

FIRE SCENARIOS FOR AN IMPROVED FABRIC FLAMMABILITY TEST

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Abstract

This project developed, analyzed, and quantified the thermal environment for four fire scenarios created in a modified standard room. Eight propane burners were placed in four different configurations while temperature and flux measurements were collected. Fire environments were intended to simulate flashover, indirect flame exposure, and wildland fires. The results will be used for the selection of a fire environment for a full-scale garment flammability test for the Navy Clothing and Textile Research Facility.

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Executive Summary

This project began in 1996 with the development of an improved clothing test method for the United States Navy Clothing and Textile Research Facility. Research began with the investigation of typical fire environments encountered aboard Navy ships and has continued with the design and construction of a test facility. This master's thesis focuses on the data collection methods used, and the capabilities of the test facility. This research will be used to proceed with the development of a moving mannequin flammability test.

In the United States in 2001, excluding the World Trade Center disaster, 11% of the 38 fire ground fatalities and 8% of the 41,000 fire ground injuries to fire fighters were caused by burns. Between 1993 and 1997, there was an average of 47,060 fire ground injuries and 11.4% were caused by burns. Between 1990 and 2000, there were 31 firefighters who died from burns experienced in structure fires. Of these deaths, 14 were caught or trapped by fire progress, backdraft, or flashover. In 2002, 5% of 44 fire ground operation deaths were caused by burns. The purpose of this research is to develop better fire fighting clothing that will help minimize such injuries in the future.

The testing facility is located in a warehouse at Alden Research Laboratories in Holden, Massachusetts. The facility contains a modified ISO standard room that measures 2.4 x 3.6 x 2.4 m (8 x 12 x 8 ft), which contains two doors and a track system that moves the mannequin through the enclosure. The fire scenarios are created with eight 30.5 cm (12 in) square sand burners that are movable to create various fire scenarios. Four different burner configurations were analyzed to represent a variety of

fire situations. The fire scenarios created ranged from flashover conditions with 0.6 m (2 ft), 1.2 m (4 ft) of direct flame to indirect flame exposure and a perimeter fire that was intended to simulate a wildfire. The direct flame exposure scenarios produced a flux of 84 kW/m², which is comparable to existing test standards. Temperature and flux profiles were created from several point measurements that were collected on two different days to account for differences in weather conditions. The temperature profiles were created from 432 different measurement locations using a movable thermocouple tree that contained 24 thermocouples. Flux profiles were produced from 36-point measurement locations using a Schmidt-Boelter gage. Overall, the facility has the capabilities to create any realistic structure or ship fire environment to test clothing , including a firefighter's protective clothing.

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1 Introduction

In the United States in 2001, there were 38 fire ground fatalities not including the World Trade Center disaster. Of these deaths, four deaths (10.5%) were caused by burn injuries (LeBlanc, 2002). Also during 2001, there were 41,395 fire ground injuries, 3,255 (7.9%) attributed to burns. The fire ground injury rate is 23.9 per 1000 fires (Karter, 2003). Between 1993 and 1997 there was an average of 47,060 fire ground injuries, of these injuries there were 5,370 (11.4%) burn injuries. 49.6% of fire ground injuries occur during fire suppression operations (Karter, 2000). Between 1990 and 2000, there were 31 firefighters who died of burns in structure fires. Of these deaths, 14 were caught or trapped by fire progress, backdraft, or flashover, and 12 were caught in structural collapses (Fahy, 2002). In 2002 there were 44 fire ground operation deaths, and of these there were two fatalities caused by burns.

This project began in 1996 with the development of an improved clothing test method for the United States Navy Clothing and Textile Research Facility. David LeBlanc (WPI, MS Fire Protection Engineering, 1998) began research into the typical fire environments encountered aboard Navy ships. Terry Fay (MS in Fire Protection Engineering, WPI, 2002) continued the research with the design and construction of a test facility. This master's thesis focuses on the data collection and capabilities of the test facility. These capabilities are presented by temperature and flux profiles for four different fire scenarios. The research will be used to proceed with the development of a moving mannequin flammability test. The profiles were created from 432 temperature and 36 flux locations there were in the path of the mannequin.

