

Annex B – Plenum Spaces

Introduction

Considerable work has been undertaken in characterising fire travel through plenum spaces via cables. In the context of this study the term 'plenum' has been used to describe a ceiling void that can be used to carry building services such as communication and power cabling and is typically used as part of the building HVAC (Heating Ventilation and Air Conditioning) system. By building on this work, a series of the tests were undertaken to investigate the conditions that arise inside a ceiling void when a fire occurs in the room below, and to measure the effectiveness of a cavity barrier installed in the ceiling void.

The tests were carried out on the BRE Real Scale Cable Fire Test Facility, which is a purpose built fire test scenario that offers a test building, containing a suspended ceiling, linked to an exhaust duct to induce a draft across the test sample in the ceiling void, see Photograph B1. Temperature measurements were taken in the ceiling void and the fire room below. Measurements of the combustion products generated during the test are made in the exhaust duct to determine the rate of heat release.

Three scenarios were considered:

- Test 1 - 'Control' test with no cavity barrier system installed within the ceiling void.
- Test 2 - Test with a cavity barrier system installed and the cables running through the cavity barrier without the use of fire stopping, see photographs B3 to B5.
- Test 3 - Test with a cavity barrier system and fire stopping installed. The cable ladder was also wrapped on both sides with the cavity barrier material with 1m length next to the burner and 0.6m on the opposite side, see photographs B6 to B8.

Test Facility

The BRE Real Scale Cable Fire test facility used in this study had internal dimensions 7370 mm x 5700 mm x 4060 mm. The walls were constructed from 215 mm thick 'Stranlite' concrete blocks with a strength specification of 7.0 N/mm². The roof consisted of 200 mm thick 'Thermalite' concrete planks. A suspended ceiling was installed at a height of 3.06 m from the floor to form a 1.00 m void above the ceiling (the ceiling void) and a fire room below it. To provide ventilation to the fire room, holes were provided in the walls of the test building below suspended ceiling. The total area of the ventilation holes was 8.35 m². During the tests, the doorway into the fire room was closed with a piece of 12.5 mm thick calcium silicate board. The BRE Real Scale Cable Fire Test Facility is shown in Figures B1, B2 and B3.

Extract system

A high volume air extract system was fitted to the test building, which extracted air from the ceiling void. The extract system had a controlled extract rate up to 11 m³/s, exhausting into a 760 mm diameter horizontal duct through a 0.45 m² opening in the wall (extract end wall) remote from the gas burner. The test building and the extract system are shown in Figures B1, B2, B3 and B5.

Suspended ceiling

The suspended ceiling consisted of a suspended steel grid holding 600 mm x 600 mm x 9 mm thick calcium silicate ceiling tiles. Ceramic fibre blanket was wrapped around some of the steelwork to provide thermal protection. The calcium silicate tiles were screwed to the steel framework and to provide additional support, 100 mm square metal plates were inserted between the calcium silicate tiles and the fixing screws. Apart from the additional fire protection and additional support for the tiles, the suspended ceiling was of normal construction as typically found in commercial applications in the UK.

The ceiling tile situated directly above the centre of the fire source had a 450 mm x 450 mm (0.2 m²) hole cut in it to provide a breach into the ceiling void. An additional tile in the centre of the back wall (burner end wall) was also removed to allow for additional ventilation in the ceiling void.

Cable support

The cables used in each test were supported in the middle of the ceiling void on a 7200 mm x 380 mm steel ladder. The ladder was supported on five hanging frames sized and fixed so as to maintain the position of the ladder along the centre line of the ceiling void as shown in Figure B4.

Gas analysis and measurements

Measurements of gas temperature and velocity, oxygen concentration, carbon monoxide concentration and carbon dioxide concentration were taken. All measurements were taken from a point at least 8180 mm along the duct from the ceiling void space to ensure good mixing of the exhaust gases before the measurement point. The instrumentation used was as follows.

Gas velocity

The velocity of the gases passing through the duct was measured continuously using a bi-directional probe, positioned as shown in Figure B1. The pressure difference between the two chambers of the probe was measured using a micromanometer. The bi-directional probe was calibrated using a wind tunnel and the micromanometer was calibrated against a null-reading tilting U-tube micromanometer.

Gas analysis

A continuous sample of the combustion gases in the duct was drawn off so that the oxygen, carbon monoxide and carbon dioxide concentrations could be measured. The position of the measuring point is shown in Figure B1. The gas sampling probe consisted of a 10 mm OD stainless steel tube that extended across the full diameter of the duct. Gas was drawn through a series of 2 mm holes distributed at equal intervals along the probe. The sampled gas was passed through an anhydrous calcium chloride filter to dry the gas and a glass wool filter to remove any particulate matter. It then passed through 10 mm ID PVC tubing to the gas analysers situated in the control room.

In order to measure the oxygen content of the gases present in the ceiling void, a gas sampling tubes were inserted into the ceiling void. The probe was located along the centre of the ladder, 3.5 m from the burner end wall of the test building and extended 0.3 m into the ceiling void. The sampled gas was passed through an anhydrous calcium chloride filter to dry the gas and a glass wool filter to remove any particulate matter. The sample then passed through 8 mm ID PVC tubing to the gas analysers situated in the control room.

The oxygen content of the gas sample was measured using paramagnetic oxygen analysers. Calibration of the oxygen analyser was achieved using oxygen free nitrogen and air (assumed to be 20.95 % oxygen). The concentration of carbon monoxide and carbon dioxide in the combustion gas was measured using a specifically tuned non-dispersive-infra-red (NDIR) carbon monoxide and carbon dioxide analysers. Calibration was achieved using oxygen free nitrogen (0% CO and CO₂) and certified carbon monoxide/carbon dioxide/balance nitrogen gas mixtures. The time taken for the gas sample to travel from the duct to the analysers was measured and the results have been adjusted accordingly.

Ladder assembly loading and withdrawal

Prior to each test the ladder assembly (cable ladder and cable sample) was slid onto the supports in the ceiling void space through the ladder withdrawal port. The end of the ladder was positioned approximately 50 mm from the inside of the burner end wall. The ladder withdrawal port was then closed with a cover made of calcium silicate board lined with ceramic fibre blanket. The ladder withdrawal after the test was the reverse of the loading procedure.

Experimental

The fire room, ceiling void and exhaust duct were comprehensively instrumented so that measurements of temperature, and exhaust gas composition could be taken.

Thermocouples

Thermocouples were installed in the ceiling void, the fire room and attached to the cable bundles, details of which are given below. In all cases, the error in thermocouple location was ± 50 mm or 10%, whichever was the lower value. These tolerances were acceptable as they allowed for the differences arising from the variation in cable loading volumes for

the cable ladders and the location of physical details such as the cavity barrier. Unless stated otherwise, the thermocouples used were 1.0 mm diameter, Type K, chromel/alumel, mineral insulated, stainless steel insulated thermocouples.

Room thermocouples

Four thermocouple 'trees', consisting of four thermocouples per tree, were installed in the fire room. Each thermocouple was constructed from 0.2 mm diameter, Type K, fibreglass insulated, thermocouple wire. The thermocouples were positioned 1500 mm, 2000 mm, 2400 mm, and 2700 mm above the floor, as shown in Figure B5.

The two thermocouple trees nearest the heat source were insulated with ceramic fibre blanket and aluminium foil. The thermocouple hot junctions (the measuring sensors) projected horizontally from the insulation at the measuring height and faced away from the fire.

Ceiling Void thermocouples

The location of the ceiling void thermocouples are shown in Figures B5 and B6, and in Table B1. Thermocouples O, P, Q, S, T and U were positioned level with the bottom of the cable ladder. Thermocouple M was positioned immediately above the sample cables over the breach opening. Thermocouples K and L were positioned in the breach opening, where the burner flame enters the ceiling void, each nominally horizontally 200 mm from each adjacent edge of the opening and level with the lower surface of the plenum tiles.

