without extreme temperatures or heavy rainfalls.

Ideally the furniture in the test room should be *conditioned* before testing, however, since such facilities are not available, it is desirable that the atmospheric temperature and humidity be recorded for a duration of at least 24 hours before the test using a thermo-hydrograph.

The weight of the eight telephone books within the test room (described in Section 10.3.7) are to be accurately recorded just before the tests begin. These weights will be later compared to the weight of identical phone books that have been completely dried to give an indication of the moisture content of the books.

8 START TIME AND DATA RECORDING

Start all recording and measuring devices and record data for at least 2 min prior to the crib being ignited. Make the following observations:

1. The time when two sides of the crib have been ignited.
2. The time at which the crib ceases flaming.

Notes on the construction of the wooded cribs.

From "A Protocol for Assessment of Fire Behaviour of Furniture using Large Ignition Sources (Part 1)", G. C. Ramsay and V.P. Dowling, CSIRO Division of Building Research, 1983.

The sticks for the cribs are cut with a fine-tooth circular saw from *Pinus radiata* (or other *Pinus* species of similar calorific value) of density 500 ± 50 kg/m^3. The density is calculated on essentially knot-free blocks of wood of maximum dimensions 150 x 50 x 1000 mm that have been conditioned for 7 days at 20 ± 2°C and 65 ± 5% RH. The stick sizes required are given in Table C1.

After selecting the appropriate sticks, weigh out the number necessary to achieve the tolerances shown in Table C1. The crib is constructed *in situ* by building cross-piles of evenly spaced sticks, using the number of sticks per layer shown in Table C1.

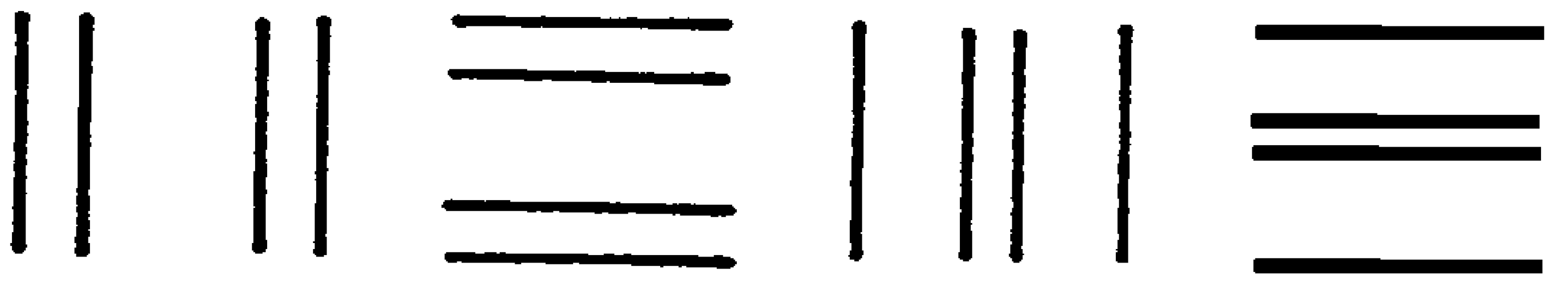
Table C1

Details and tolerances for wood cribs

Crib mass (g)	Stick width (mm)	Stick length (mm)	No. of sticks per layer
50±0.5	2.0±0.2	200±1	4
100±1.0	3.0±0.2	200±1	5
150±1.5	3.5±0.2	200±1	7
200±2.0	4.0±0.2	200±1	8
300±3.0	5.0±0.2	200±1	10
400±4.0	6.0±0.2	200±1	11

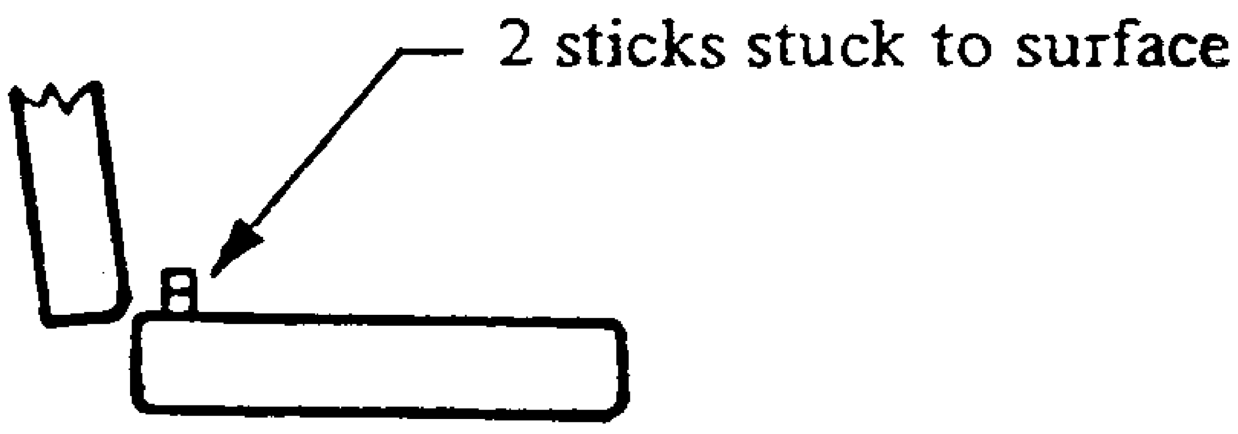
The number of sticks required for an individual crib is controlled solely by mass, but will generally be in the range 100 to 130 sticks, with the theoretical number varying between cribs of different mass.

NB. For the 50 g crib, the sticks are staggered so that four sticks per layer results in six vertical rows.



1st layer 2nd layer 3rd layer 4th layer
5th layer 6th layer etc.

For ease of construction on a seat it is sometimes necessary to use one or two of the weighed measures of sticks to aid in 'levelling' the surface.



It is permissible also to use a first layer of only two sticks.

9 CONSTRUCTION OF INTERNAL SUSPENDED CEILING

9.1 Panels

Materials:
RH90 Fine Fissured Board (1200 x 600).
Item No. 3570B.

Price: $5.20 per square meter (May 1997 for CSIRO).

Supplier. Armstrong World Industries Pty. Ltd.
Unit 36 Slough Business Park
Holker St.
PO Box 6765
Silverwater NSW 2128

Phone: (02) 9748 1588
Fax: (02) 9748 7244

Contact: Wayne Carter.

9.2 Suspended Grid System

Corrosion-resistant roll-formed exposed grid ceiling components, manufactured by Rondo Building Services Pty. Limited. These components are manufactured from galvanised steel, with main and cross runners supplied with pre-painted white fibre-bond finish.

9.2.1 Suspension Components

Part No.
187 Lipped Wall Angle- aluminium
188 Wall Angle Junction Bracket
235 Shadowline Wall Angle- aluminium
236 Bulkhead Trim- aluminium
247 Suspension Rod Angle Bracket
273 Suspension Purlin Clip
274 Suspension Rod Bracket
283 Lipped Wall Angle- steel 32 x 19 mm
284 Lipped Wall Angle- steel 19 x 19 mm
285 Suspension Clip- thread adjusted
367 Cross Runner- 32 mm balanced tee
374 Shadowline Wall Angle- steel
440 Main Runner- 38 mm balanced tee
441 Suspension Clip- one piece
444 Cross Runner- 38 mm balanced tee

9.2.2 Installation

It is advisable that the main runners run at right angles to purlins. Centre the ceiling area both ways, ensuring the centre lines are at right angles to each other. Plan for even margins of closure panels at opposite sides of ceiling.

Fix wall angle to perimeter walls at the correct height and check for level. (The wall angle will be fixed to the masonry test wall using ¾" to 1" masonry nails, nailed into the wall joints). Mitre corners around piers and columns.

Fix suspension rods with suspension clips attached, to approximate height at 1200 mm maximum centres in both directions.

Attach main runners to suspension clips, ensuring the claws firmly engage the runner head. Adjust height of runners to a line stretched between wall angles; by adjusting the suspension clips (Part No. 442) or by thread adjustment (Part No. 285).

Insert cross runners at 600 mm centres and check all fittings for tightness and safety.

Install panels.

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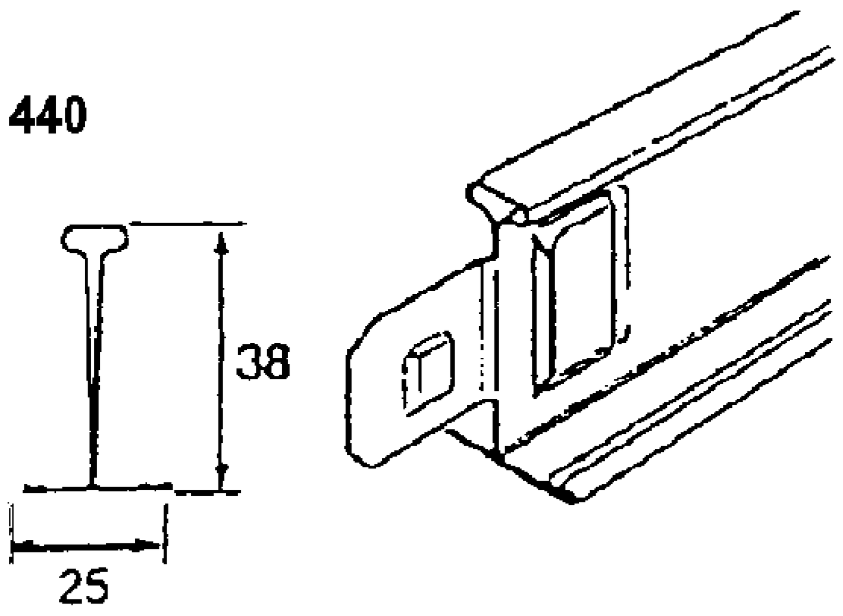

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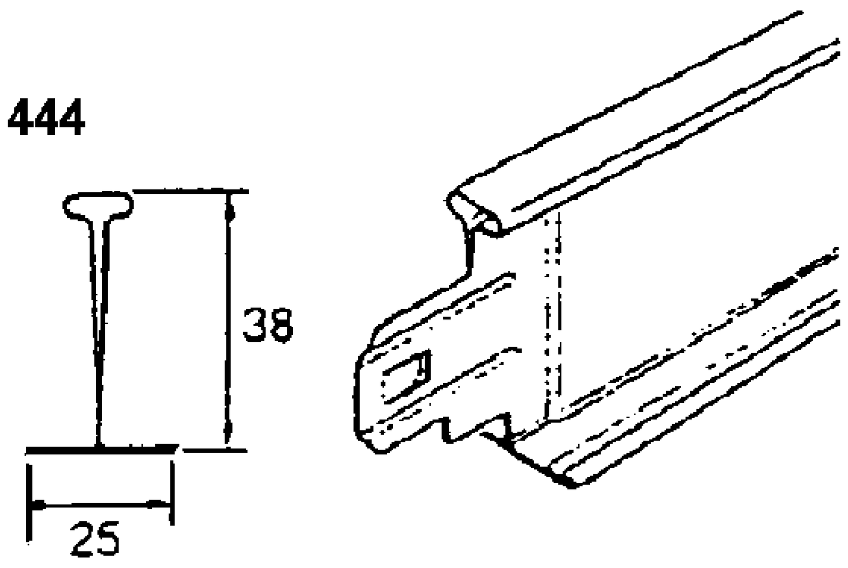

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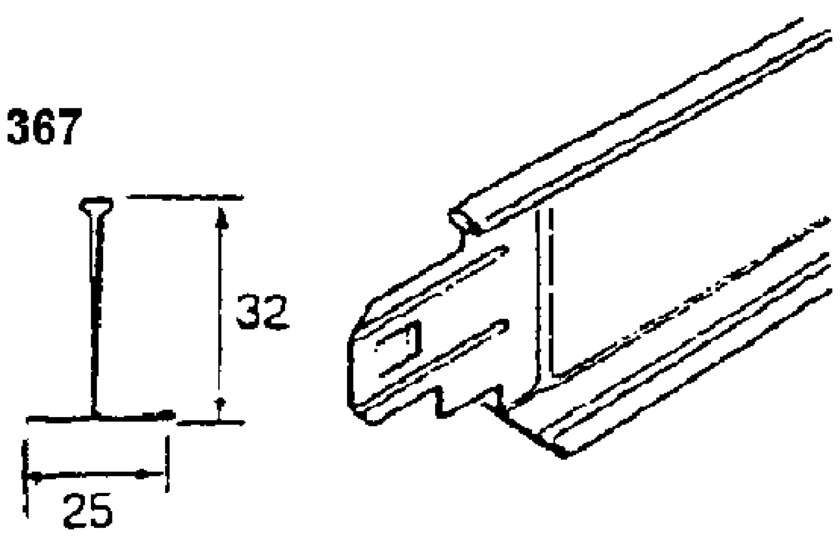

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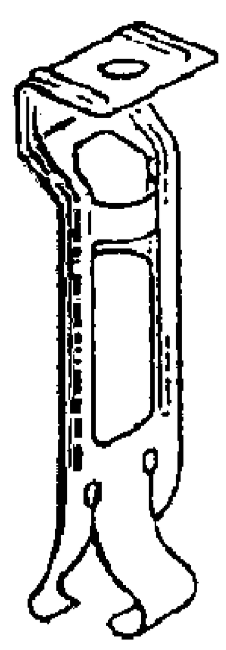

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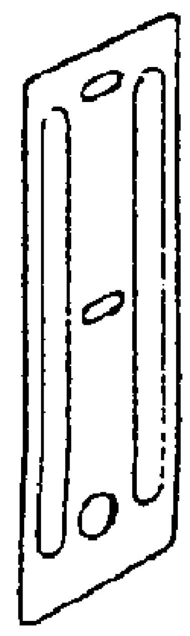

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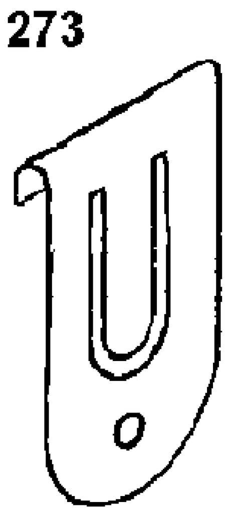

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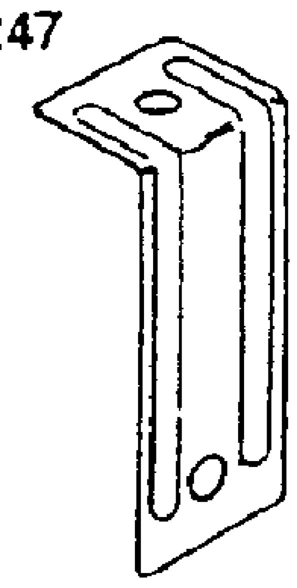