The testing facility is located in a leased warehouse at Alden Research Laboratories in Holden, Massachusetts. The facility contains a modified standard room that measures 2.4 x 3.6 x 2.4 m (8 x 12 x 8 ft) which contains two doors and a track system that moves the mannequin through the enclosure. The fire scenarios are created with eight 30.5 cm (12 in) square sand burners that are movable to create various fire scenarios. Four burner configurations were analyzed because they create very different fire situations. The burner configurations provide a good analysis of the environment that may be produced by the facility.

2 Literature Review

This basic literature review is a summary of current testing methods and past projects relating to the development of this new test method. For more detailed information refer to the past project report section of this literature review.

2.1 Current Testing Methods

There are two types of test methods used to evaluate the thermal performance of clothing. Small-scale tests are performed on a bench top and use samples to produce the garments. These inexpensive tests are used as an indication of the performance of the actual garments. Large-scale tests are more complicated because they evaluate the entire system, but provide a much better picture of performance of the materials. Comparatively, these tests are much more expensive than small-scale testing, but the result is invaluable in evaluating the performance of clothing.

2.1.1 NFPA 1971

NFPA 1971 is the **Standard of Protective Ensemble for Structural Fire Fighting**. “The purpose of this standard is to establish a minimum level of protection for fire fighters against adverse environmental effects during structural fire-fighting operations and certain other emergency operations where certain physical hazards are likely to be encountered, such as during non-fire-related rescue operations, emergency medical operations, and victim extrication” (NFPA 1971, 2000). “Controlled laboratory tests used to determine compliance with the performance requirements of this standard cannot be deemed as establishing performance levels for all situations to which structural

fire-fighting personnel can be exposed” (NFPA 1971, 2000).

NFPA 1971 evaluates the performance of multilayer protective garment composites, hoods, wristlets, and gloves by conducting a thermal protective performance test. A sample that measures 15.2 cm (6 in) square is placed into a holding assembly which has a 10.2 cm (4 in) square sample of the specimen applied with a thermal flux. The thermal flux consists of a convective source that is produced by two Meker or Fisher burner, and a radiant source that consists of nine T-150 infrared tubes. The specimen shall be exposed to a thermal flux of $83 \pm 4 \text{ kW/m}^2$ that is measured by a copper calorimeter (NFPA 1971, 2000).

2.1.2 ASTM F 1930

ASTM F1930 is the **Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Mannequin**. “This test method covers quantitative measurements and subjective observations that characterize the performance of single layer garments or protective clothing ensembles in a simulated flash fire environment having a controlled heat flux, flame distribution, and duration” (ASTM F1930, 2000). The test apparatus contains an instrumented mannequin that contains at least 100 heat sensors. The mannequin is surrounded by at least eight induced air combustion industrial style propane burners that are positioned to produce a uniform laboratory simulation of a flash fire. This fuel delivery system must provide a uniform heat flux of at least 84 kW/m^2 for an exposure time of a minimum of five seconds. Exposure time is very critical to thermal protective performance tests, so the fuel delivery system must be controlled to within ± 0.1 seconds

of the set exposure time (ASTM F1930, 2000). This testing standard is referred to as **DuPont Thermo-man®** or **The North Carolina State University PyroMan System**.

2.2 Past WPI Research Projects

David LeBlanc analyzed and developed fire scenarios that would be experienced aboard Navy ships. The nearly infinite number of possible fires are reduced to 6 typical cases involving spray fires, pool fires and furniture fires in both compartmented and unconfined cases (LeBlanc, 1998). Terry Fay continued the research by the design and construction of the testing facility. To reduce the number and severity of burn incidents for navy personnel, a new full scale test was developed with the primary goal of evaluating navy clothing for protection against short duration fire exposures (Fay, 2002). The traversing mechanism for the mannequin was designed and constructed by a WPI Major Qualifying Project (MQP) team concurrently with the design and construction of the test facility (Bradbury et al, 2001). Another MQP team assisted with the collection of the preliminary temperature and flux measurements. This data was analyzed and compared to Jasmine computational fluid dynamic simulations to estimate the fire size and then validated with actual fire conditions (Batbouta et al, 2002). The most recent MQP team assisted in the collection temperature and flux measurements for four different fire scenarios and conducted Jasmine simulations for comparisons to actual fire conditions (Carnazza et al, 2003).