Thermocouples 1 – 10 were positioned 150 mm above the top of the cable ladder support. These were retracted to allow the installation and removal of the cable ladder, and returned to their normal position prior to the start of the test.

Thermocouples A, B and C, were positioned 80 mm below the ceiling void roof and thermocouples D, E and F positioned 190 mm below the roof. Thermocouples G, H and I were fixed 80 mm above the suspended ceiling.

Cable thermocouples

Thermocouples V, W, and X were attached to one of the cables on the cable ladder. They were wound around a cable, mid-way across the cable ladder and in the middle of the cable bundle. The thermocouple locations can be seen in Figures B5 and B6 and in Table B1.

Cable loading

200 lengths of a PVC jacketed communication cable, with a nominal 6 mm outside diameter (OD), were used as the fire load for all three tests. This loading was taken as being representative of typical values found when upgrading or refurbishment of these systems occur in practice. The lengths of cable were tied to the 7.20 m long by 0.38m wide cable ladder. The cables were attached to the ladder in 4 bundles of 50 cable

lengths. The ladder and sample were then positioned along the centre of the 1.0 m deep ceiling void in each test.

Table B1. Thermocouple locations (see also Figures B4, B5 and B6)

Thermocouple designation	Location from burner end wall (mm)
1	6780
2 A D G V	6120
O	6100
3	5460
4	4800
5 B E H P W	4140
6	3480
U	2950
7 S	2820
8 C F I Q X	2160
T	1830
9	1500
M	1450
10	500

Cavity barrier installation

In Tests 2 and 3 the cavity barrier was installed 2.9m from centre of breech hole, 4.4m from end of rig the layout of the barrier, see photograph B4. The cavity barrier systems used for these tests was a commercially supplied system designed to meet the ½ hr fire resistance requirements set out in AD B. It was installed in accordance with manufacturer's instructions.

Fire stopping description

A quick setting, fire rated expanding foam, tested to BS 476 part 20/22 and DIN 4102 (B1) was used to fire stop the gap around the opening in the cavity barrier.

Data logging

Signal outputs from all the measurement devices were connected to a data logging system which consisted of four Schlumberger 3595a series isolated measurement pods connected via an S-Net to a control computer. Commercially available control software was used to drive the logging system. During each test the data channels were scanned frequently and the data recorded to disk every 5 seconds. A 'real time' graphical data was also provided to facilitate observation of important parameters during a test. Post test, all logged data were transferred into Excel™ spreadsheets for final data processing and graph plotting.

Photographic and video recording

During each test, continuous colour video coverage and still photographic records were taken. Two video cameras were used to view the ceiling void through windows fitted with heat resisting glass. One was located at the burner end wall and one on the side of the rig. The locations of the cameras are shown in Figure B1.

Gas Burner

A 1 MW methane gas burner was placed below a missing ceiling tile in each test see Photograph B2, 1.5 m along the support ladder, with the burner flames impinging upon the underside of the test cable. The smoke and combustion products were initially withdrawn from the ceiling void by an induced draft at the opposite end of the ladder from the gas burner, into an exhaust duct, for further analysis.

The horizontal burner was 1m x 1m square, and was filled with 10mm pea shingle. The fuel using for the burner was mains piped natural gas, which was controlled via a series of valves and flow meters and a rapid shut off valve. A gas flow rate of 1900 litre/min was used to give a heat release rate of 1MW.

The 1 MW burner application time was greater than 30 minutes in each tests. The data records were initiated approximately 5 minutes before ignition of the burner and continued for at least 10 minutes after the burner was extinguished or the cable had burnt out, whichever was the longer time period.

Results

The data from Tests 1 to 3 are presented in Figures B7(a) to B9(c) respectively. Figures (b) and (c) for each set of test data present the temperature data recorded at various locations within the test facility. Tables B3, B5 and B7 summarise the maximum temperature and time of occurrence at three locations (TCA, TCB and TCC) within the ceiling void space. These locations were selected for ease of comparison between tests. In addition the peak HHR and THR at 20 minutes are also given in the tables.

Test 1 - 'Control' test with no cavity barrier installed.

The visual observations made during the tests are summarised in Table B2 below.

Table B2. Summary of Observations – Test 1

Test	Logging Time
Ignition	02:15
All flaming on cable ladder ceased	30:00

Table B3 summarises the maximum ceiling void temperatures at locations TCA, TCB, TCC and heat release values. Figures B7(a) to (c) show the temperature profiles and gas measurement records.

Table B3 – Summary of Test 1 Data

Test parameter	Value
Maximum Ceiling Void Temperatures (°C)	
Location A (see figure B4 & B5)	833°C @ 955s from ignition
Location B (see figure B4 & B5)	830°C @ 700s from ignition
Location C (see figure B4 & B5)	766°C @ 15s from ignition
Heat Release Values	
Peak HRR 20	546 kW
THR 20	242 MJ

Test 2 - Test with cavity barrier installed - no fire stopping.

The visual observations made during the tests are summarised in Table 4 below. The layout of Test 2 can be seen in photographs B3,B4 and B 5.

Table B4. Summary of Observations – Test 2

Test	Logger time
Ignition	01:45
Flames break through barrier	17:07
Cable burning at the end of ladder	28:10
All flaming on cable ladder ceased	42:03

Table B5 summarises the maximum ceiling void temperatures at locations TCA, TCB, TCC and heat release values. Figures B8(a) to (c) show the temperature profiles and gas measurement records.

Table B5 – Summary of Test 2 Data

Test parameter	Value
Maximum Ceiling Void Temperatures (°C)	
Location A (see figure B4 & B5)	831°C @ 1490s from ignition
Location B (see figure B4 & B5)	833°C @ 820s from ignition
Location C (see figure B4 & B5)	774°C @ 80s from ignition
Heat Release Values	
Peak HRR 20	424 kW
THR 20	121 MJ

Test 3 –Test with cavity barrier and fire stopping installed.

The cavity barrier was installed with the cables running through the cavity barrier and fitted with fire stopping. The cable ladder was also wrapped on both sides with the cavity barrier material with 1m length next to the burner and 0.6m on the opposite side, see photographs B6 to B8. The visual observations made during the tests are summarised in Table B6 below.

Table B6. Summary of Observations – Test 3

Test	Logger Time
Ignition	01:45
Burner off	31:45
All Flames out	69:00
Re-ignition of wrapping around cables at cavity barrier	101:00

Note:

1. Damage on the burner side appeared to be caused by smouldering/growing of material soaked into the cavity barrier, this reignited when the smouldering reached the barrier was exposed to air, see Photograph B10.

Table B7 summarises the maximum ceiling void temperatures at locations TCA, TCB, TCC and heat release values. Figures B9(a) to (c) show the temperature profiles and gas measurement records.

Table B7 – Summary of Test 3 Data

Test parameter	Value
Maximum Ceiling Void Temperatures (°C)	
Location A (see figure B4 & B5)	346°C @ 1615s from ignition
Location B (see figure B4 & B5)	518°C @ 380s from ignition
Location C (see figure B4 & B5)	828°C @ 95s from ignition
Heat Release Values	
Peak HRR 20	444 kW
THR 20	85 MJ

Discussion

The cable ladder in Test 1, with no cavity barrier in place, burnt the full cable length in under 28 minutes. When the cavity barrier was installed, in Test 2, the fire passed through the unstopped cavity barrier approximately 16 minutes after ignition and reached the end of the ladder at around 27 minutes from ignition.