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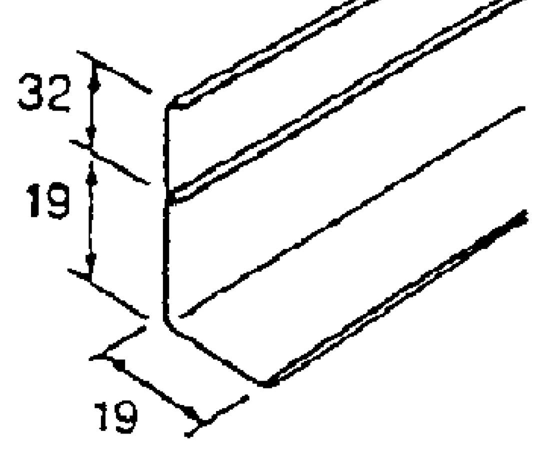

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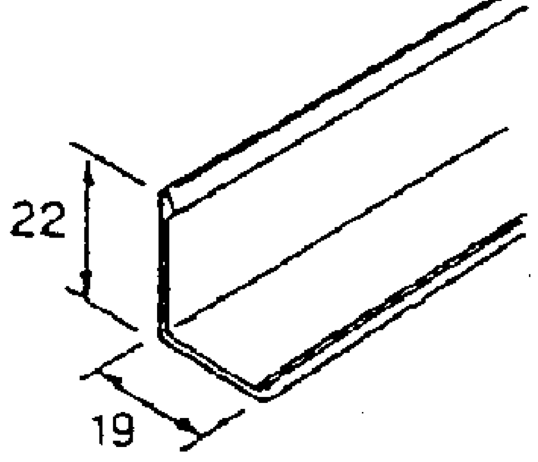

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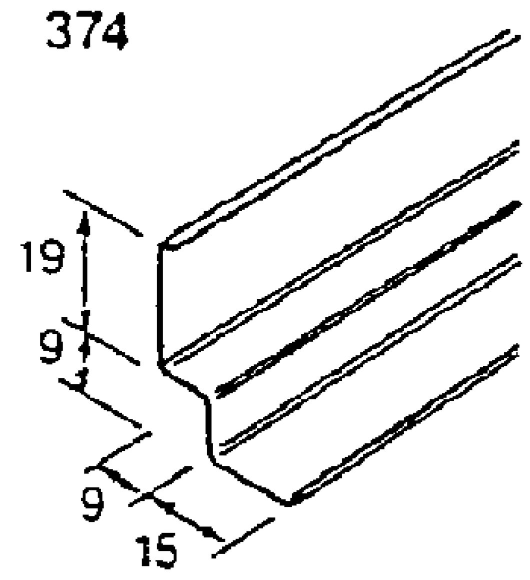

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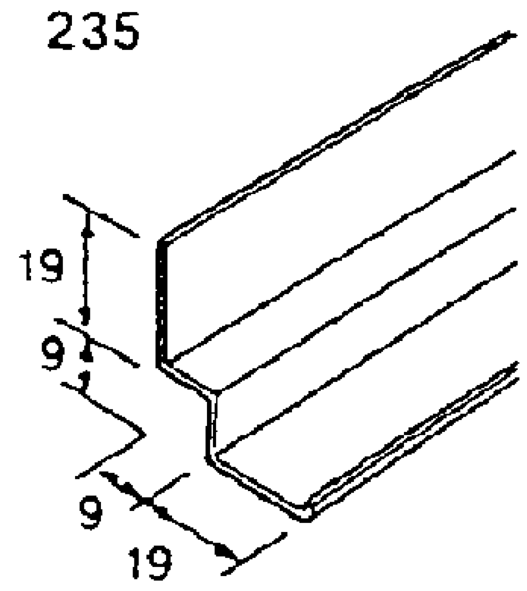

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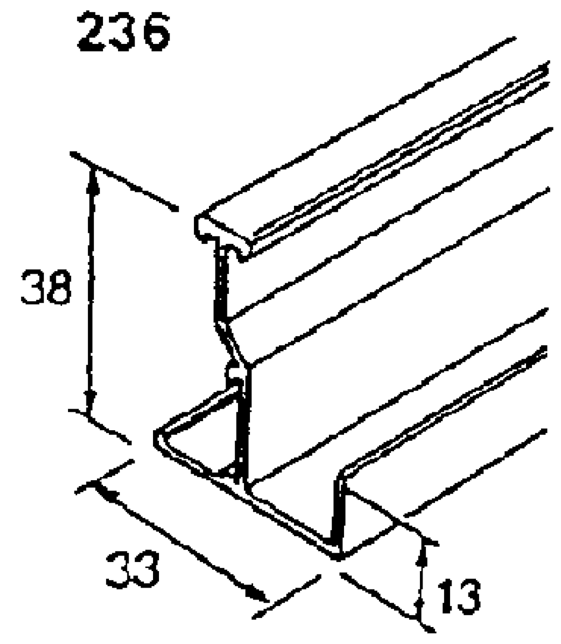
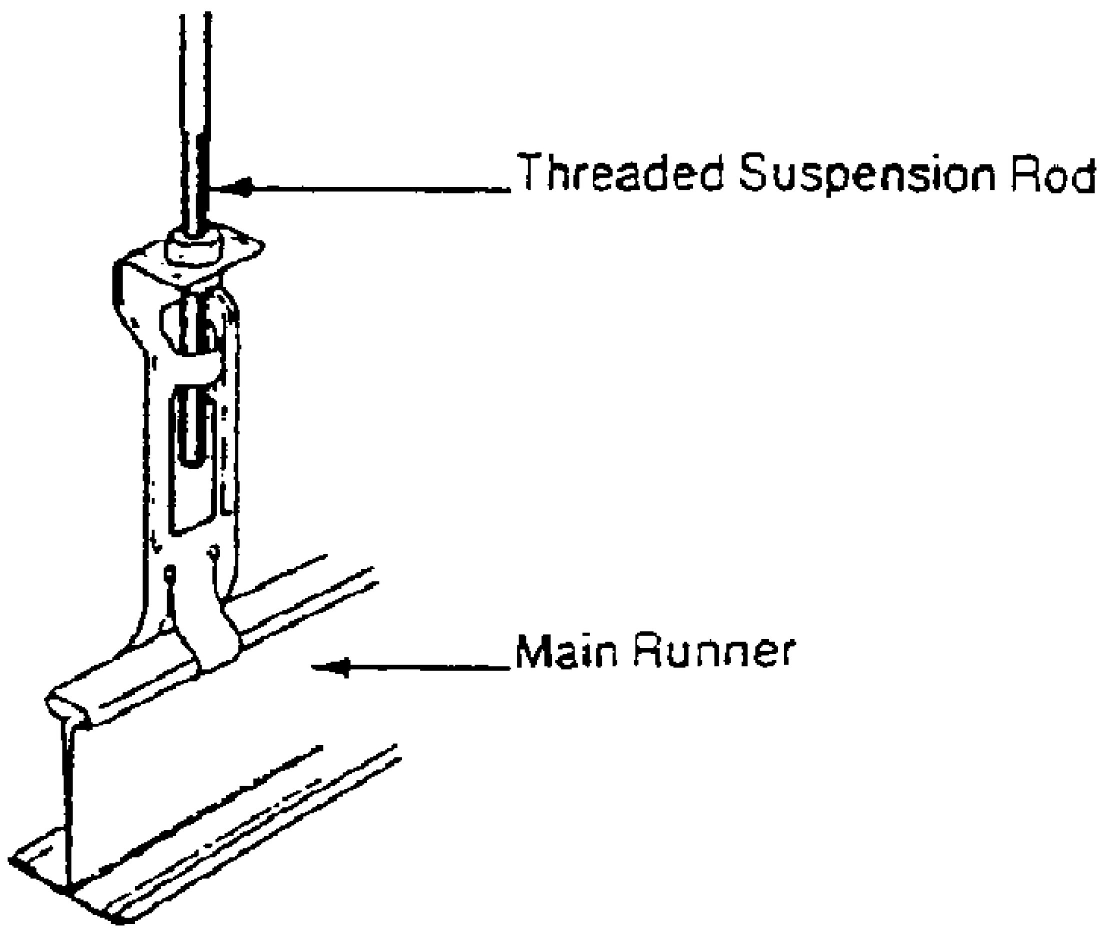
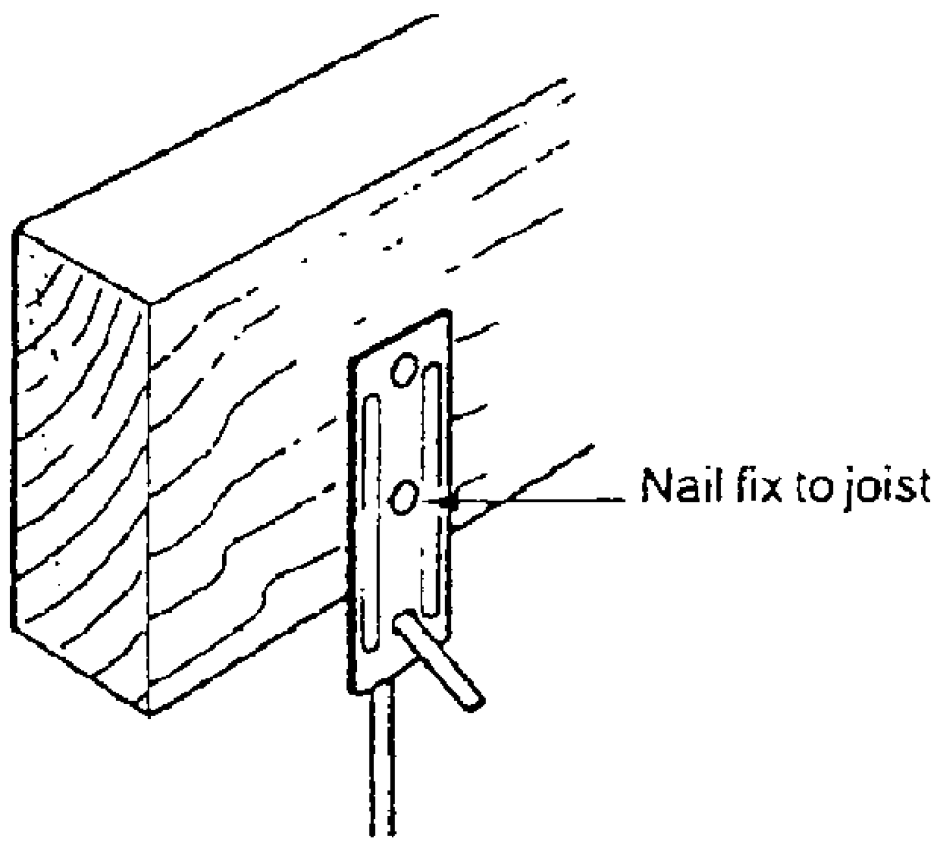