3 Methodology

3.1 Test Facility Overview

The test facility is located in Building 11 at Alden Research Laboratory in Holden, Massachusetts. The fire environments are created in a modified ASTM and ISO full-scale room fire test enclosure that is shown in Figure 3-1. This room contains two openings that are at each end of the enclosure that measure 0.81 x 2.4 m (2.7 x 8 ft). Each opening flows into a 3.05 m (10 ft) square exhaust hood that is connected to a 7.08 m³/s (15,000 cfm) blower that exhausts the products of combustion.

A track system traverses through the room that transports a mannequin through the fire environment at a constant speed up to 0.92 m/s (3 ft/s). The area that the mannequin passes through will be considered the “pass through” area of the burn room. Eight 30 cm (12 in) square sand burners create the fire environment that is fueled by the propane delivery system.



Figure 3-1: Test room with the doors open

The propane delivery system consists of four 45 kg (100 lb) tanks that provide liquid propane to a ThermoFlo Vaporizer, which has a vaporizing capacity of 200 kg/hr (120 gal/hr). The vaporized propane then flows to the burner control station manifold where each burner is controlled by two ball and needle valves. There are two sets of a ball and needle valves that are installed in series are shown in Figure 3-2. One set of

valves is used to ignite the burners and produce flames that are 0.30 to 0.45 m (1 to 1.5 ft) while the other set is also opened to provide additional propane to produce flames to the ceiling which are test conditions. The needle valves were calibrated so the burners were as balanced as possible, and then the needle valves were not adjusted during testing with the four different burner configurations. The burners are created with 6.4 mm (0.25 in) steel and the propane flows through 10 cm (4 in) of 4 to 8 mm and 5 cm (2 in) of 2 to 3 mm of varying grain sizes of sand. Brass wire gauze is placed on the bottom of the burner to prevent sand from entering the supply hose and between the different particle sizes of sand. To ensure safety, nitrogen is used to pressurize the propane delivery system to check for leaks before propane is allowed to enter the system. When testing is completed, nitrogen is used to purge the propane from the system.



Figure 3-2: Burner control valves

The facility contains several safety features to ensure the safe operation of the test facility. There is a simplified sprinkler system containing seven sprinkler heads that are located directly above the test room. To monitor if a propane leak occurs there is a Mine Safety Appliance, Ultima Gas Monitor System that has a sensor placed near the floor by the vaporizer and is connected to a light and horn alerting system. A fire alarm system that contains smoke and fixed temperature detectors is connected to a horn strobe alerting system that is monitored by ADT. During testing, a garden hose is used to protect

personnel.

3.2 Burner Configurations

There were three major fire scenarios that were created. The first, being the original configuration that would apply even flames to the entire mannequin, this will be referred to as burner configuration A, pictured in Figure 3-3. The second design was to create intense radiation with limited flame impingement to the mannequin, the burners were moved into two lines and placed 0.46 m (18 in) from the wall. This design will be referred to as burner configuration B and is shown in Figure 3-4. The third design was the worst possible fire scenario that is created with the burners and provides 1.22 m (4 ft) of direct flame impingement. This burner configuration produces flashover conditions at the bottom of the doorway within 90 seconds, as indicated by a ball of newspaper igniting. This setup is displayed in Figure 3-5 and is referred to as burner configuration C. The final configuration was developed to simulate a wild land or brush fire with flames waist high with two 0.30 m (1 ft) flame exposures and is identified as burner configuration D that is shown in Figure 3-6.