The introduction of fire stopping around the cavity barrier, in Test 3, significantly slowed the rate of fire progress and the flame front did not reach the end of the cable ladder. On examination of the ladder after the test, all burning had been confined to the fire side of the barrier, that is, the fire did not pass the cavity barrier. When the unexposed side of the barrier wrap was removed, the cables beneath the wrap were fused together but appeared unburnt. Photographs B9 to B13 show the post test damage.

The maximum ceiling void temperatures recorded at locations TCA, B and C (see figures B4 and B5) during Tests 1, 2 and 3 are reported in Tables B3, B5 and B7 respectively. They show the effectiveness of the fully stopped cavity barrier (Test 3) in reducing the void temperature by reducing the fire spread, immediately in front of and behind the barrier, when compared with the same locations in Tests 1 and 2. Both TCB, located on the fire side of the barrier and TCA, located downstream of the cavity barrier location, reached temperatures in excess of 830°C and 760°C respectively, in both Tests 1 and 2. In Test 3 the maximum temperatures were reduced to 518°C and 340°C respectively.

The maximum heat release rate occurred in Test 1, 546 kW at 165sec. The maximum heat release rates recorded in Tests 2 and 3 were similar at 424 kW at 230sec and 444kW at 210 sec respectively.

Recommendation

This work has shown that in order to prevent fire spread along a potentially combustible route, such as cabling, effective fire stopping around any penetration through a cavity barrier will be required.

