NBSIR 88-3695

Quick Response Sprinklers in Office Configurations: Fire Test Results

William D. Walton
Edward K. Budnick

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Gaithersburg, MD 20899

January 1988

Supported in part by:
General Services Administration
Washington, DC

and

U.S. Fire Administration
Emmitsburg, MD

NBSIR 88-3695

QUICK RESPONSE SPRINKLERS IN OFFICE CONFIGURATIONS: FIRE TEST RESULTS

William D. Walton
Edward K. Budnick

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Gaithersburg, MD 20899

January 1988

Supported in part by:
General Services Administration
Washington, DC

and

U.S. Fire Administration
Emmitsburg, MD

U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

QUICK RESPONSE SPRINKLERS IN OFFICE CONFIGURATIONS: FIRE TEST RESULTS

William D. Walton

Edward K. Budnick*

ABSTRACT

A series of fire tests in several typical office occupancy configurations were conducted in order to address the use of quick response sprinkler technology. These tests included 1) heat release rate tests, 2) compartment fire tests and 3) a large office test. The heat release rate tests were designed to characterize the burning rates of a computer work station and open shelf office storage. The compartment fire tests were designed to examine the effectiveness of quick response sprinklers in typical office fires involving a computer work station or an open office module. Measurements of heat release rate, air temperature, and the concentration of oxygen, carbon monoxide and carbon dioxide were taken. A test was conducted in a large office test configured with multiple open office modules to complement the compartment test results and examine the possibility of multiple sprinkler activation. Measurements of air temperature and the concentration of oxygen, carbon monoxide and carbon dioxide were taken.

Key Words: burning rate; calorimetry; compartment fires; fire growth; fire tests; heat release rate; oxygen consumption; quick response sprinklers; room fires; sprinklers; toxicity.

* Presently with Hughes Associates, Inc.

1. INTRODUCTION

The General Services Administration has expressed a need for developing sprinkler design criteria for use in government office spaces which ensure adequate, cost effective fire protection. The Center for Fire Research at the National Bureau of Standards under the sponsorship of the General Services Administration, has completed the first phase of a multi-phase research project addressing the use of quick response sprinkler technology in office occupancies. The major emphasis in the first phase of this project was to 1) examine the potential applicability of quick response technology to office occupancies and 2) characterize office fuel packages. The work to date has demonstrated some of the potential benefits of using quick response sprinkler technology and provided part of the basis for developing design criteria.

Automatic sprinkler technology has been used to protect commercial and industrial property for more than a century. The success of this technology in reducing property damage and life loss from fire is widely accepted. Advances in sprinkler technology have lead to the development of quick response sprinklers which actuate faster than conventional sprinklers. The use of quick response sprinklers offers the potential for improved life and property protection by actuating earlier in the fire growth than conventional sprinklers. Research into the use of quick response sprinklers has lead to the development of NFPA 13D, Standard for the Installation of Sprinkler Systems In One- and Two-Family Dwellings and Mobile Homes[1][1].

In addition, the Early Suppression Fast Response (ESFR) Program coordinated by the National Fire Protection Research Foundation (NFPRF) focuses on the development of criteria and hardware to apply quick response sprinkler technology to warehouse and high challenge fires [2].

Currently there are no design criteria for the use of quick response sprinklers in office occupancies. The benefits of applying quick response sprinkler technology to office occupancies include the potential for:

1) Improved life safety. By suppressing fires in the early stages, fast responding sprinklers can reduce the quantity of smoke and toxic gases generated. In critical occupancies where total evacuation in the event of a fire is not desirable, fast responding sprinklers have the potential for improving the survivability of the remaining occupants.

2) Improved property protection. Particularly in occupancies where down time is critical, fast responding sprinklers can reduce property loss and thus down time.

3) Reduced system cost. The potential exists to reduce piping sizes and water supply requirements.

---

[1] Number in brackets indicate literature references at the end of the paper.

In order to address the use of existing quick response sprinkler technology in office occupancies, the Center for Fire Research conducted a series of feasibility tests for the General Services Administration. These tests included; 1) heat release rate tests designed to characterize the burning rate of several typical office fuel packages, 2) compartment fire tests designed to examine the effectiveness of quick response sprinklers in several typical office fires and 3) a large office test to complement the compartment test results and examine the possibility of multiple sprinkler activation.

2. HEAT RELEASE RATE TESTS

A series of four heat release rate or so called free burn tests were conducted to characterize two typical office fuel packages. The office fuel packages consisted of a computer work station and an open shelf storage configuration. The heat release rates of these fuel packages were compared to the fire growth rates used in the 1984 edition of NFPA 72E Appendix C Guide for Automatic Fire Detector Spacing[3].

2.1 Heat Release Rate Test Configuration

The heat release rate tests, using oxygen consumption calorimetry, were conducted under a large exhaust collection hood. A discussion of the principles of oxygen consumption calorimetry can be found in reference [4] and its use in determining the heat release rate of large furniture items in reference [5]. To summarize the method of oxygen consumption calorimetry, all of the gaseous combustion products from the burning item are designed to flow through a duct where the mass flow rate and oxygen concentration are measured as a function of time. From these measurements the rate at which oxygen is consumed by the fire in the combustion process can be determined. For most common fuels the rate of heat release is proportional to the rate of oxygen consumption regardless of the fuel burned. In these tests the collection and processing has been computerized with measurements taken and reported every 10 seconds.

Two fuel packages were chosen in cooperation with the project sponsors to be representative of high challenge fires in office occupancies. These consisted of a computer work station and open shelf storage.

The computer work station consisted of a computer desk and a book case each constructed of 5/8 in. (16 mm) thick particle board covered with a simulated wood, plastic laminate. The book case shelves were 3/4 in. (19 mm) thick. The desk was 60 in. (1.52 m) tall by 49 in. (1.24 m) wide by 23.5 to 9.5 in. (0.60 to 0.24 m) deep with a weight of 128 lb (58.1 kg). The desk was loaded with a total of 99 lb (44.9 kg) of paper materials. Figure 1 shows the dimensions of the computer desk and distribution of the load of paper materials. The book case was 72 in. (1.83 m) tall by 36 in. (0.91 m) wide by 12 in. (0.30 m) deep with a weight of 102 lb (46.3 kg). The book case was loaded with a total of 160 lb (72.6 kg) of paper materials. Figure 2 shows the dimensions of the book case and the distribution of the load of paper materials. Figure 3 shows a plan view of the computer work station consisting of the computer desk and book case. Computer work stations with this loading were used in free burn tests 101 and 102.

The open shelf storage consisted of common open steel shelving with vertical steel supports at each corner. The shelving units were 71 in. (1.8 m) tall by 36 in. (0.91 m) wide by 18 in. (0.46 m) deep with a weight of 22 lb (9.98 kg). A total of four shelving units were used in each test. The units were arranged in two parallel sets of back to back units separated by a 30 in. (0.7 m) aisle in free burn test 201 and a 24 in. (0.61 m) aisle in free burn test 202. Each shelving unit consisted of six shelves loaded with paper products. The bottom two shelves contained horizontally stacked paper, the next two shelves, paper in open top vertical file holders and the top shelf, horizontally stacked paper in closed cardboard boxes. The total weight of these paper products was 265 lb (120 kg) per unit. Figure 4 shows the dimensions and loading of the shelving units and Figure 5 is a plan view of the open shelf storage fuel package. The open shelf storage used in test 201 consisted of an open aisle. For test 202, two boxes of paper products with a total weight of 7 lb (3 kg) were placed in the aisle between the burner and one set of shelf units.

The ignition source for the heat release rate tests consisted of a rectangular 50 kW diffusion flame natural gas burner representing a typical wastebasket fire. The burner was an open top steel box 9.75 in. (248 mm) wide by 7.25 in. (184 mm) deep by 2.75 in. (70 mm) high. The box was filled with sand covered by a fibrous refractory material and the top was expanded metal. An opening for the natural gas supply was centered on the 7.25 inch (184 mm) side of the box. The top of the burner was positioned 14.5 in. (368 mm) above the floor. The burner was located in the corner between the desk and the book case for the computer work station tests and centered in the aisle adjacent to one set of shelves in the storage tests. A listing of the heat release rate tests and ignition exposures is given in Table 1.

2.2 Heat Release Rate Test Results

The free burn heat release tests consisted of two tests of the computer work station (tests 101 and 102) and two tests of the open shelf storage (tests 201 and 202).

2.2.1 Computer Work Station Test Results

The heat release rates for tests 101 and 102 are shown in Figure 6. The integrated or total heat released for tests 101 and 102 is shown in Figure 7. The maximum rates of heat release for all tests are given in Table 2.

In addition to the heat release rate determined from the tests, figures 6 and 8 show heat release rates for the fast, medium and slow fires specified in NFPA 72E Appendix C Guide for Automatic Fire Detector Spacing[3]. The fast, medium and slow fires are based on fires that grow with the square of time and are sometimes referred to as time squared fires. These fires are often compared to the early stages of fire growth for the purposes of estimating activation time of thermal devices such as heat detectors or sprinklers. The comparison of time squared fires to actual fires is sensitive to the location of time zero. In the tests analyzed here, no attempt has been made to adjust the starting times of the time squared fires in order to provide an exact match. Instead, a general comparison is made with the slope of the growth rates.

Figures 6 and 7 indicate that the two computer work stations burned in a very similar manner, well within the variation expected for fire tests. The agreement is particularly good considering the variation expected in the burning of the paper products loaded in the desk and book case. Figure 7 shows that by 1700 seconds the same total amount of heat had been released in both fires. Test observations show that by 120 seconds the fire had spread half way across the book case and to the shelves above the burner on the desk. At 250 seconds the fire had spread across the front of the book case above the level of the burner and at 500 seconds across the desk and inside the desk. The initial fire growth was a result primarily of the burning paper materials. Beyond 750 seconds the work station began to collapse resulting in erratic burning.

Although there is good overall agreement between the two computer work station tests the initial growth rate for test 101 follows more closely the slow fire while test 102 is more like the medium to fast fire. This initial growth period is very important in determining the sprinkler activation time.

2.2.2 Open Shelving Test Results

The heat release rates for tests 201 and 202 are shown in Figure 8 and the integrated or total heat released for tests 201 and 202 in Figure 9. Figures 8 and 9 show a significant difference in the two open shelving tests. This difference is a result of the change in configuration between tests 201 and 202. In test 201 only one set of the back to back shelving units became involved while in test 202 the addition of two boxes of paper in the aisle and the reduction of the aisle from 30 in. (0.7 m) to 24 in. (0.61 m) allowed fire to spread to both sets of shelving units. Test observations show that in both tests the fire spread up the face of the shelves above the burner and by 120 seconds had spread into the adjacent back unit. At approximately 200 seconds the first set of back to back units had become well involved and for test 202 fire was beginning to spread to the second set of units across the aisle. In test 201 the maximum heat release rate of approximately 1 MW was reached at 280 seconds while in test 202, the maximum of 1.6 MW was reached at 330 seconds. Prior to the involvement of the second set of shelving units the two tests demonstrate very good agreement.

The initial growth rate of the shelving unit fires tends to follow the rate of the medium time squared fire. At approximately 200 seconds the growth rate increases and its slope is more nearly like that of the fast fire.

3. COMPARTMENT FIRE TESTS

A series of seven office compartment fire tests were conducted to examine the conditions resulting with no sprinklers, conventional sprinklers and so called quick response sprinklers. Two office fuel packages, a computer work station and an office module were used in these tests. The computer work station was of the same type as used in the heat release rate tests and the office module was of the type used in some Federal office buildings. Measurements of heat release rate, temperature and gas concentrations were used to evaluate the test results.

3.1 Compartment Test Configuration

The compartment fire tests were conducted in the ASTM standard room, the specifications for which are contained in the ASTM Proposed Method for Room Fire Test of wall and Ceiling Materials and Assemblies[6]. The room is 8 ft (2.44 m) wide by 12 ft (3.66 m) deep by 8 ft (2.44 m) high. A 30 in. (0.76 m) wide by 80 in. (2.03 m) high door is centered in one of the 8 ft by 8 ft walls. The room is lined with 0.5 in. (12 mm) thick calcium silicate board and the concrete floor was covered with 0.5 in. (12 mm) gypsum board.

The same large exhaust hood used in the heat release tests was located outside the room over the door and it collected the fire exhaust gases for determining rate of heat release. Instrumentation inside the room consisted of 0.02 in. (0.05 mm) diameter chromel-alumel thermocouples located in the corner of the room near the door, 12 in. (0.3 m) from each wall, on the ceiling and 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, and 90 in. (0.15, 0.30, 0.46, 0.61, 0.76, 0.91, 1.07, 1.22, 1.37, 1.52, 1.68, 1.83, 1.98, 4.11 and 2.29 m) below the ceiling. A thermocouple was also located adjacent to the sprinkler which was centered in the room. Gas sampling probes for carbon dioxide, carbon monoxide and oxygen were located in the corner near the thermocouples 12 in. (0.3 m) from each wall and 60 in. (1.52 m) above the floor. The compartment dimensions and instrument positions are shown in Figure 10.

Two fuel packages were used in the compartment fire tests. The first was the computer work station used in heat release rate tests 101 and 102. A plan view of the location of the work station in the compartment is shown in Figure 11. The second fuel package was an office module similar to the type used in some Federal office buildings. The office module was made up of a desk, chair, file cabinet and partitions. The desk had a 70 in. (1.8 m) by 23.75 in. (0.60 m) plastic covered top positioned 30 in. (0.76 m) above the floor. The desk weighed 130 lb (59 kg) and was loaded with 31 lb (14 kg) of paper. A 70 in. (1.8 m) by 12 in. (0.30 m) steel shelf supported by clips at each end was located 22 in. (0.56 m) above the desk top. The shelf was loaded with 16 open top file boxes filled with paper with a total weight of 70 lb (32 kg). Below the desk on the left side was a conventional two drawer steel file cabinet 15.25 in. (0.39 m) wide. The file cabinet weighed 81 lb (37 kg) and each drawer was loaded with 14 lb (6 kg) of paper. Figure 12 shows the dimensions and loading of the office desk.

The chair was supported with a single steel base shaft centered under the seat with four casters on arms. The back and base of the chair seat was a lightly padded molded plastic covered with a synthetic fabric. The chair arms were steel with lightly padded arm rests. The chair was approximately 20 in. (0.5 m) square with a seat height of 20 in. (0.5 m) and a back height of 35 in. (0.9 m). The weight of the chair was 43 lb (19.5 kg).

The file cabinet was constructed of steel with overall dimensions of 36 in. (0.91 m) wide by 18 in. (0.46 m) deep by 64.75 in. (1.64 m) high with a total weight of 298 lb (135 kg). The cabinet was made up of 5 shelf units each 12 in. (0.3 m) high. Each self unit had a cover hinged at the top which swung out toward the user and slid back over the top. The suspension files opened towards the user such that all files in a drawer shelf were exposed when the cover was raised. During the tests the bottom three drawer units were empty and closed. The top two units were open and each loaded with 43 lb (20 kg) of paper.

The partitions were constructed of a steel frame with a hardboard panel center covered with fiberglass and synthetic fabric on both sides. The partitions were 66.5 in. (1.7 m) high by 1.6 in (41 mm) thick and in widths of 24, 36 and 48 in. (0.61, 0.91 and 1.22 m) with weights of 42, 52 and 63 lb (19, 24 and 29 kg) respectively. A plan view of the location of the office module in the compartment is shown in Figure 13.

The ignition source for the compartment fire tests was a round steel trash can with an upper diameter of 13.5 in. (343 mm), a lower diameter of 10 in. (254 mm), a height of 14.5 in. (368 mm) and a weight of 4 lb (1.8 kg). The trash can was loaded with 3.8 lb (1.7 kg) of paper. An electrically activated book of matches was used to ignite the fire. The trash can was located in the corner between the desk and the book case in the computer work station tests and in the corner between the desk and the side partition in the office module tests.

Two types of sprinklers were used in the compartment tests. The first was a standard spray pendent (SSP) operated with a flow of 16.3 gpm (62 L/min) and the second was a residential quick response sprinkler operated with a flow of 18 gpm (68 L/min) both in accordance with manufacturers recommendations. The activation temperature of both types of sprinklers was 165 °F (74 °C). A listing of the compartment tests is given in Table 3.

3.2 Compartment Fire Test Results

The compartment fire test series included three tests with the computer work station and four tests with the office module. The computer work station tests included two with quick response sprinklers (tests 110 and 111) and one with no sprinklers (tests 120). The office module tests included one with a quick response sprinkler (test 310), one with a standard sprinkler (test 311) and two with no sprinklers (tests 320 and 321). The data shown for each of these tests includes heat release rate, total heat released, upper layer temperatures, gas temperature near the sprinkler and concentrations of O_2, CO and CO_2.

3.2.1 Computer Work Station Test Results

The heat release rates for the two computer work station tests with quick response sprinklers are shown in Figure 14 along with the fast medium and slow time squared fires. The total heat released for these tests is shown in Figure 15. The heat release rates for these tests was so low that the instrumentation noise is evident in the results and a comparison with the time squared fires is not possible. Figure 16 shows, for test 110, the temperature of thermocouple 3 located 12 in. (0.30 m) below the ceiling and thermocouple 7 located 36 in. (1.07 m) below the ceiling. In addition the average of thermocouples 3, 4, 5, 6 and 7 located 12, 18, 24, 30 and 36 in. (0.30, 0.46, 0.61, 0.76 and 1.07 m) down from the ceiling is shown. In most of the tests thermocouple 2, located 6 in. (0.15 m) below the ceiling, was also used. Thermocouple 2 failed to function in test 110. An analysis of all of the thermocouple data revealed that these thermocouples spanned the hot upper gas layer in the compartment. A list of the maximum average upper layer temperatures is given in Table 4.

Observations from test 110 showed that the paper on the desk above the trash can ignited at 15 seconds and the flames from the trash can were below the top of the can by 120 seconds. At 200 seconds, the upper part of the compartment was obscured by smoke. The fire appeared to intensify on the top of the desk and began to spread up the corner face of the book case at 300 seconds. The sprinkler activated at 317 seconds. A list of sprinkler activation times for all tests is given in Table 5. Figure 17 shows the temperature of the thermocouple located near the sprinkler in tests 110 and 111. This figure shows that the gas temperature in test 110 was only slightly above the activation temperature. The gas temperature in test 111 rose more quickly above the activation temperature resulting in sprinkler activation in a shorter period of time.

Figure 18 shows the gas concentrations of CO, CO_2 and O_2 measured at the 60 in. (1.52 m) level in the room. Maximum concentrations for CO and CO_2 and the minimum for O_2 are given in Table 6. Although a complete analysis of the gas concentration data is beyond the scope of this report, a simple comparison to CO lethality data can be made. LC_{50} values for carbon monoxide as a function of exposure time for rats is provided in Table 7[7]. LC_{50} (Lethal Concentration 50%) is the concentration of gas which will cause 50% lethality in test animals exposed for a specified period of time. For example, from Table 7, the minimum concentration of CO required to cause 50% lethality over a continuous 3600 second exposure is 0.49%. The maximum concentration of CO in test 110 was well below the 3600 second LC_{50} value.

Observations for test 111 show the paper on the desk above the trash can ignited at 15 seconds and by 90 seconds the flames in the trash can had receded below the top of the can. The fire involvement was similar to that in test 110 when the sprinkler operated at 127 seconds. The upper part of the room was not completely obscured by smoke at the time of sprinkler activation. In all tests the room became completely obscured after sprinkler activation.

The upper layer temperatures for test 111 are shown in Figure 19 and the gas concentrations in Figure 20. As in test 110, the concentration of CO in test 111 was below the 3600 second LC_{50} value.

The primary difference between the results of test 110 and test 111 was a slight difference in burning rate. This difference in burning rate resulted in a difference in upper layer temperature. Since the temperatures were very close to the activation temperature of the sprinkler, a small temperature difference resulted in a significant difference in sprinkler activation time.

Test 120 consisted of the same configuration as tests 110 and 111 except there was no sprinkler. Figure 21 shows the heat release rate and Figure 22 the total heat released. The overall trend of the heat release rate tended to be much slower than the slow time squared fire. Figure 23 shows the upper layer temperatures, Figure 24 the temperature of the thermocouple near the sprinkler and Figure 25 the gas concentrations. Test observations showed that at 30 seconds the paper above the trash can ignited, and by 150 seconds the flames in the trash can were below the top of the can. At 200 seconds flames were across the top of the book case, and at 900 seconds half way across the ceiling. At 1200 seconds the work station was well involved, and at 1400 seconds flashover conditions existed within the compartment. At 1500 seconds the work station was collapsing and flames were out the door. The test was terminated shortly thereafter.

The conditions in the compartment without sprinklers would certainly have been lethal by the time of flashover. A comparison of the average upper layer temperatures from the computer work station tests 110, 111 and 120 is shown in Figure 26.

3.2.2 Office Module Test Results

Test 310 consisted of an office module with a quick response sprinkler and test 311 an office module with standard response sprinkler. Figure 27 shows the rate of heat release for these tests along with the fast, medium and slow time squared fires. Again it is difficult to make a comparison between the test results and the time squared fires because of the short duration of growth and the low rate of heat release. Figure 28 shows the total heat released for tests 310 and 311.

Figure 29 shows the upper layer temperatures for test 310 and Figure 30 the temperature of the thermocouple located near the sprinkler for tests 310 and 311. Observations for test 310 showed the paper on the desk above the trash can ignited at 30 seconds and by 100 seconds the flames in the trash can were below the top of the can. At 130 seconds the rate of burning of papers on top of the desk began to increase, and at 177 seconds the quick response sprinkler activated. Prior to sprinkler activation the smoke did not completely obscure visibility in the upper part of the room. Figure 31 shows the gas concentrations in test 310. The maximum concentration of CO in test 310 was below the 3600 second LC_{50} value.

Figure 32 shows the upper layer temperatures in test 311. Observations from test 311 show that at 30 seconds flames had spread from the trash can to the paper on the desk, and by 250 seconds the flames in the trash can were below the top of the can. At approximately 400 seconds the rate of burning of the papers on the desk began to increase, and at 438 seconds the conventional response sprinkler activated. Prior to sprinkler activation the smoke did not completely obscure visibility in the upper part of the room. Figure 33 shows the gas concentrations in test 311. The maximum concentration of CO in test 311 was below the 3600 second LC_{50} value.

A comparison of tests 310 and 311 reveals that the average upper layer temperatures in test 311 with the conventional response sprinkler were approximately 54 °F (30 °C) higher than in test 310 with the quick response sprinkler. The maximum temperature of the thermocouple near the sprinkler was 108 °F (60 °C) higher. These high temperatures reflect the longer response times for the conventional sprinklers.

Two tests, 320 and 321, were conducted using the office module with no sprinklers. Figure 34 shows the heat release rate in test 320, and Figure 35 the total heat released. Upper layer temperatures for test 320 are shown in Figure 35, and the temperature of the sprinkler near the thermocouple for tests 320 and 321 is shown in Figure 37. Observations from test 320 showed the flames from the trash can ignited the paper on the desk at 30 seconds, and by 250 seconds the flames in the trash can were below the top of the can. In test 320, the fire failed to spread beyond the top of the desk and ultimately burned out. Gas concentrations for test 320 are shown in Figure 38. This test points out the variability in burning realistic fuel packages. Test 321 is a repeat of test 320 with minor rearrangement of the paper materials on top of the desk.

Figure 39 shows the rate of heat release for test 321 along with the fast medium and slow time squared fires. The initial heat release rate in test 321 appears to follow that of the medium fire. The total heat released is shown in Figure 40. Upper layer temperatures are shown in Figure 41 and gas concentrations in Figure 42. Observations show that at 30 seconds fire spread from the trash can to the paper on the desk, and by 75 seconds the fire had grown on the desk. At 210 seconds, the flames in the trash can were below the top of the can and the flames on the top of the desk had receded. At 220 seconds, the shelf above the desk collapsed resulting in renewed flaming, and by 270 seconds there was fire on the desk and the floor. This fire continued at a relatively steady rate until the chair became involved at 1200 seconds. The involvement of the chair was followed by the development of a dark smoke layer and flashover conditions at 1300 seconds. The test was terminated shortly thereafter.

The conditions in the compartment in test 321 without sprinklers would certainly have been lethal by the time of flashover. A comparison of the average upper layer temperatures from the office module tests 310, 311, 320 and 321 is shown in Figure 43.

4. OPEN OFFICE FIRE TEST

A single test was conducted in a large open office space containing two back to back office modules and quick response residential sprinklers. The office modules were of the same type as those used in the compartment fire tests. Measurements of temperature and gas concentrations were used to evaluate the test results.

4.1 Open Office Test Configuration

The test was conducted in a building undergoing renovation and modified to have the appearance of an open office space. The room was basically rectangular in shape with a small rectangular extension in one corner. The overall dimensions of the room were 48 ft (14.6 m) by 18 ft (5.5 m) with a total floor area of 963 ft^2 (89 m^2). The room had an asphalt tile covered concrete floor, concrete block walls, and fiber board suspended ceiling under a concrete slab. The finished ceiling height was 8.5 ft (2.59 m) in the fire area and 9.25 ft (2.82 m) in a 216 ft^2 (20 m^2) area away from the fire. All doors and windows to the room were closed. A plan view of room is shown in Figure 44.

Instrumentation included a string of 0.02 in. (0.05 mm) diameter chromel-alumel thermocouples in one corner of the room 1 ft (0.3 m) from each wall and 102, 96, 90, 84, 78, 72, 66, 60, 54, 48, 42, 36, 30, 24, 18, 12 and 6 in. (2.59, 2.44, 2.29, 2.13, 1.98, 1.83, 1.68, 1.52, 1.37, 1.22, 1.07, 0.91, 0.76, 0.61, 0.46, 0.30 and 0.15 m) from the floor. In addition, thermocouples were located above the point of ignition 1, 6 and 10 in. (0.03, 0.15 and 0.25 m) below the ceiling. Gas sampling probes for carbon dioxide, carbon monoxide and oxygen were located near the thermocouples, 60 in. (1.52 m) above the floor. Heat release measurements were not available for this test.