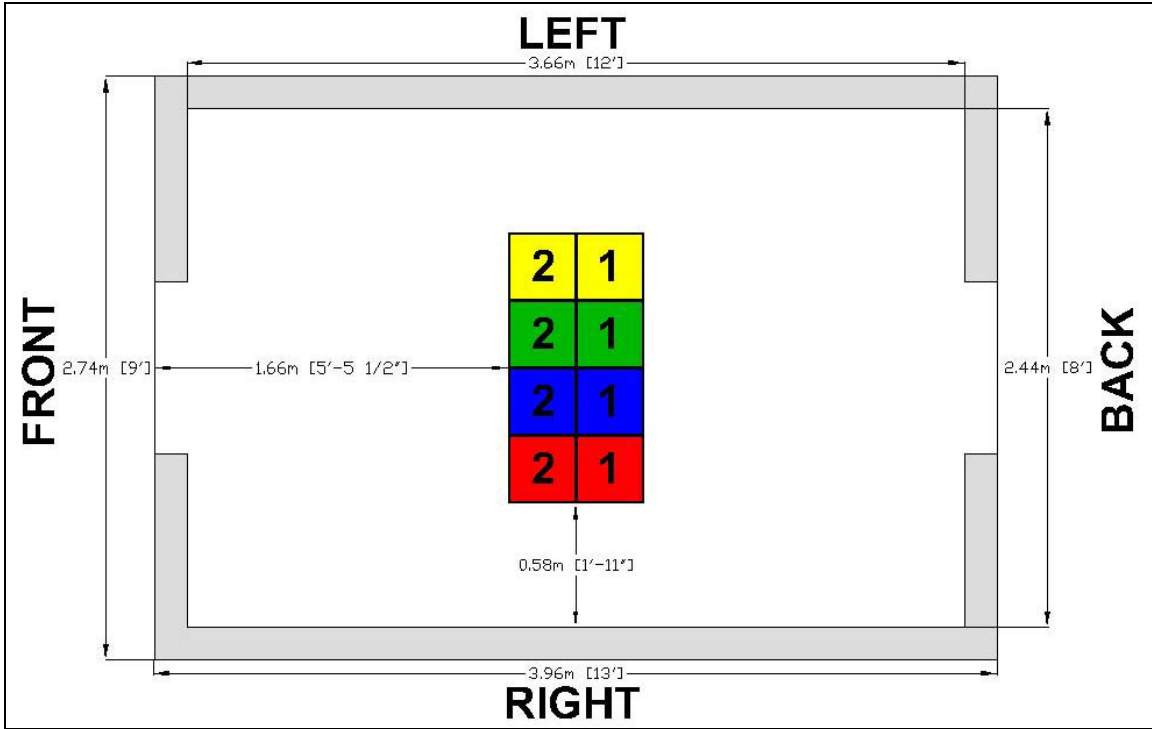


Figure 3-3: Layout of Burner Configuration A

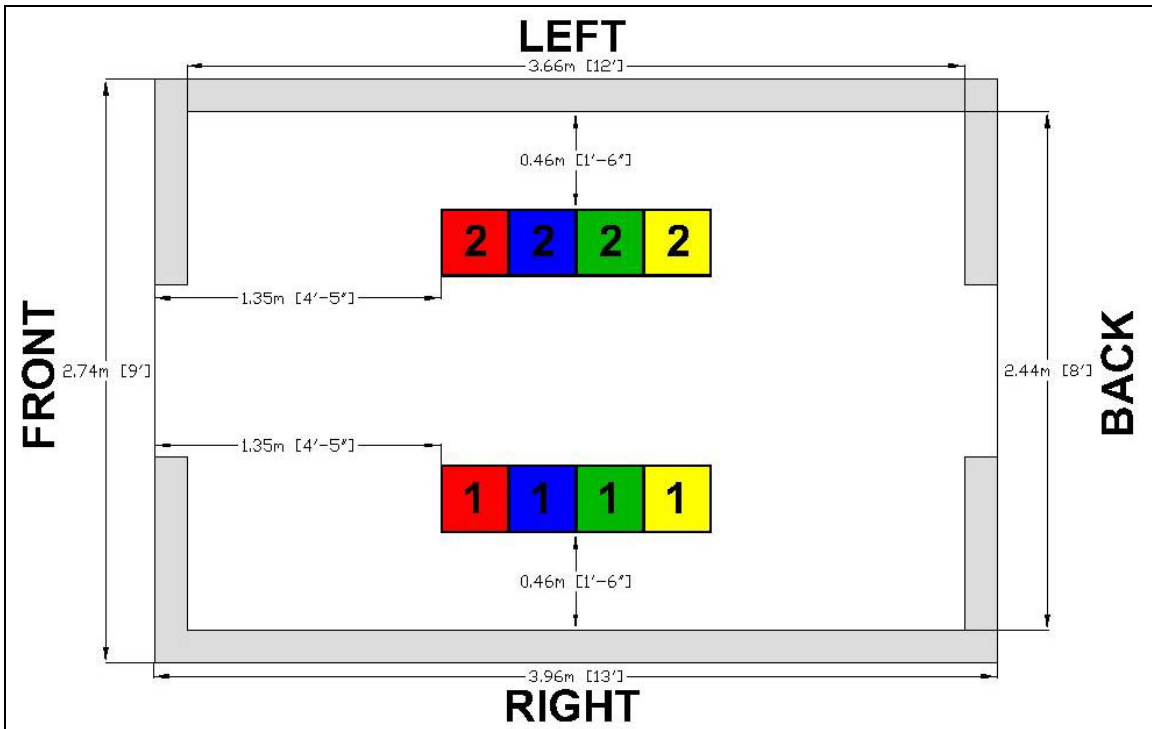


Figure 3-4: Layout of Burner Configuration B

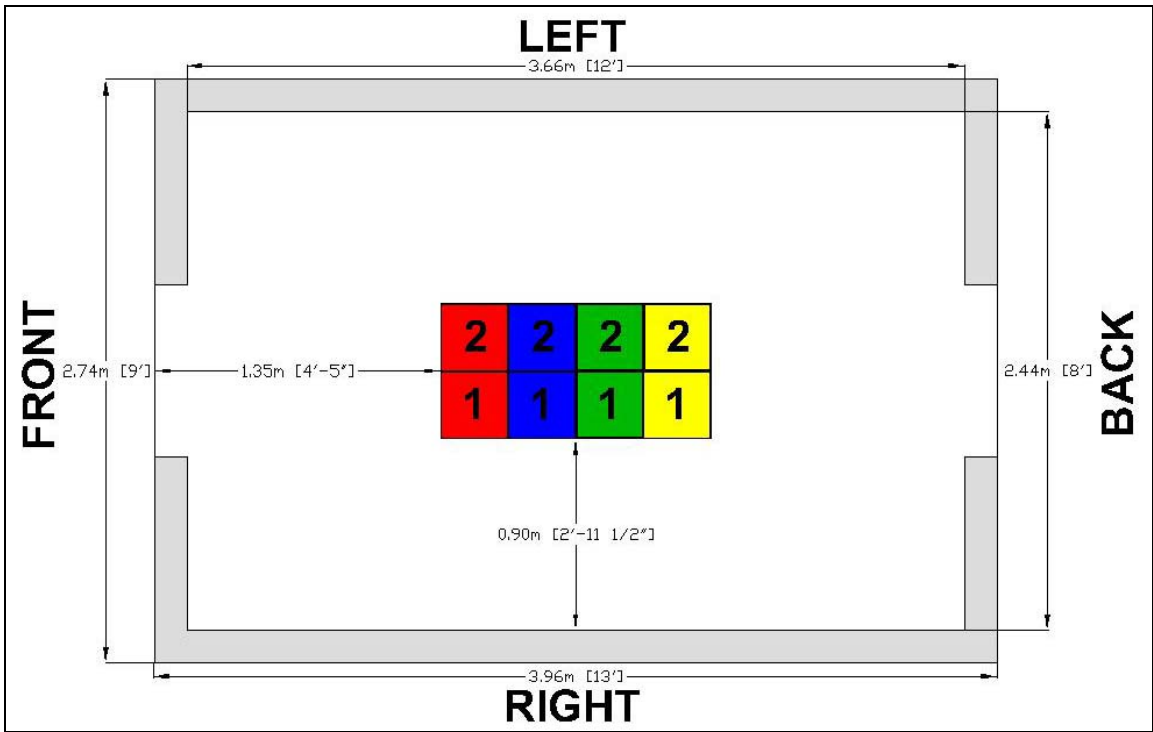


Figure 3-5: Layout of Burner Configuration C

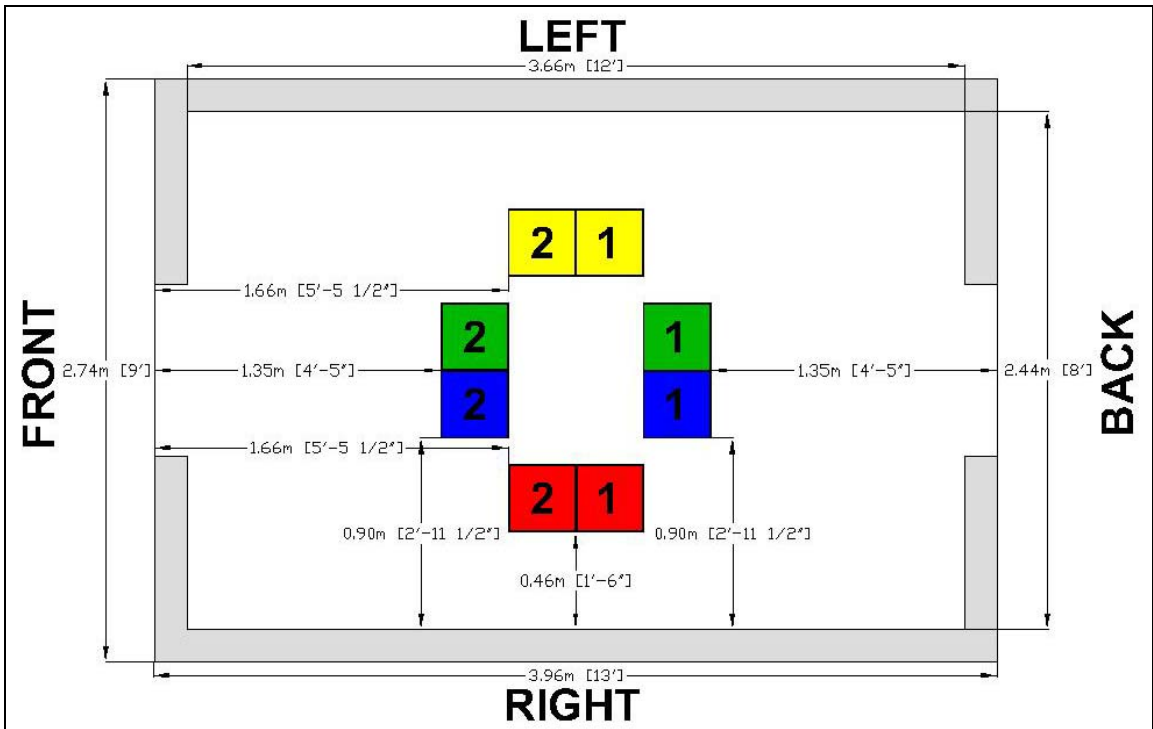


Figure 3-6: Layout of Burner Configuration D

3.3 Flux Measurements

Flux measurements were collected with a Schmidt-Boelter gage that was installed in a 32 mm (1-1/4 in) schedule 40 steel pipe. The steel pipe was 3.66 m (12 ft) long and had two 45° elbows that were separated by a 10 cm (4 in) and 15 cm (6 in) pieces of pipe on the end inside of the room. The pipe that was inside of the burn room was covered in Kaowool, a fire resistant insulation material to minimize heating of the pipe support structure. Figure 3-7 shows the wooden support structure and the pipe used to protect the gage. A closer view of the exposed part of Schmidt-Boelter gage can be observed in Figure 3-9. These measurement locations diagramed in Figure 3-8 allowed point flux measurements to be collected in the path of the side of the mannequin.