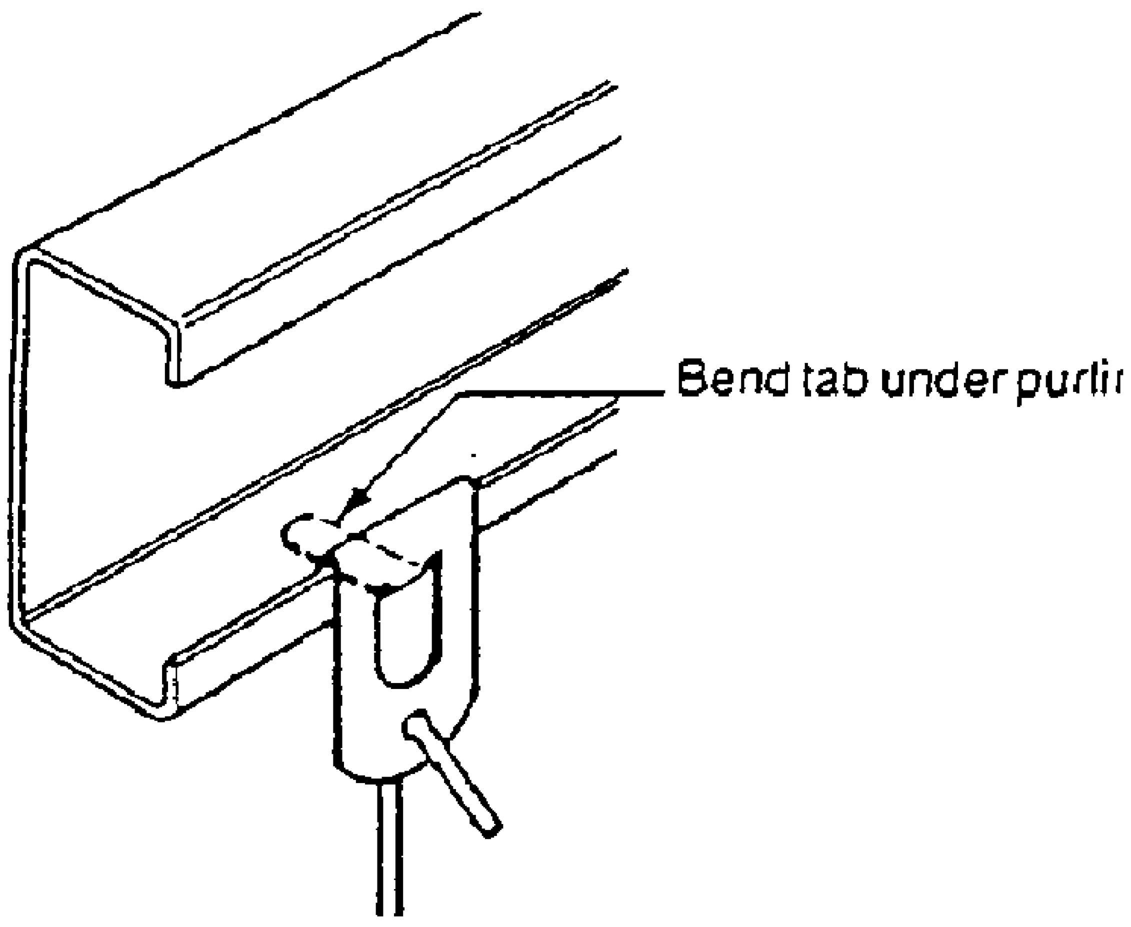
Suspension Clip Thread adjusted



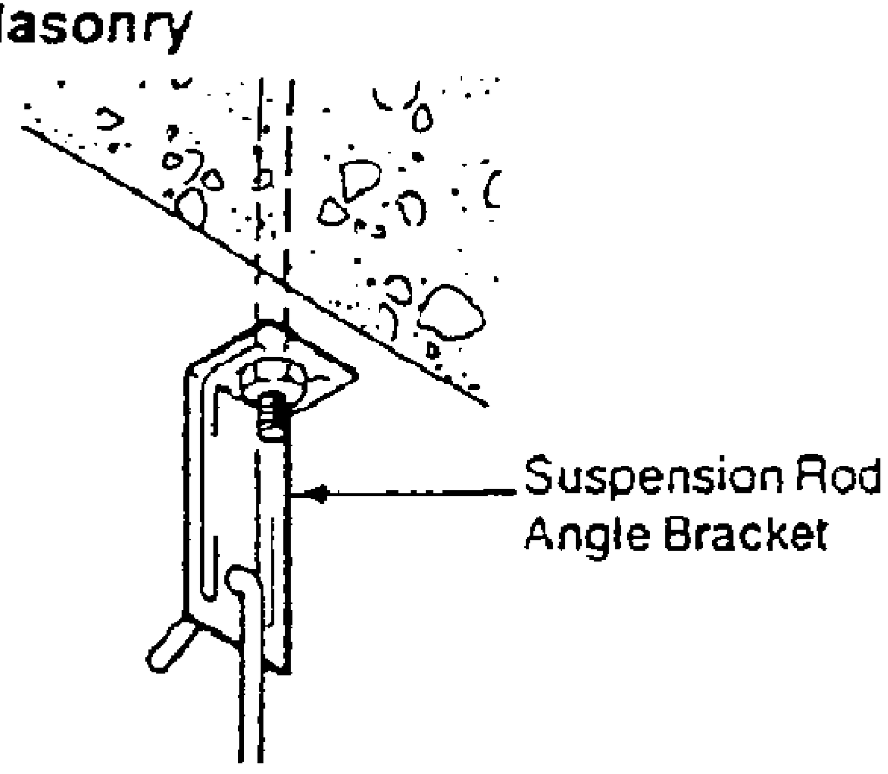
Suspension Rod Bracket



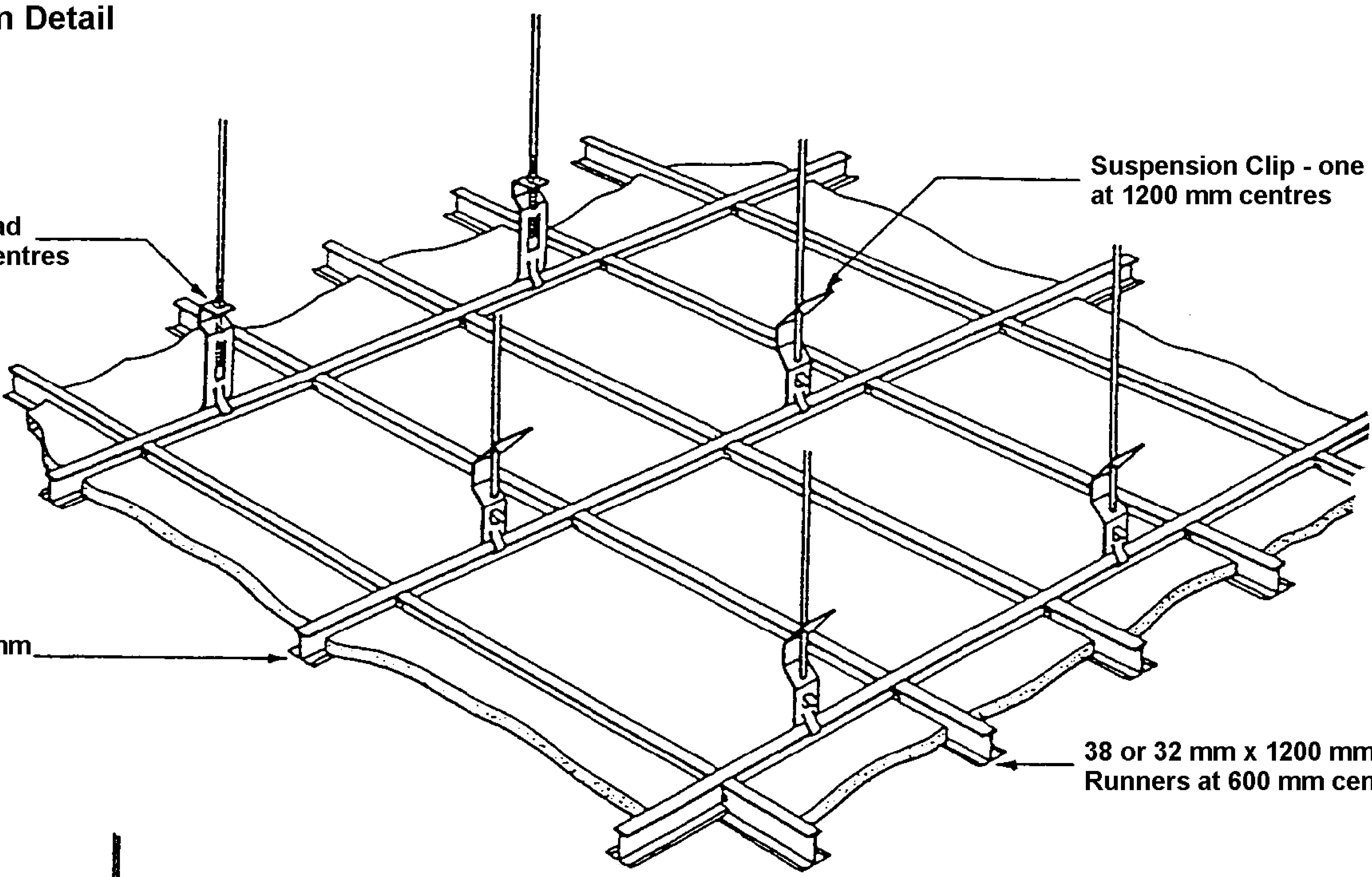
Suspension Purlin Clip



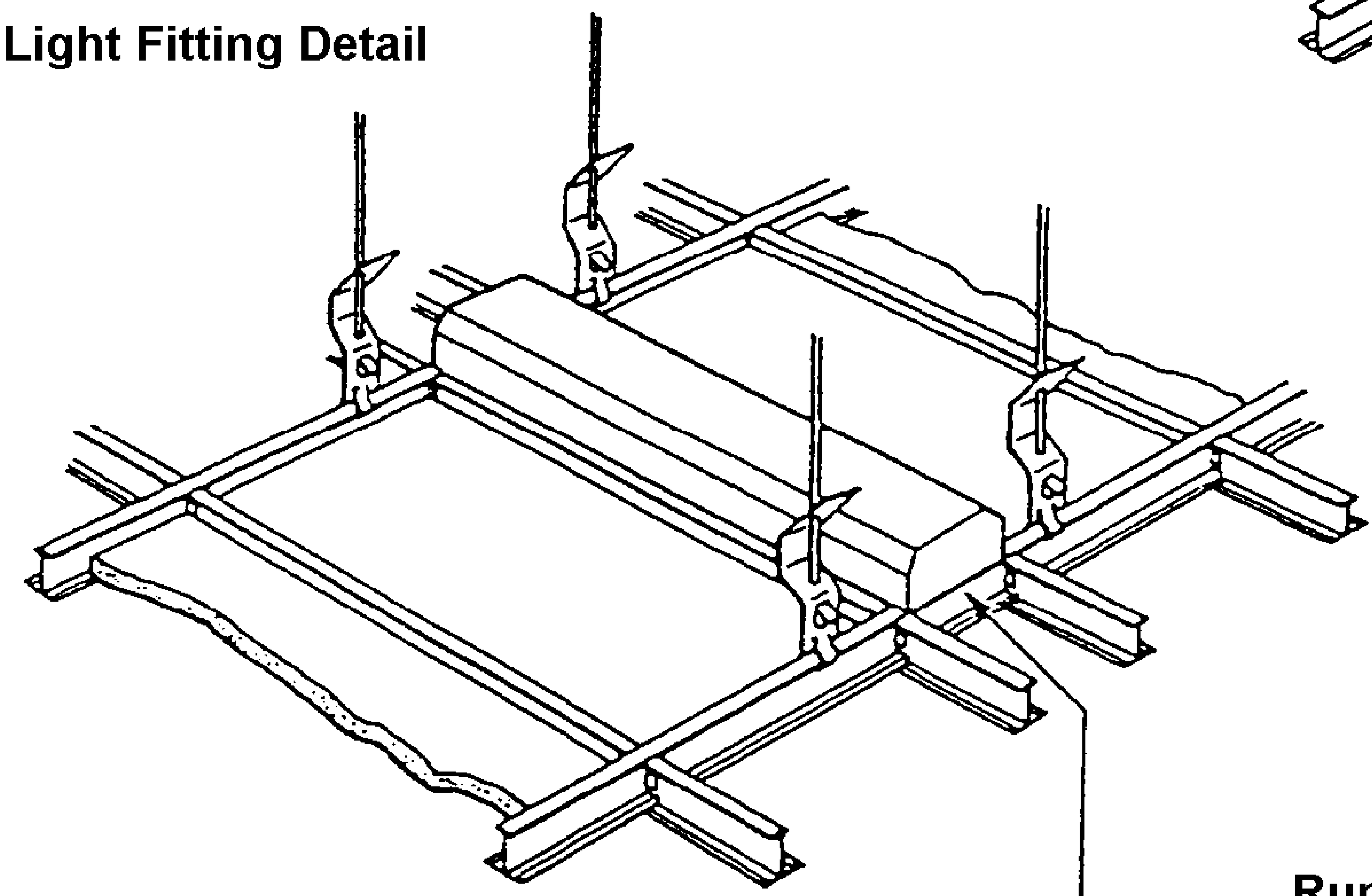
Fixing to Masonry



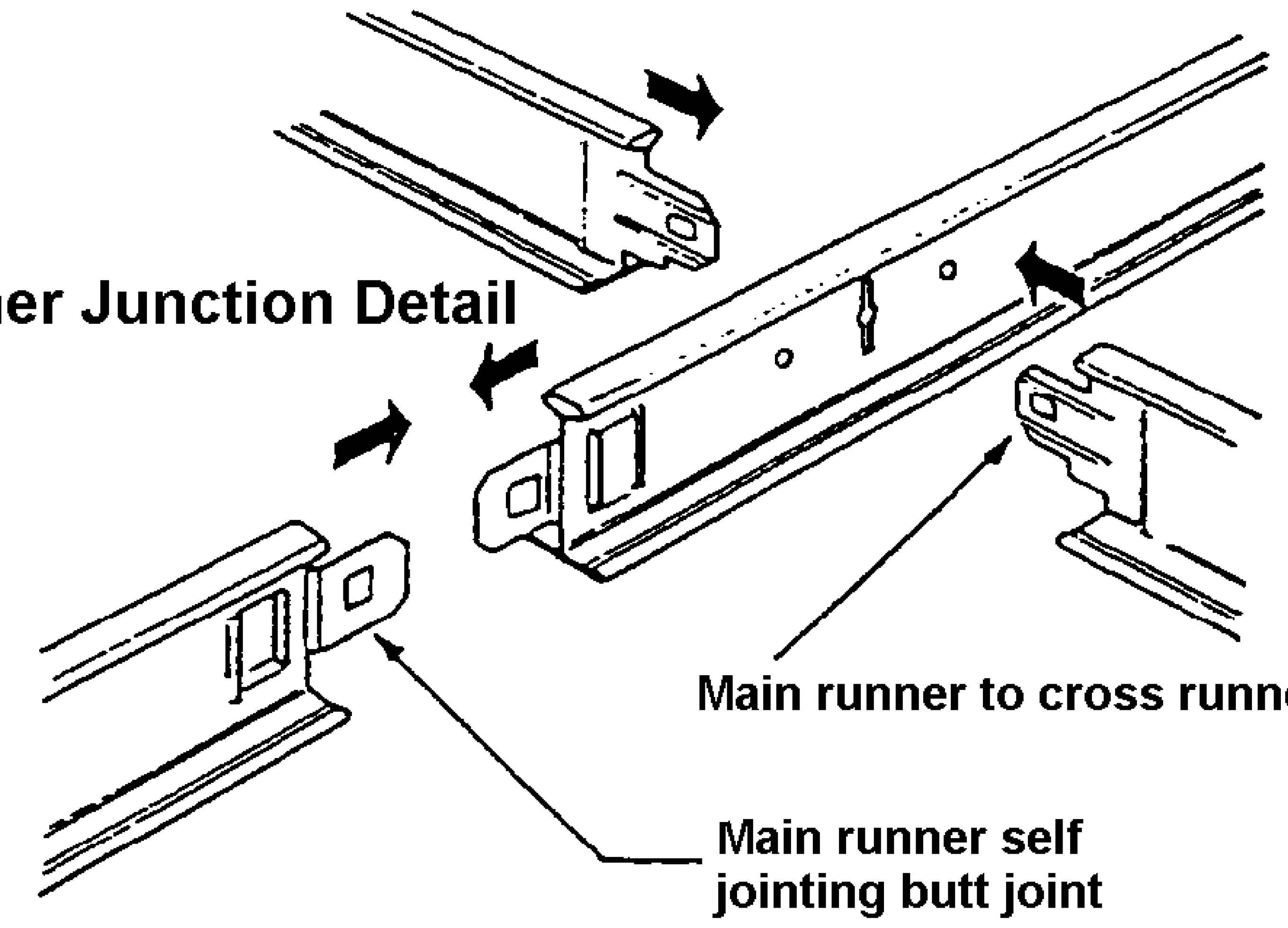
Typical Installation Detail



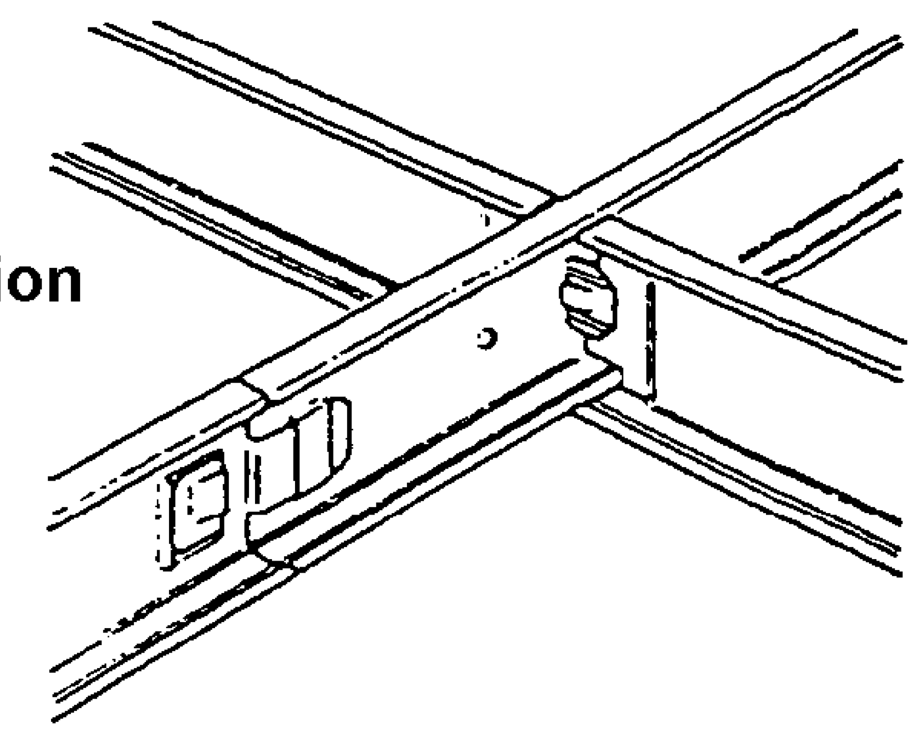
Light Fitting Detail



Runner Junction Detail



Assembled Junction



10 FIRE LOAD

10.1 Required Fire Load

The combustible items in the test room will be equivalent to a fire load of 800 MJ/m² of floor area. This fire load approximates that present in residences with a high-level of combustible material. This value was determined from a literature survey of moveable fire loads conducted for FCRC Project 3.