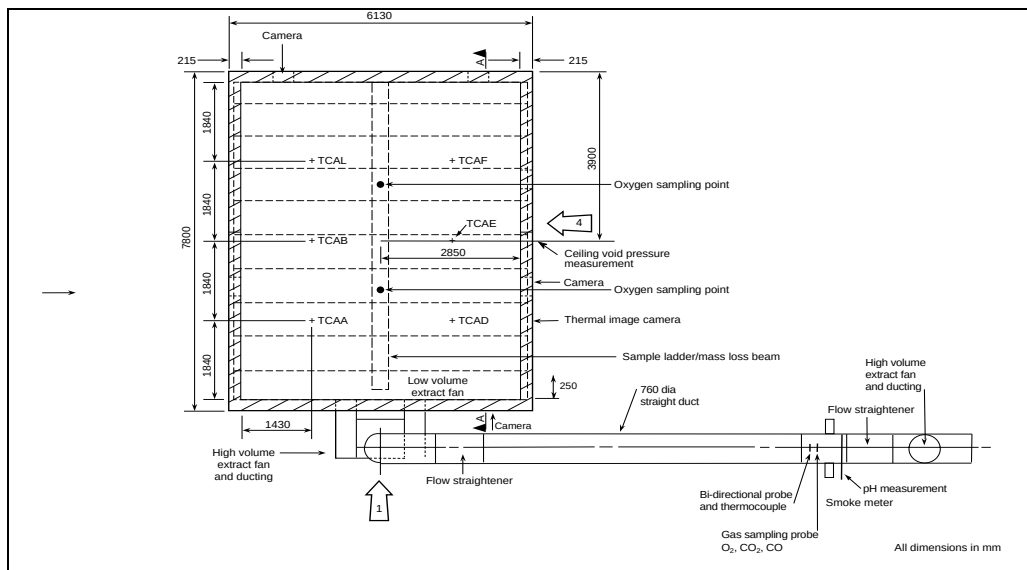


Figure B1 BRE Real Scale Cable Fire Test Facility - roof plan

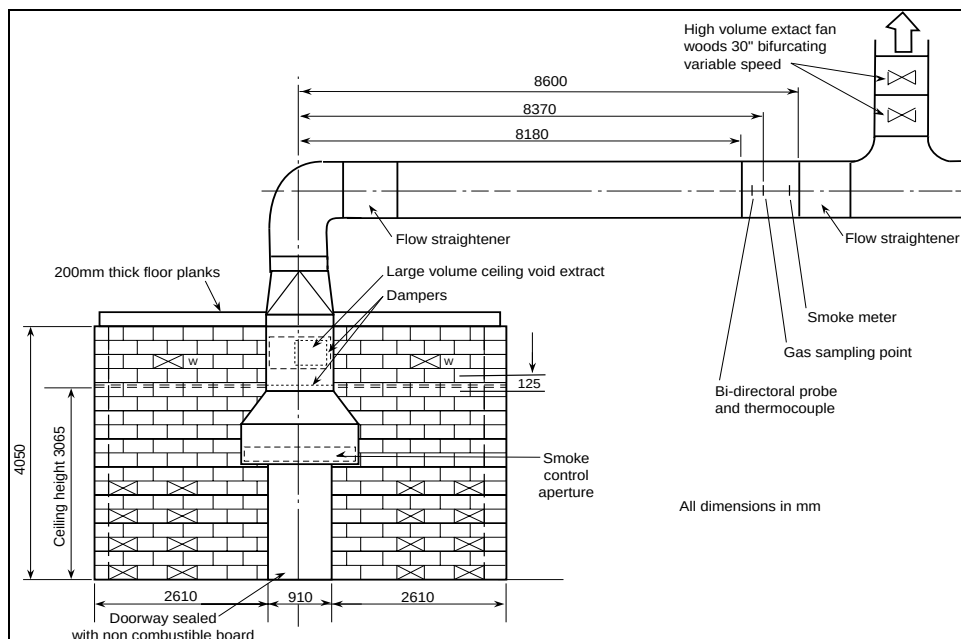


Figure B2 BRE Real Scale Cable Fire Test Facility - front elevation

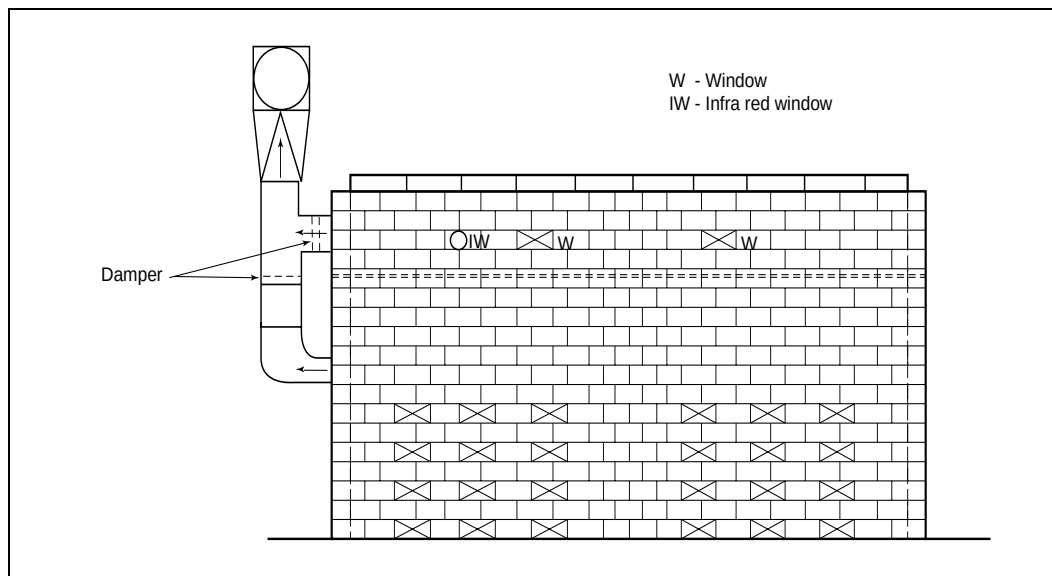


Figure B3 BRE Real Scale Cable Fire Test Facility - side elevation

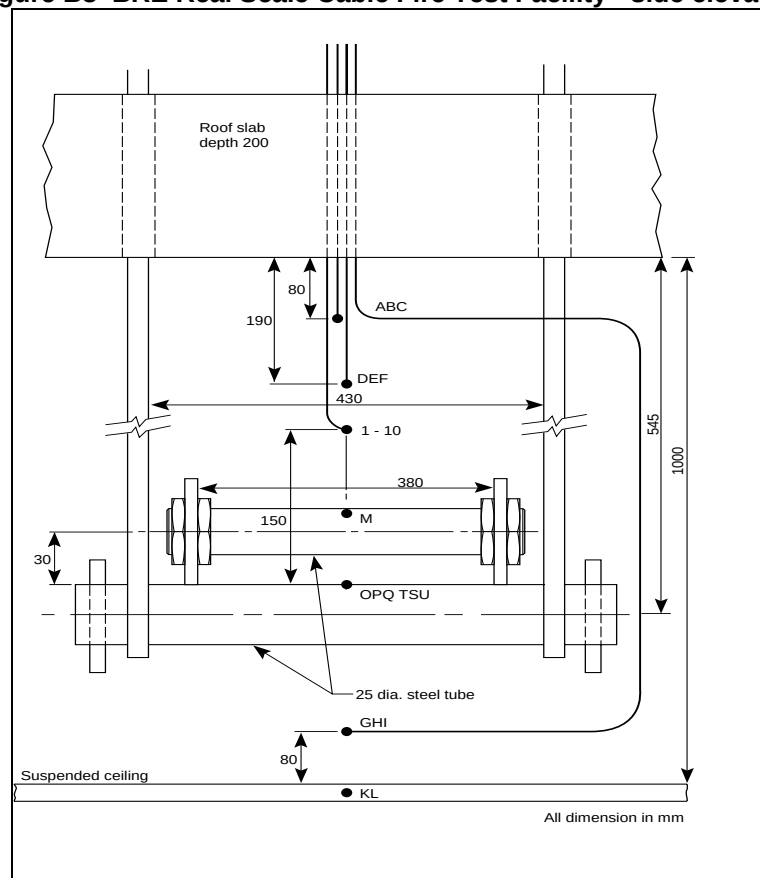


Figure B4 BRE Real Scale Cable Fire Test facility - Ladder and Support Assembly