Nine pendent residential quick response sprinklers were installed with piping above the suspended ceiling. The sprinklers had an activation temperature of 160°F (71°C) and the flow was set to 25 gpm (95 L/min) in accordance with the manufacturers recommendations. Two sets of office modules with the same load of paper as used in the compartment tests were positioned to be centered under four of the sprinklers. The center of the fuel package was approximately 7.8 ft (2.4 m) from each of the four sprinklers. The ignition source was the same type of trash can used in the compartment fire tests.

4.2 Open Office Test Results

The upper layer temperatures for the open office test are shown in Figure 45. Shown in this figure are the temperatures of thermocouple 5 located 102 in. (2.59 m) above the floor and thermocouple 8 located 84 in. (2.13 m) above the floor. Also shown is the average of thermocouples 5, 6, 7, and 8 located 102, 96, 90 and 84 in. (2.59, 2.44, 2.29 and 2.13 m) above the floor. An analysis of all of the thermocouple data revealed that these thermocouples spanned the hot upper gas layer in the compartment. Although these thermocouples were on the opposite side of the room from the only sprinkler activated and approximately 14 ft (4.3 m) from the fire, the average upper layer temperature was approximately equal to the activation temperature of the sprinkler at the time of activation. Figure 46 shows the average upper layer temperature and the temperature measured 1 in. (0.03 m) below the ceiling above the trash can. This indicates that gas temperatures on the ceiling above the fire were as high as 302 °F (150 °C).

Figure 47 shows the gas concentrations for the large office test. The changes in gas concentration from ambient were very small. The spikes in the CO_2 data were created by the instrumentation. The maximum concentration of CO was below the 3600 second LC_{50} value.

Test observations show that paper on the desk above the trash can ignited at 20 seconds, and at 60 seconds the fabric on the partition over the trash can was melting. At 140 seconds, the flames in the trash can were below the top of the can. At 155 seconds, the flames on top of the desk were impinging on the shelf, but by 180 seconds, the flames on the desk had receded and were slowly spreading on the desk. At 330 seconds, flames were visible in the corner above the shelf, and by 360 seconds were 2 ft. (0.6 m) above the shelf. At 408 seconds, a single sprinkler activated mixing the light smoke in the room and obscuring the fire, although the overhead fluorescent lights were still visible. The sprinkler which operated was the one closest to the corner of the desk where the initial burning took place. The sprinkler water flow was continued for 600 seconds after activation. When the sprinkler flow was terminated the only fire visible was smoldering in the bottom of the trash can. The fire damaged area included the partitions next to the trash can and in back of the desk, the top three quarters of the desk surface and the papers up to 2 ft. (0.6 m) from the corner on the self above the desk. One of the shelving clips holding the shelf above the desk had failed, but the shelf had not fallen.

5. SUMMARY AND CONCLUSIONS

The heat release rates of several office fuel packages including a computer work station, open shelving and an open office module have been characterized. The initial growth rates of these fires ranged from fast to slow as compared to the NFPA 72E standard time squared fires. This suggests that the selection of a single growth rate to represent office fire scenarios may be inappropriate.

Fires in the fuel packages tested, when uncontrolled, in an ASTM standard size compartment generally lead to the development of flashover and associated lethal conditions in 1300 to 1500 seconds. For the tests conducted, quick response residential sprinklers operating within their design limits actuated at 177 to 317 seconds and controlled the office type fires as long as water was flowing. The fire damage in all sprinkler tests was limited to a relatively small area, and conditions within the compartments did not appear to be lethal. In the single test conducted with a standard response sprinkler, the sprinkler actuated at 438 seconds and the upper layer temperatures were higher than those in a similar test with a quick response sprinkler, but conditions still did not appear to reach lethal levels.

In the single large office test conducted, a single residential quick response sprinkler activated in 408 seconds and controlled the fire even though the fire was nearly equidistant from four sprinklers and the partitions provided some blockage of the spray pattern. The fire damage was limited to a relatively small area, and conditions within the space did not appear to be lethal.

In conclusion, these tests have provided some limited evidence that residential quick response sprinklers can substantially improve life safety and property protection in office occupancies as compared to occupancies without sprinklers.

6. ACKNOWLEDGEMENTS

Appreciation is extended to J. Breese, D. Evans, D. Madrzykowski, T. Maher, P. Martin, R. McLane, W. Rinkinen, G. Roadarmel, J. Steel, M. Womble and R. Zile of the Center for Fire Research for assistance in conducting these tests. Appreciation is also extended to J. Morehart and the NIH safety and fire departments as well as the Bethesda and Kensington fire departments, Bethesda Chevy Chase Rescue Squad and Livingston Fire Protection for support in conducting the large office test. In addition, appreciated is extended to D. Bathurst and W. Blazek of GSA and T. Smith of USFA for their support of this project.

7. REFERENCES

[1] Standard for the Installation of Sprinkler Systems In One- and Two-Family Dwellings and Mobile Homes 13D. Quincy, MA: Nat. Fire Prot. Assn.; 1984.

[2] Fleming, R.P. Quick Response Sprinklers: A Technical Analysis. Quincy, MA: Nat. Fire Prot. Assn. Research Foundation; 1986.

[3] Standard on Automatic Fire Detectors 72E. Quincy, MA: Nat. Fire Prot. Assn.; 1984.

[4] Parker, W.J., Calculations of the Heat Release Rate by Oxygen Consumption for Various Applications. Nat. Bur. Stand. (U.S.) NBSIR 81-2427-1; 1982 March. 41 p.

[5] Babrauskas, V. Lawson, J.R., Walton, W.D. and Twilley, W.H. Upholstered Furniture Heat Release Rates Measured with a Furniture Calorimeter. Nat. Bur. Stand. (U.S.) NBSIR 82-2604; 1982 December. 73 p.

[6] Proposed Method for Room Fire Test of Wall and Ceiling Materials and Assemblies. Philadelphia, PA: ASTM; Section 4: 958-978; 1983.

[7] Levin, B.C., Gurman, J.L., Paabo, M., Baier, L. and Holt, T., Toxicological Effects of Different Time Exposures to The Fire Gases: Carbon Monoxide or Hydrogen Cyanide or to Carbon Monoxide Combined with Hydrogen Cyanide or Carbon Dioxide. Proceedings U.S./Japan Cooperative Program on Natural Resources. Fire Research and Safety; 1987 May 4-8; Norwood, MA; 1-16.

Table 1. Heat Release Rate Tests

Test No.	Fuel Package	Ignition Mode
101	Computer Station	50 kW for 420 s
102	Computer Station	50 kW for 180 s
201	Office Storage	50 kW for 180 s
202	Office Storage	50 kW for 180 s

Table 2. Maximum Heat Release

Test No.	Fuel Package	Sprinkler	Maximum Heat Release Rate (MW)	Total Heat Released (MJ)
101	Computer Station	Free Burn	1.42	1200.
102	Computer Station	Free Burn	1.83	1350.
110	Computer Station	QR	0.041	6.33
111	Computer Station	QR	0.039	1.14
120	Computer Station	None	2.48	658.
201	Office Storage	Free Burn	0.98	318.
202	Office Storage	Free Burn	1.60	560.
310	Office Module	QR	0.062	19.0
311	Office Module	SSP	0.049	11.8
320	Office Module	None	0.058	24.1
321	Office Module	None	2.20	421.

Table 3. Compartment Tests

Test No.	Fuel Package	Ignition Mode	Compartment	Sprinkler
110	Computer Station	Trash Can	ASTM	QR
111	Computer Station	Trash Can	ASTM	QR
120	Computer Station	Trash Can	ASTM	None
310	Office Module	Trash Can	ASTM	QR
311	Office Module	Trash Can	ASTM	SSP
320	Office Module	Trash Can	ASTM	None
321	Office Module	Trash Can	ASTM	None
4126	Office Module	Trash Can	Large Area	QR

Table 4. Maximum Average Upper Layer Temperature

Test No.	Fuel Package	Sprinkler	Temperature (°C)
110	Computer Station	QR	93
111	Computer Station	QR	88
120	Computer Station	None	811
310	Office Module	QR	80
311	Office Module	SSP	113
320	Office Module	None	88
321	Office Module	None	763
4126	Office Module	QR	62

Table 5. Sprinkler Activation Time

Test No.	Fuel Package	Sprinkler	Time (s)	Maximum Sprinkler Thermocouple Temperature (°C)
110	Computer Station	QR	317	90
111	Computer Station	QR	127	102
310	Office Module	QR	177	93
311	Office Module	SSP	438	153
4126	Office Module	QR	408	-

Table 6. Gas Concentrations

Test No.	Fuel Package	Sprinkler	CO (%) (maximum)	CO_2 (%) (maximum)	O_2 (%) (minimum)
110	Computer Station	QR	0.20	1.1	19.8
111	Computer Station	QR	0.31	0.84	19.7
120	Computer Station	None	0.85	20.4	0.35
310	Office Module	QR	0.075	0.93	20.0
311	Office Module	SSP	0.10	1.2	19.6
320	Office Module	None	0.74	1.0	19.8
321	Office Module	None	3.19	17.5	1.0
4126	Office Module	QR	0.05	3.4	20.6

Table 7. LC_{50} Values for Carbon Monoxide [7]

Exposure Time (s)	CO Concentration (%)	CO Concentration (ppm)
60	10.7	107000
120	4.25	42500
300	1.4	14000
600	0.98	9800
1200	0.74	7400
1800	0.66	6600
3600	0.49	4900