Floor area of room: $(3.6)(3.0) = 10.8\ m^2$
Required fire load: (800)(10.8) = 8 640 MJ.

10.2 Carpet

The entire floor surface area is to be covered with carpet and a rubber underlay. CSIRO-DBCE (North Ryde) will purchase and distribute the carpet for both test sites.

Carpet: Mossvale Maple 50/50 (Acrylic/Wool) carpet cut into 6 x 3 m lengths. Batch 5504.

Rubber Underlay: Bridgestone Australia 29/06/97 19:38 N Manufactured to AS4288 (INT).

Price: $1190.00 total (for 18 meters).

Supplier. Carpetland
PO Box 662
Brookvale NSW 2100

Phone: (02) 9905 5650

10.2.1 Carpet and Underlay Properties

Samples of the carpet and underlay in combination were tested in a cone calorimeter to the draft Australian test method (technically identical to ASTM E 1354). Three nominally identical tests were performed on carpet-underlay specimens at a cone irradiance of 50 kW/m^2 and using a horizontal sample orientation. The average results from these tests are shown in Table 1.

Using the properties indicated in Table 1, the theoretical total mass of carpet/underlay in the room will be 21.3 kg.

Table 1. Details of Carpet/Underlay from Cone Calorimeter Tests. (From McArthur, Bowditch, and Leondard, 1997).

Mass per Unit Area (kg/m^2)	1.97
Total Heat Evolved (MJ/m^2)	57.4
Time to Sustained Flaming (s)	5
Average Mass Loss Rate (g/m^2s)	11.6
Peak Heat Release Rate (kW/m^2)	544
Effective Heat of Combustion (MJ/kg)	29

10.3 Furniture and Contents

The furniture in the room will consist of one three-seat sofa chair, one single-seat arm chair, one desk, and two book cases. All the furniture will be constructed by BHP.

Note, all furniture should be stripped and weighed before the room test so that details of the fire load can be determined.

The theoretical fire load of the test room and contents is evaluated in this Section using the following equation

$$Q = \chi \cdot \Delta H_c \cdot m$$

where Q is the total net heat release, ΔH_c is the net heat release per unit weight of the combustible material, m is the mass, and χ is a factor that has been given the value unity. Note that ΔH_c was usually determined from tabulated values in the literature for a particular material (That is, experimental values of heat release for a particular furniture item were not used).

10.3.1 Sofa and Arm Chair

Three-seat sofa frame from Nordtest Standard (1987) “Upholstered Furniture: Burning Behaviour – Full-Scale Test”, NT Fire 032. Nordtest, Helsinki.

Single-seat armchair is a local derivation from CSIRO Highett.

The sofa and arm chair are to be assembled according to the supplied figures (see Figure 3, Figure 4 and Figure 5), and arm rest cushions are to be used on the sofa.

The back and seat cushions for the sofa and the armchair are all identical. All cushions and the arm rests are made from Dunlop polyurethane A23-130, which is grey, medium quality, and has no fire-retardant additives. Several fire properties of the cushions have been experimentally determined, and are indicated in Table 2.

Table 2. Details of Back and Seat Cushions (From Dowling, McArthur and Webb, 1996, and Personal Communication, 1997).

Number	6 on the sofa, and 2 on the arm chair.
Material	Dunlop general purpose polyurethane foam, A23-130
Grade (AA 2281)	N23-130
Dimensions	560 x 560 x 100 mm
Density	23 kg/m^3
Mass	750 g per cushion
Max Heat Release	13.2 MJ per cushion

Cushion material supplier:

Dunlop Flexible Foams
36 Commercial Drive
South Dandenong. VIC 3164,
Phone: (03) 9215 2020
Fax: (03) 9215 2010
Contact: Andrew Ward or Dianne Moran.

Price: Oct. 1996 price $6.50 per cushion.

Q. code 81796.

Back and Seat Cushions

Six cushions will be used on the sofa, and two on the arm chair. This indicates a total mass (all eight cushions combined) of 6 kg of polyurethane.

Polypropylene covers are to be used on all the cushions, to provide fast and thorough ignition: Jacka Wortley "Java" in flame red. Density 218 g/m^2. The total mass of the eight cushion covers is estimated to be 1.48 kg of polypropylene.

Sofa Arm-Rest Cushions

The total mass of the two arm-rest cushions is estimated to be 0.721 kg of polyurethane foam.

The total mass of the two arm-rest cushion covers is estimated to be 0.210 kg of polypropylene.

10.3.2 Bookcases

The frames of the two bookcases will be constructed of 25 mm x 25 mm square section steel to the dimensions provided (see Figure 6). Both sides, all shelves, and the top and bottom are to be lined with 18 mm particle board. The back is to be lined with 3 mm plywood.

Theoretical calculations (see attached spread-sheet table), using the properties indicated in Table 3, indicate a total mass of 81 kg of wood for the two bookcases combined.

Table 3 Material Properties used in Theoretical Fire Load Calculations.

Material	Density	Theoretical ΔH_c (MJ/kg)
Particle Board	625 kg/m^3	18
Plywood	545 kg/m^3	18
Books/Magazines	580-650 kg/m^3	18
Newspapers	-	18
Polypropylene Seat Covers	0.218 kg/m^2	43
Acrylic/Wool/Rubber Carpet	1.97 kg/m^2	29
PVC	1380 kg/m^3	16
Polyurethane foam	23 kg/m^3	27
Other plastics	-	16

10.3.3 Desk

The frame of the desk is to be constructed from of 25 mm x 25 mm square section steel to the supplied dimensions (see Figure 7). The top of the desk, one short side (dimensions 900 mm x 700 mm, located furthermost from Bookcase #1, see Figure 11), and the back (1600 mm x 700 mm), are to be lined with 33 mm particle board. An additional 900 mm x 700 mm sheet of 33 mm particle board is to be placed at the centre line of the desk parallel to the short side.

Theoretical calculations indicate a total mass of 78.8 kg of wood.

10.3.4 Coffee Table

The frame of the coffee table is to be constructed from of 25 mm x 25 mm square section steel to the supplied dimensions (see Figure 8). The top of the table is to be lined with 18 mm particle board.

Theoretical calculations indicate a total mass of 6.8 kg of wood.

10.3.5 Skirting Board

The total length of skirting board consists of 13.2 m (floor perimeter), 4.8 m (door perimeter), and 7.6 m (window perimeter); giving a total length of 25.6 m. Assuming a density of 0.86 kg/m, the total mass is 22.0 kg.

10.3.6 Additional Office Furniture

One computer terminal with associated keyboard, one rotary telephone, and two mail *in/out* trays will be place on the desk. One waste paper bin will be placed on the floor of the test room, beside the desk.

The computer terminal is a Beehive International MICROB/DM2S terminal, originally supplied by Datatel and used on a VAX computer system in the early 1980s. The dimensions of the monitor are 460 mm wide, 340 mm high, and 420 mm depth. The keyboard has dimensions 455 mm long, 200 mm width, and 70 mm thick. The monitor and keyboard both have PVC cases.

The rotary telephone is inscribed with *Telecom Aust STC 8021 80 S1/252*, and has dimensions approximately 200 mm long, 150 mm wide, and 100 mm high. The total weight of the phone and cord is 1.53 kg. The combustible components are an unknown plastic. Theoretical heat release values are assumed to be the same as PVC.

The total mass of combustible plastic from the computer terminal, keyboard, and telephone, are estimated to be 10 kg.

One 0.53 kg polypropylene waste-paper bin, and two 0.30 kg PVC *in/out* mail trays, will also be placed in the test room. The waste paper bin has dimensions 325 mm x 250 mm at the top (opening) of the bin, 250 mm x 170 mm at the base of the bin, and a height of 280 mm. The *in/out* mail trays are inscribed with *SWS Mark 2* have a length of approximately 353 mm, width of 260 mm, and a height of 80 mm.

Several fire properties of the computer, keyboard, telephone, waste-paper bin, and a mail tray were experimentally determined, and are shown in Table 4.

The window of the test room is to be covered with two layers of clear, 100-micron thick, PVC film. The heat release from these plastic sheets has not been determined.

Table 4. Details of Computer Terminal, Keyboard, Telephone, and Waste-Paper Bin Calorimeter Tests. (From McArthur, N., Personal Communication, 1997).

Components	Total Mass (kg)	Mass of combustible material (kg)	Mass consumed (kg)	Peak heat release rate (kW)	Total heat release (MJ)	Effective heat of combustion (MJ/kg)
Terminal & Keyboard	18.2	?	1.1	-	-	-
Phone, bin, & one tray	2.4	?	1.3	-	-	-
Total	20.6	?	2.4	180	37	15

10.3.7 Additional Fire Load

To achieve the required fire load, additional paper items are to be added to the room. Note that it is the *total* mass of the items that is important, rather than the total number of items. However, the *thickness* of the items, and the *spacing* on the shelves, need to be controlled so that uniform and reproducible combustion of the materials can be achieved. The books and magazines should be loosely stacked on the shelves so that there is the maximum spacing between the items possible. Several sheets of 3 mm plywood will be placed on each shelf of the book case to act as spacers and to help support the books and magazines in upright positions.

- Eight telephone books. Each book is to be approximately 2.1 kg (Acceptable range 1.9-2.3 kg). *Total mass approximately 16.8 kg*. Each book with dimensions approximately 276 mm high x 235 mm wide x 56 mm thick. Any thick glossy pages or cardboard covers are to be removed, however, the glossy spine is to be retained. The glossy spine is to face towards the back of the book case.

- 120 Books. Each book is to be simulated by using 0.9 kg wads of paper made from cut telephone books (described above) or similar material. Any thick glossy pages or cardboard covers are to be removed, however, the glossy spine is to be retained. The glossy spine is to face towards the back of the book case. *Total mass 108 kg*.

- 340 Magazines. Each magazine is to be approx. 0.3 kg. If required, the magazines may be simulated by using 0.3 kg wads of paper cut from telephone books (as described above) or similar material. The glossy spine is to face towards the back of the book case. *Total mass 102 kg*.

- 14 Newspapers. Each weighing approximately 0.35 kg. When folded the surface area will be approximately 400 mm x 290 mm. *Total mass 4.9 kg*.

- Fluffed waste paper placed in the waste paper bin. *Total mass 0.15 kg*.

- Two stacks of loose paper, 0.15 kg each, are to be constructed from cut telephone books (as described above), with all glossy pages, covers, and spines removed. One stack is to be placed on the top *in/out tray*, and one stack in the lower *in/out tray*. *Total mass 0.3 kg*.

- 16 book dividers (used to help support the books and magazines in a vertical position), made from 3 mm plywood, with a width of 224 mm, and a height matching the height of the book case shelves. *Total mass approx. 3.0 kg.*

- Approximately 96 book spacers (used to help space the books and magazines evenly on the shelves), made from 3 mm plywood, with a width of 25 mm and a height matching the book case shelves. *Total mass approx. 2.1 kg*.

10.3.8 Distribution of Additional Fire Load

Details of the location and distribution of the additional fire load are given in Figure 12. The books are magazine are distributed according to the following Table.

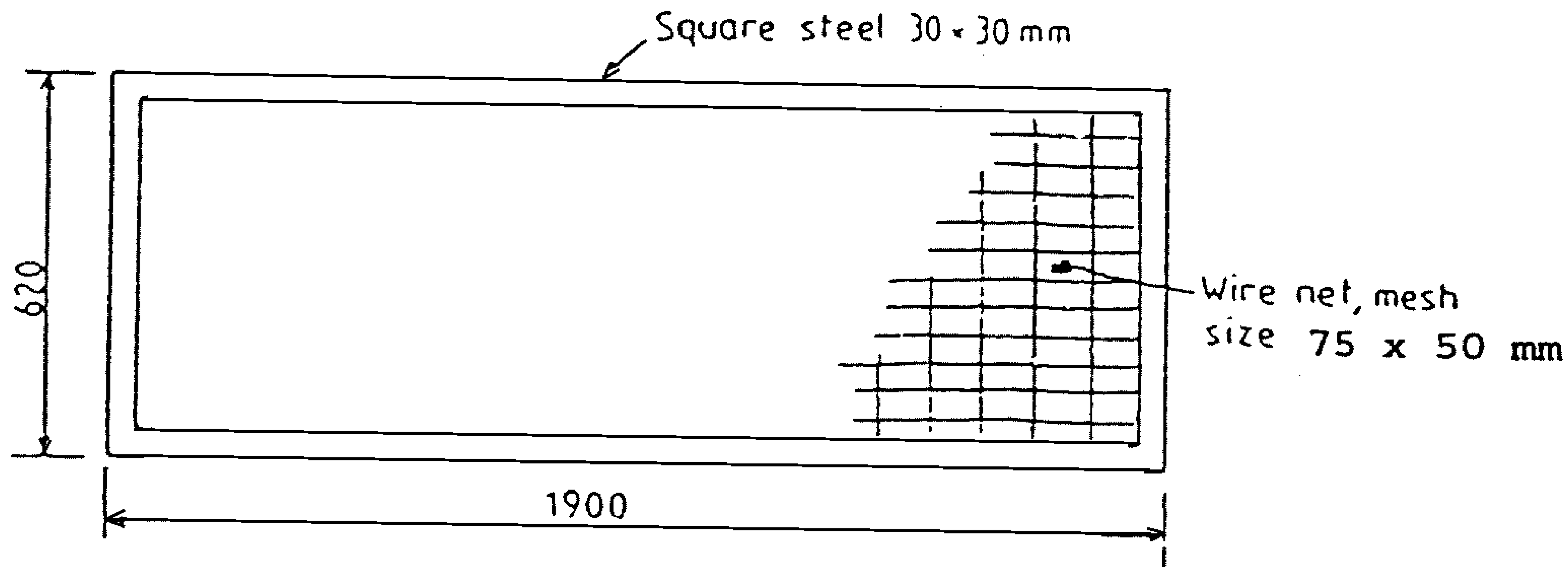
Table 5 Location of Books and Magazines.