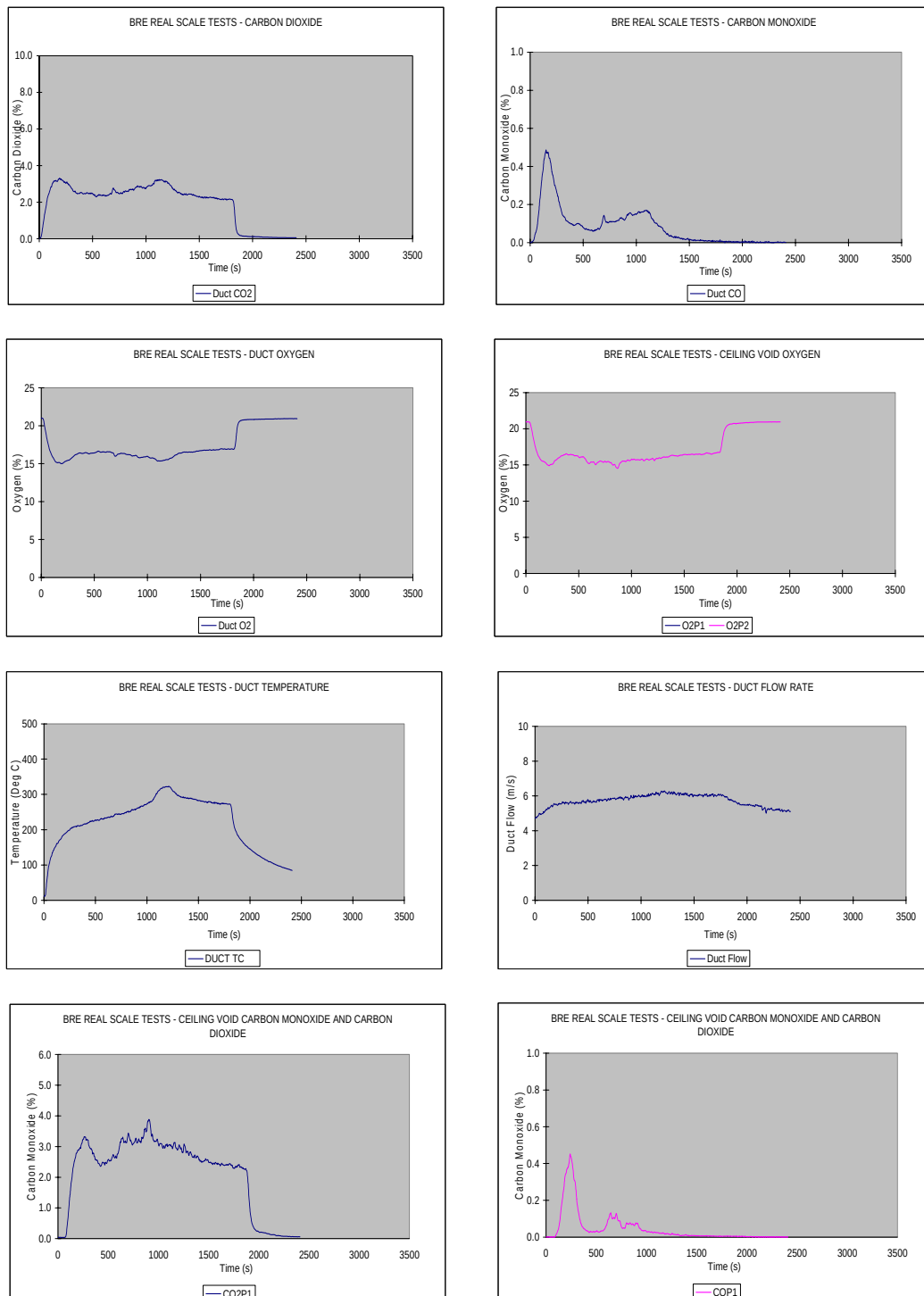


Figure B7(a). Test 1 Gas Measurements

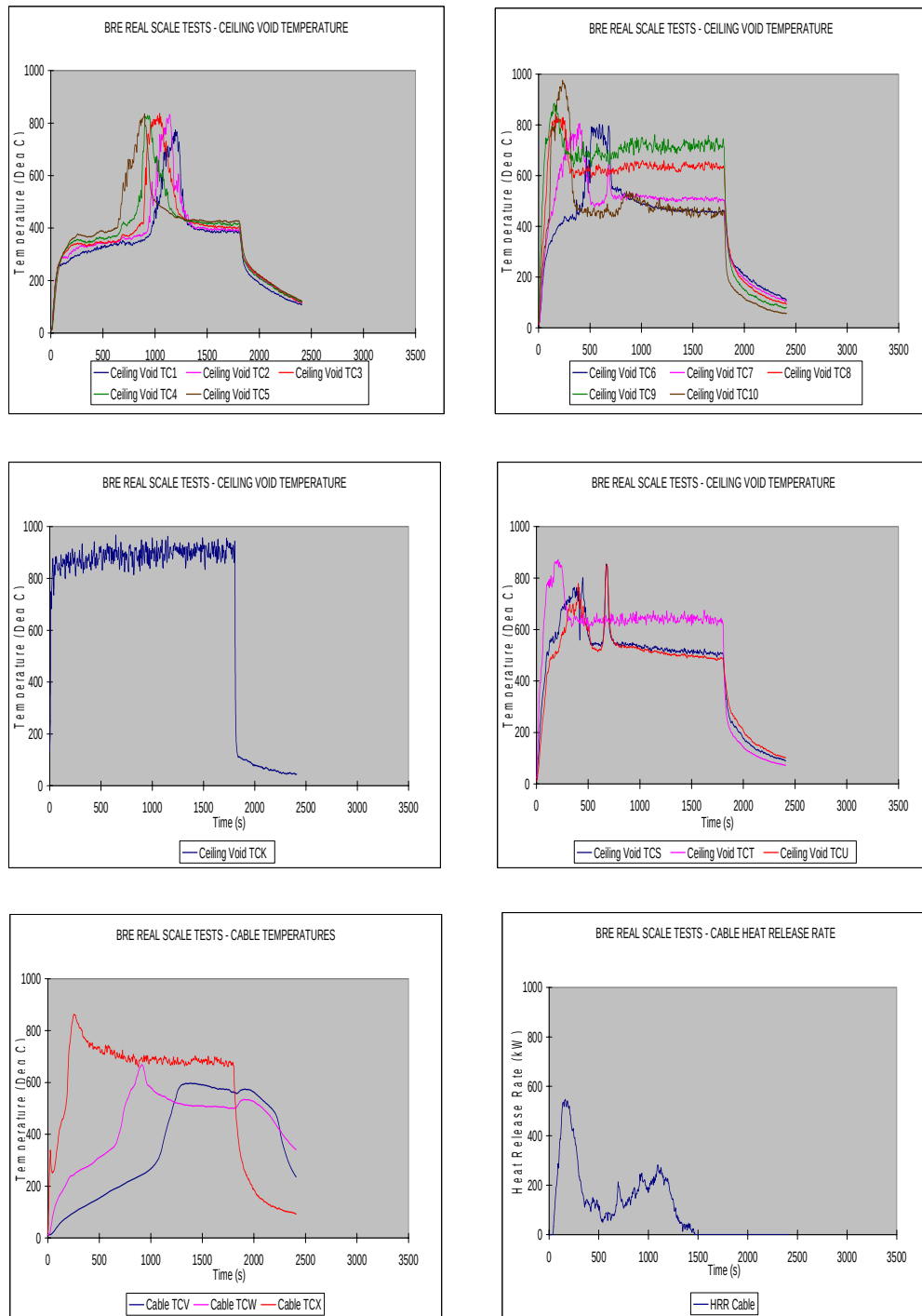


Figure B7(b) Test 1 Temperatures & HRR

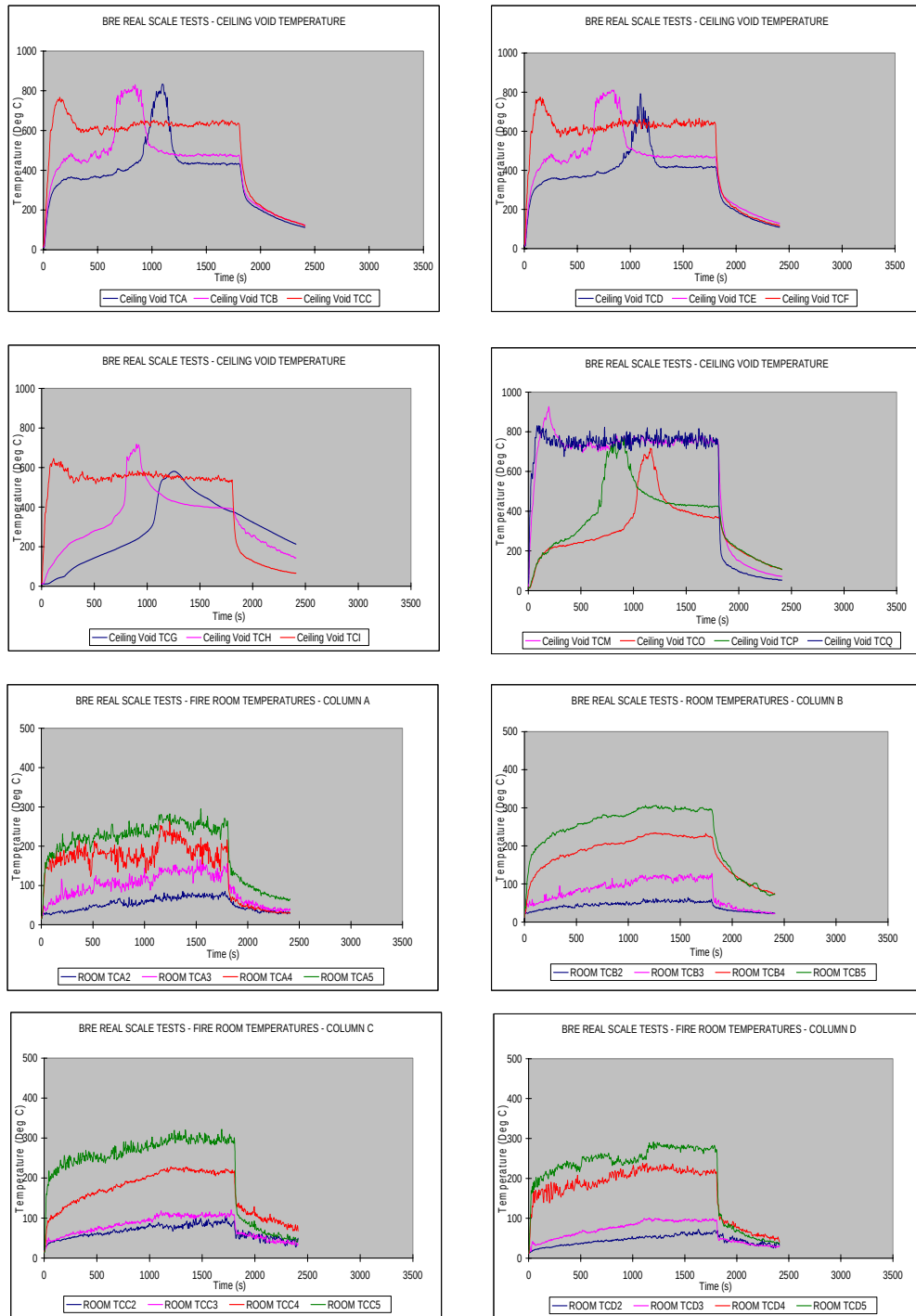


Figure B7(c) Test 1 Temperatures

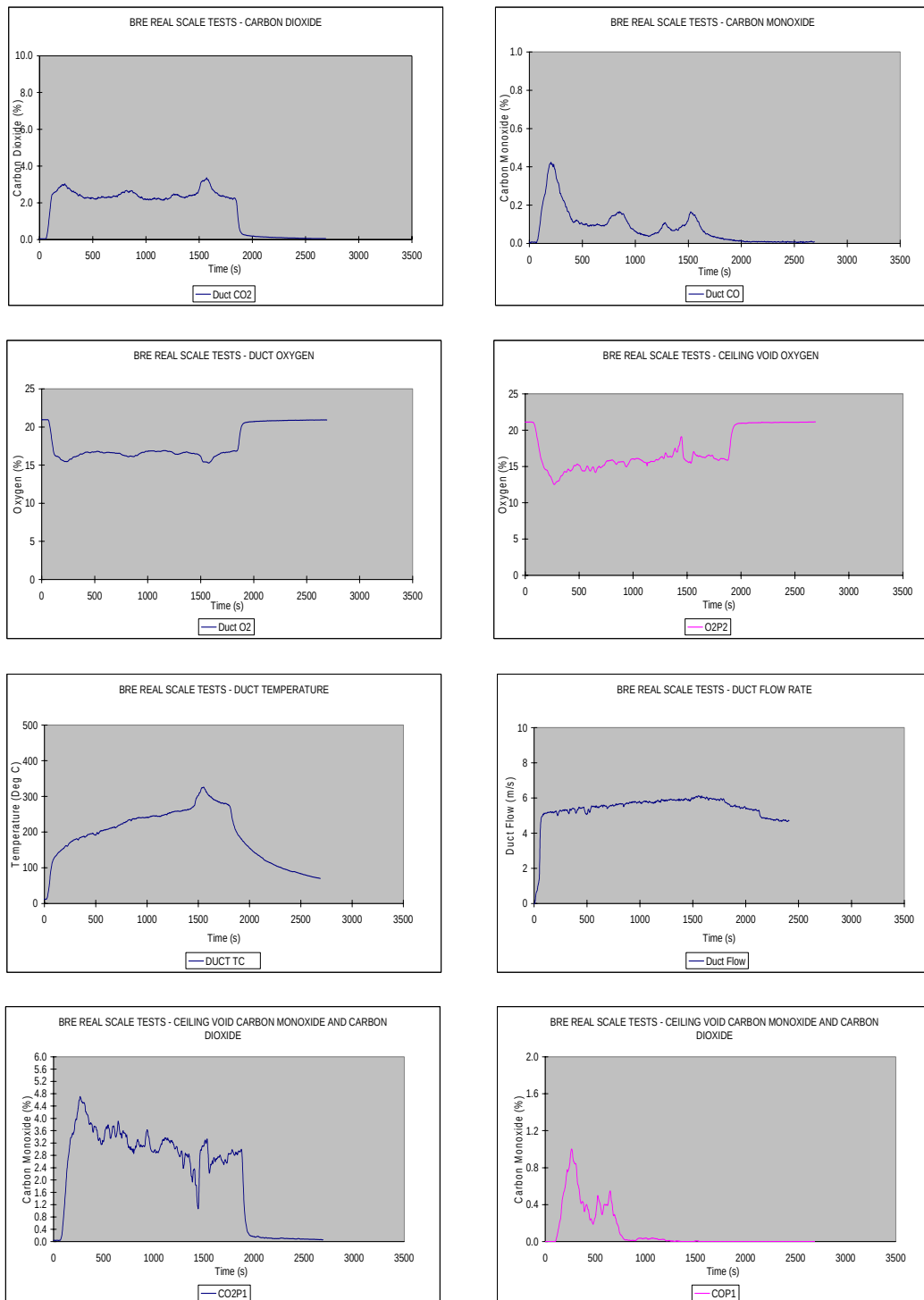


Figure B8(a) Test 2 Gas Measurements

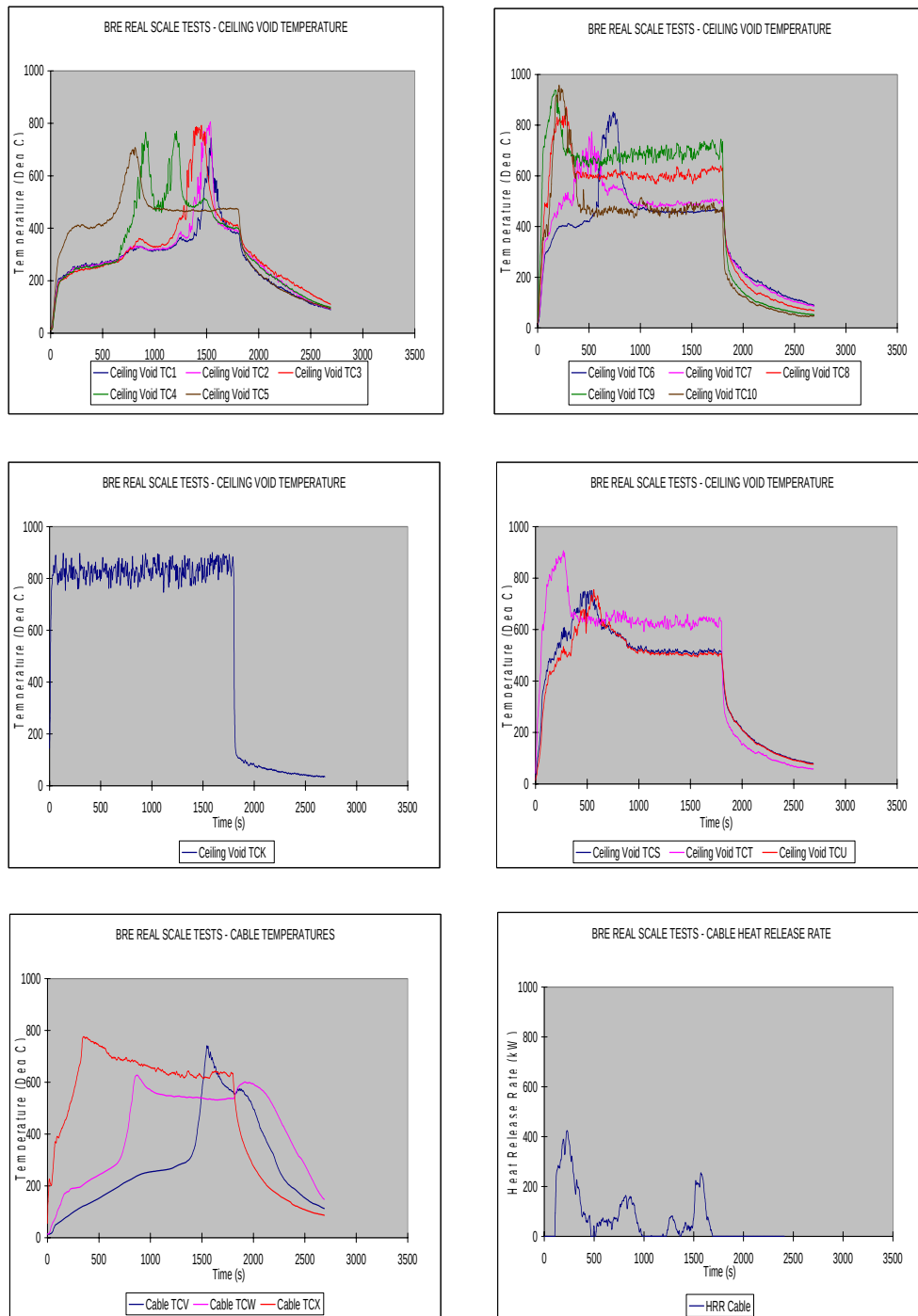


Figure B8(b) Test 2 Temperatures