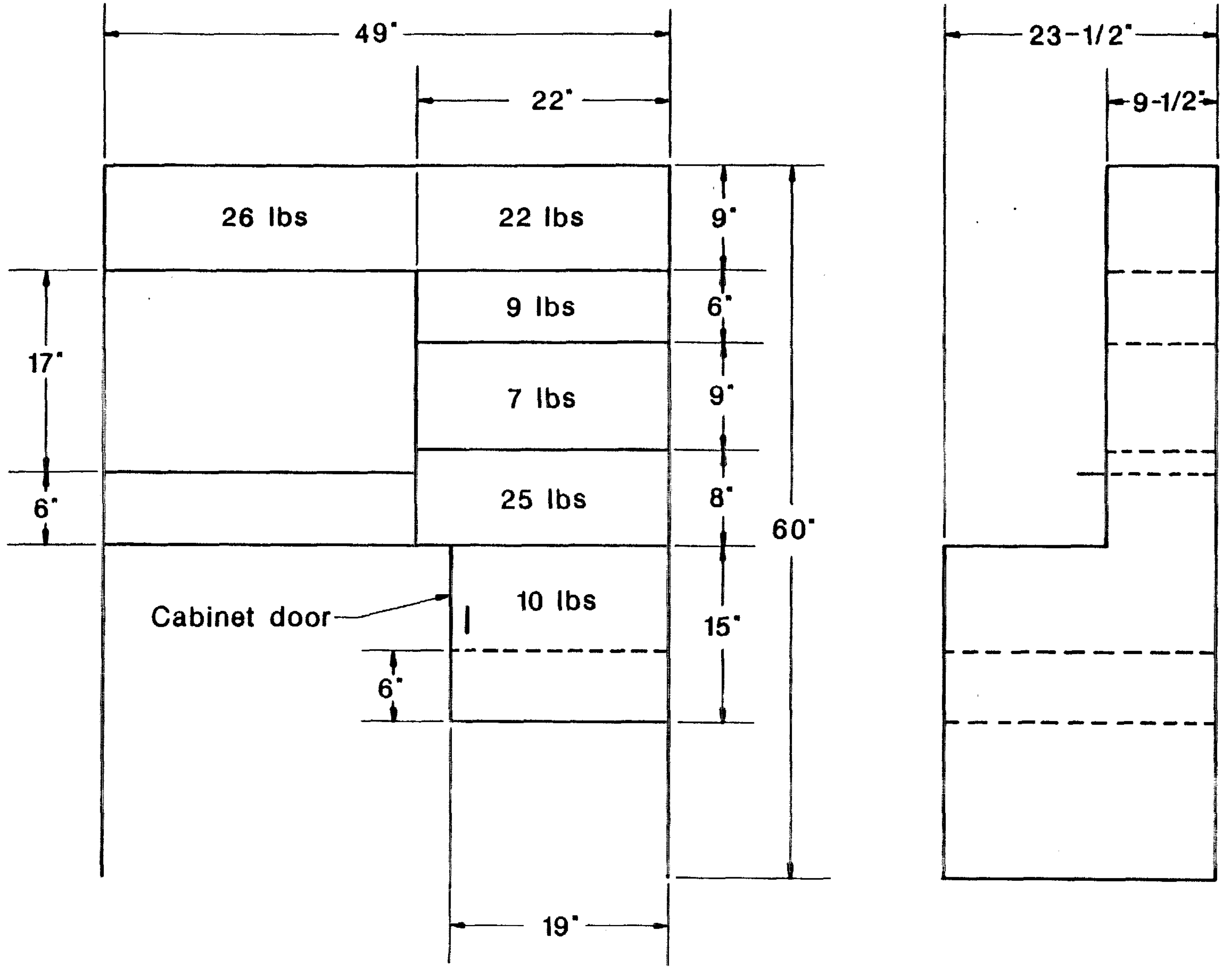

Figure 1. Computer Desk

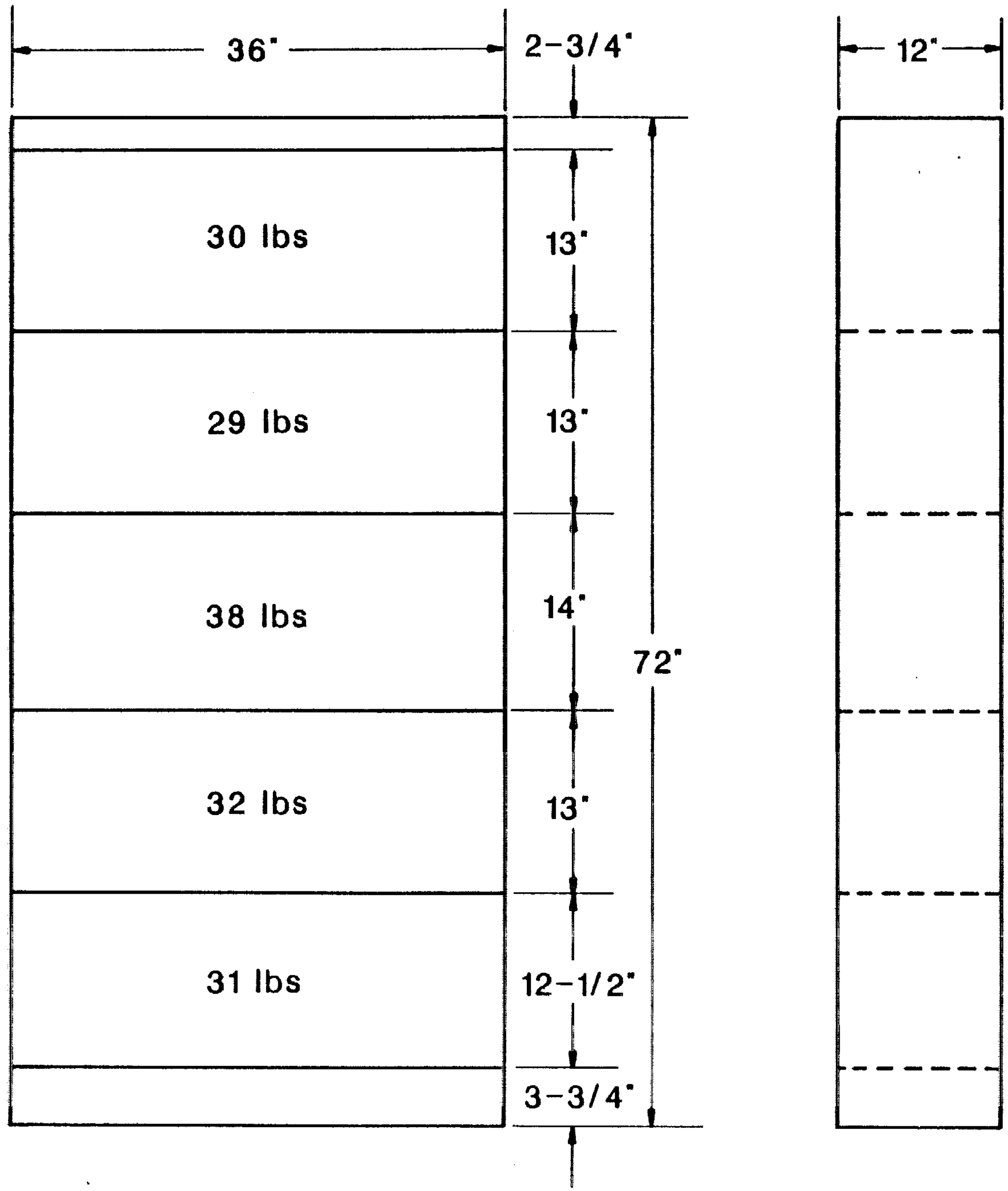

Figure 2. Book Case

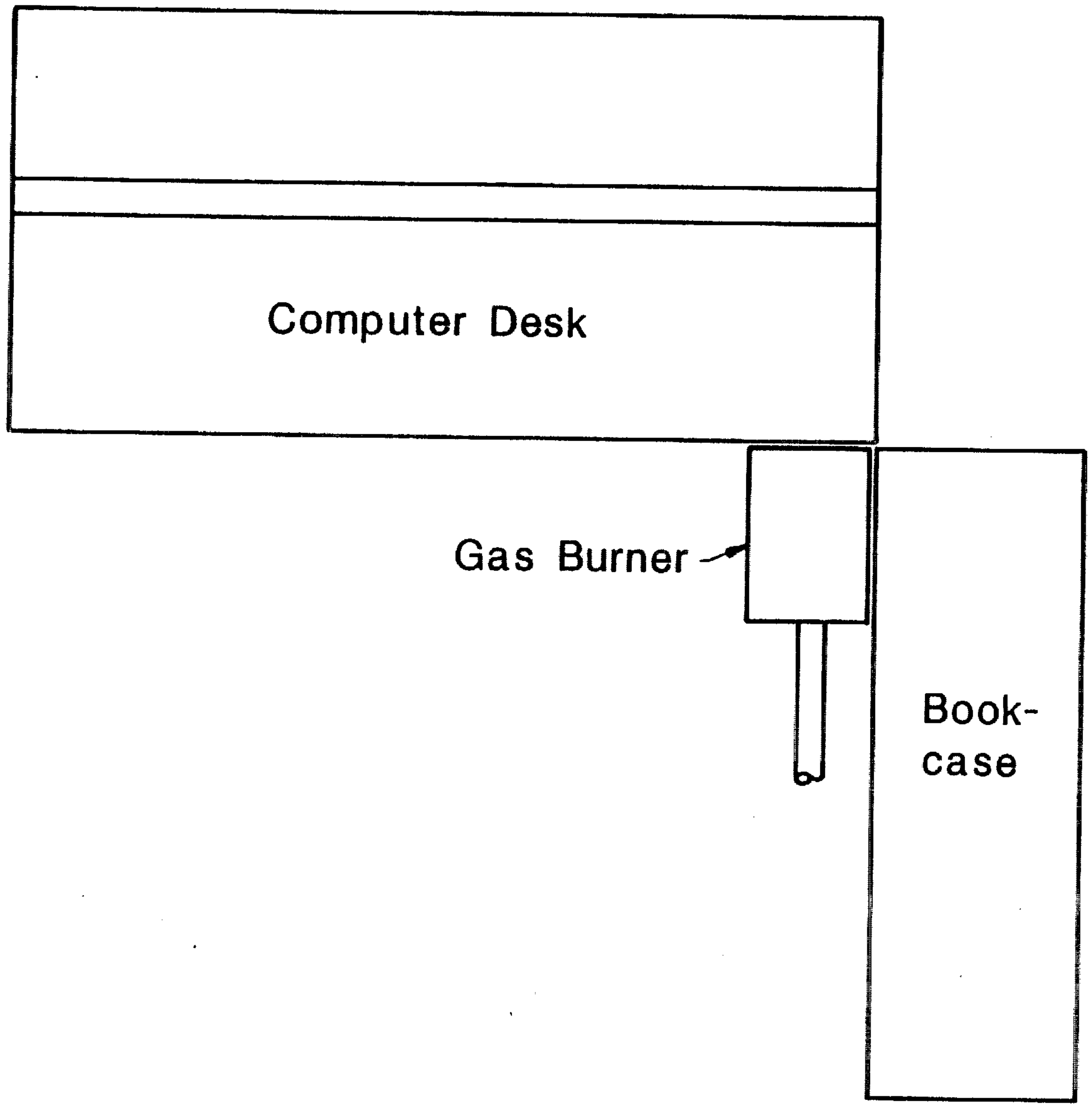

Figure 3. Computer Work Station Plan View

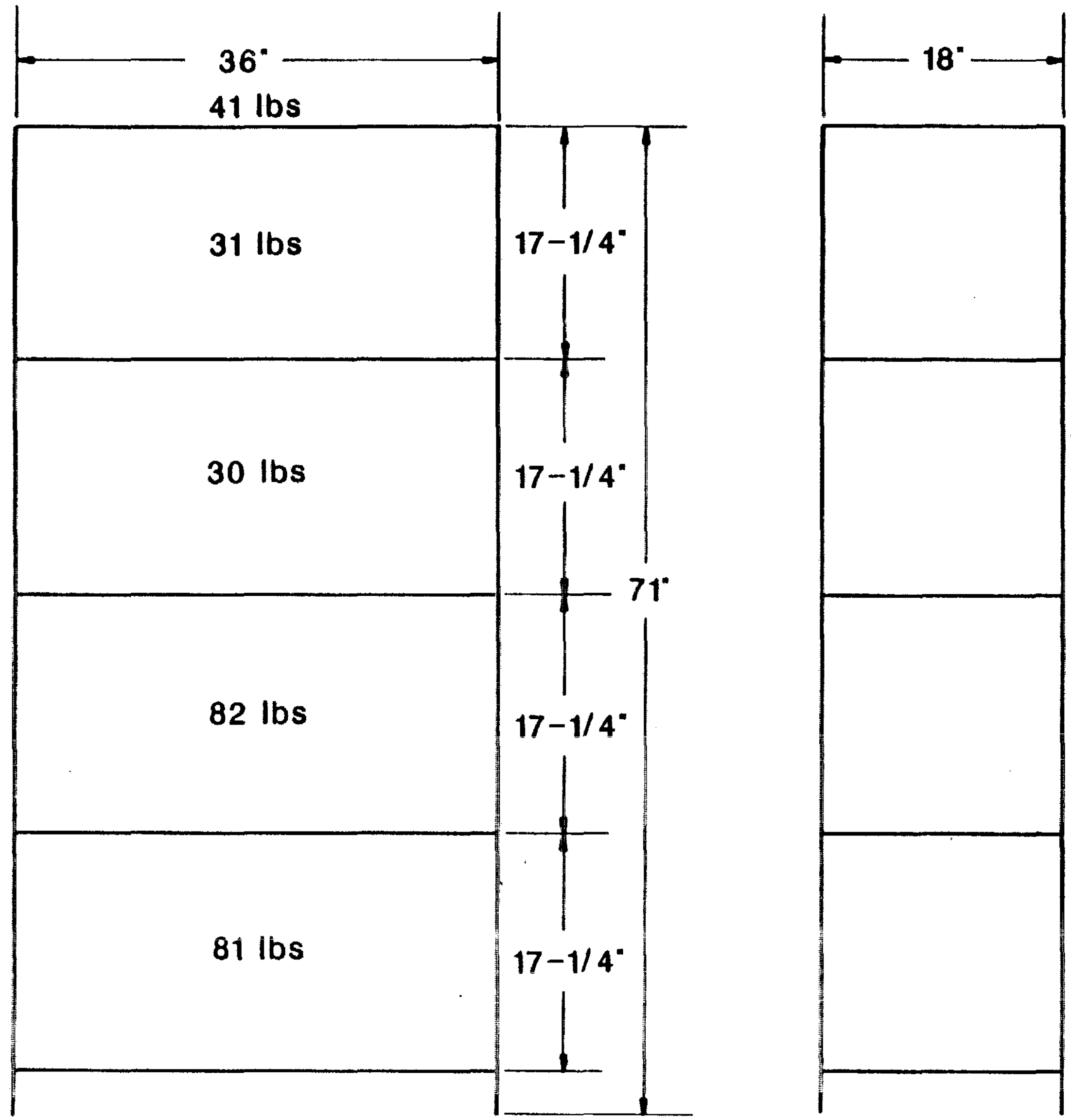

Figure 4. Open Steel Shelving

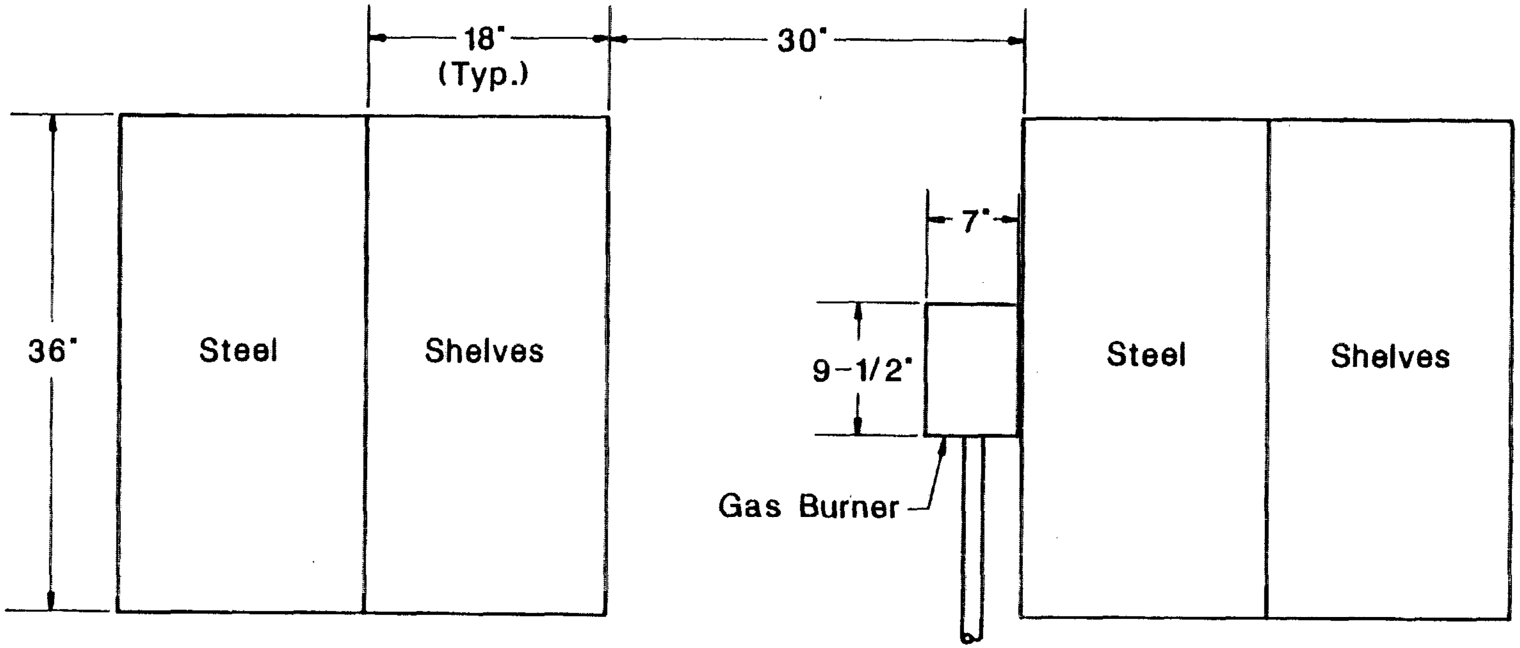

Figure 5. Office Storage Plan View

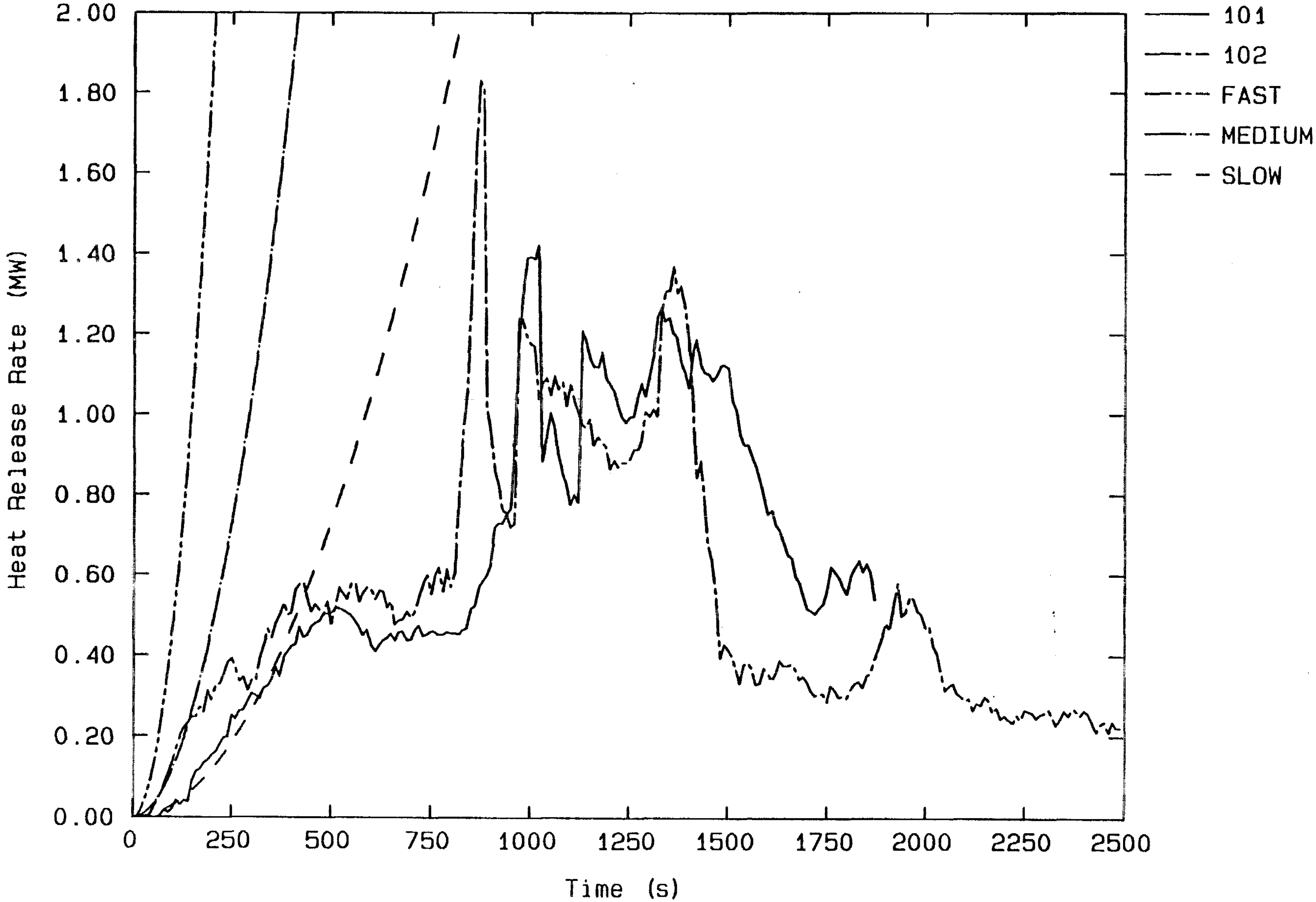

Figure 6. Computer Station, Heat Release Rate, Tests 101 and 102 (free burn)

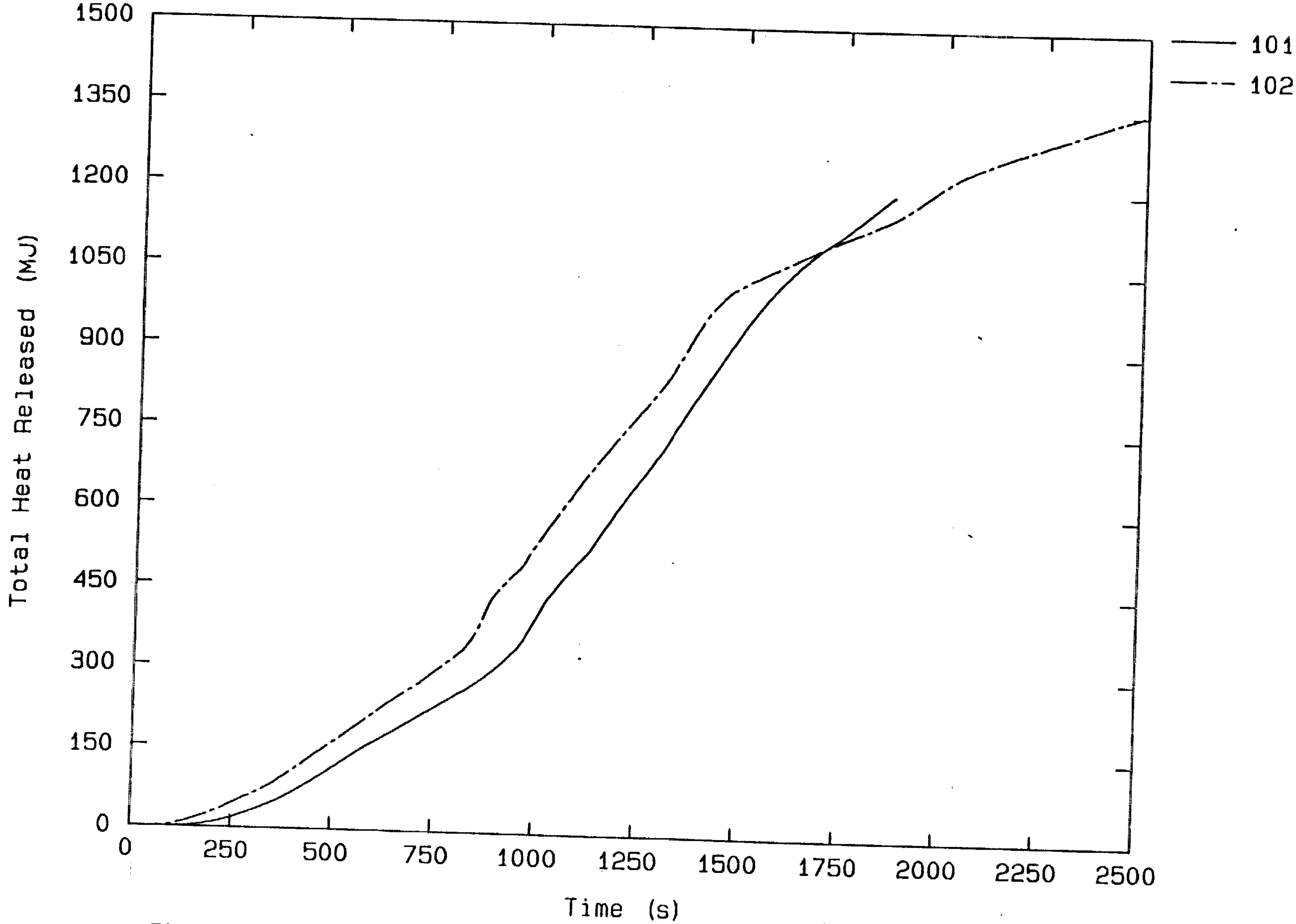

Figure 7. Computer Station, Total Heat Released Tests 101 and 102 (free burn)

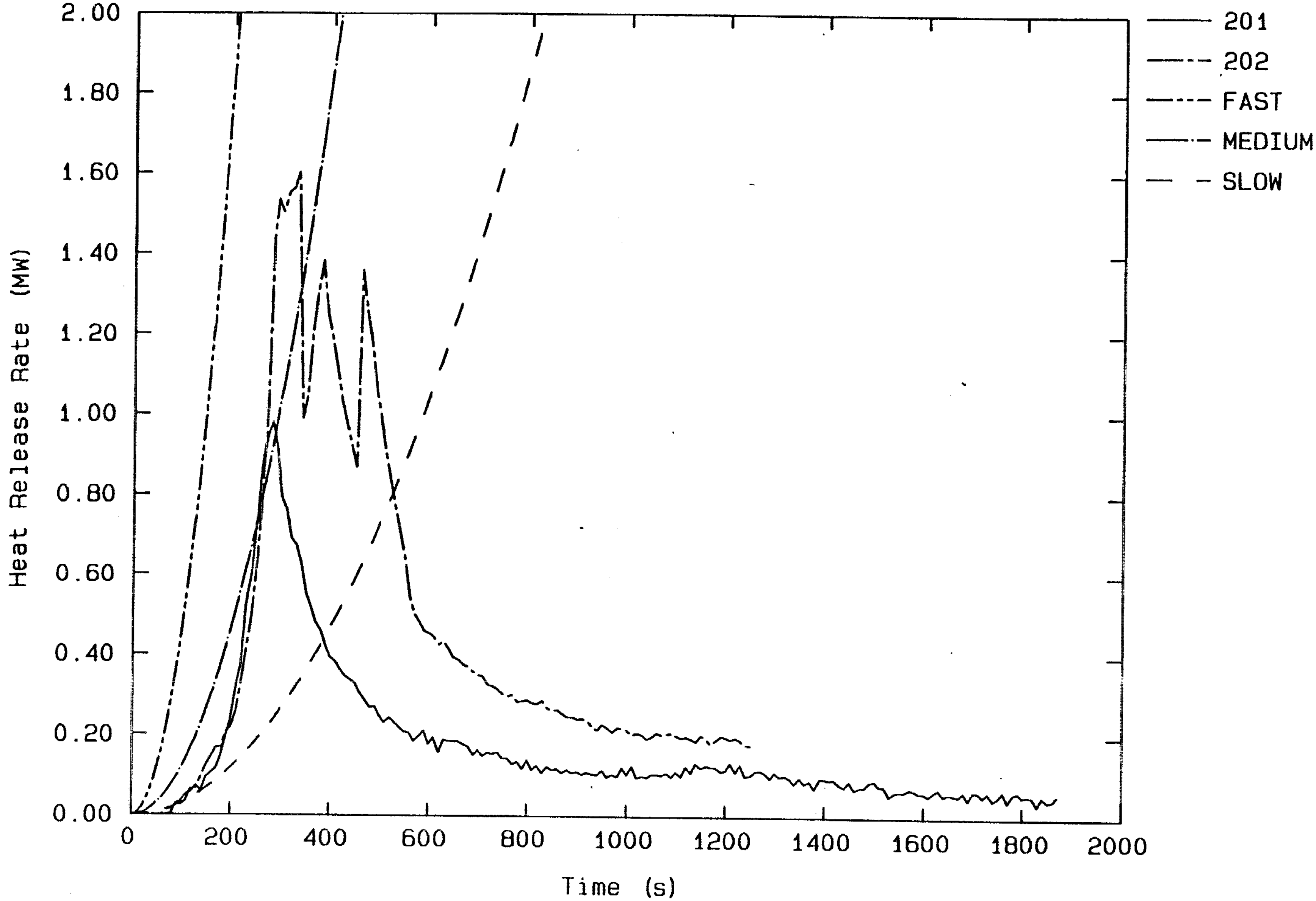

Figure 8. Office Storage, Heat Release Rate Tests 201 and 202 (free burn)

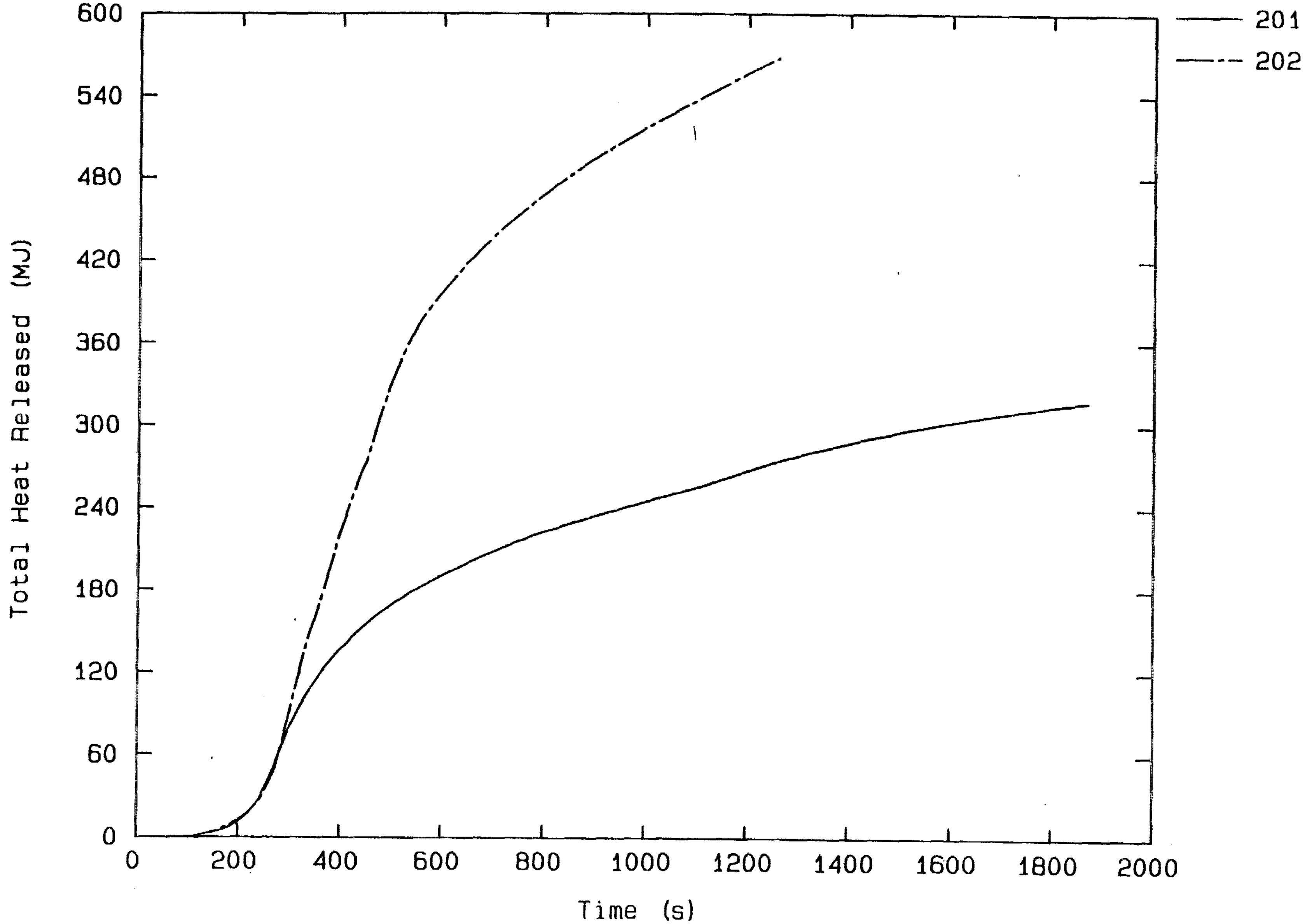

Figure 9. Office Storage, Total Heat Released Tests 201 and 202 (free burn)