Location	Number of Books	Number of Magazines
Under desk	8	36
Under sofa	9	22
On computer	0	5
Under chair	7	0
Floor near bookcase #2	8	0
Book case #1	48	110
Book case #2	39	124
On desk	1	19
Top of coffee table	0	10
Under coffee table	0	10
Floor near sofa	0	4
Total	120	340

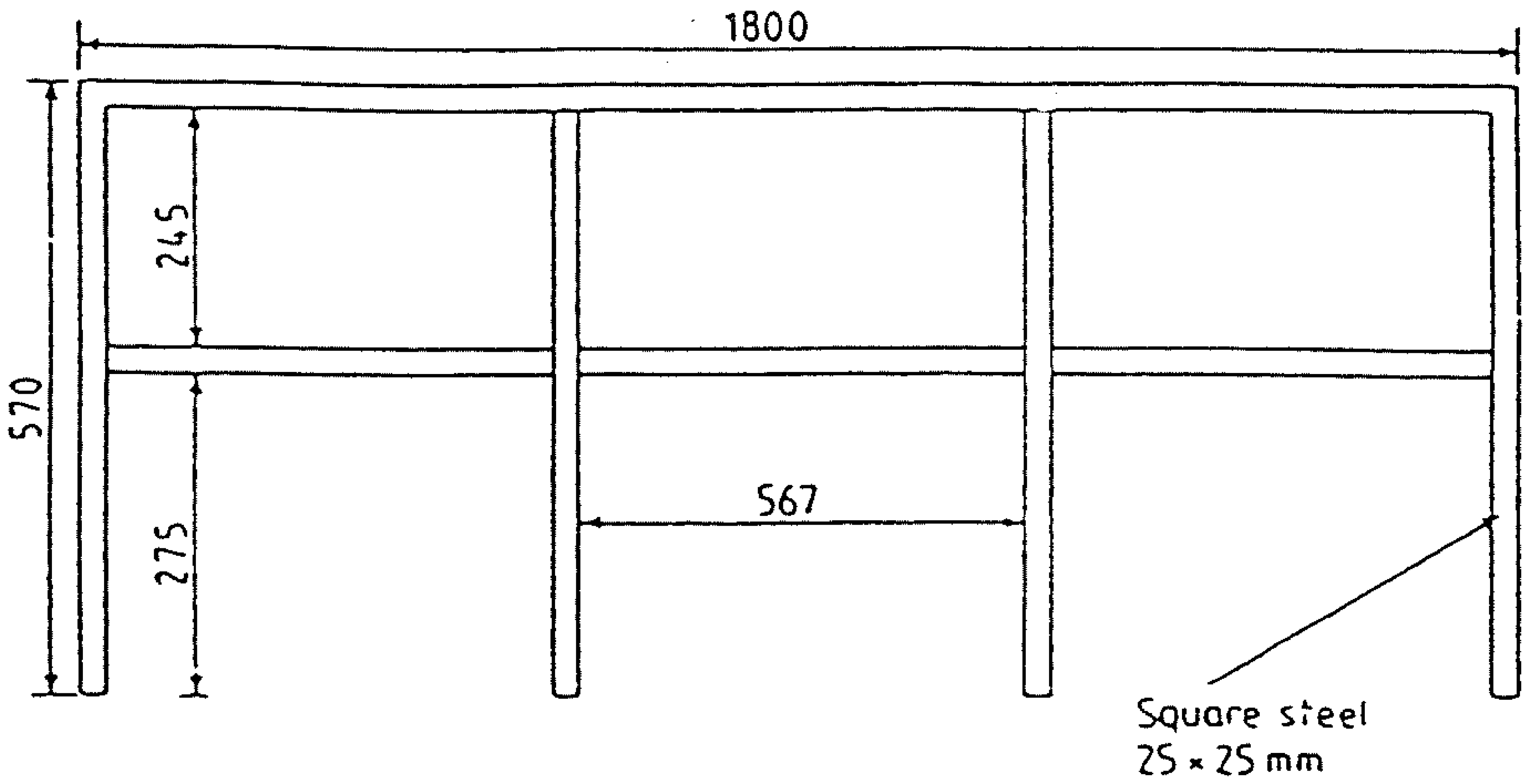
10.4 Total (Theoretical) Fire Load of Test Room

Table 3. Total (Theoretical) Fire Load of Test Room.

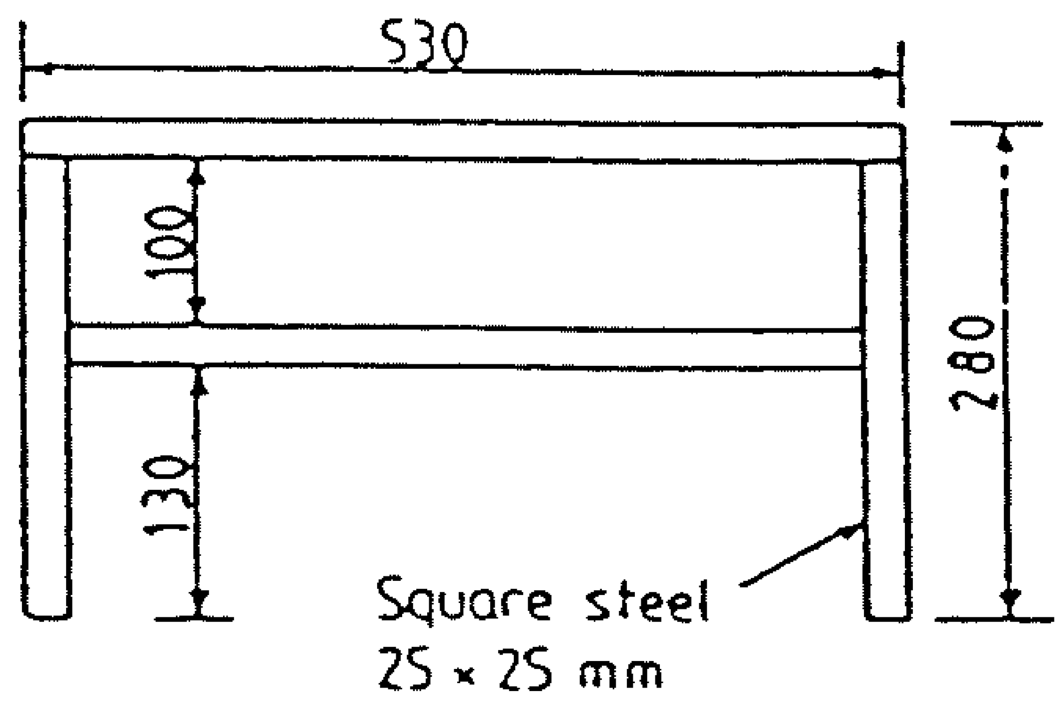
Item	Combustible Material	Mass (kg)	ΔH_c (MJ/kg)	Q (MJ)
Two Book Cases	Wood	81.00	18	1458.0
Desk	Wood	78.80	18	1418.4
Carpet & Underlay	Acrylic/wool/rubber	21.30	29	617.7
Skirting Board	Wood	22.00	18	396.0
Computer & Phone	PVC/plastic	10.00	16	160.0
Coffee Table	Wood	6.80	18	122.4
Sofa cushions	Polyurethane Foam	4.50	27	121.5
Sofa covers	Polypropylene	1.11	43	47.9
Arm-chair cushions	Polyurethane Foam	1.50	27	40.5
Waste paper bin	Polypropylene	0.53	43	22.8
Arm-rest cushions	Polyurethane Foam	0.72	27	19.5
Arm-chair covers	Polypropylene	0.37	43	16.0
Two mail in/out trays	PVC	0.60	16	9.6
Arm-rest covers	Polypropylene	0.21	43	9.0
Ignition crib	Wood	0.15	18	2.7
Sub Total		**229.60**		**4461.9**
120 Books	Paper (0.9 kg each)	108.00	18	1944.0
340 Magazines	Paper (0.3 kg each)	102.00	18	1836.0
8 Phone Books	Paper (2.1 kg each)	16.80	18	302.4
14 Newspapers	Paper (0.35 kg each)	4.90	18	88.2
16 Book dividers	Plywood	3.00	18	54.0
96 Book spacers	Plywood	2.10	18	37.8
2 stacks for in/out tray	Paper (0.15 kg each)	0.30	18	5.4
Waste Paper in Bin	Paper (0.15 kg)	0.15	18	2.7
Sub Total		**237.25**		**4270.5**
Grand Total		**466.8**		**8732**



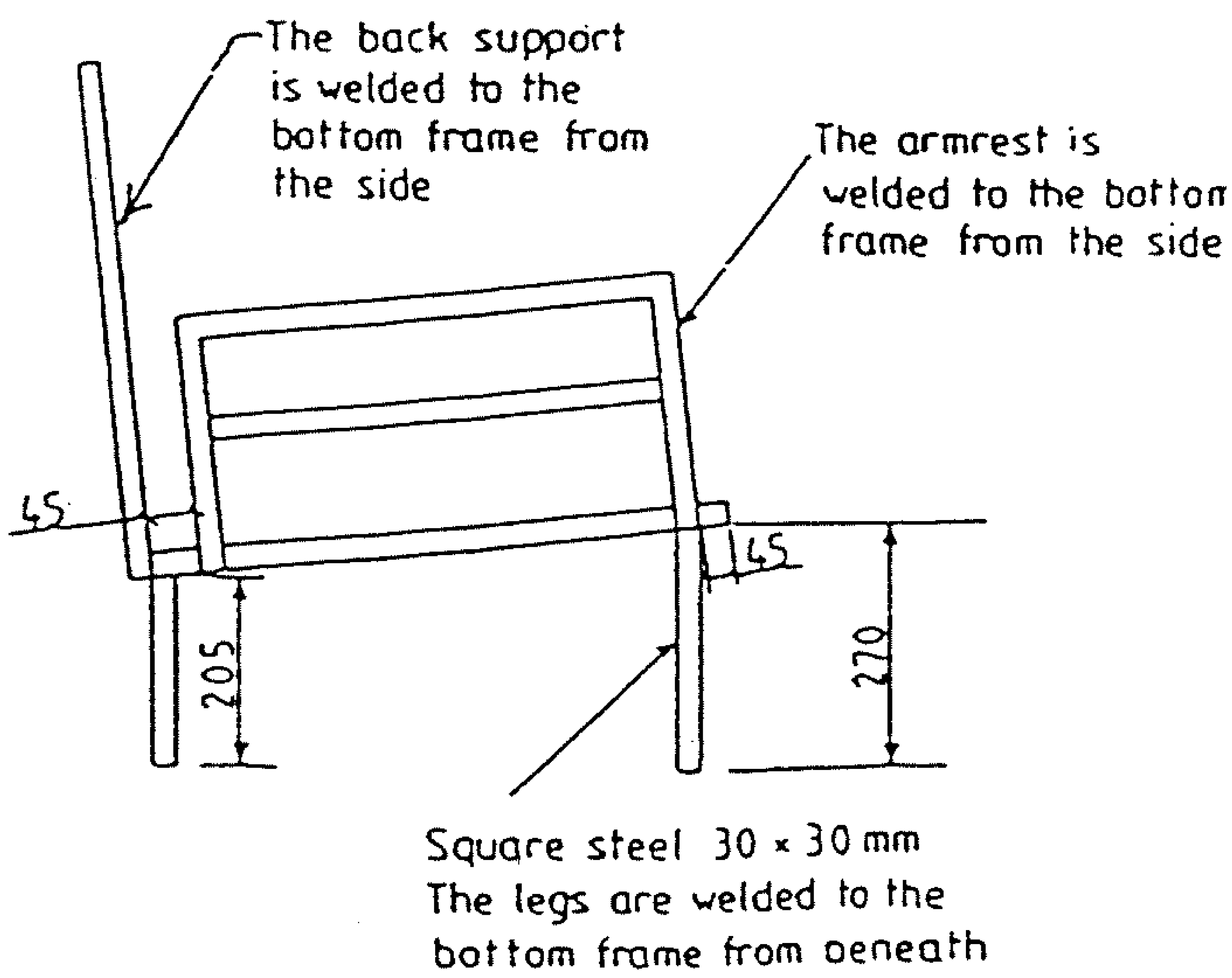
a) Bottom frame.



b) Back support.

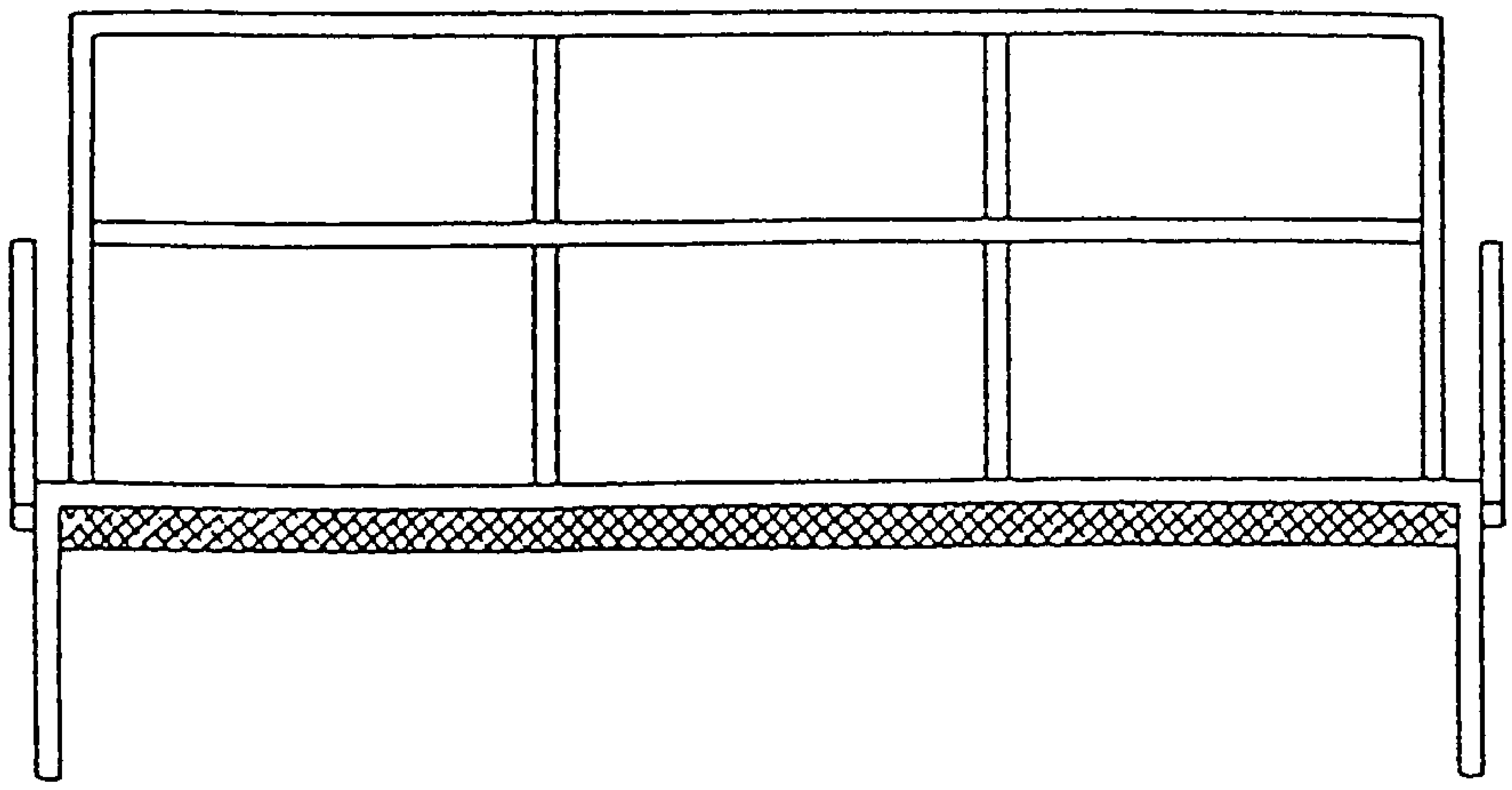


c) Arm rest.