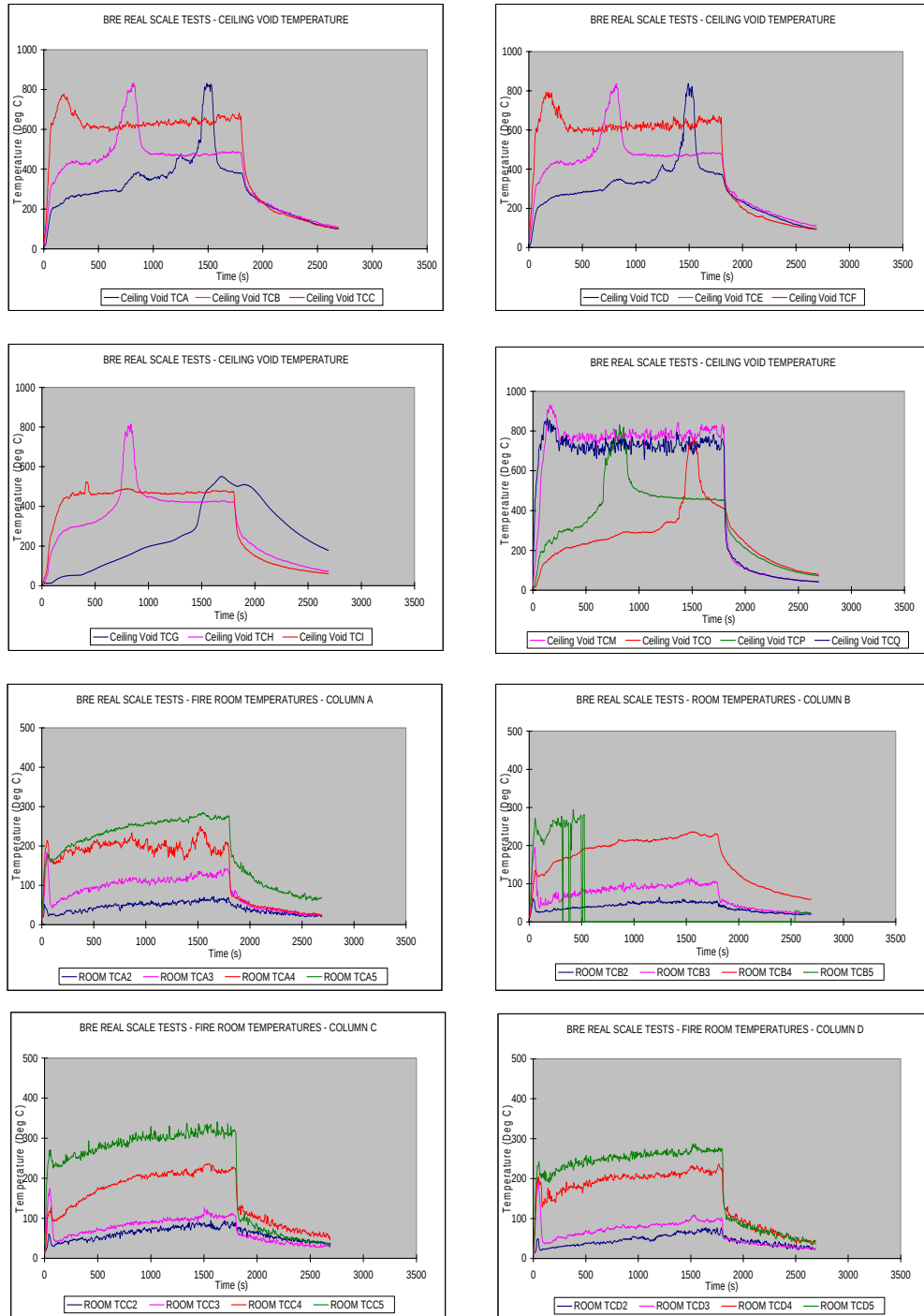


Figure B8(c) Test 2 Temperatures

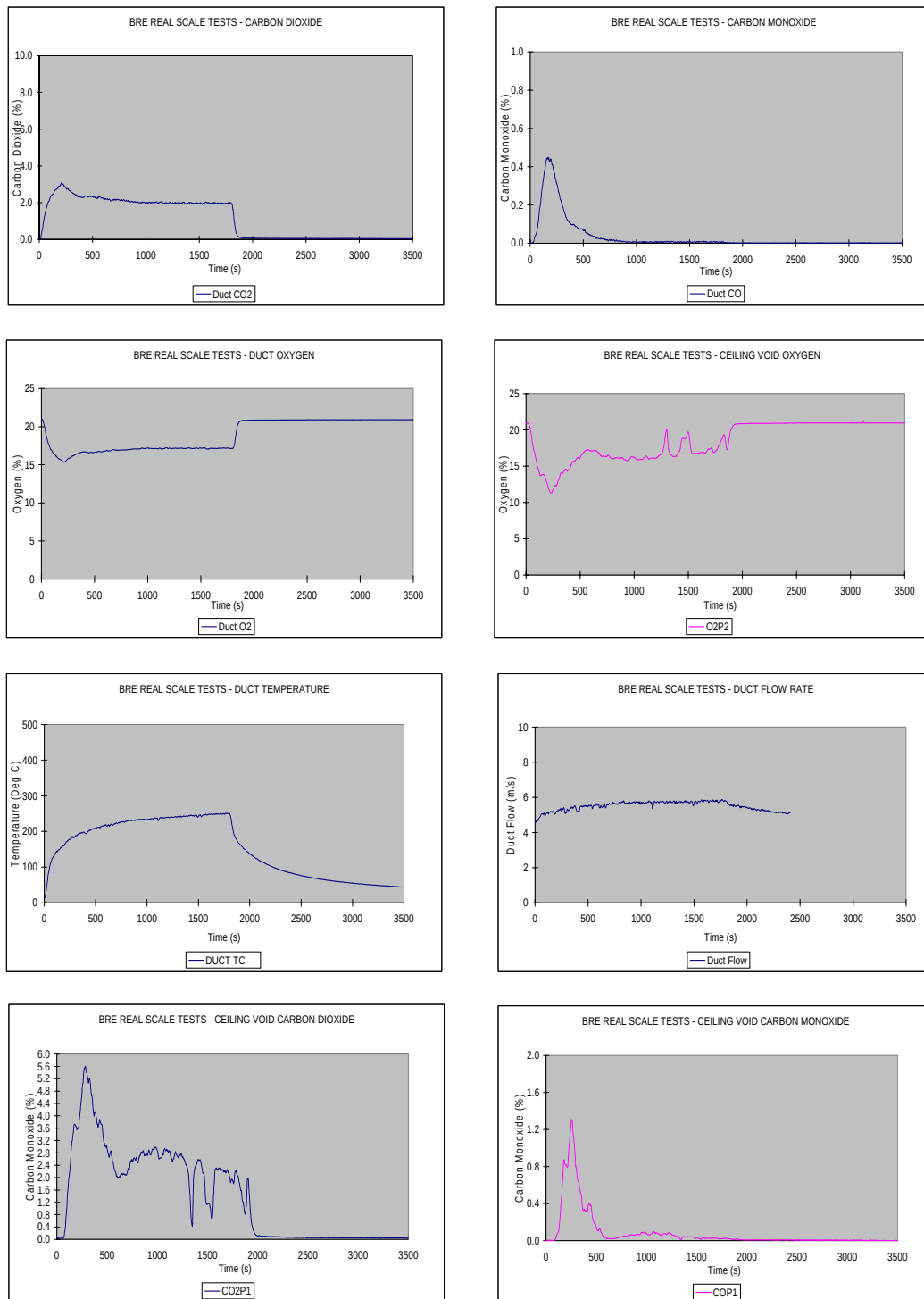


Figure B9(a) Test 3 Gas Measurements

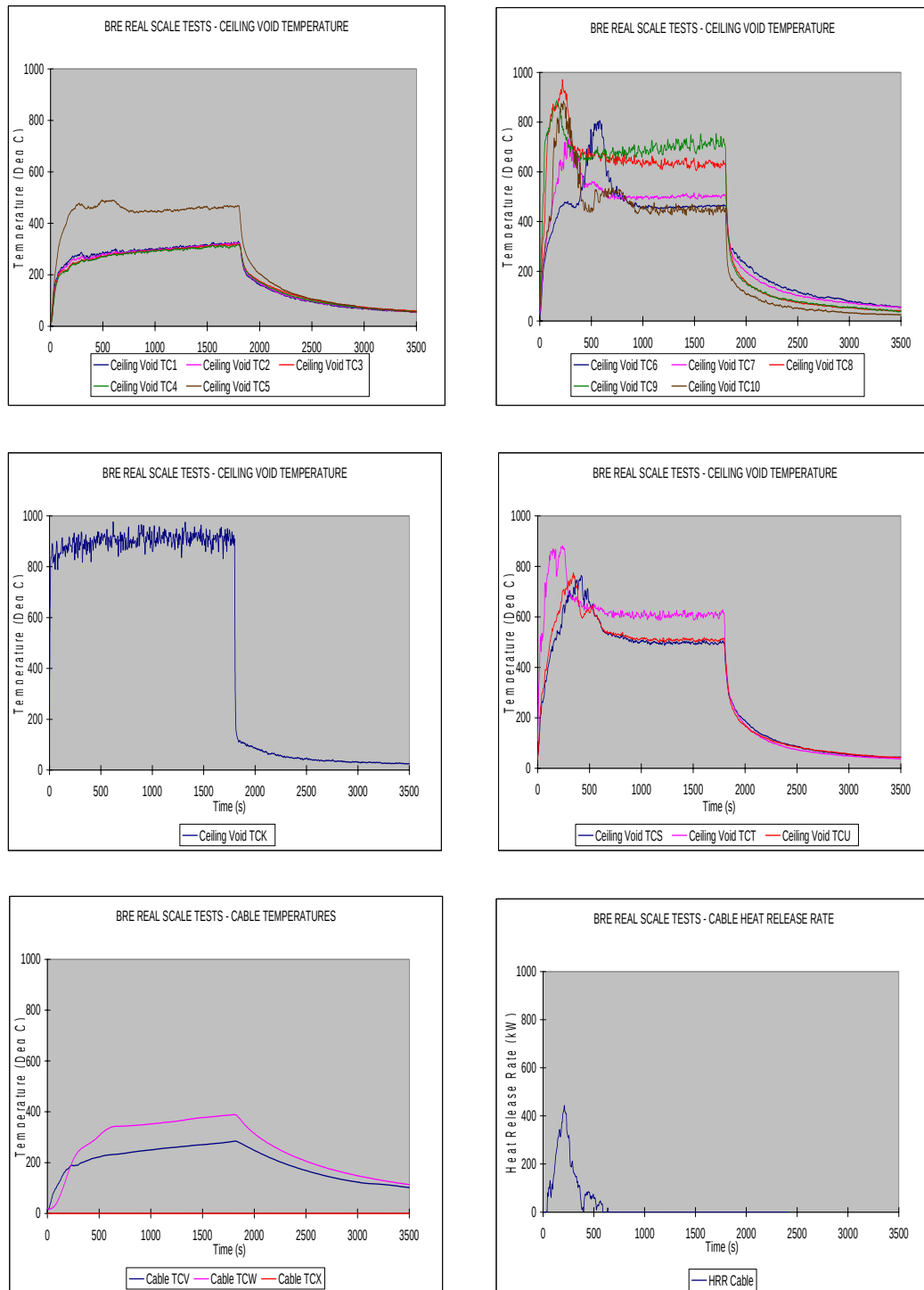


Figure B9(b) Test 3 Temperatures

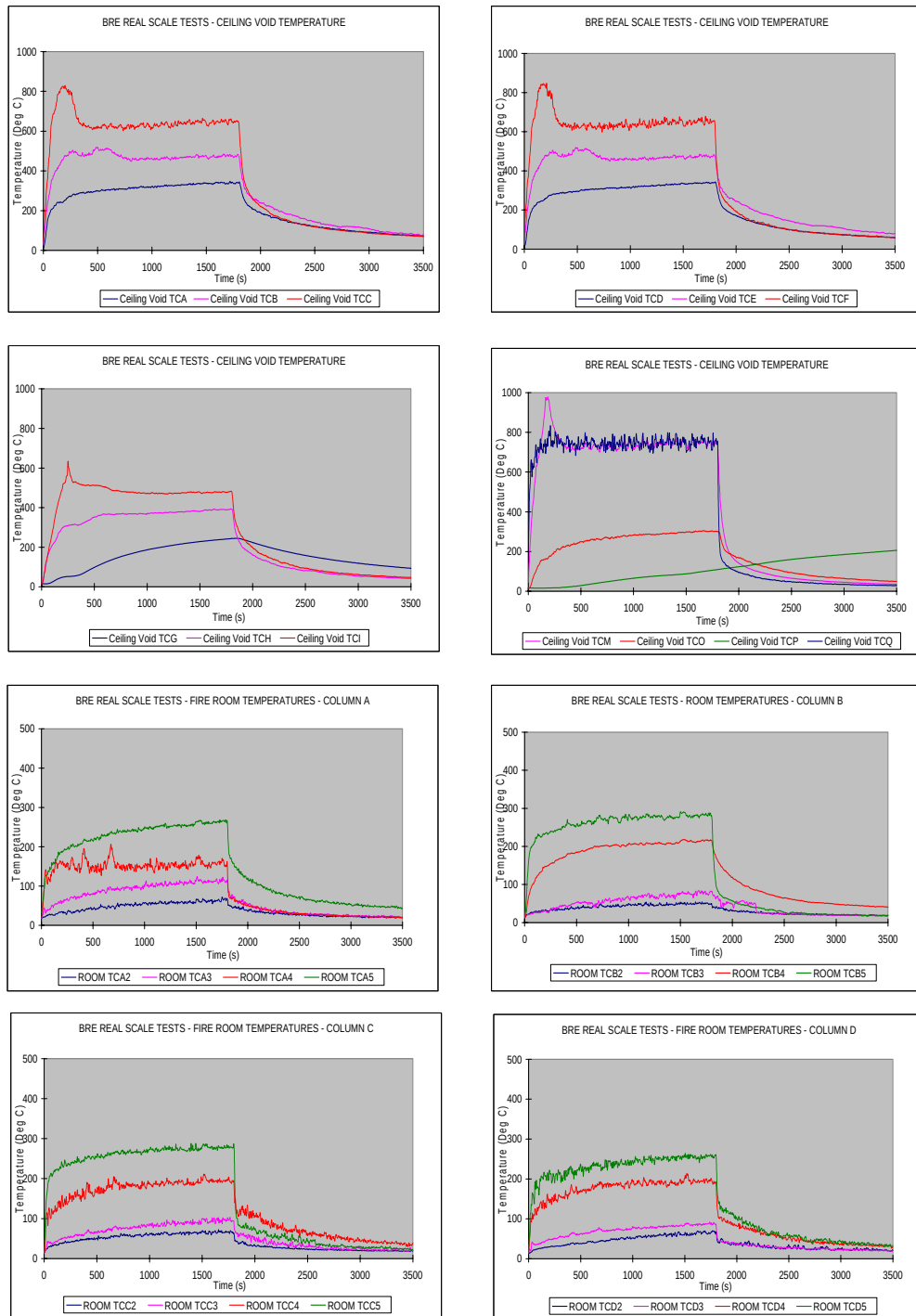


Figure B9(c) Test 3 Temperatures

Photographs



Photograph B1. BRE Real Scale Cable Fire Test Facility



Photograph B2. 1 MW gas burner with flames entering ceiling void



Photograph B3. Cable ladder running through the cavity barrier.



Photograph B4. Cable ladder running through the cavity barrier.



Photograph B5. Thermocouples on the exposed side to the burner.



Photograph B6. Fire stopping in the cable ladder adjacent to the cavity barrier.



Photograph B7. Fire stopping to the underside of the cable ladder adjacent to the cavity barrier



Photograph B8. Fire stopping adjacent to the cavity barrier also shows the wrapping around the cables.



Photograph B9. Post test in the ceiling void with a cavity barrier.



Photograph B10. Cavity barrier with fire stopping around the cable ladder.



Photograph B11. Underview of the cavity barrier with fire stopping around the cable ladder.



Photograph B12. Burner flame impingement on the cable ladder



Photograph B13. Fire spread from the underside of the cavity barrier.