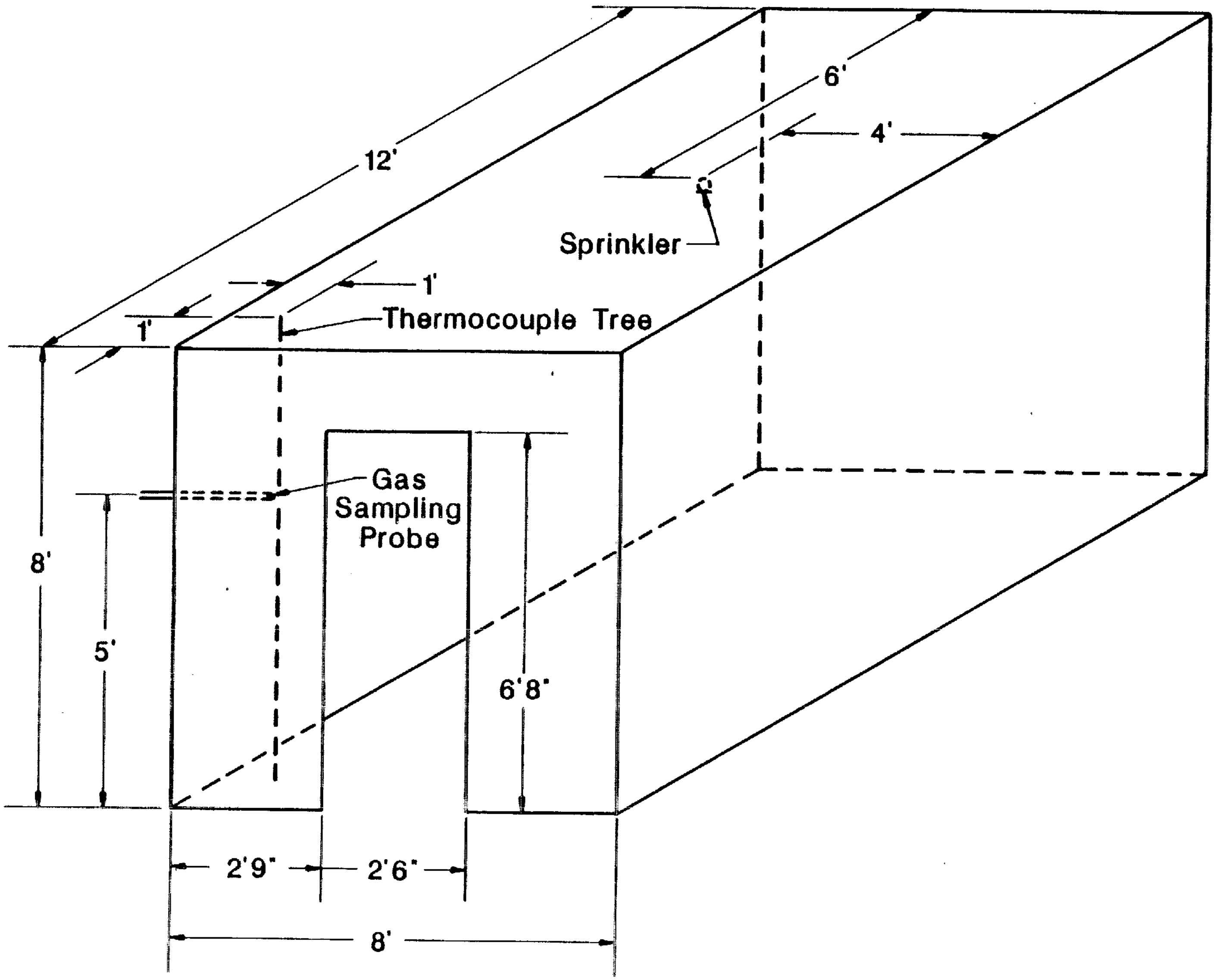

Figure 10. Compartment Instrumentation

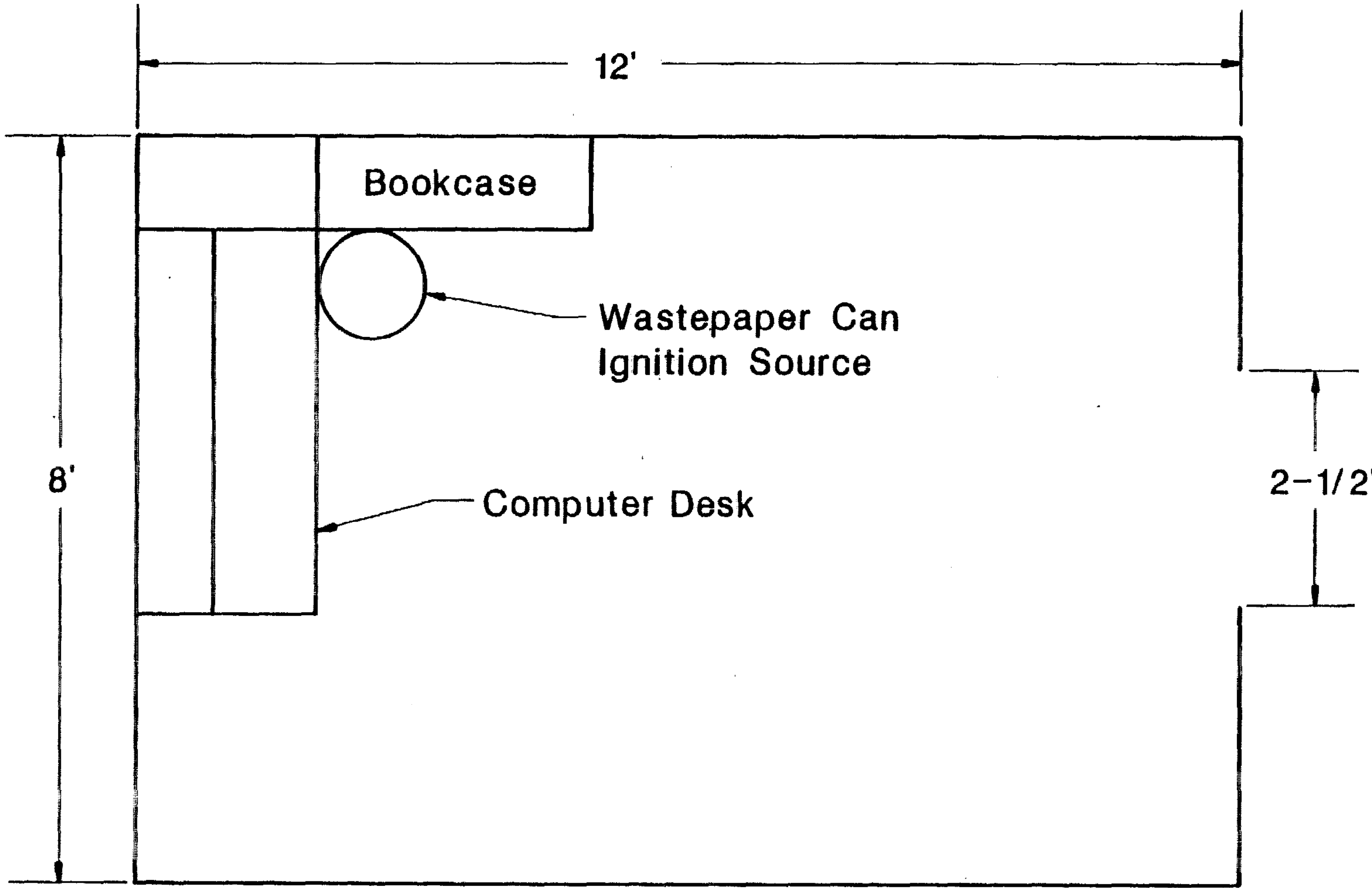

Figure 11. Compartment Computer Work Station Plan View

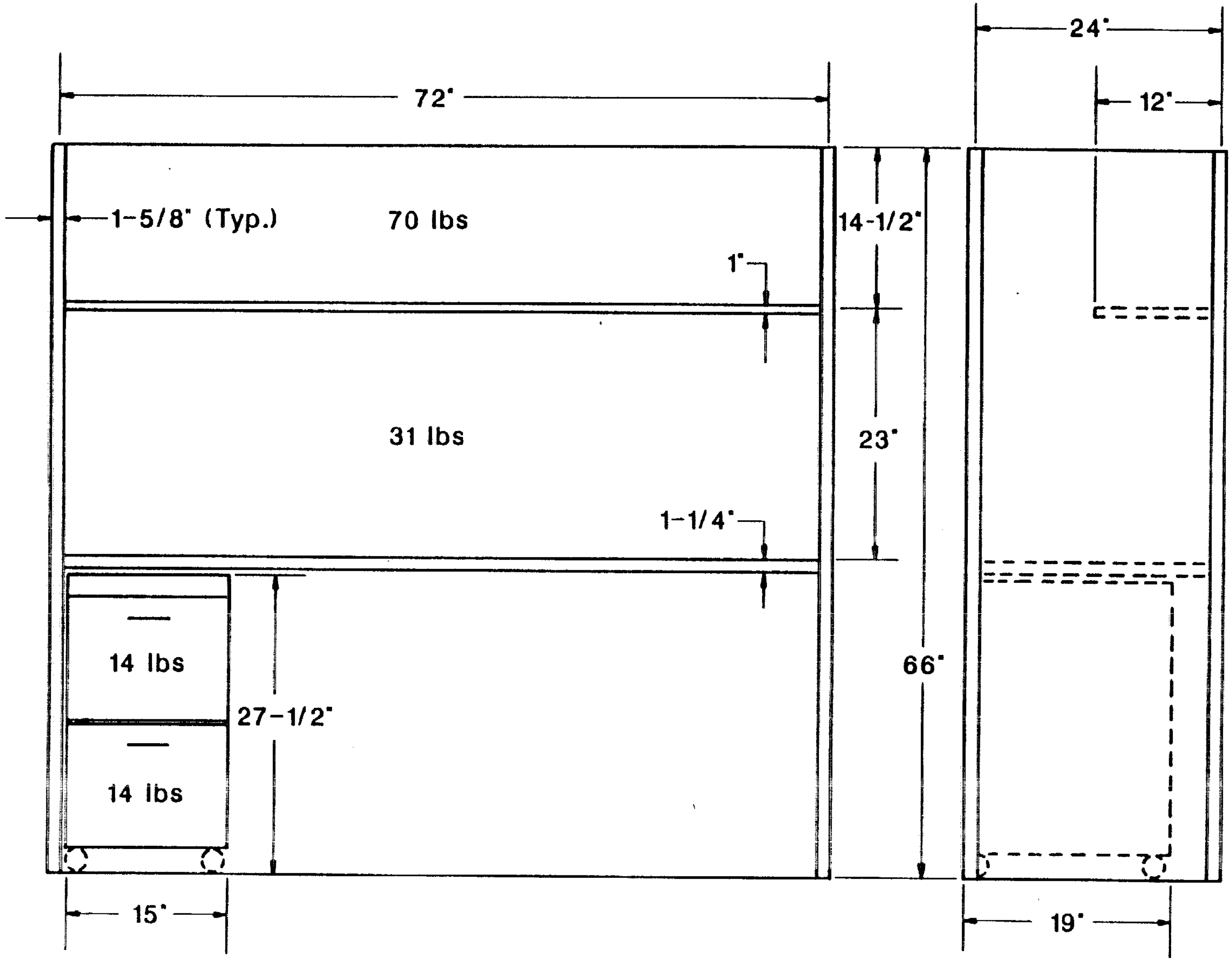

Figure 12. Office Module Desk

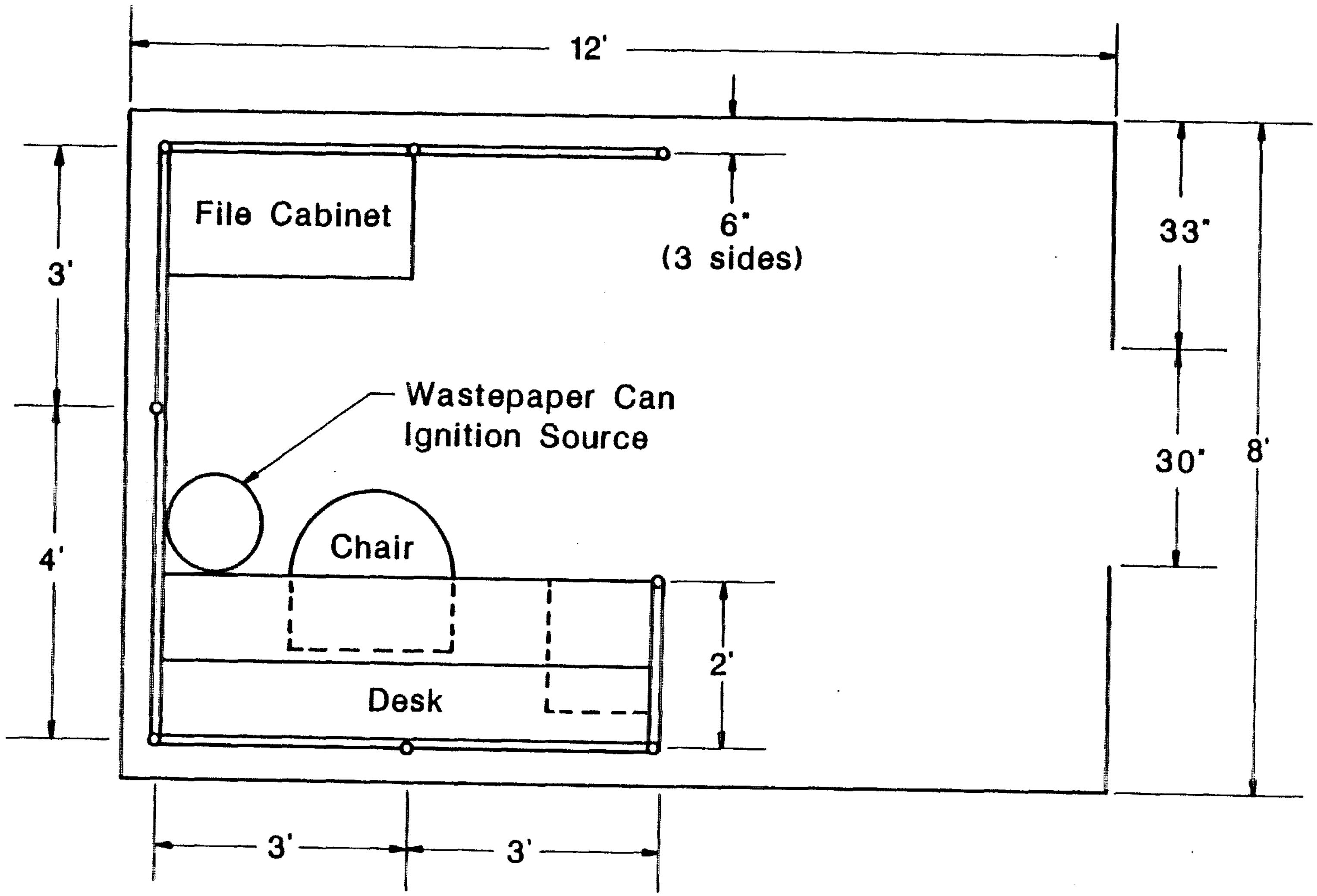

Figure 13. Compartment Office Module Plan View

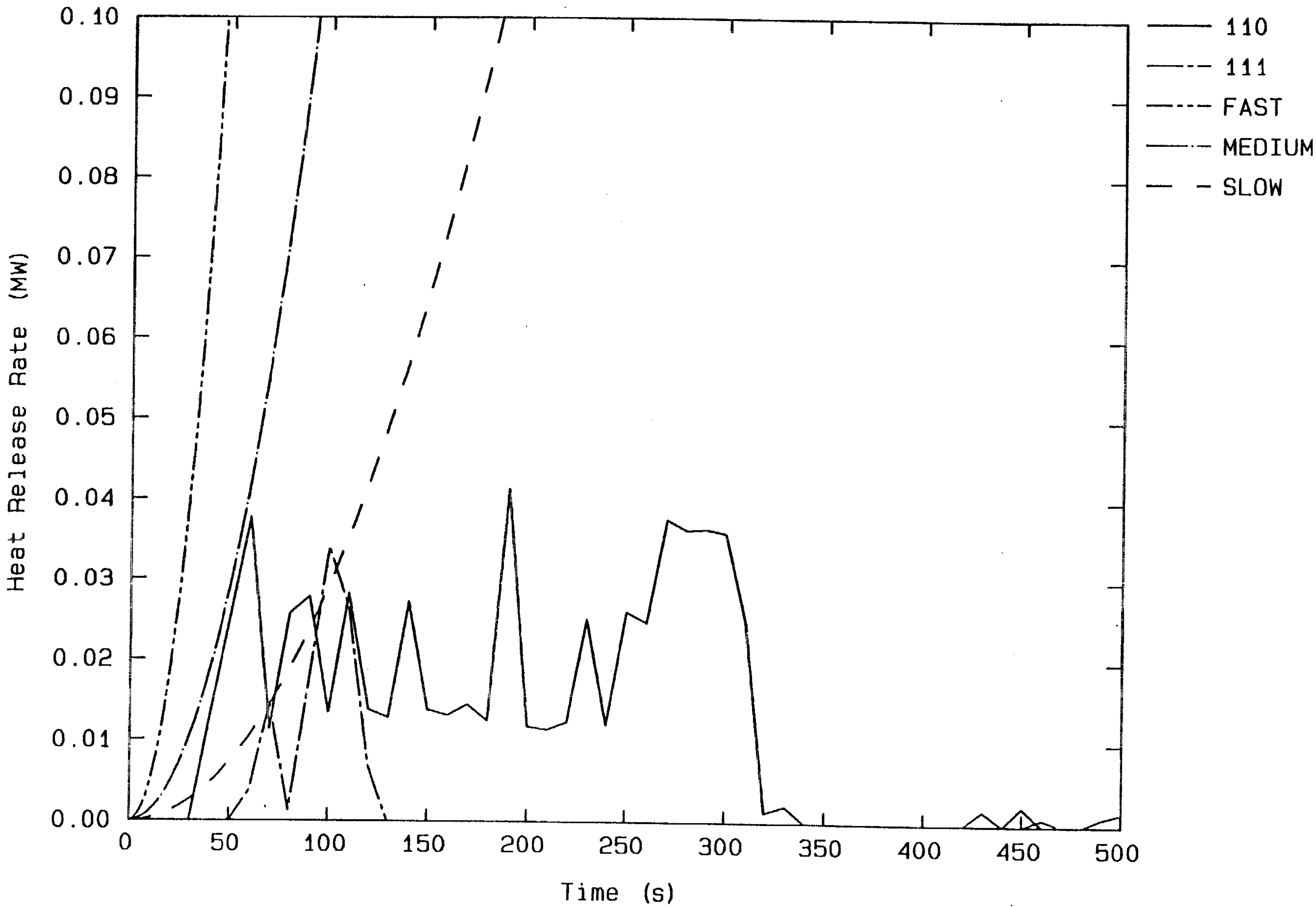

Figure 14. Computer Station, Heat Release Rate Tests 110 (QR) and 111 (QR)

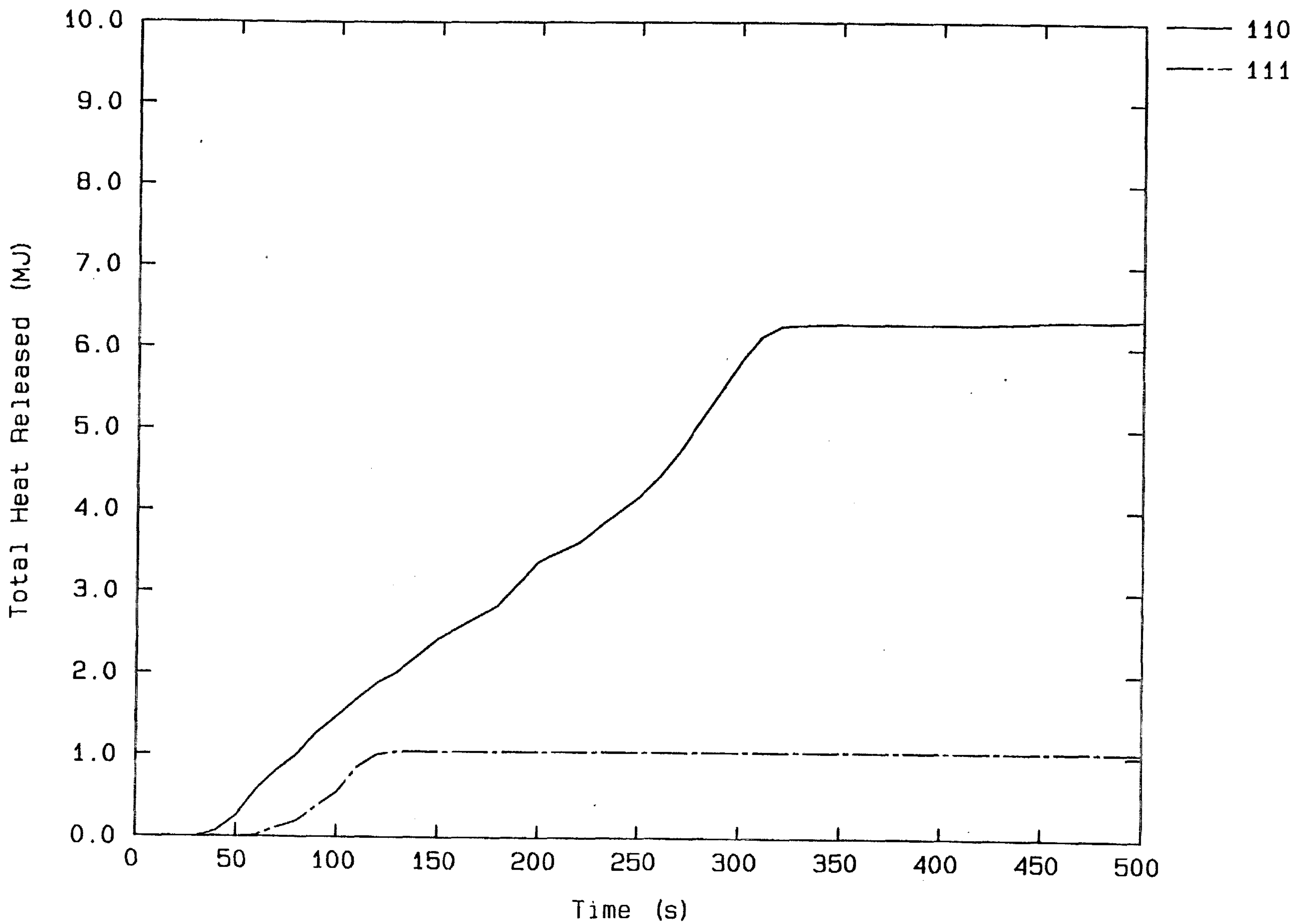

Figure 15. Computer Station, Total Heat Released Tests 110 (QR) and 111 (QR)

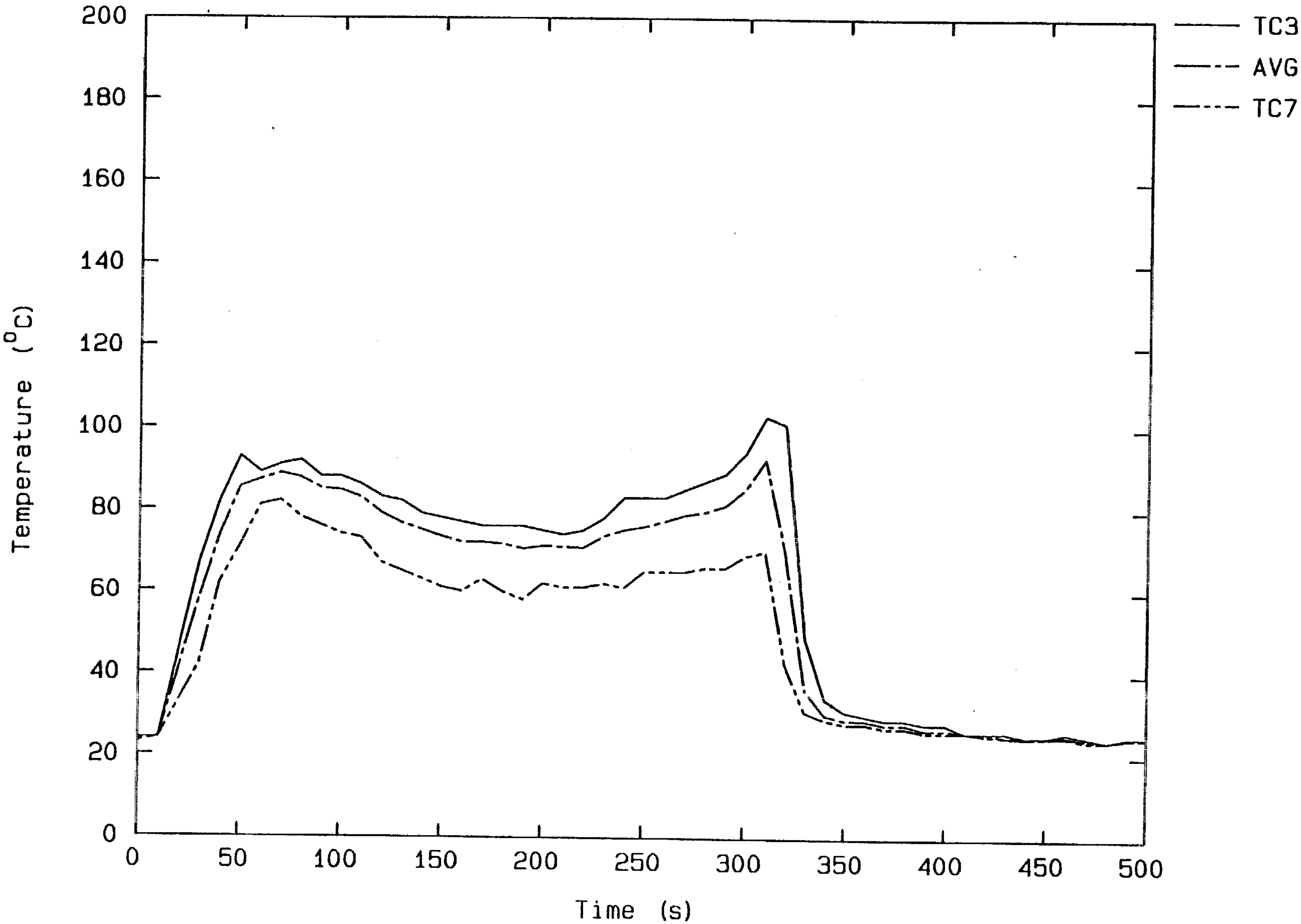

Figure 16. Computer Station, Upper Layer Temperatures Test 110 (QR)

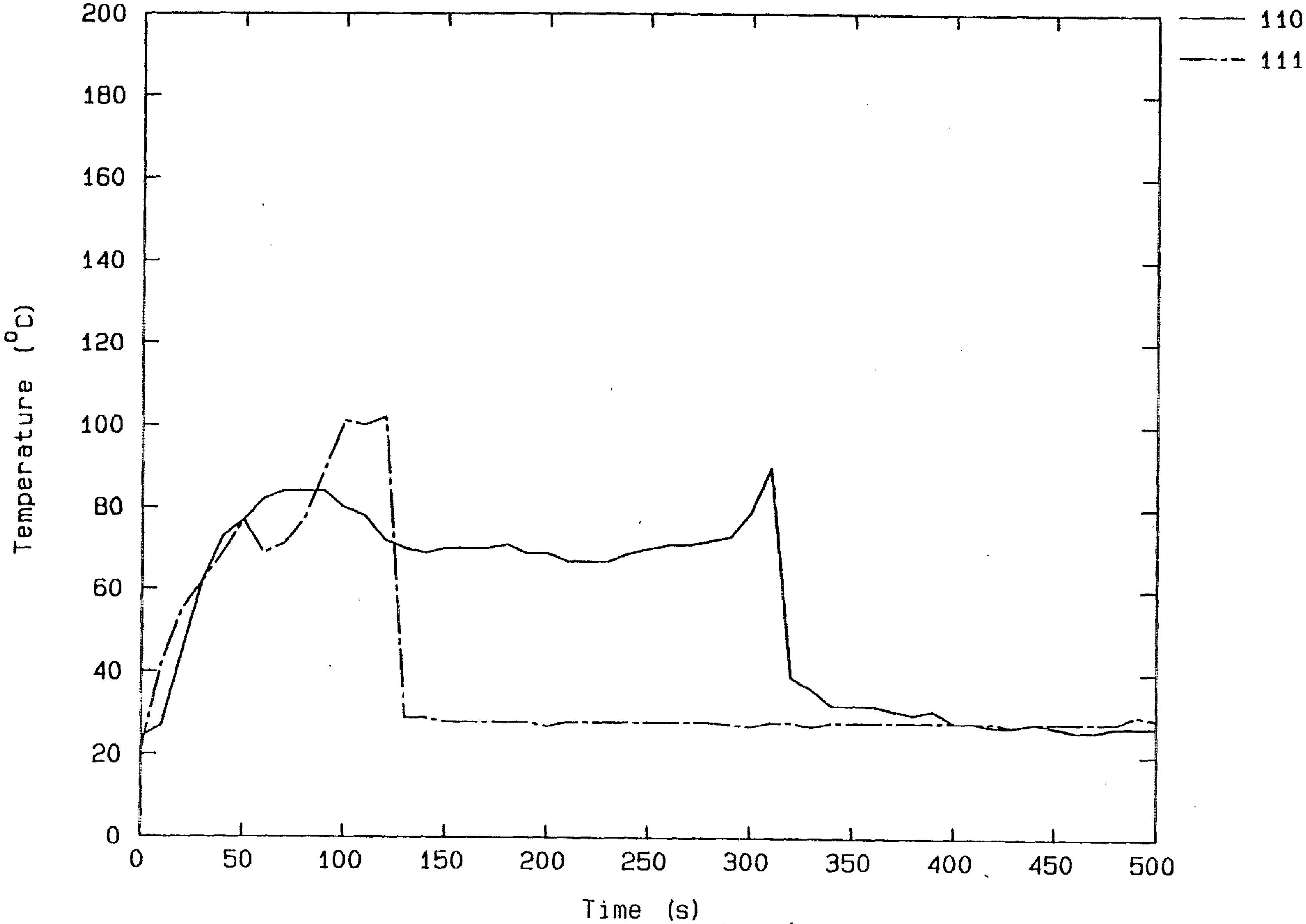

Figure 17. Computer Station, Sprinkler (near) Gas Temperature Tests 110 (QR) and 111 (QR)

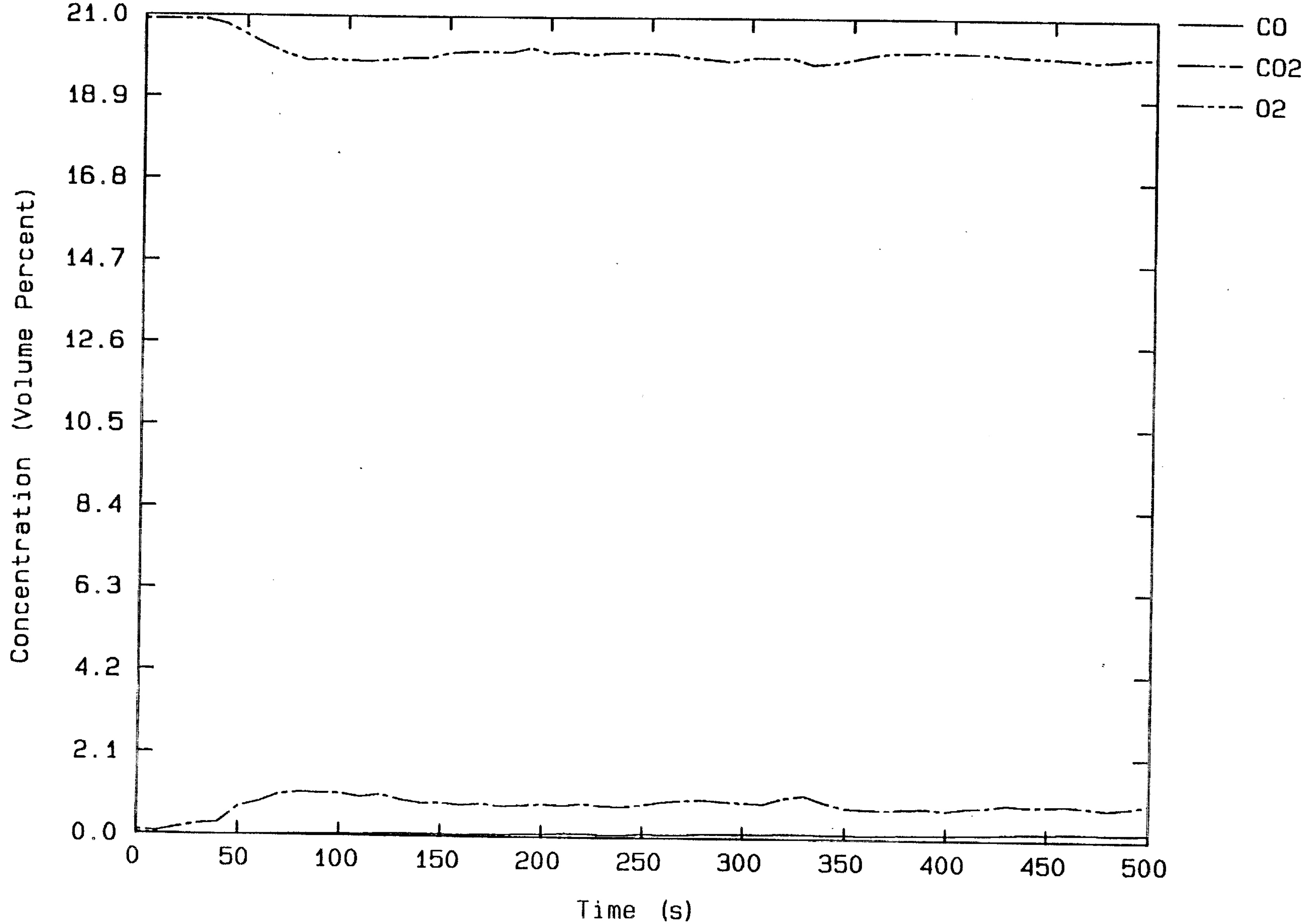

Figure 18. Computer Station, Gas Concentrations Test 110 (QR)