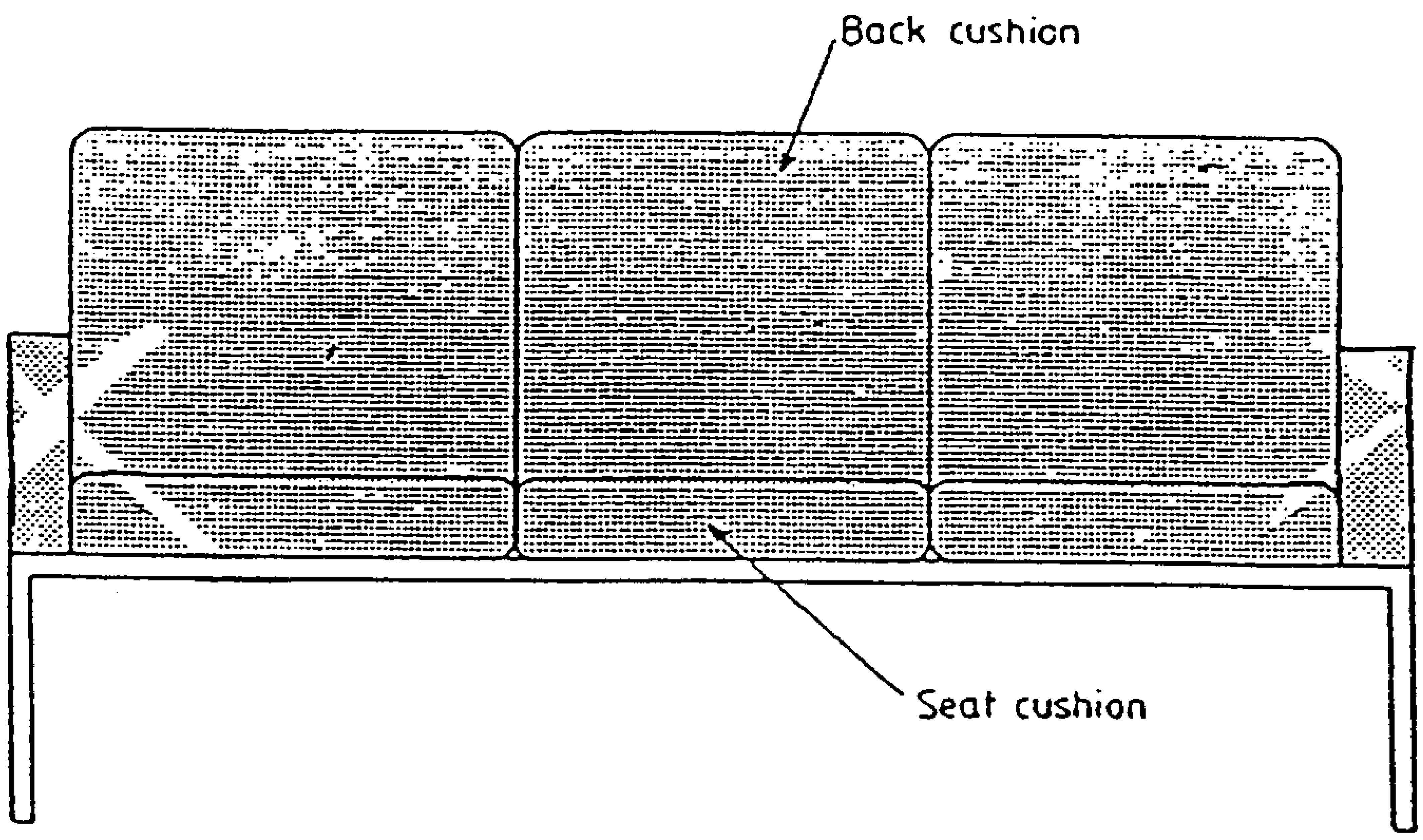


d) Side view of assembled sofa frame.

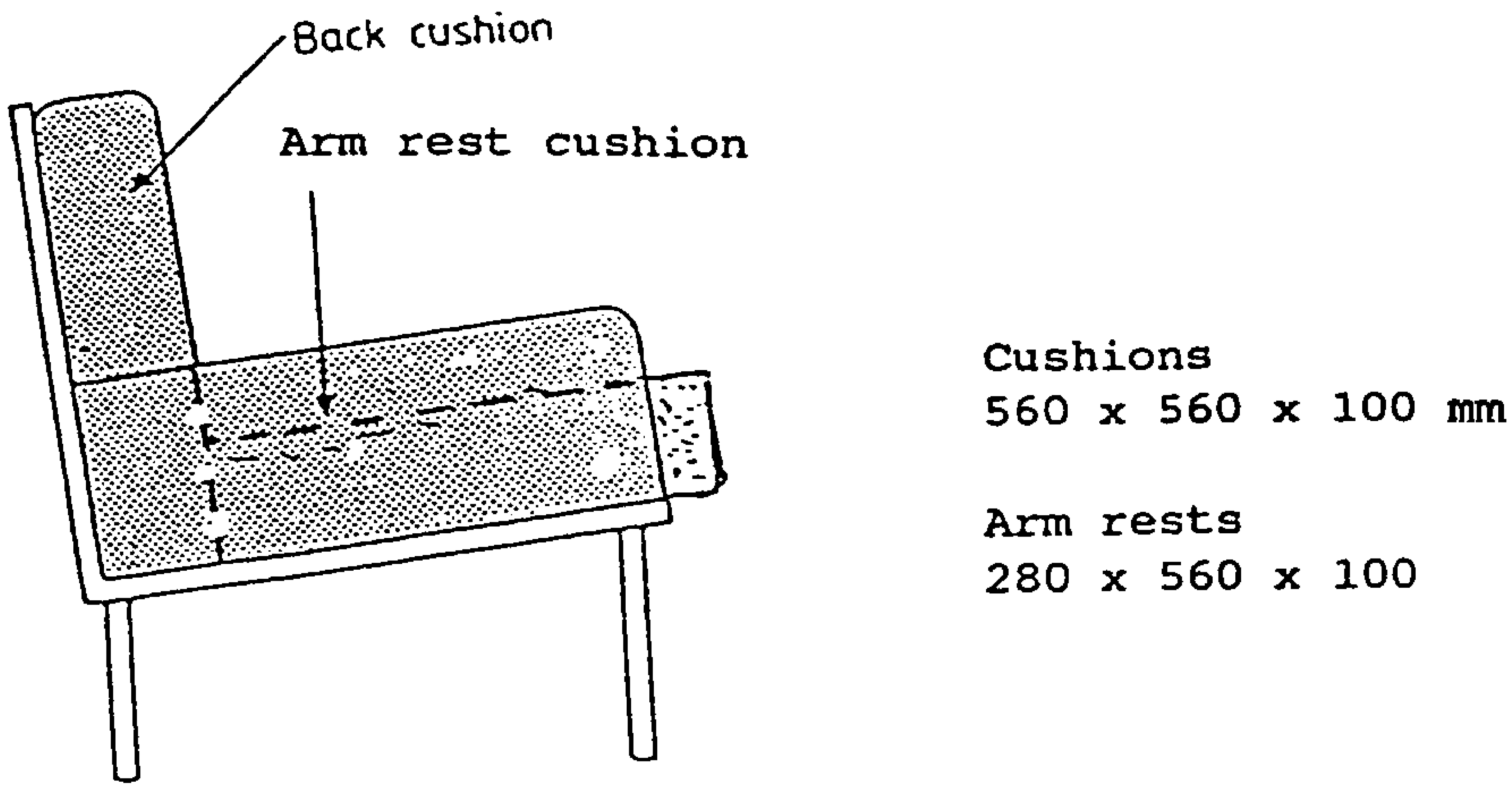
Figure 3 (a-e) Three-seat sofa frame.



e) Front view of assembled sofa frame.

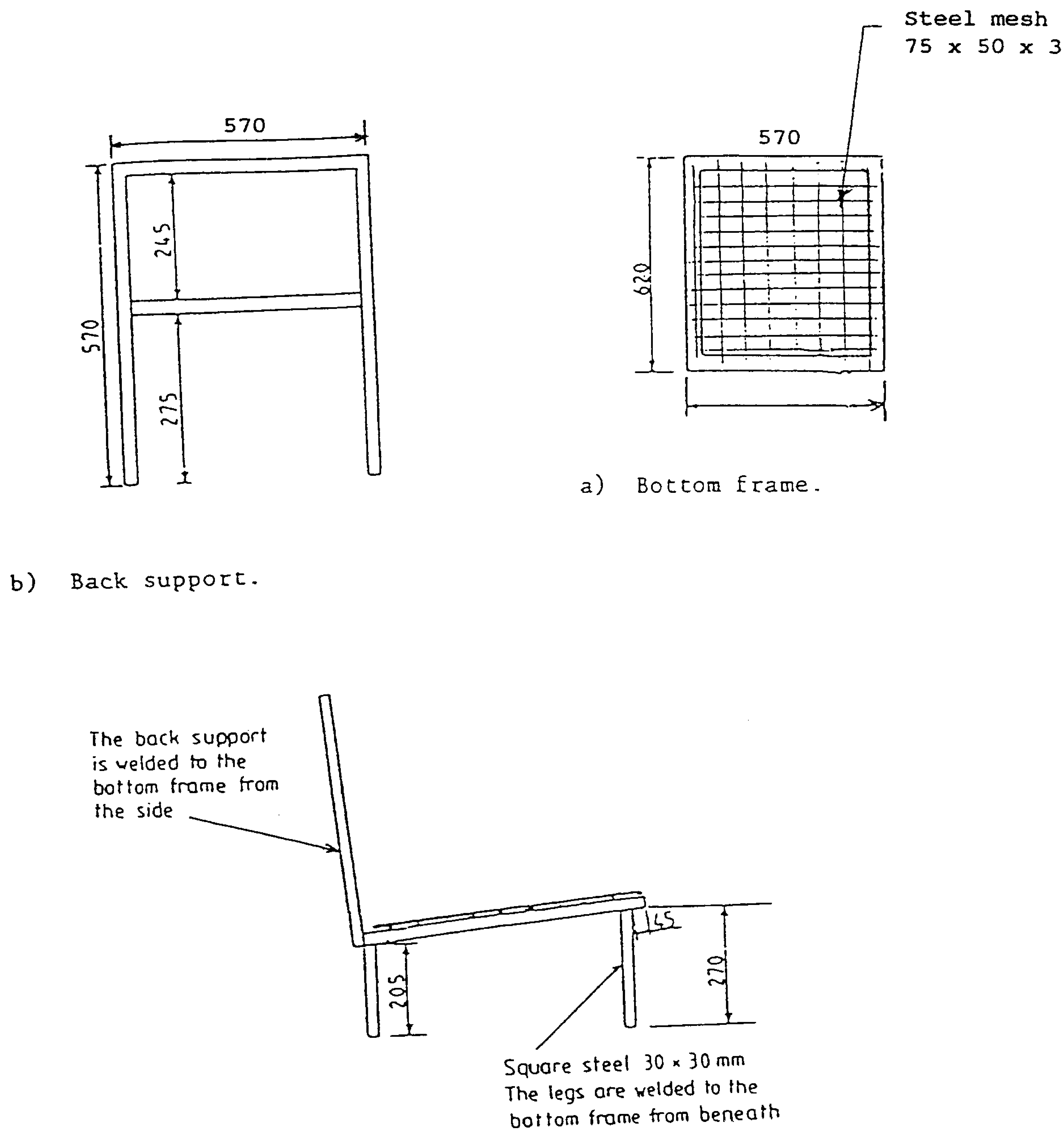


a) Front view.



b) Side view (the arm rest of the steel frame not shown).

Figure 4 (a-b) Position of cushions.



c) Side view of assembled seat frame.

Figure 5 (a-c) Single-seat frame.

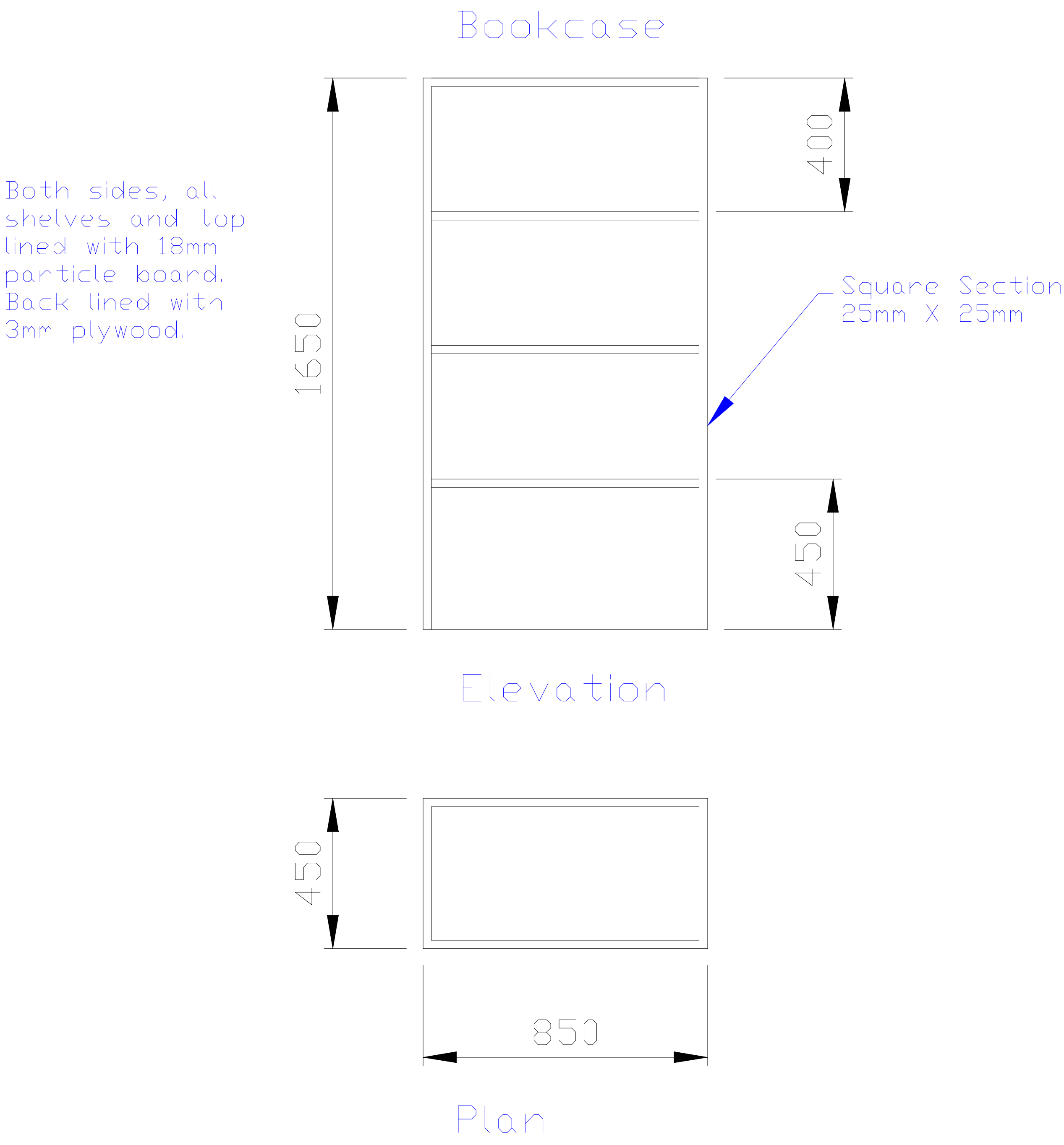
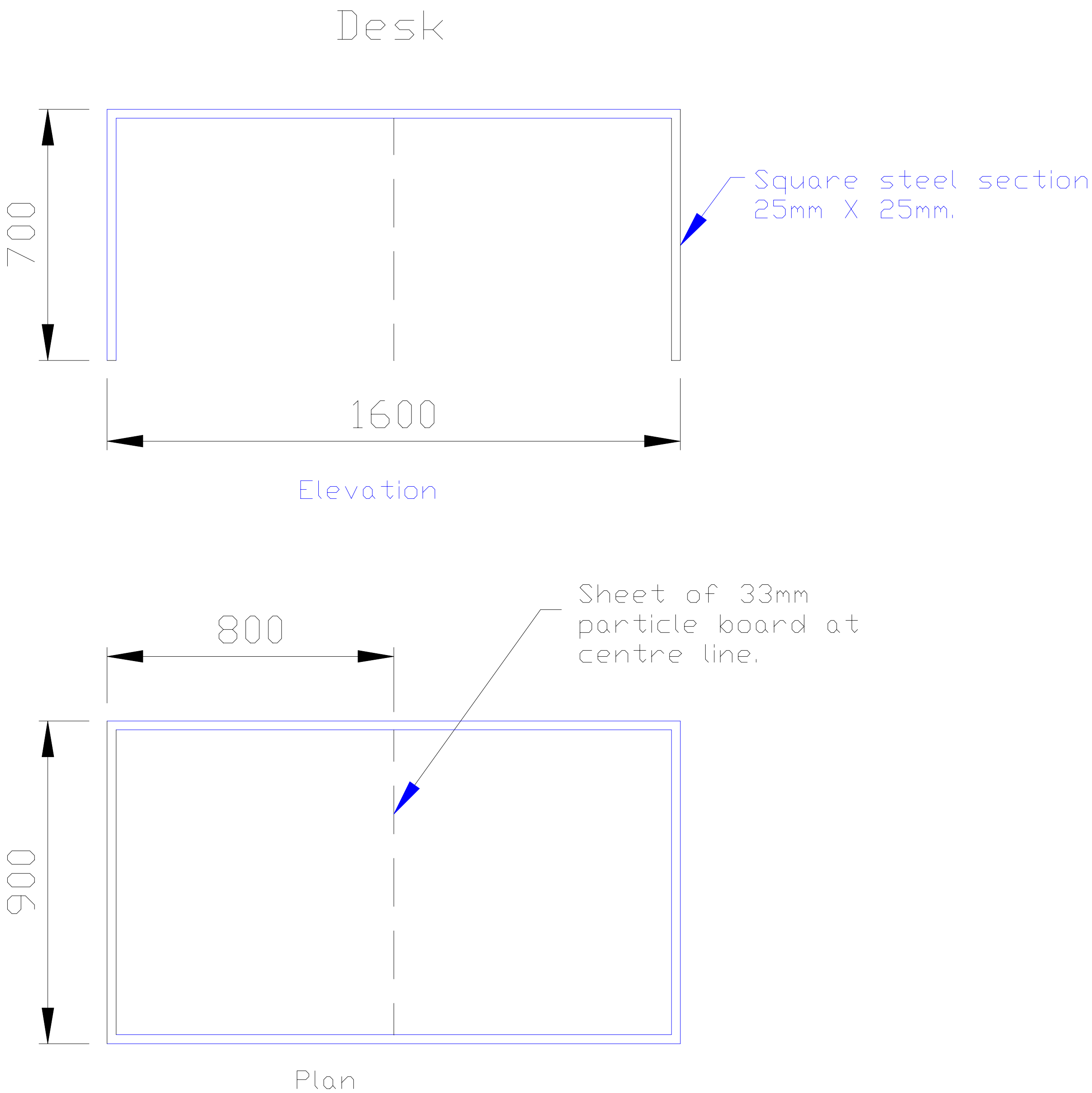


Figure 6 Bookcase.



The top, one long side (1600 x 700),
and one narrow side (900 x 700)
located furthermost from Bookcase #1,
are to be lined with 33mm particle board.
A 900mm x 700mm sheet of 33mm particle
board is also to be fitted vertically
at the centre line of the desk.

Figure 7 Desk.

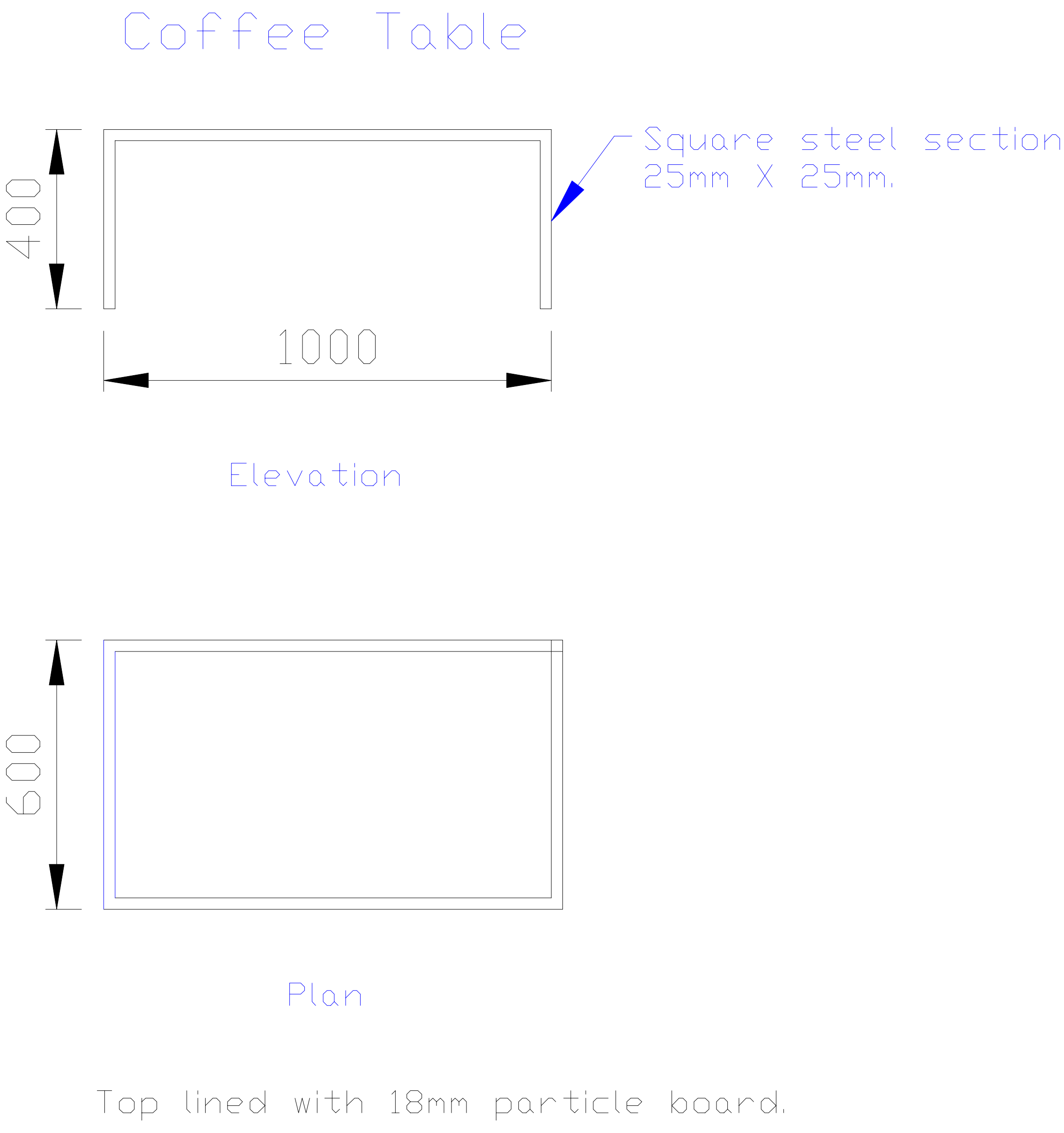


Figure 8 Coffee Table.

Item	No. of Items	Component	X (m)	Y (m)	Z (m)	Volume (m^3)	Density (kg/m^3)	Mass (kg)	H (MJ/kg)	Q (MJ)	No. of components	Total Mass (kg)	Total Q (MJ)
Bookcase	2	Shelf	0.850	0.450	0.018	0.00689	625	4.30	18	77.5	5	21.5	387.3
		Side	1.650	0.450	0.018	0.01337	625	8.35	18	150.4	2	16.7	300.7
		Back	1.650	0.850	0.003	0.00421	545	2.29	18	41.3	1	2.3	41.3
Sub Total												**81.0**	**1458.5**
Desk	1	Top	1.600	0.900	0.033	0.04752	625	29.70	18	534.6	1	29.7	534.6
		Side	0.900	0.700	0.033	0.02079	625	12.99	18	233.9	2	26.0	467.8
		Back	1.600	0.700	0.033	0.03696	625	23.10	18	415.8	1	23.1	415.8
Sub Total												**78.8**	**1418.2**
Coffee Table	1	Top	1.000	0.600	0.018	0.01080	625	6.75	18	121.5	1	6.8	121.5
Sub Total												**6.8**	**121.5**
Grand Total												**166.6**	**2998.2**

11 TEST PROGRAM

BHP	**CSIRO DBCE**
Room Tests	*Room Tests*
1 x Masonry Standard (An additional test may be required depending on the results of the bad-workmanship test).	1 x Masonry Standard
1 x Masonry Bad Workmanship	-
2 x Plasterboard Standard	1 x Plasterboard Standard
Furnace Tests	*Furnace Tests*
-	3 x Masonry Simulated[1]
-	3 x Plasterboard Simulated[1]
-	3 x Masonry Standard (Increased from 2)
-	3 x Masonry Bad Workmanship (Increased from 2)
2 x Plasterboard Standard[3] (Increased from 1)	1 x Plasterboard Standard (Decreased from 2)
2 x Plasterboard Bad Workmanship[3] (Increased from 1)	1 x Plasterboard Bad Workmanship (Decreased from 2)

Notes:

1. *Simulated* indicates that the temperature-time curve used during the furnace test will be the same as that measured during the room tests. (All other furnace tests will use the standard temperature-time curve from AS1530.4 – 1990).
2. For the masonry tests, five specimen thermocouples as specified in clause 2.2.3.2 of AS 1530.4-1990 shall be attached to the unexposed face of the test wall at the mid-point of the wall and the four quarter points. Additionally two specimen thermocouples as specified in clause 2.2.3.2 of AS 1530.4-1990 shall be attached to the unexposed face of the test wall over mortar joints, one in the top half of the wall and one in the bottom half of the wall. The deflection of the wall at the mid point shall also be measured.
3. Since BHP will be conducting tests in a furnace of reduced width (1600 mm), the standard-workmanship plasterboard test wall used by BHP during the furnace tests will be constructed as indicated on the following page. Note that *Side 2* (i.e. the side with the 600 mm and 1000 mm wide sheets) will be the *exposed* surface. For the bad-workmanship test wall, both sides will be constructed with the 600 mm and 1000 mm sheets, and the sheets will not be staggered. CSIRO DBCE will be conducting furnace tests on full size walls (3000 mm width).

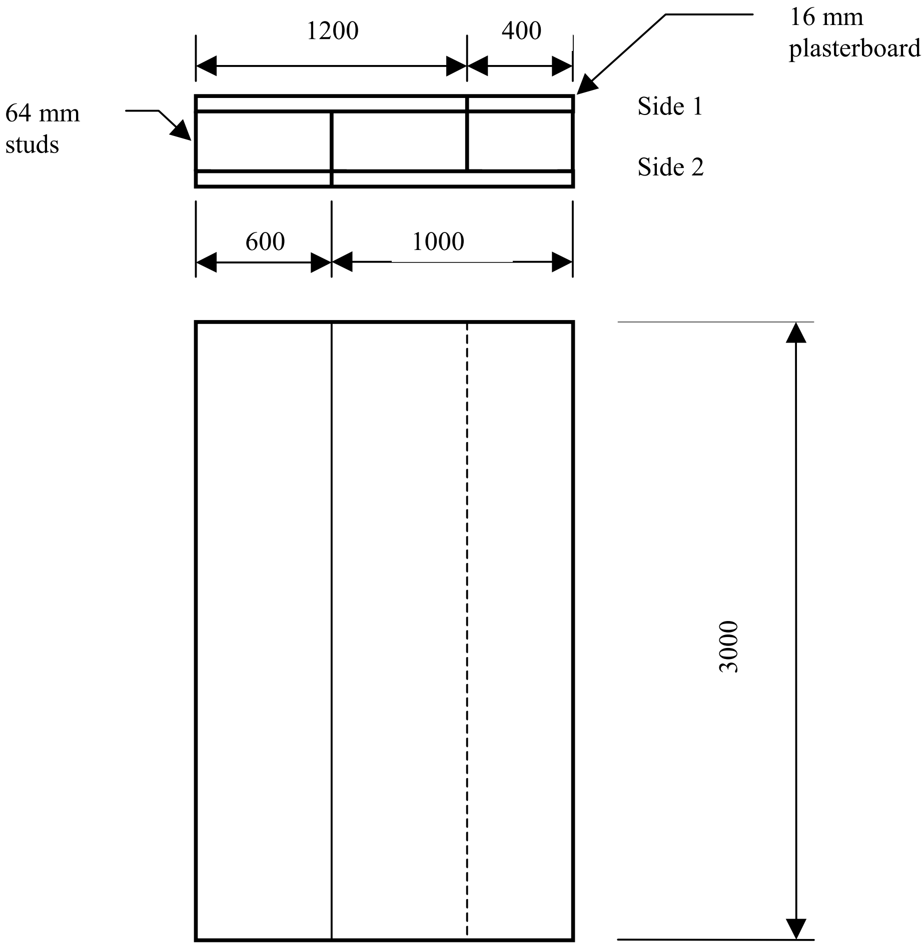


Figure 9 Standard-workmanship plasterboard test wall for BHP furnace tests.