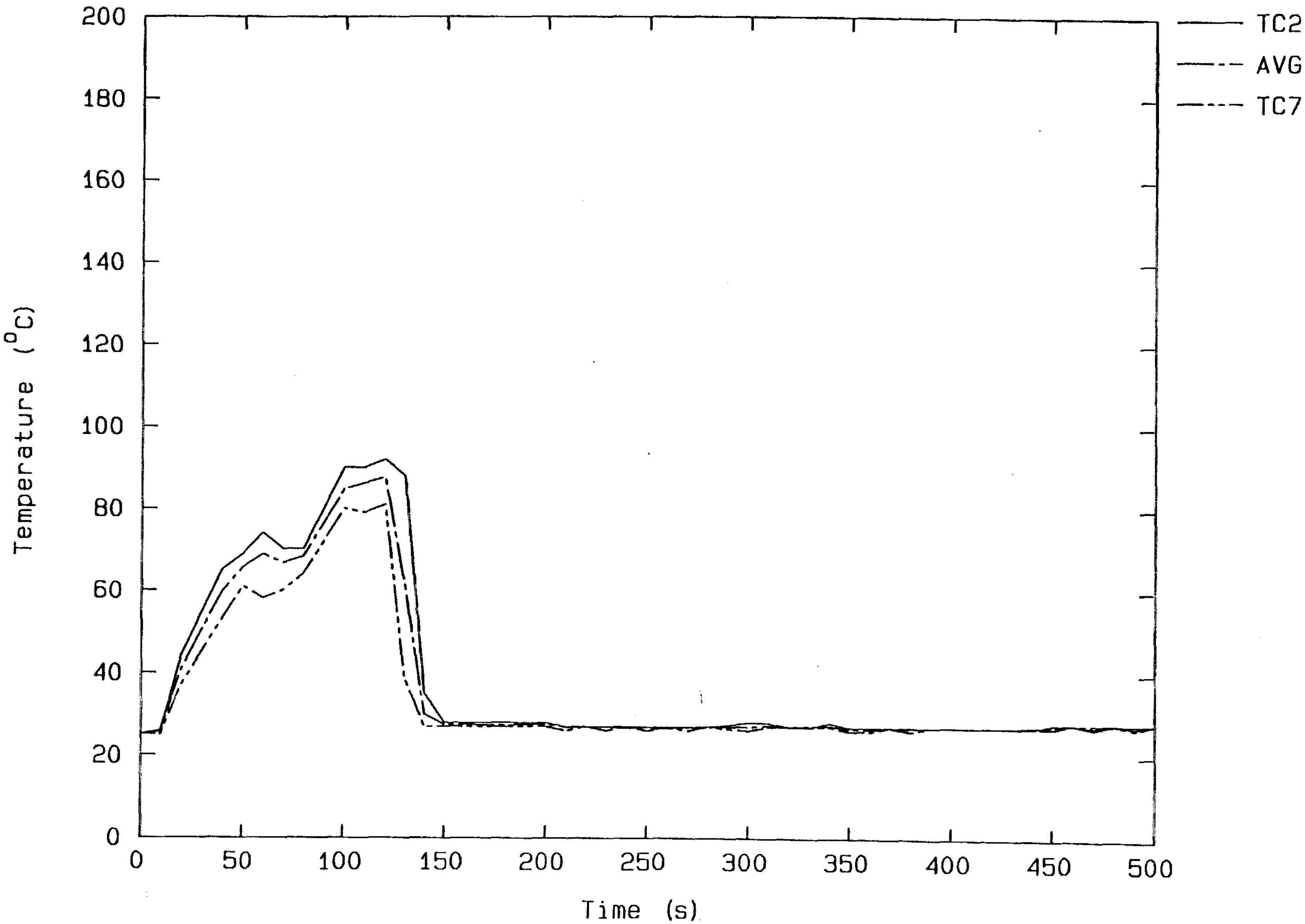

Figure 19. Computer Station, Upper layer Temperatures Test 111 (QR)

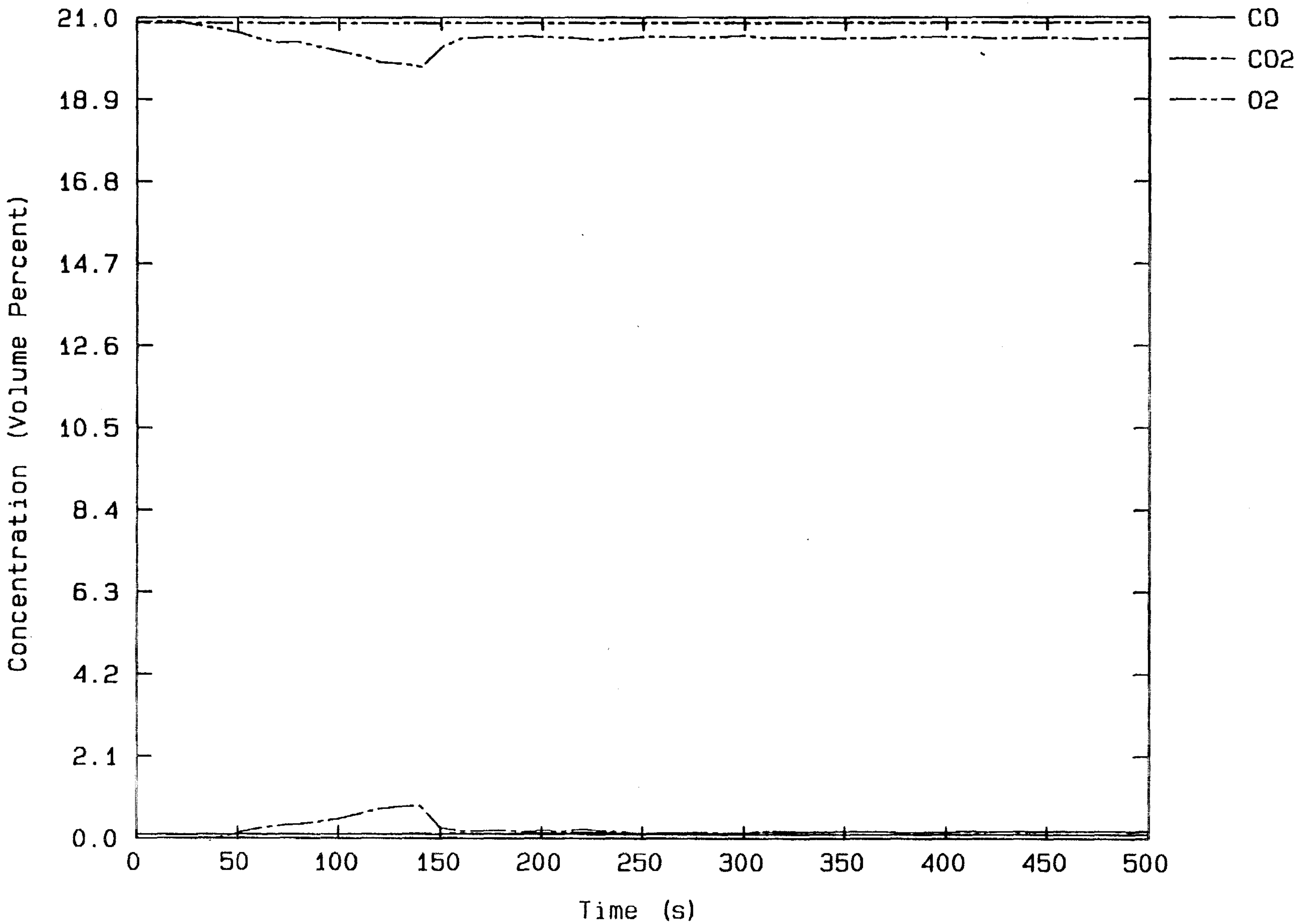

Figure 20. Computer Station, Gas Concentrations Test 111 (QR)

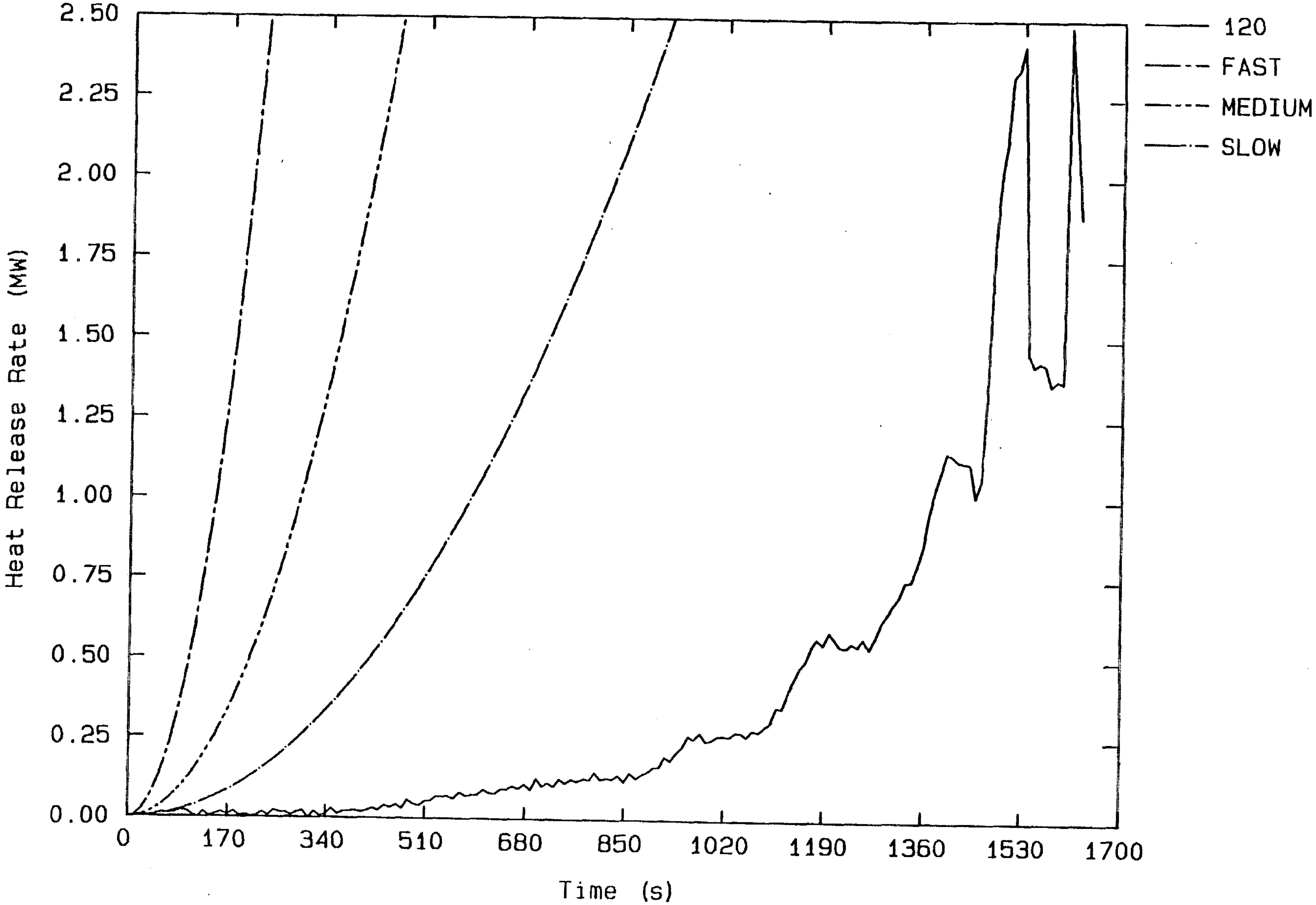

Figure 21. Computer Station, Heat Release Rate Test 120 (None)

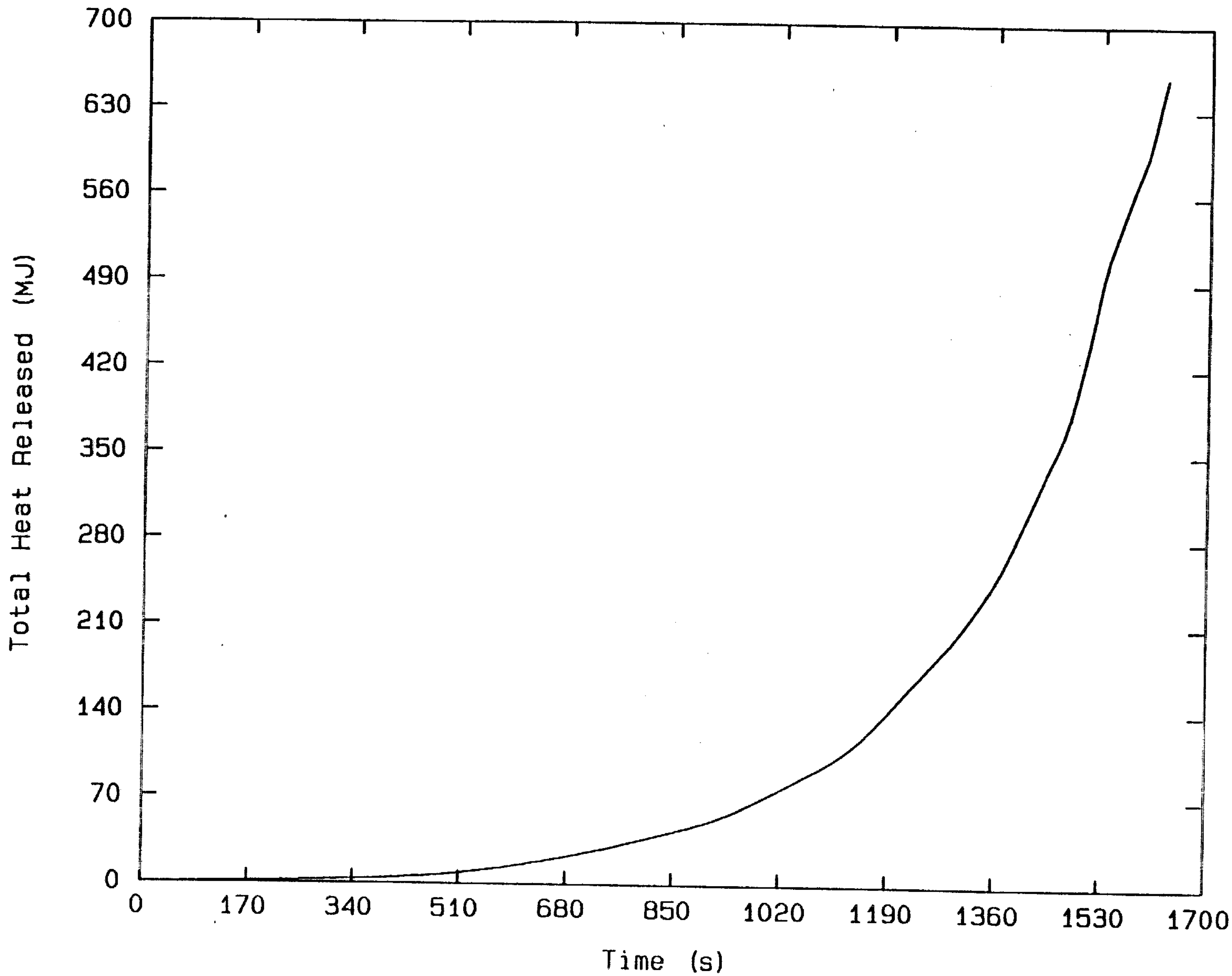

Figure 22. Computer Station, Total Heat Released Test 120 (None)

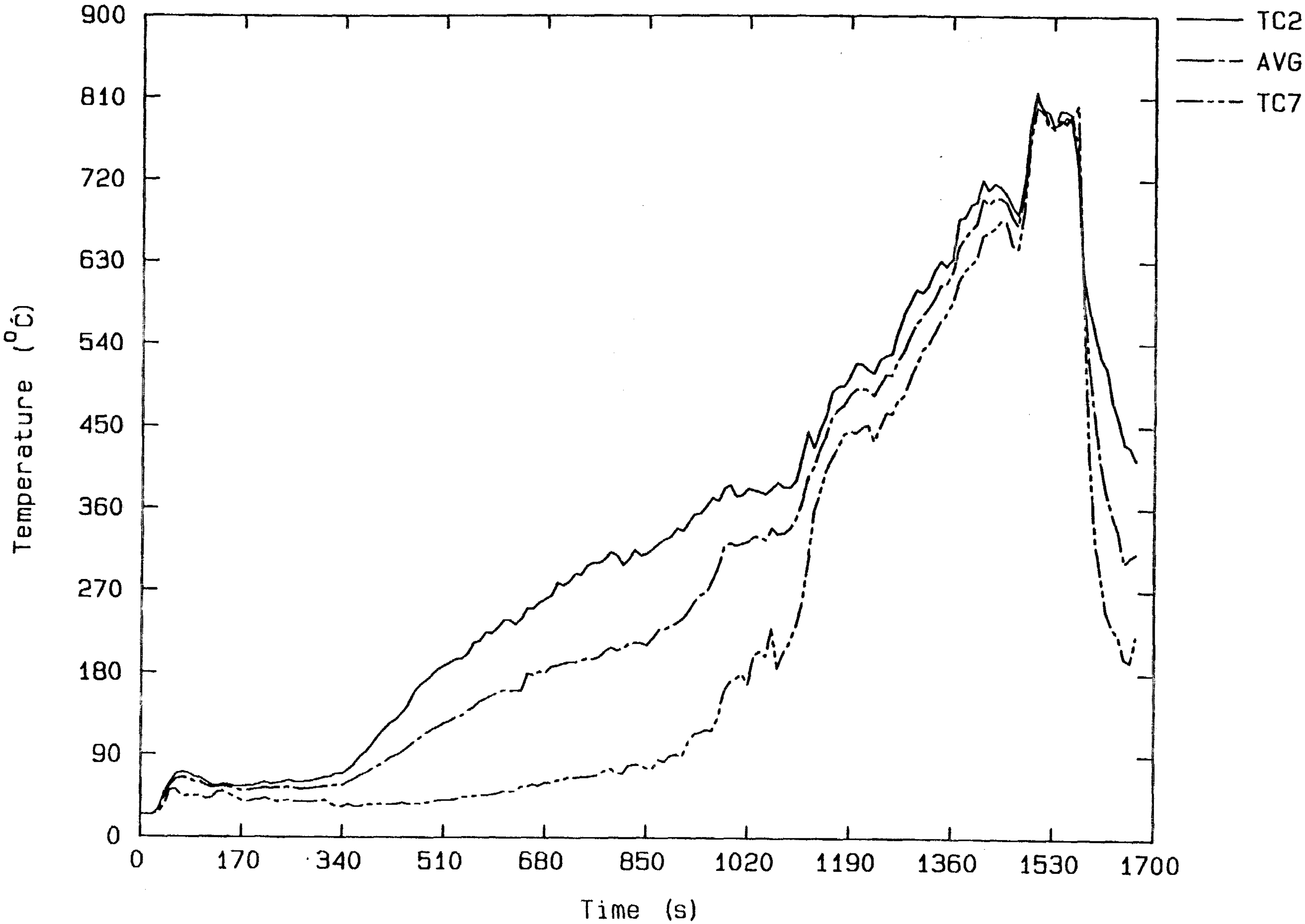

Figure 23. Computer Station, Upper Layer Temperatures Test 120 (None)

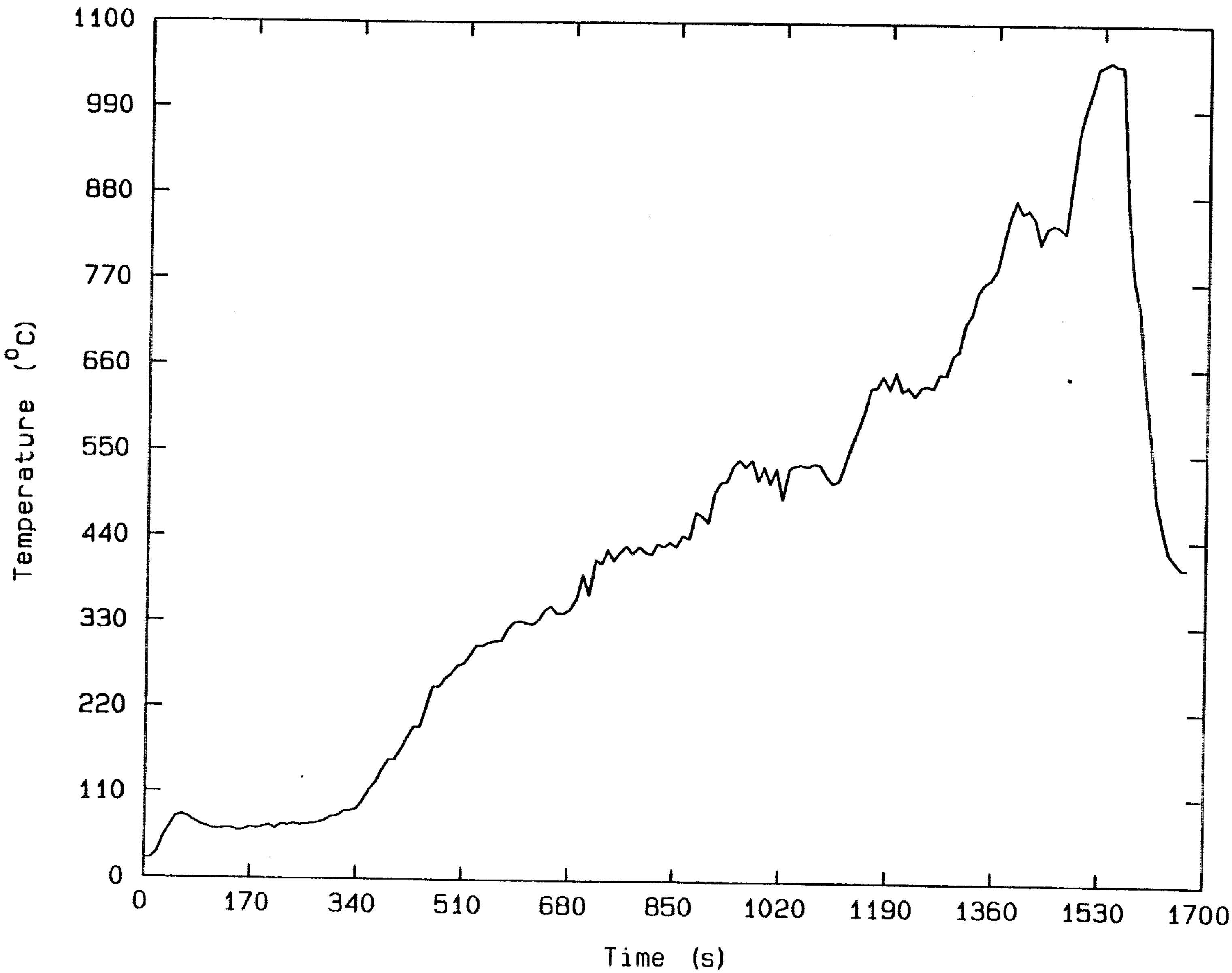

Figure 24. Computer Station, Sprinkler (near) Gas Temperature Test 120 (None)

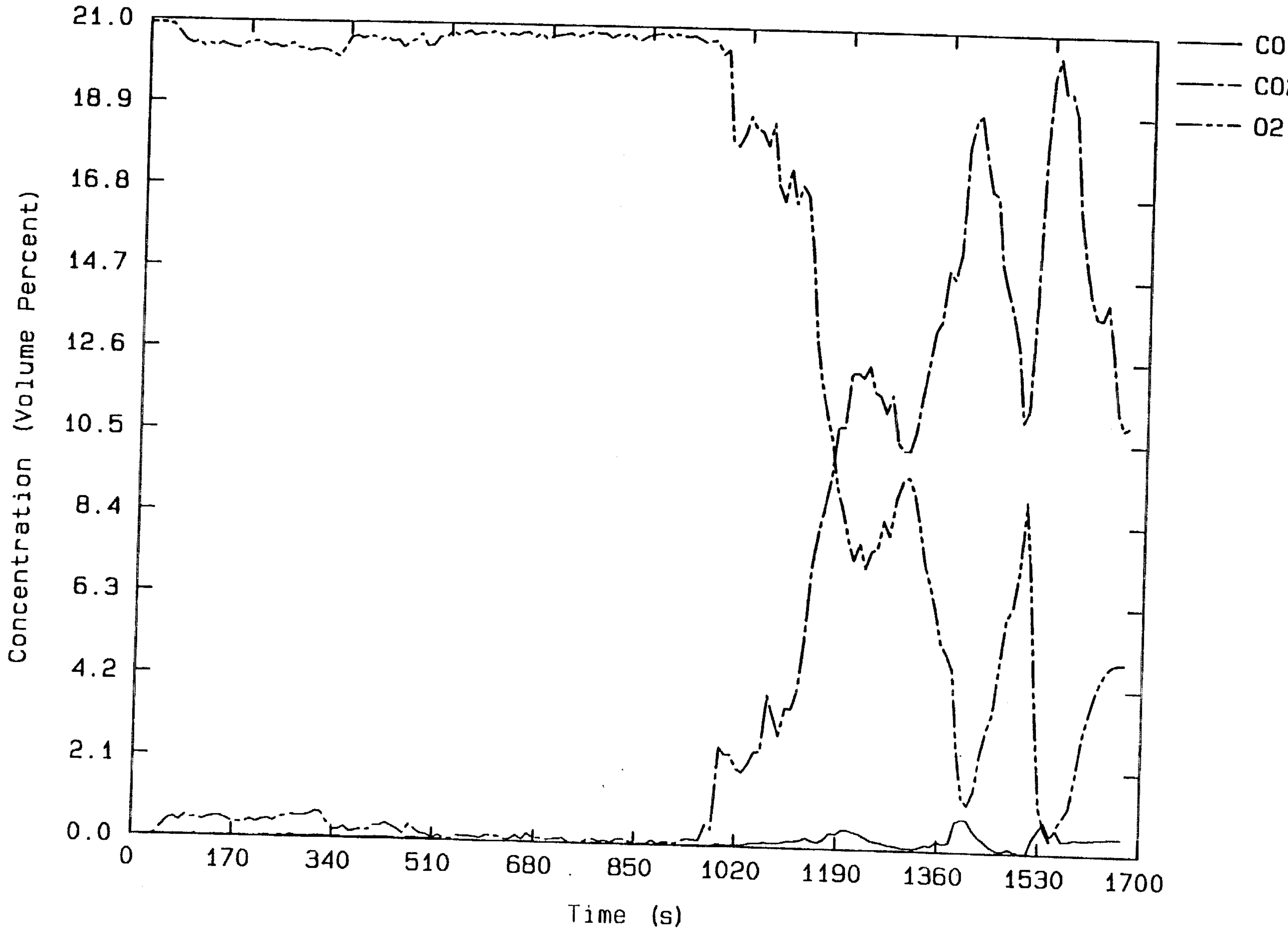

Figure 25. Computer Station, Gas Concentrations Test 120 (None)

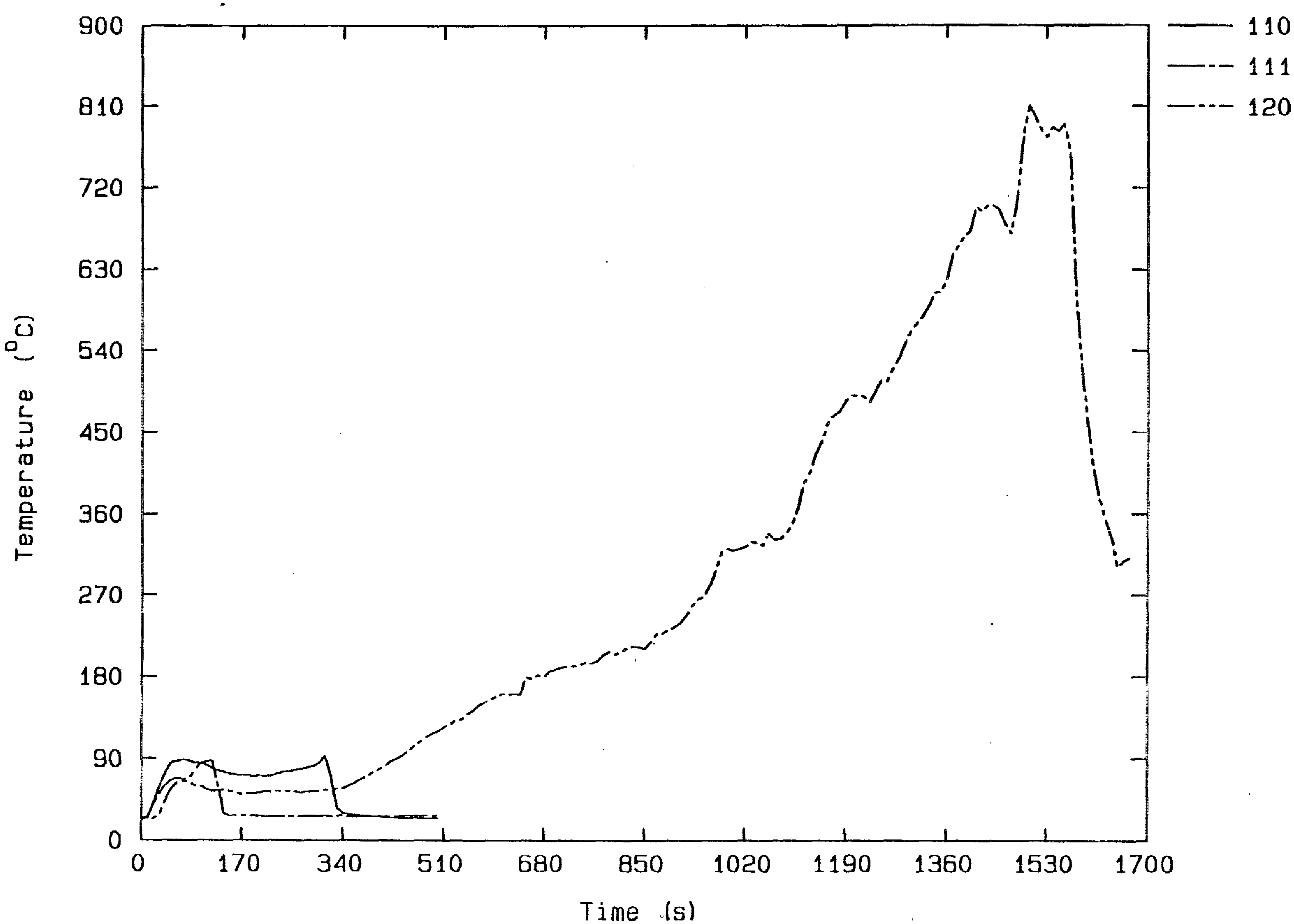

Figure 26. Computer Station, Average Upper Layer Temperature
Tests 110 (QR), 111 (QR) and 120 (None)

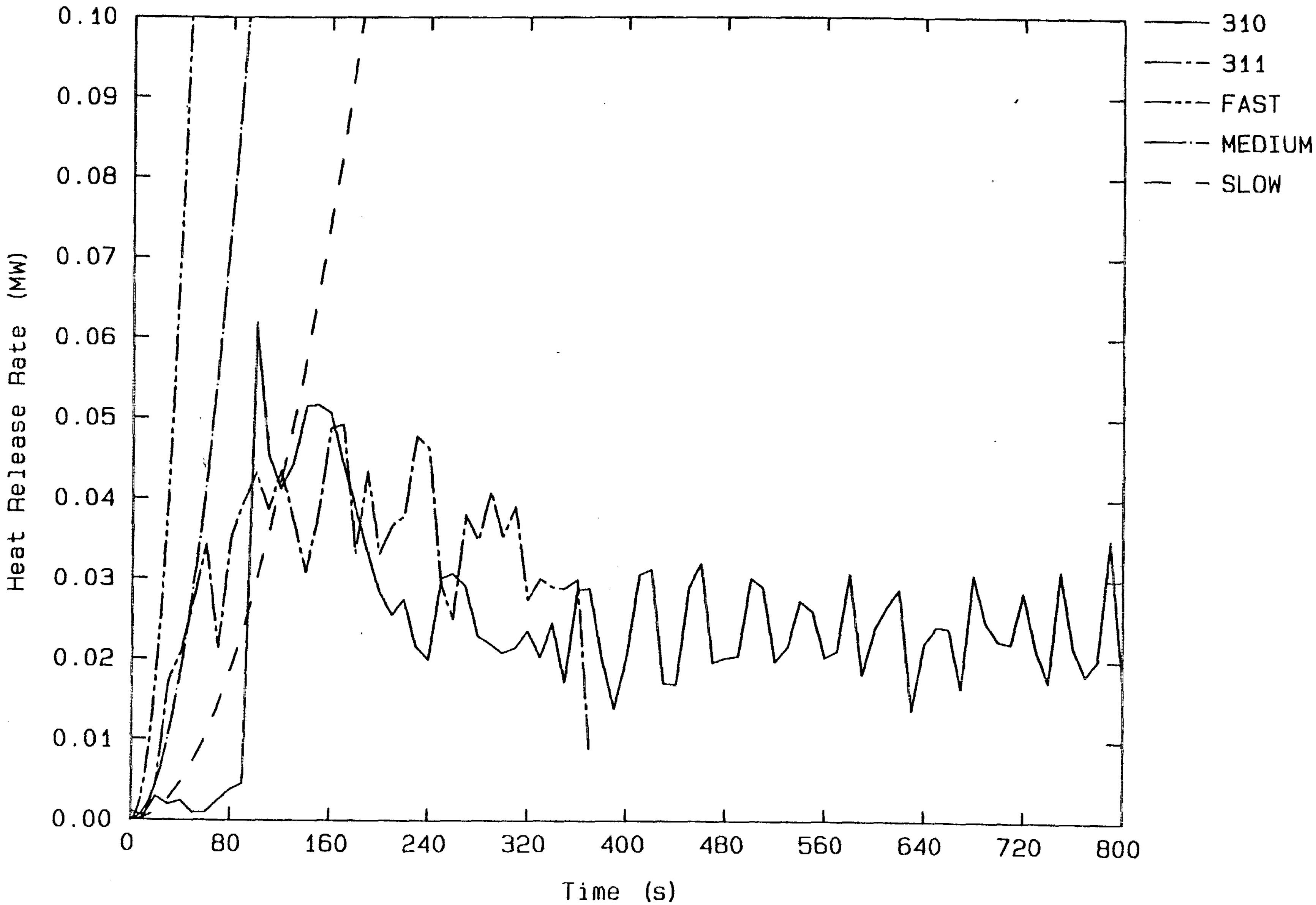

Figure 27. Office Module, Heat Release Rate Tests 310 (QR) and 311 (SSP)

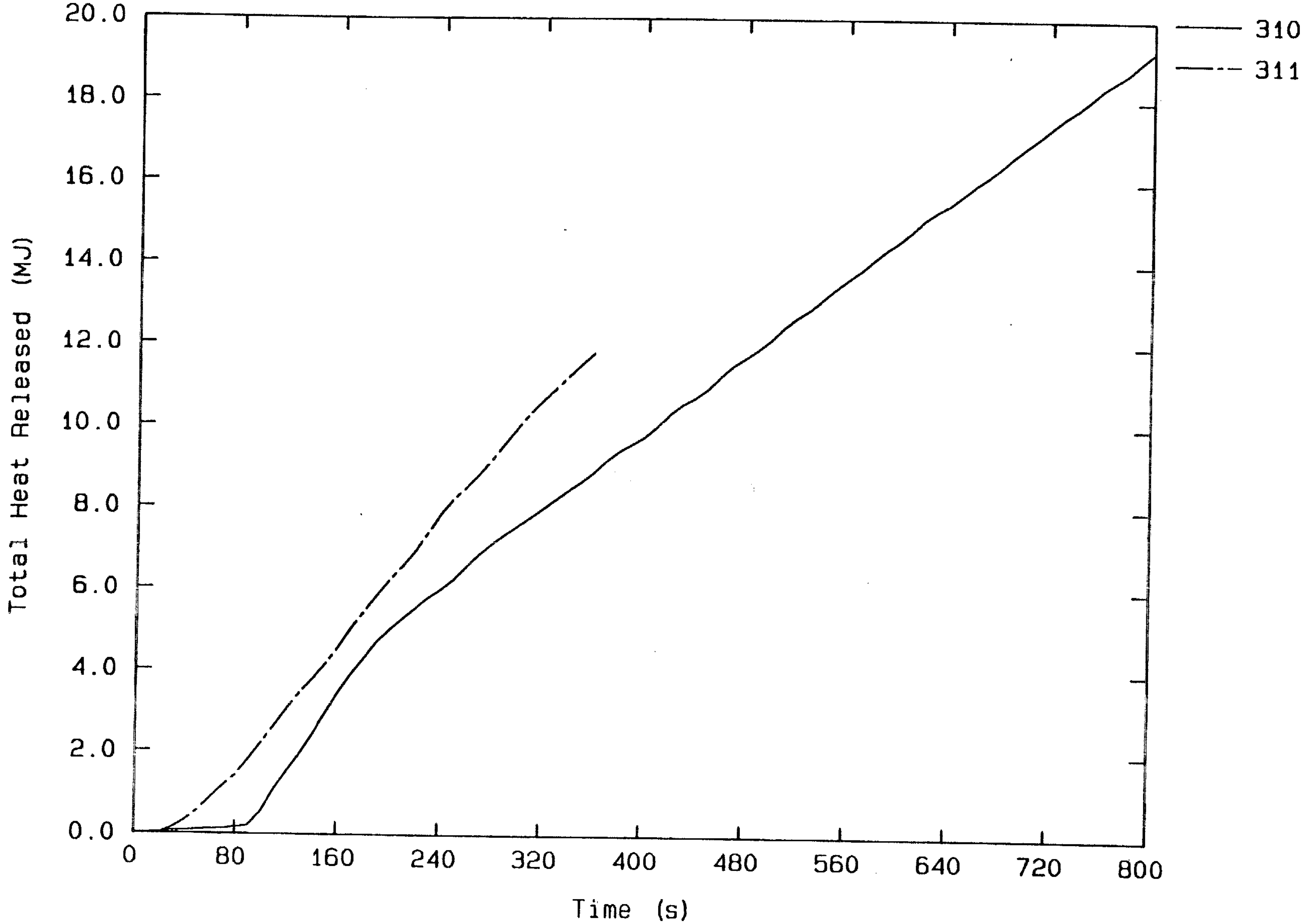

Figure 28. Office Module, Total Heat Released Tests 310 (QR) and 311 (SSP)

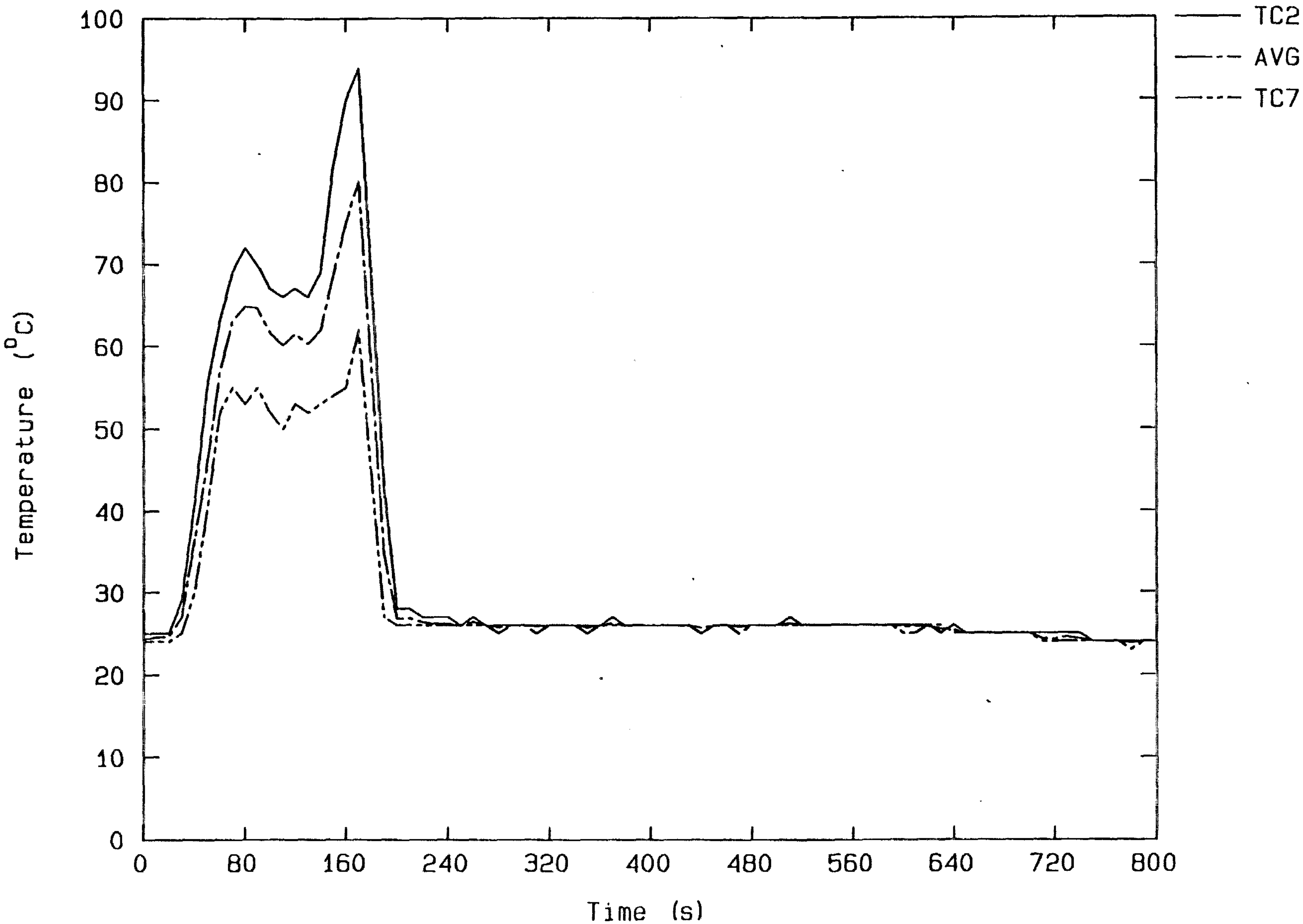

Figure 29. Office Module, Upper Layer Temperatures Test 310 (QR)

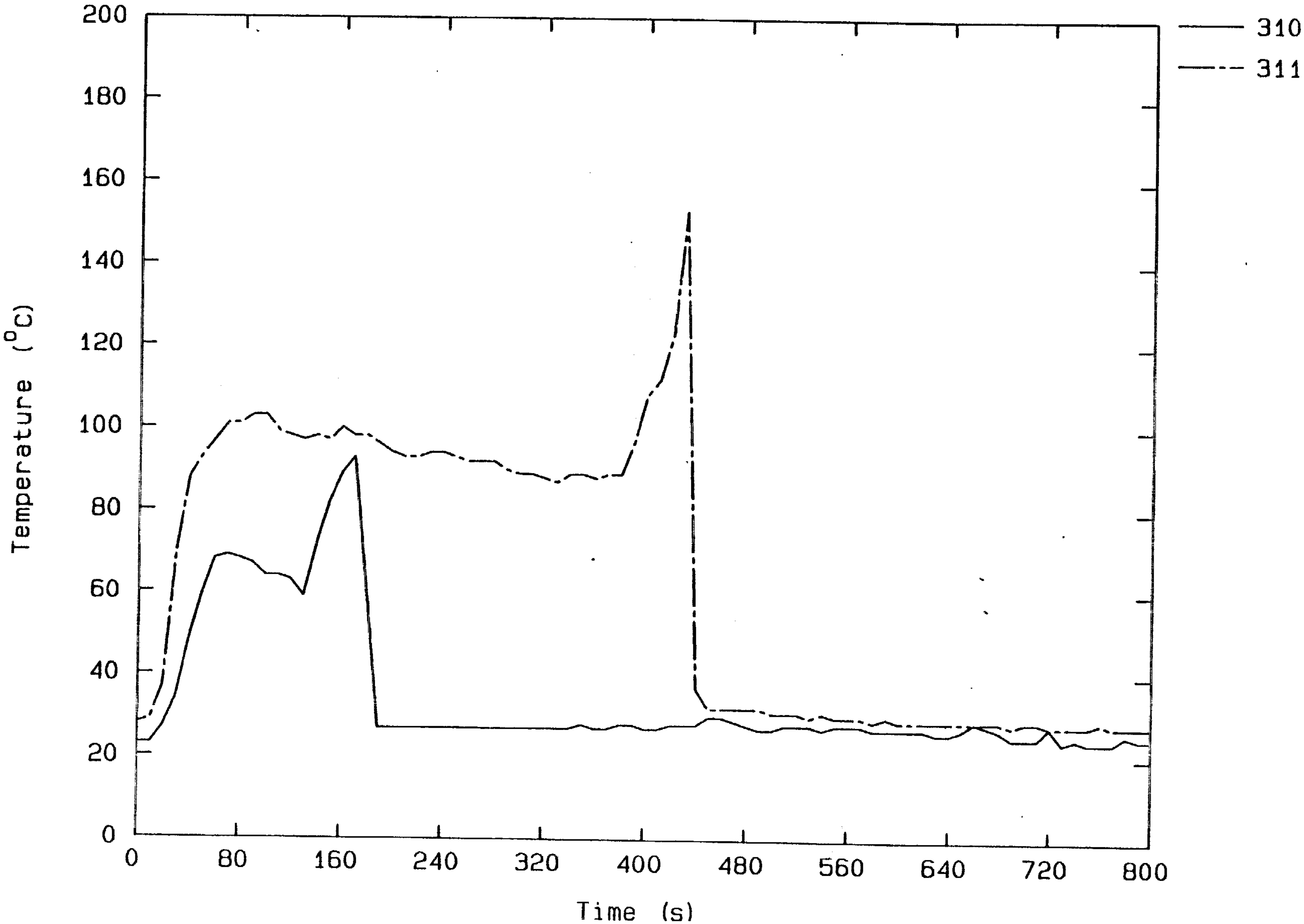

Figure 30. Office Module, Sprinkler (near) Gas Temperature Tests 310 (QR) and 311 (SSP)

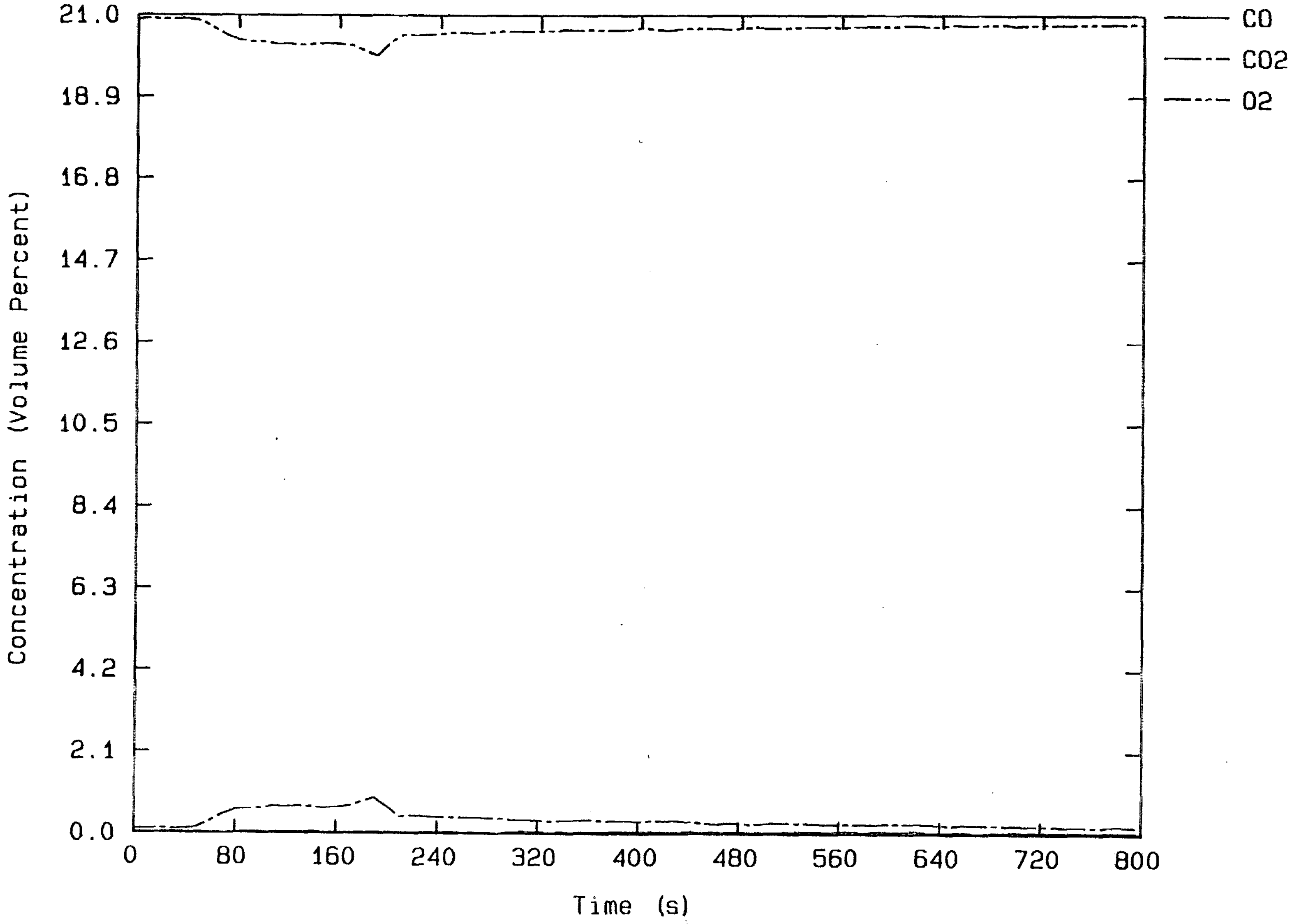

Figure 31. Office Module, Gas Concentrations Test 310 (QR)

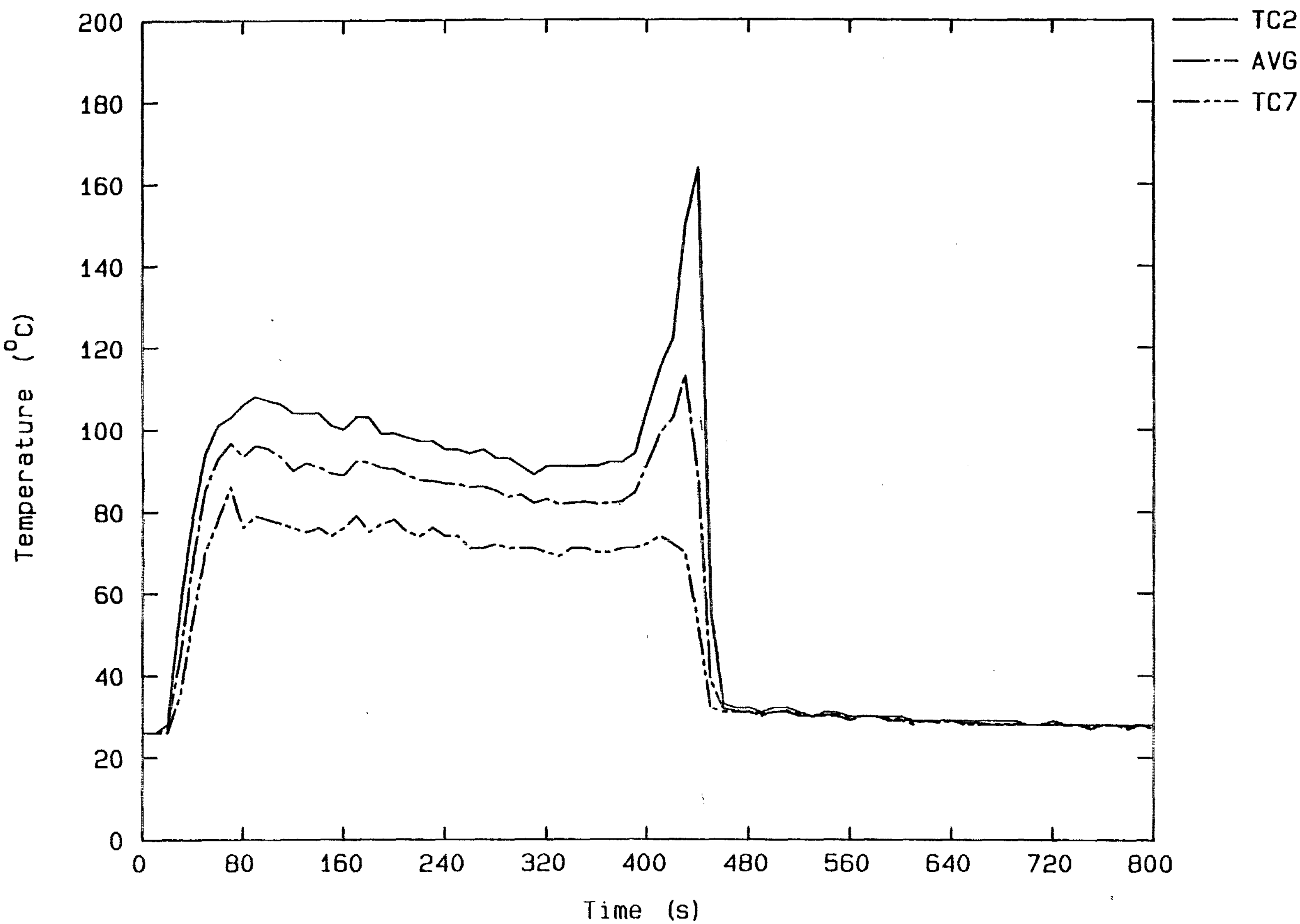

Figure 32. Office Module, Upper Layer Temperatures Test 311 (SSP)