12 BURN ROOM DIMENSIONS AND LAYOUT

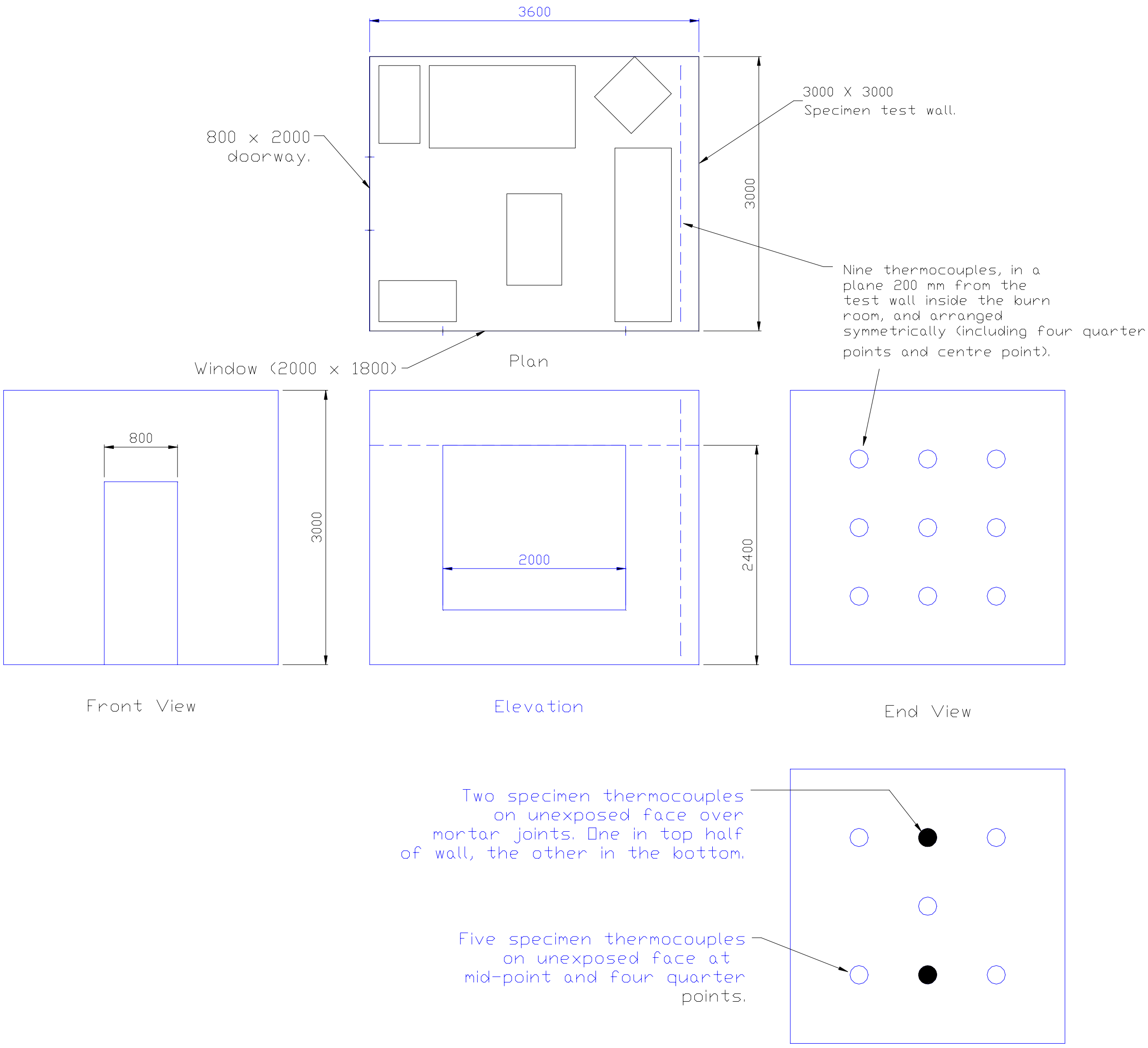


Figure 10 Burn room dimensions.

Note: When viewing the plasterboard test wall from the doorway, the 600 mm wide plasterboard sheet should be on the right hand side of the test room. (Two tests by BHP will be using a mirrored-image room layout, however, the 600 mm sheet will not be mirrored, and will remain on the right hand side).

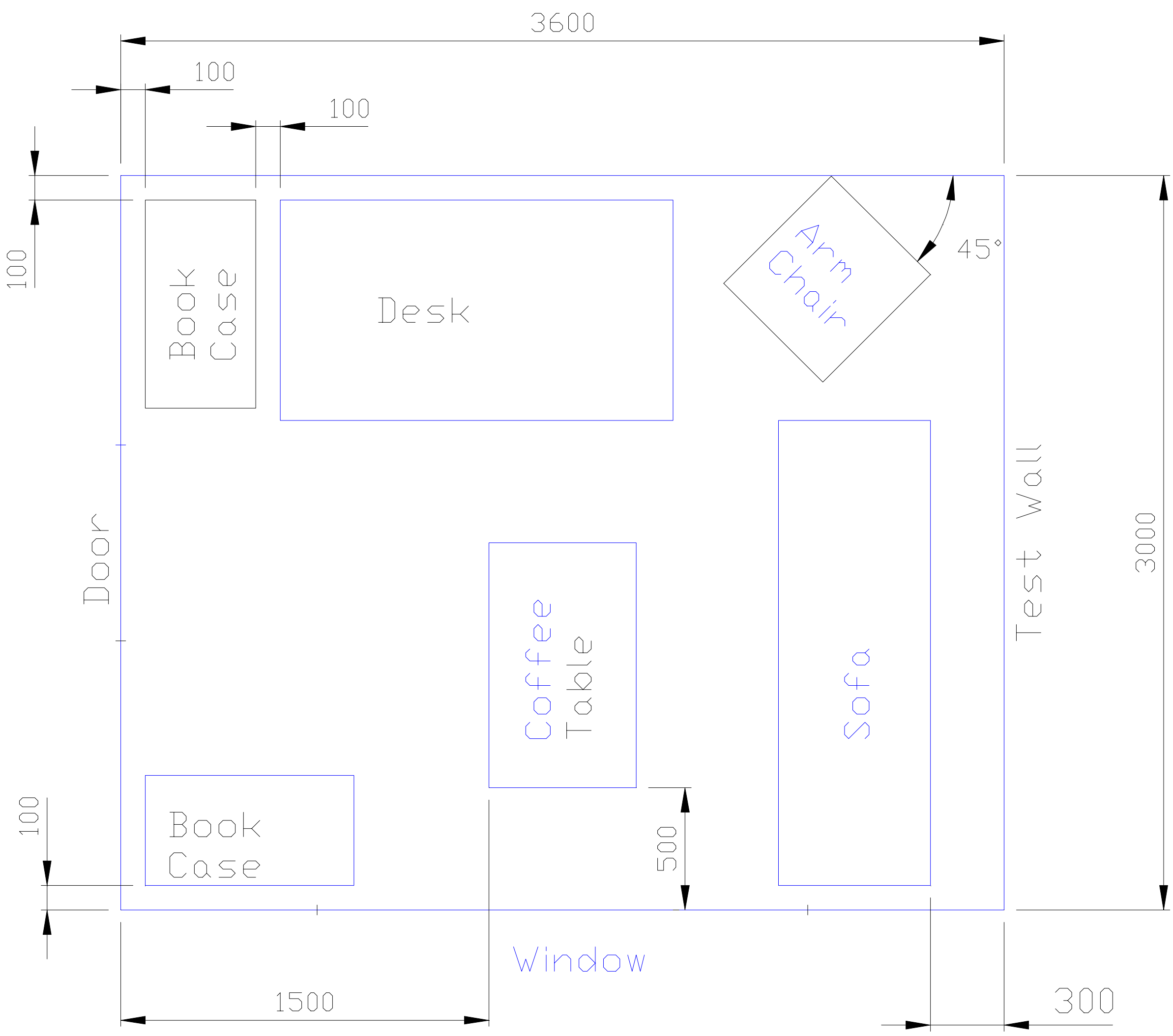


Figure 11 Burn room furniture layout.

(Note: Two tests be BHP will be using a mirror-imaged room layout).

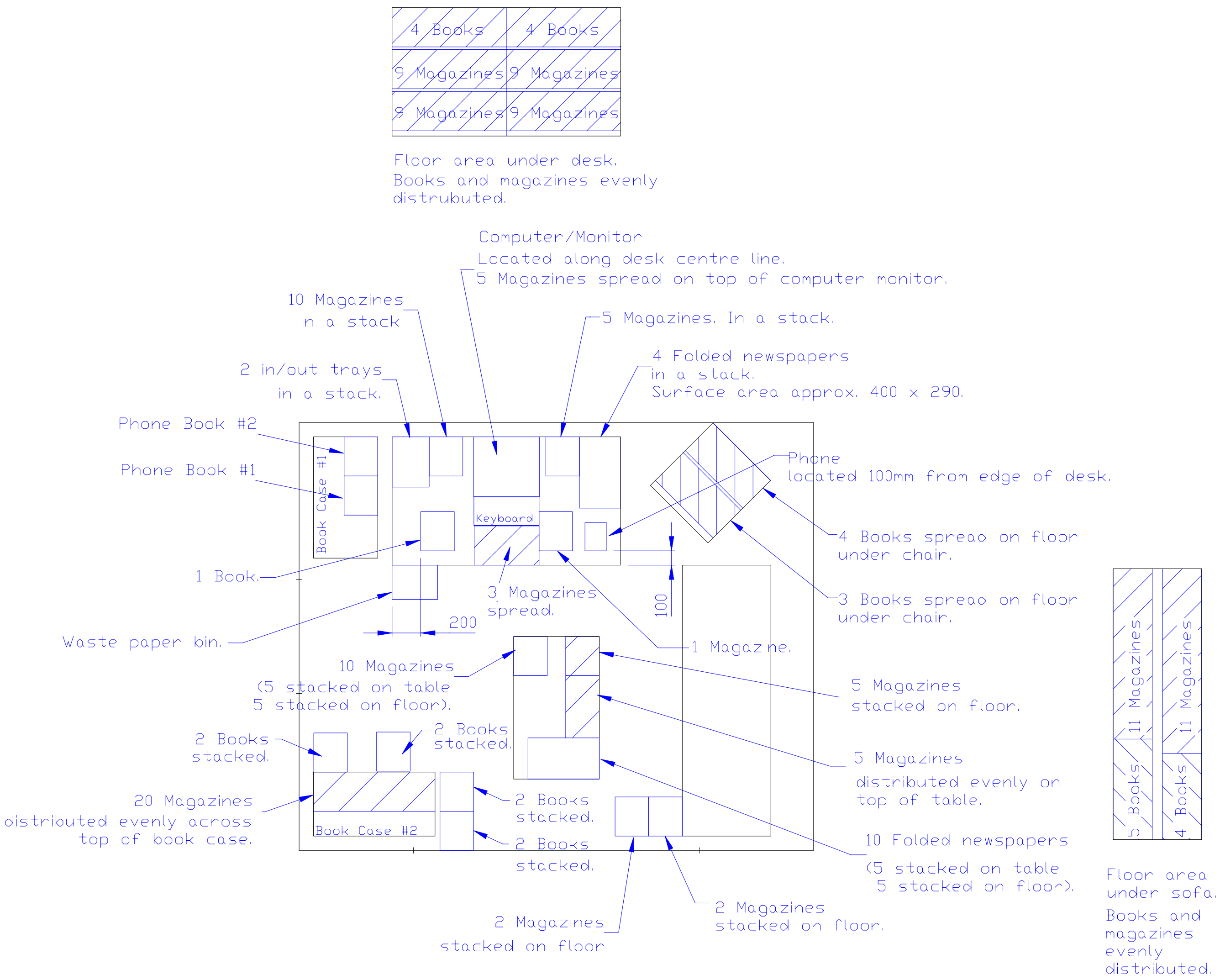


Figure 12 Additional fire load layout.

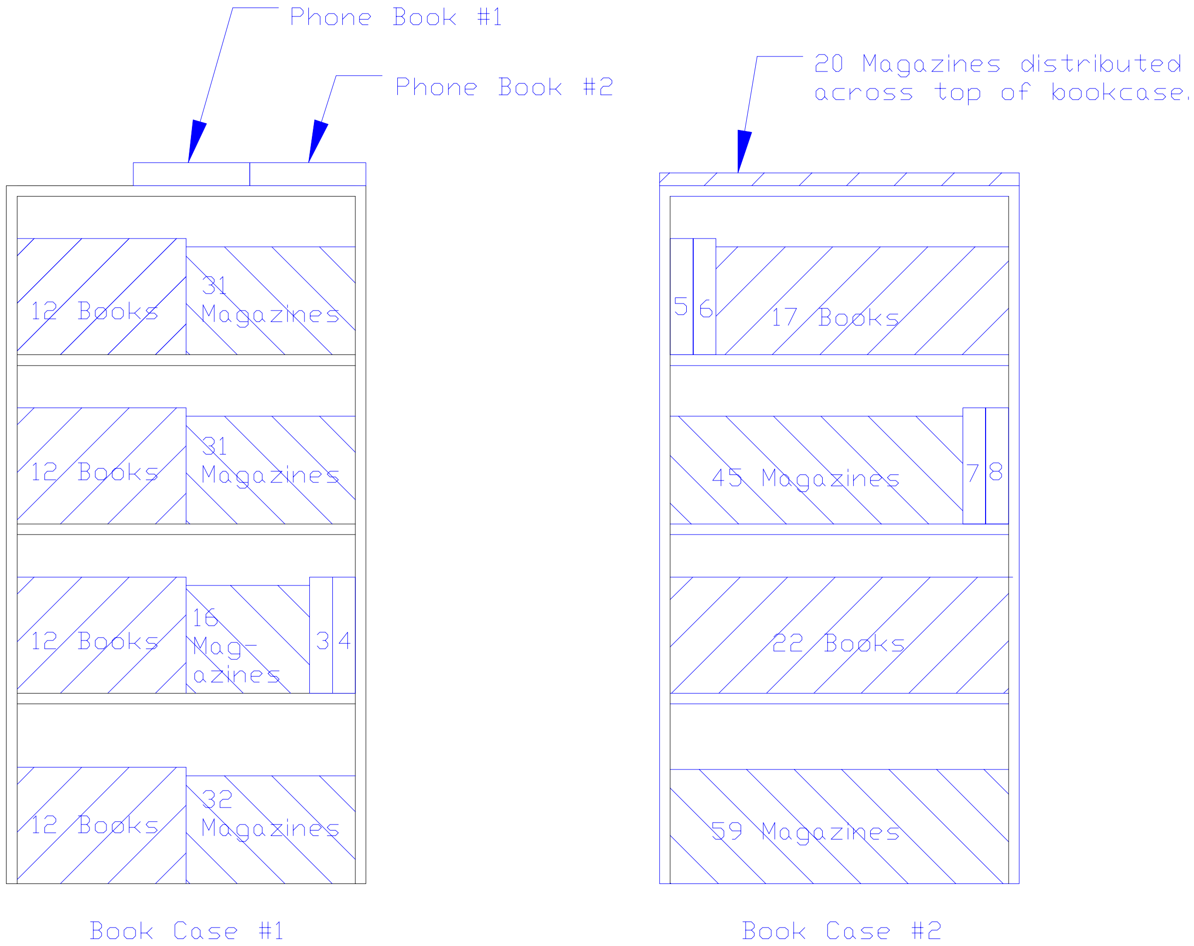


Figure 13 Fire load in book cases.

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