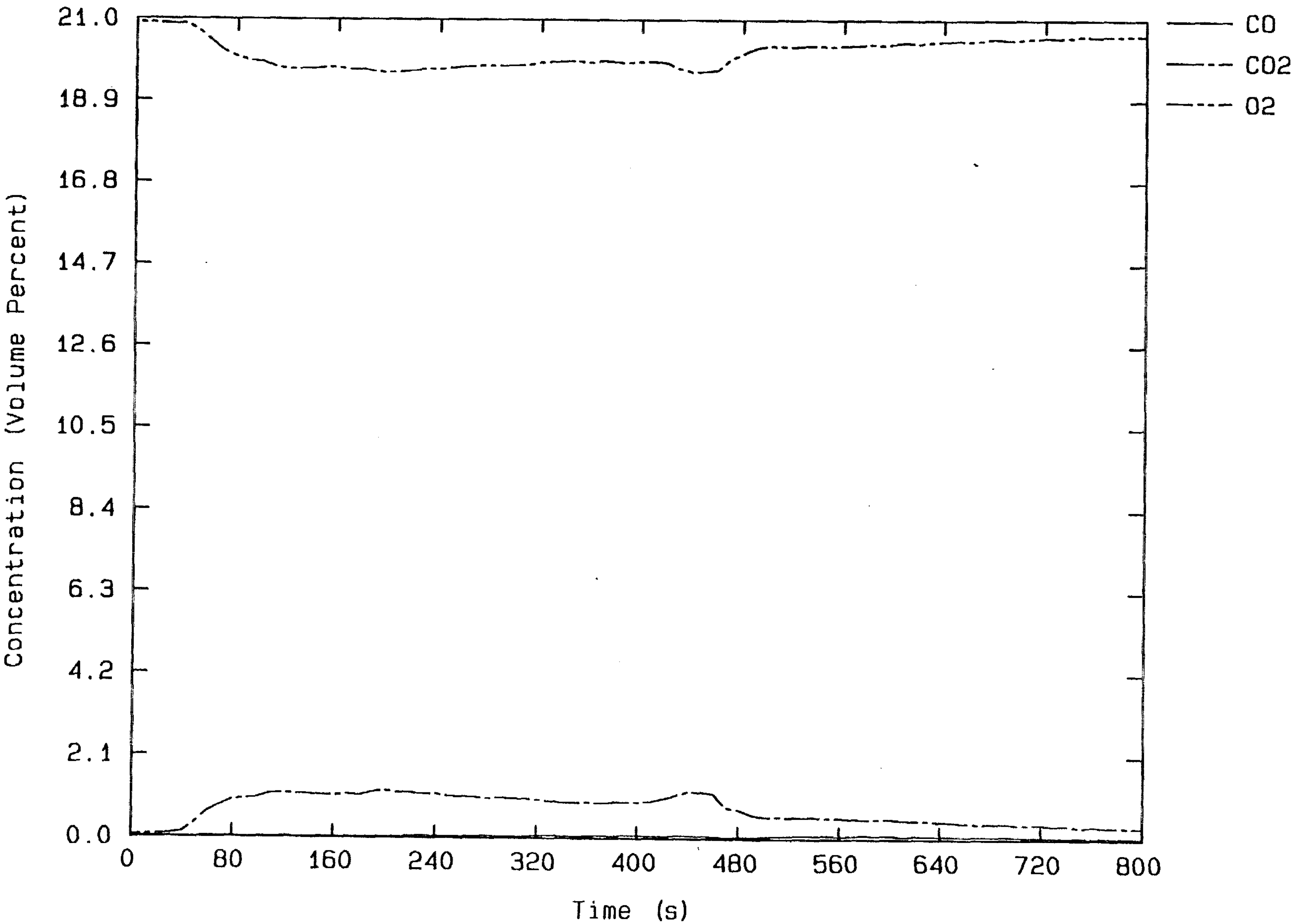

Figure 33. Office Module, Gas Concentrations Test 311 (SSP)

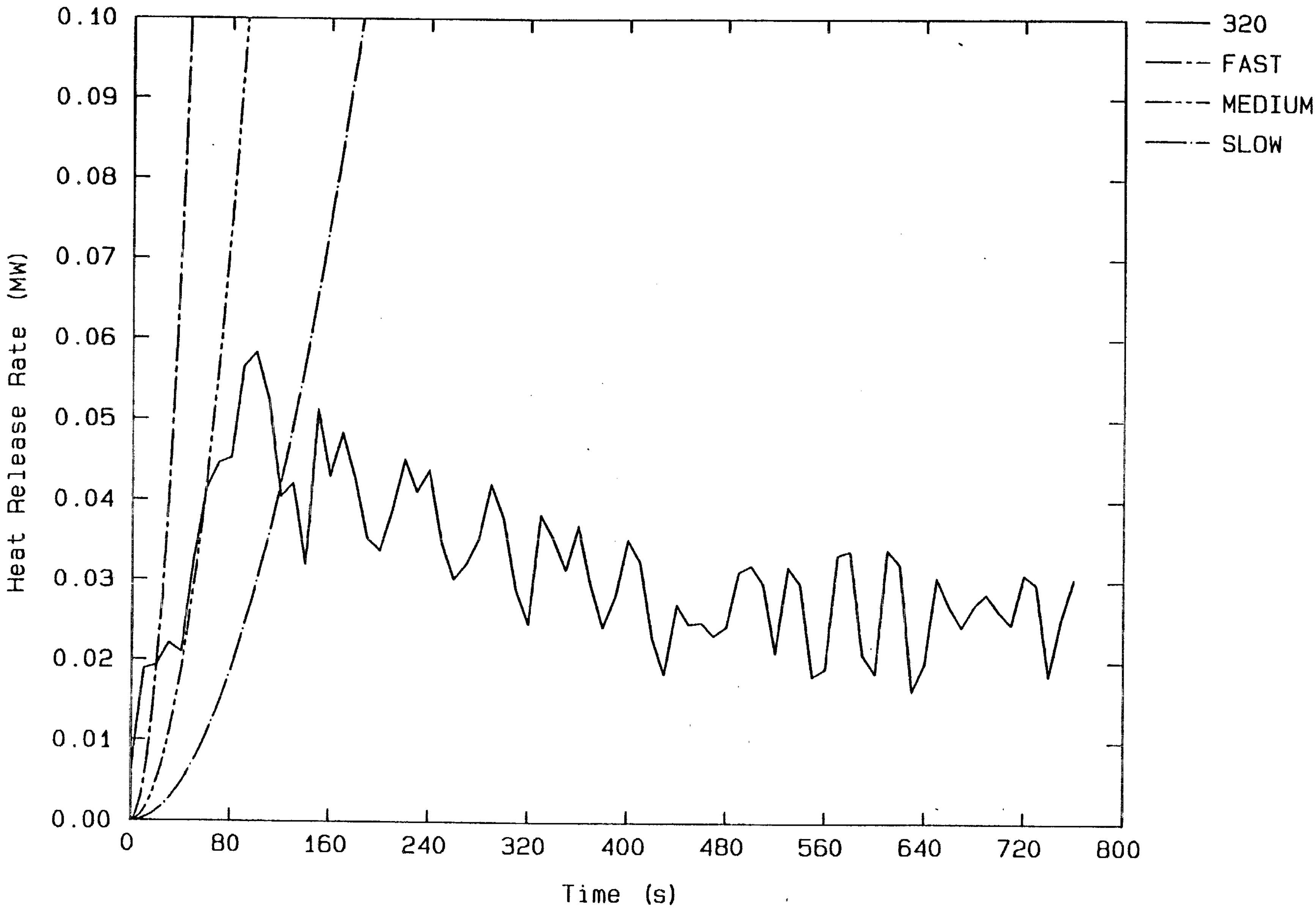

Figure 34. Office Module, Heat Release Rate Test 320 (None)

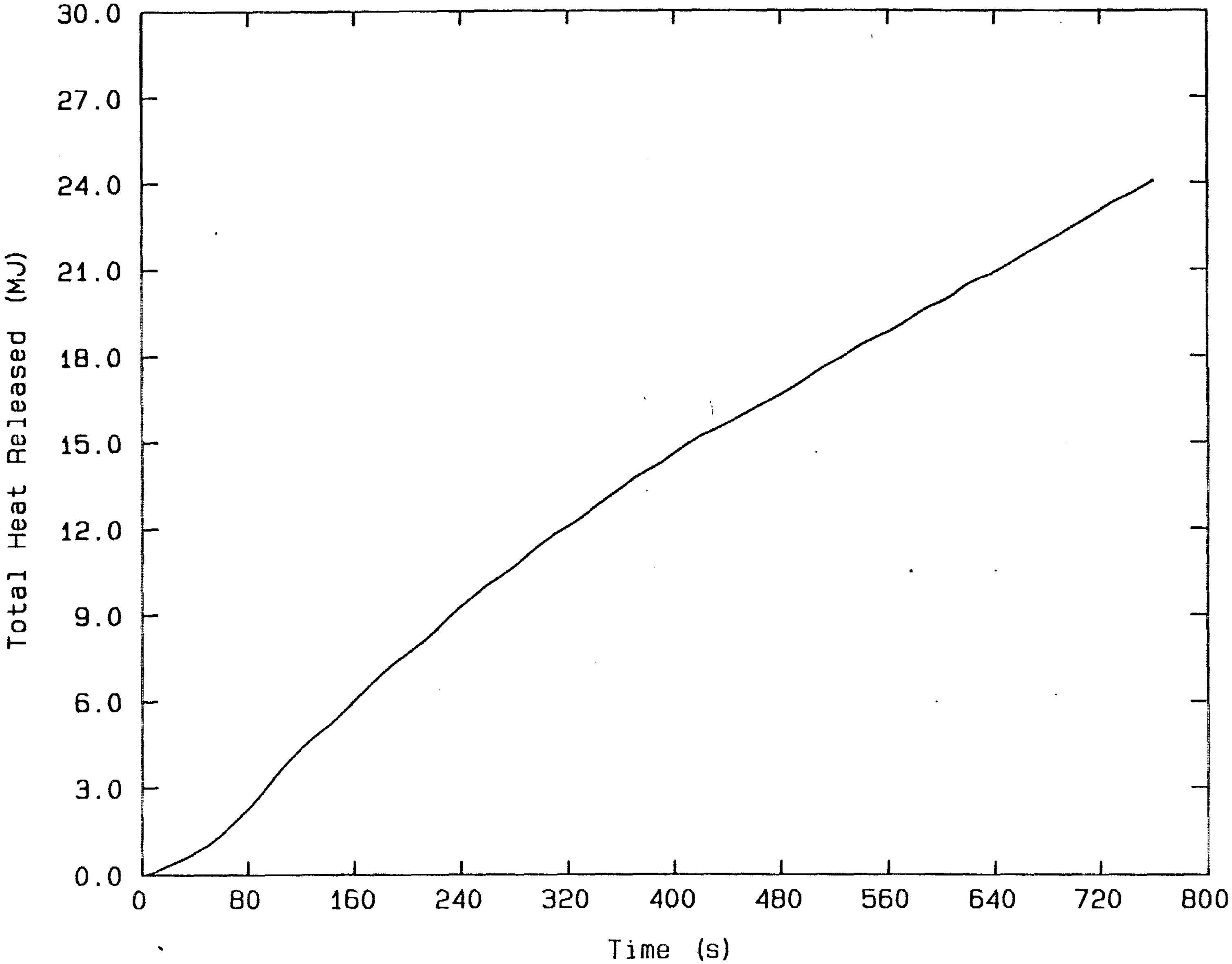

Figure 35. Office Module, Total Heat Released Test 320 (None)

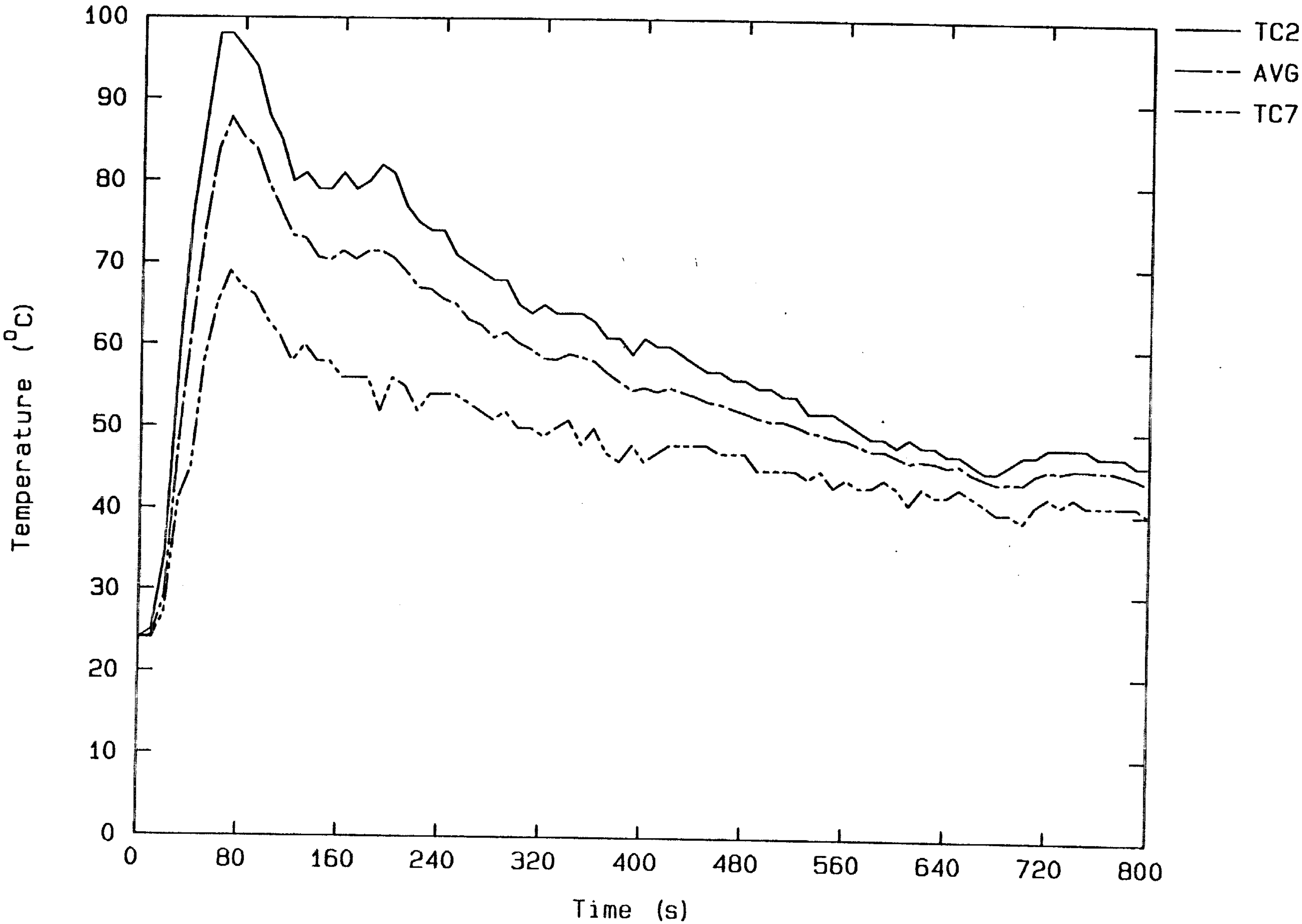

Figure 36. Office Module, Upper Layer Temperatures Test 320 (None)

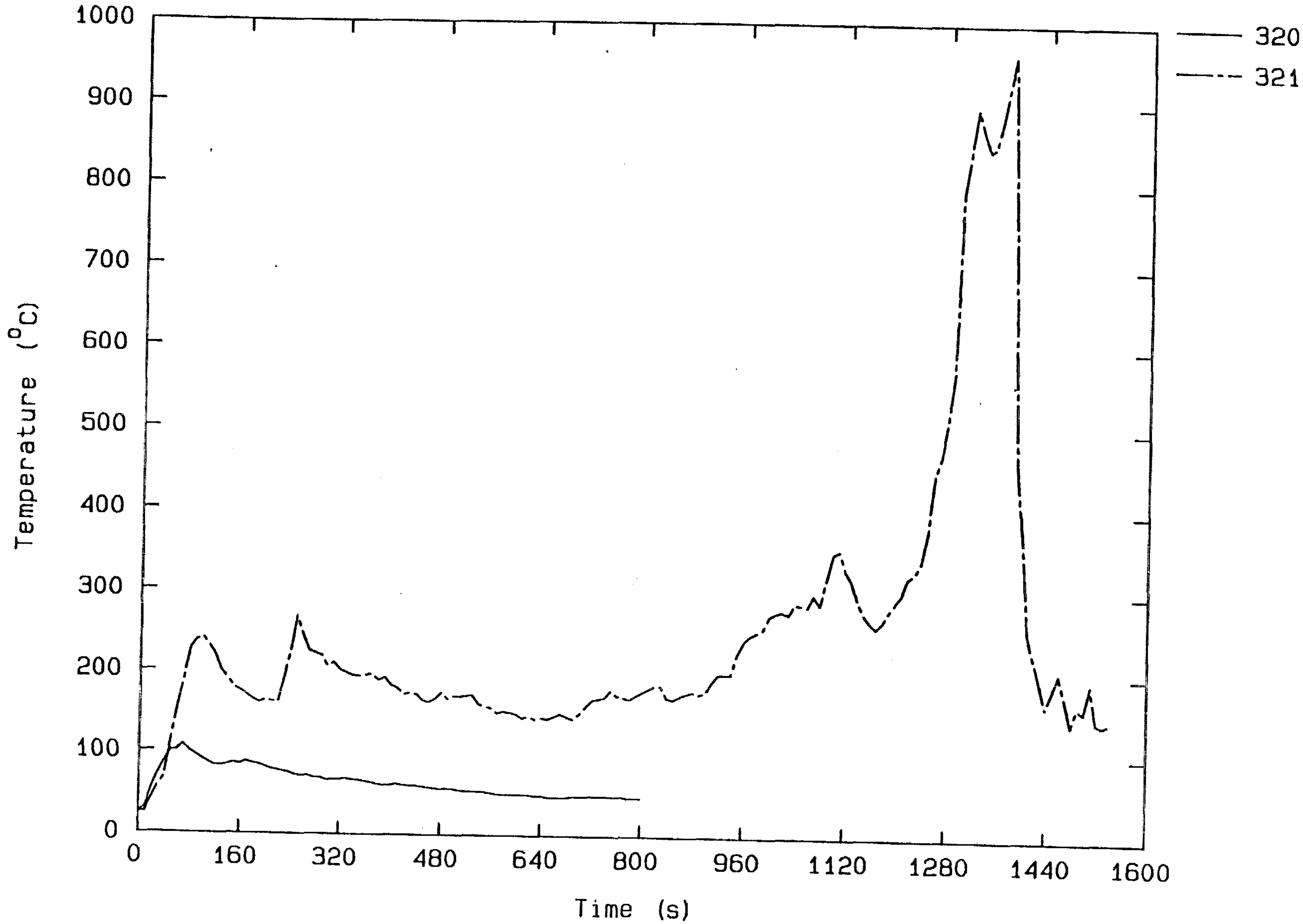

Figure 37. Office Module, Sprinkler (near) Gas Temperature Tests 320 (None) and 321 (None)

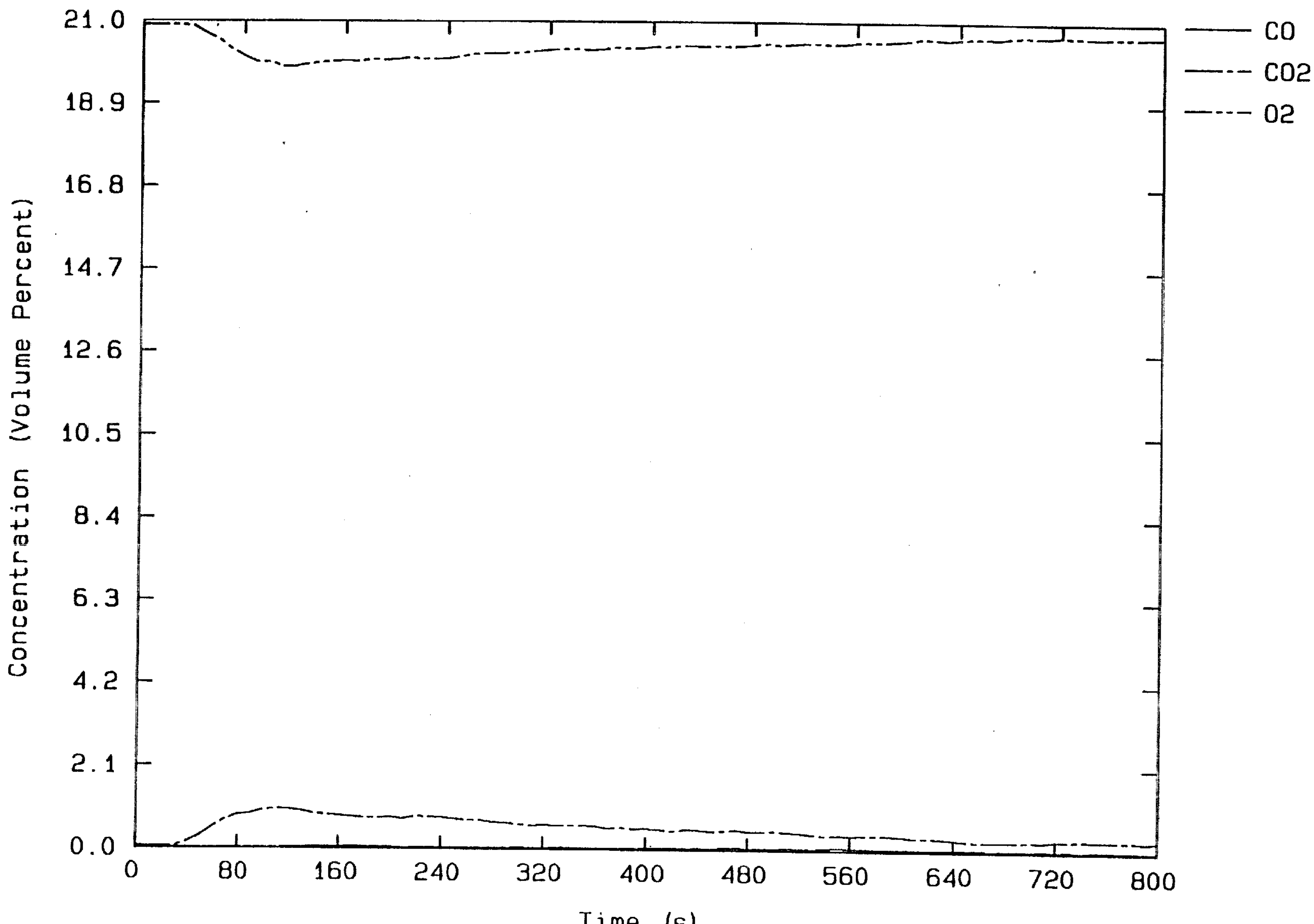

Figure 38. Office Module, Gas Concentrations Test 320 (None)

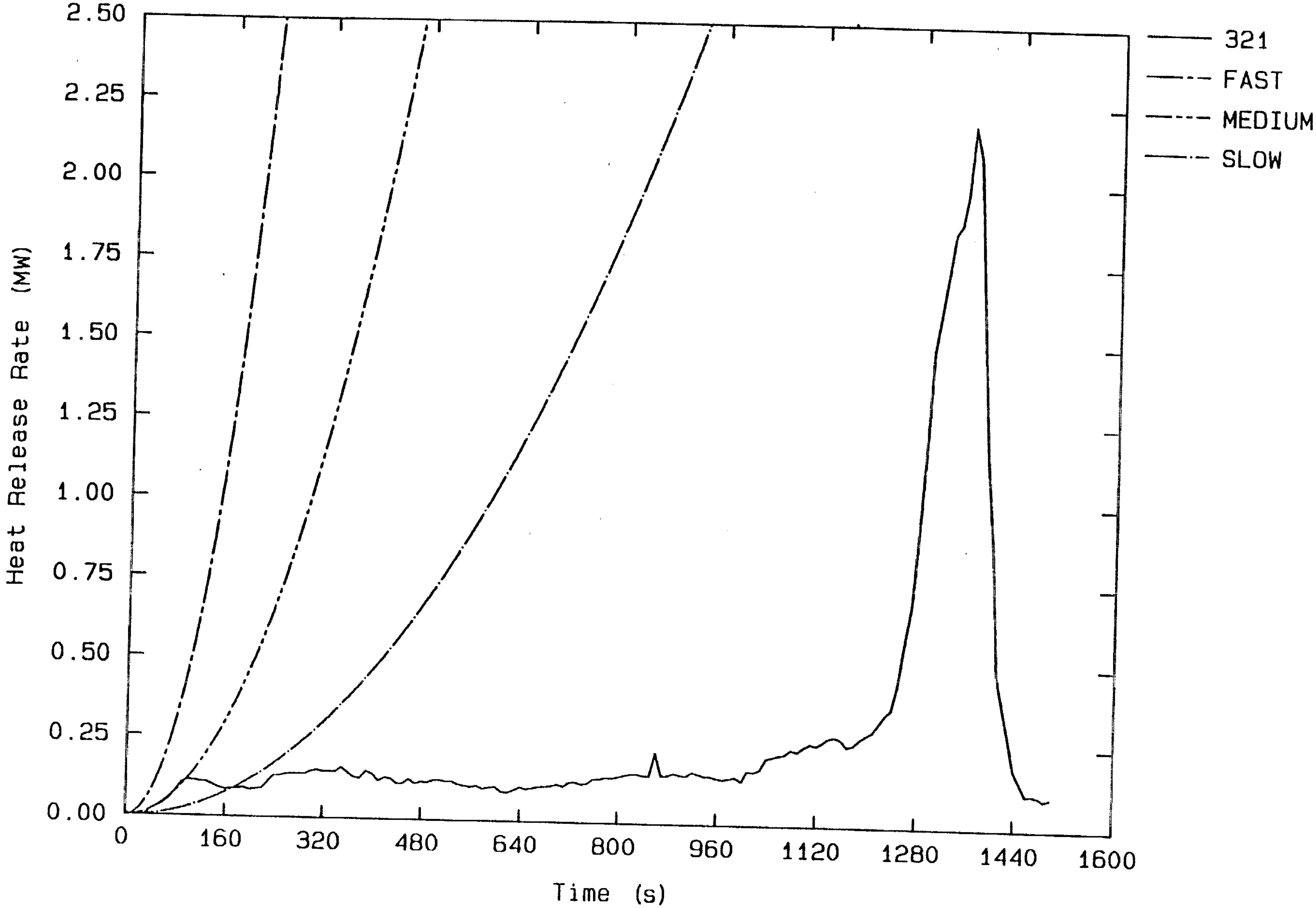

Figure 39. Office Module, Heat Release Rate Test 321 (None)

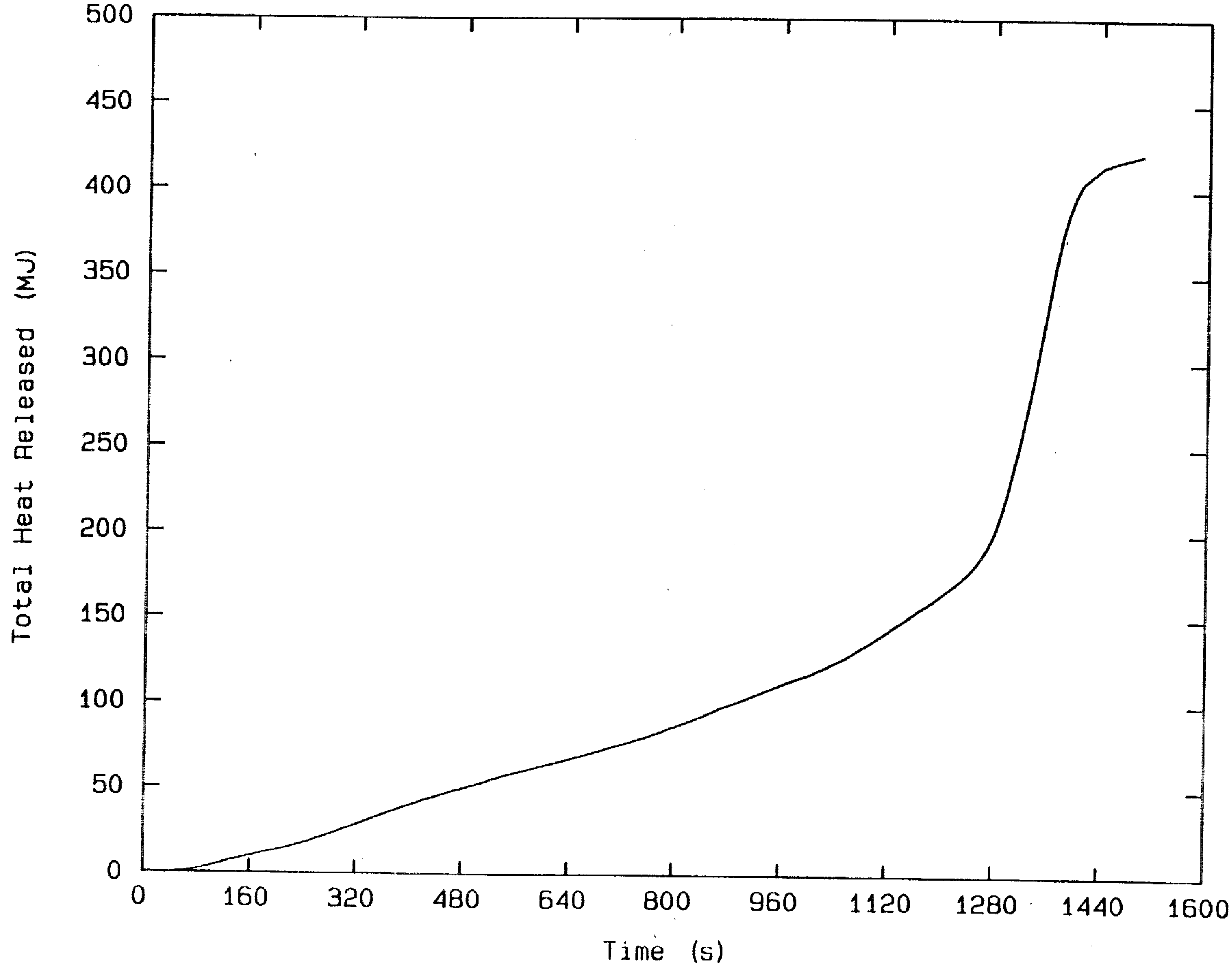

Figure 40. Office Module, Total Heat Released Test 321 (None)

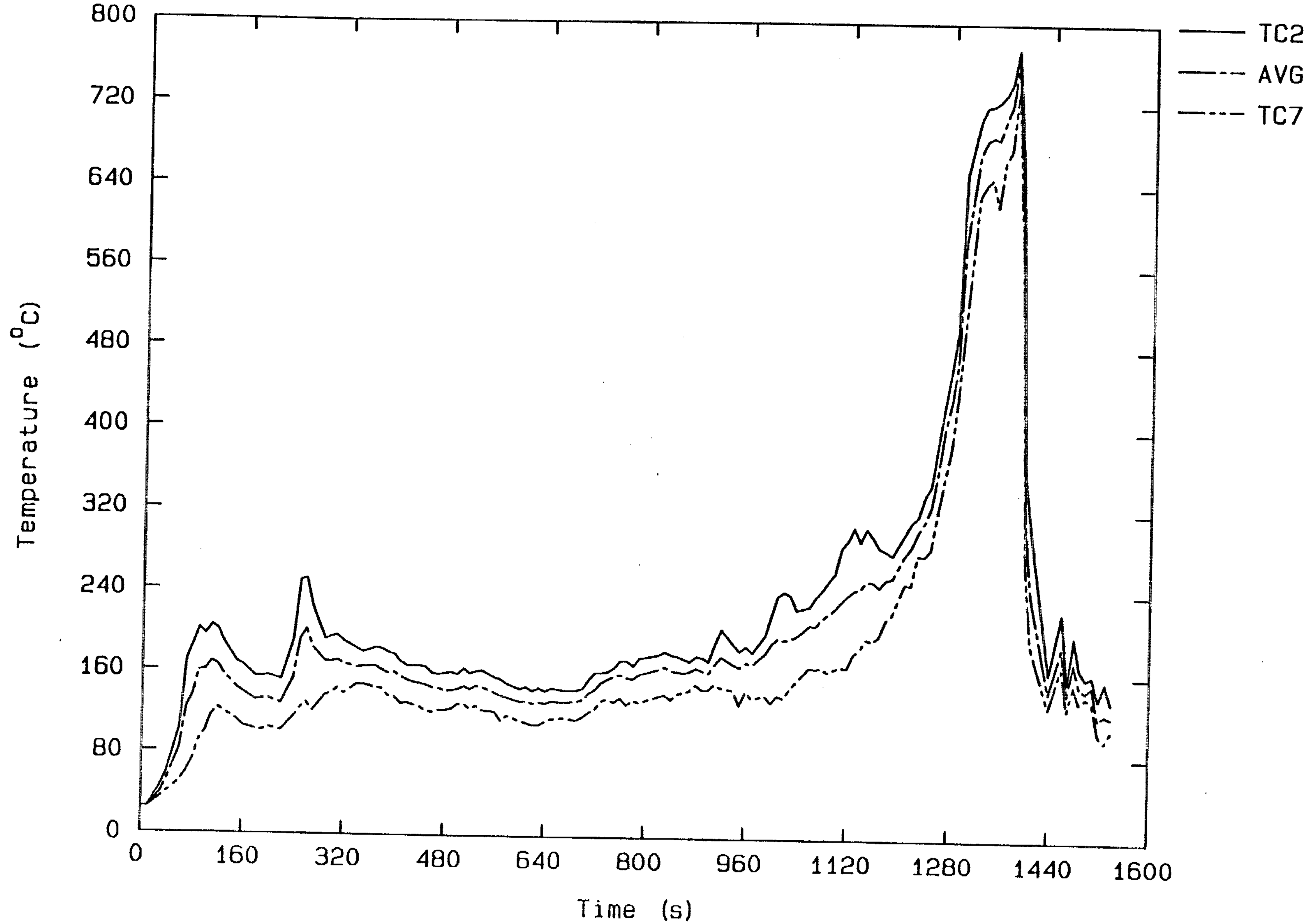

Figure 41. Office Module, Upper Layer Temperatures Test 321 (None)

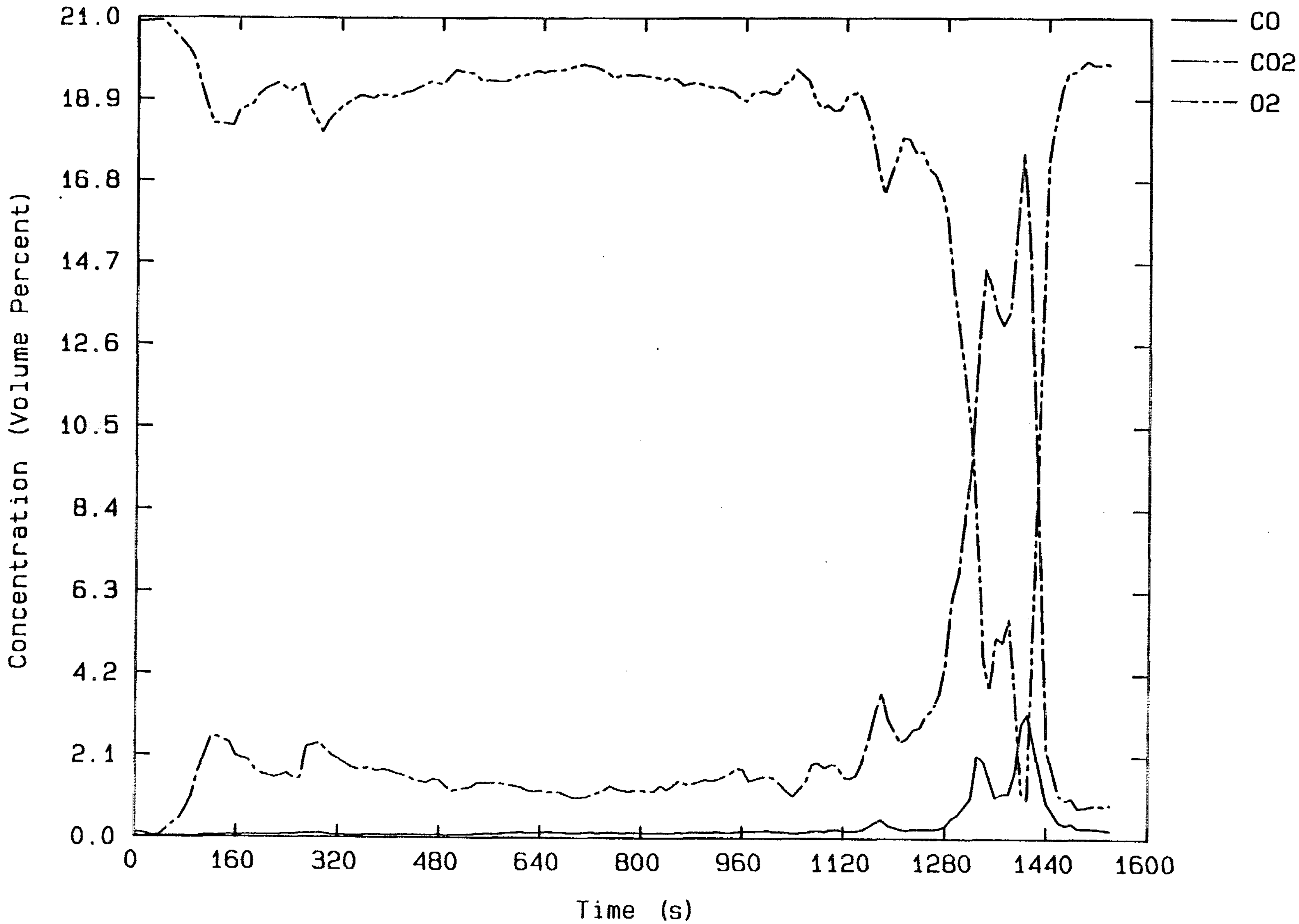

Figure 42. Office Module, Gas Concentrations Test 321 (None)

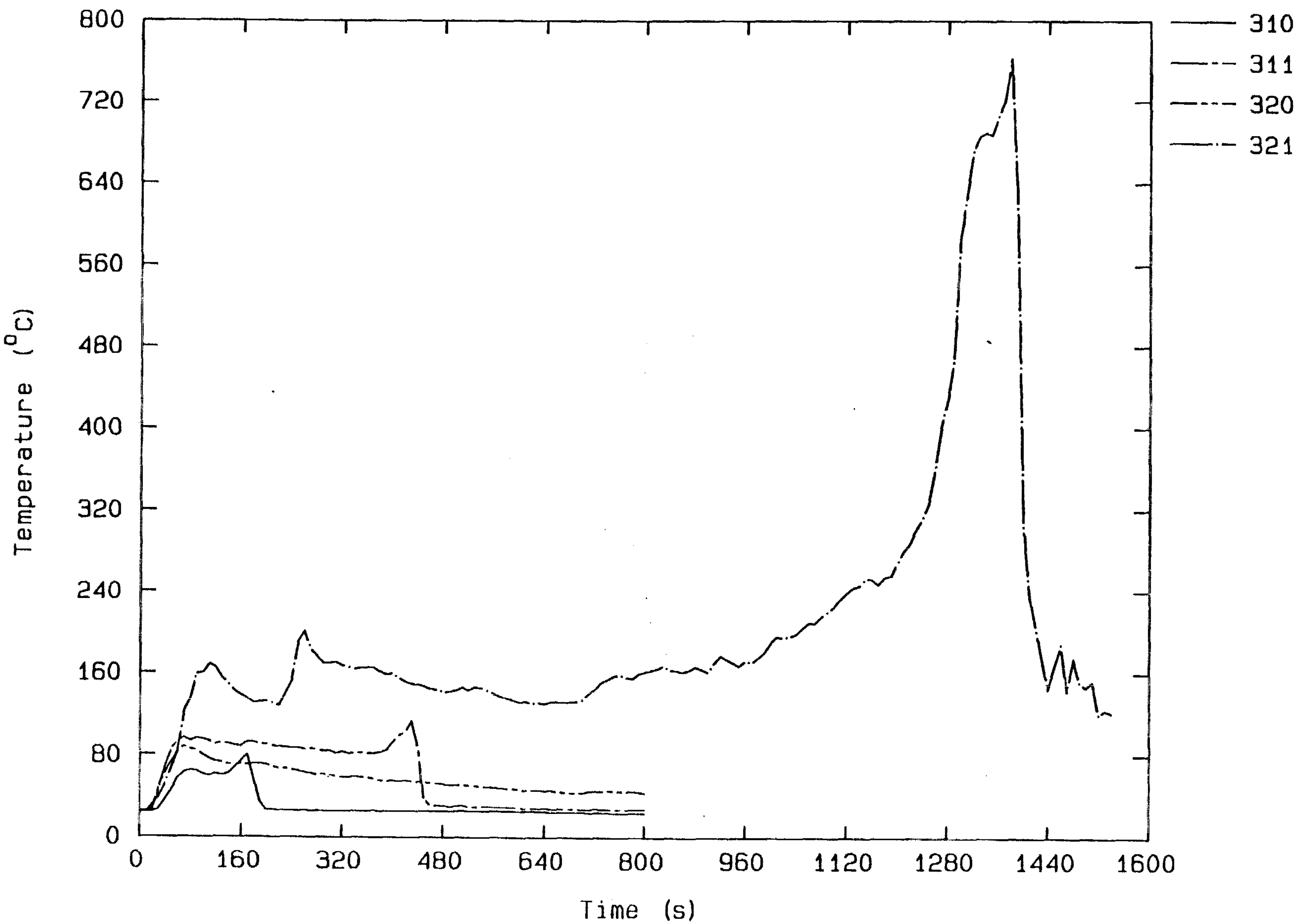

Figure 43. Office Module, Average Upper Layer Temperature
Tests 310 (QR), 311 (SSP), 320 (None) and 321 (None)

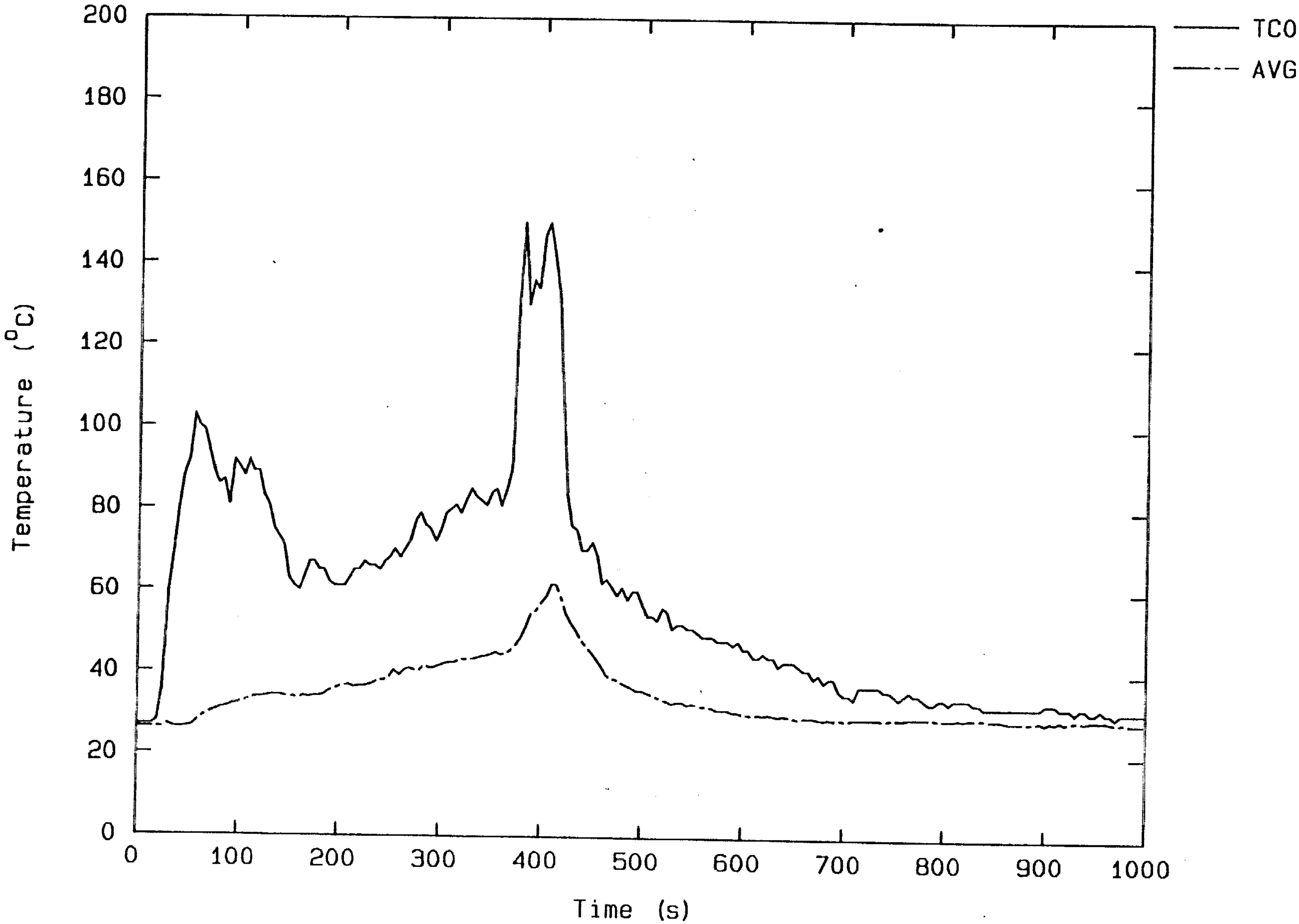

Figure 46. Large Area Office Module, Average Upper Layer Temperature Test 4126 (QR)

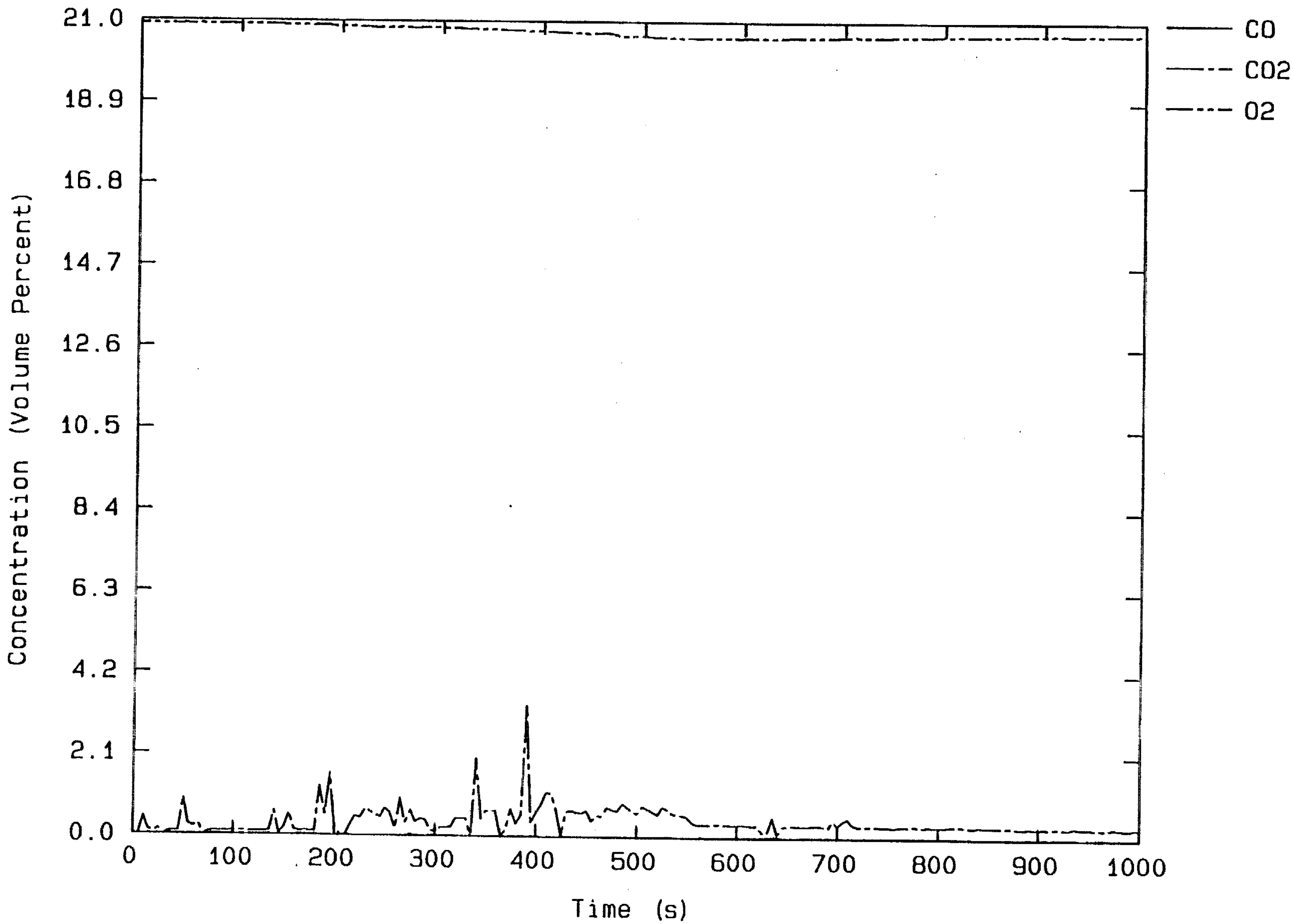

Figure 47. Large Area Office Module, Gas Concentrations Test 4126 (QR)

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR-88/3695	2. Performing Organ. Report No.	3. Publication Date January 1988

4. TITLE AND SUBTITLE

Quick Response Sprinklers in Office Configurations: Fire Test Results

5. AUTHOR(S)

William D. Walton and Edward K. Budnick

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

General Services Administration
Washington, DC

and

U.S. Fire Administration
Emmitsburg, MD

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A series of fire tests in several typical office occupancy configurations were conducted in order to address the use of quick response sprinkler technology. These tests included 1) heat release rate tests, 2) compartment fire tests and 3) a large office test. The heat release rate tests were designed to characterize the burning rates of a computer work station and open shelf office storage. The compartment fire tests were designed to examine the effectiveness of quick response sprinklers in typical office fires involving a computer work station or an open office module. Measurements of heat release rate, air temperature, and the concentration of oxygen, carbon monoxide and carbon dioxide were taken. A large office test configured with multiple open office modules was conducted to verify the compartment test results and examine the possibility of multiple sprinkler activation. Measurements of air temperature and the concentration oxygen, carbon monoxide and carbon dioxide were taken.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

burning rate; calorimetry; compartment fires; fire growth; fire tests; heat release rate; oxygen consumption; quick response sprinklers; room fires; sprinklers; toxicity

13. AVAILABILITY

[X] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

84

15. Price

$13.95