Figure 3-7: Flux gage support and protective structure

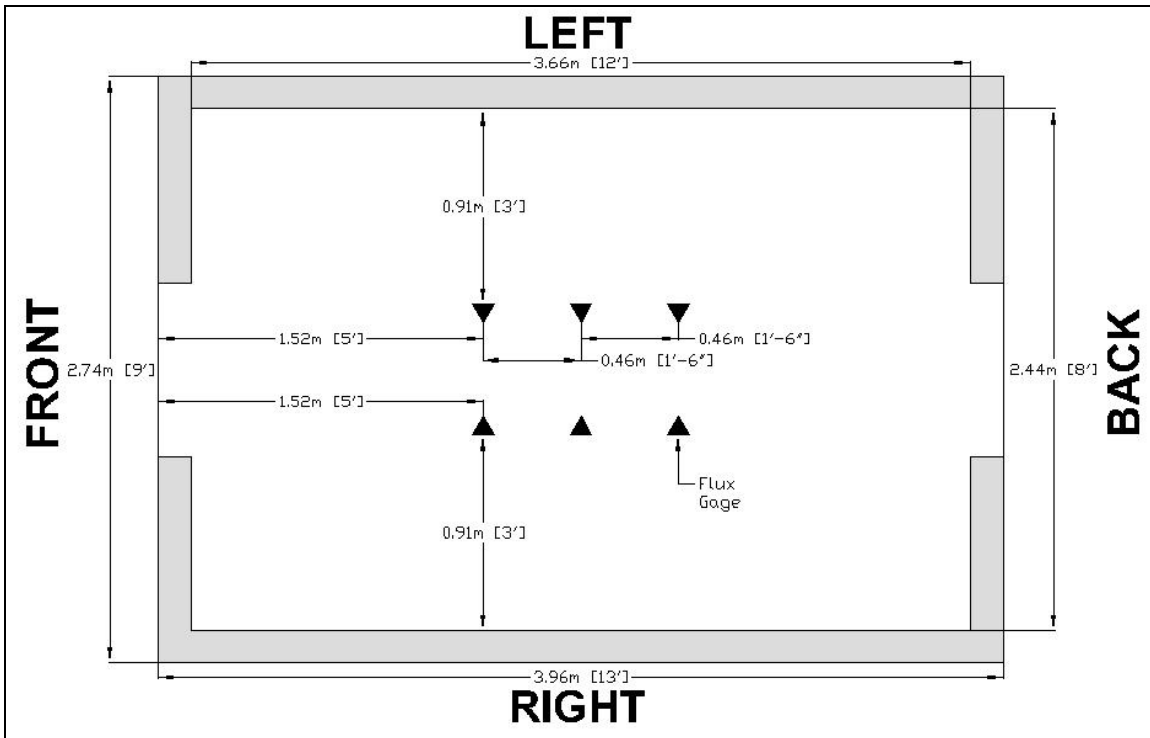


Figure 3-8: Flux gage measurement locations



Figure 3-9: The red circle indicates the exposed part of the Schmidt-Boelter gage

The Schmidt-Boelter gage is a sensitive but durable water-cooled instrument used to record the incident flux to a target that is comprised of a thermopile, which is a series of differential thermocouples. The thermopile is wired to the hot junction on the exposure side of the gage, while the

cold junction is located next to the water flow. This allows the gage to provide a continuous differential flux reading, instead of a time based differential. The major drawbacks of the gage are that a constant water supply is needed and the relative cost associated with purchase and maintenance of the device (Kidd, 1995).



Figure 3-10: Operators collecting flux measurements

Figure 3-10 above shows the team facing extreme conditions to collect flux measurements. There were several issues with data collection, but the method used was the best suited for the budget and equipment available. The major issue was the insulation on the wire melting inside of the pipe and short circuiting. The best solution was to use two thermocouple wires. Each terminal of the flux gage had a Chromega and Alomega conductor. This setup required data collection on two channels, one channel would measure the flux reading on the Chromega conductor while the other channel measured the flux over the Alomega conductor. This data collection method accounted for the effects of temperature as the wires were heated, the Chromega conductor would give a higher reading while Alomega conductor gave a lower reading. Both data channels were averaged to give the correct flux measurement. After each day of testing,

a calibration was completed to ensure that the gage recorded near zero measurements. During the eight days of testing the gage returned to within four kW/m² of zero once the gage was removed from the room.

Another issue was the angle of the face of the flux gage which could greatly affect the measurement. There was a vise grip placed on the end of the pipe outside of the burn room that was held in place during testing. The gage angle was also visually verified to be perpendicular to the floor of the burn room. This could be completed for most of the measurement locations except when the gage was surrounded by flames.

3.4 Temperature Measurements

A movable thermocouple tree collected the temperature measurements. The tree was created by a 4.9 m (16 ft) long and 25 mm (1 in) in diameter steel pipe that has 6 mm (1/4 in) holes drilled every 10 cm (4 in). The plan view of the thermocouple tree is shown in Figure 3-11. The thermocouple tree is supported by a wooden support structure that is shown in Figure 3-12. This is the same structure that is used to support the flux gage, but instead of placing both structures at the front of the room, one was placed at the front while the other was placed at the back of the room. A smaller metal pipe that is placed through holes on the wooden supports and the thermocouple tree rests on this metal pipe. The horizontal position is governed by placing the thermocouple tree next to the doorway or in-line with the track which is the centerline of the room.

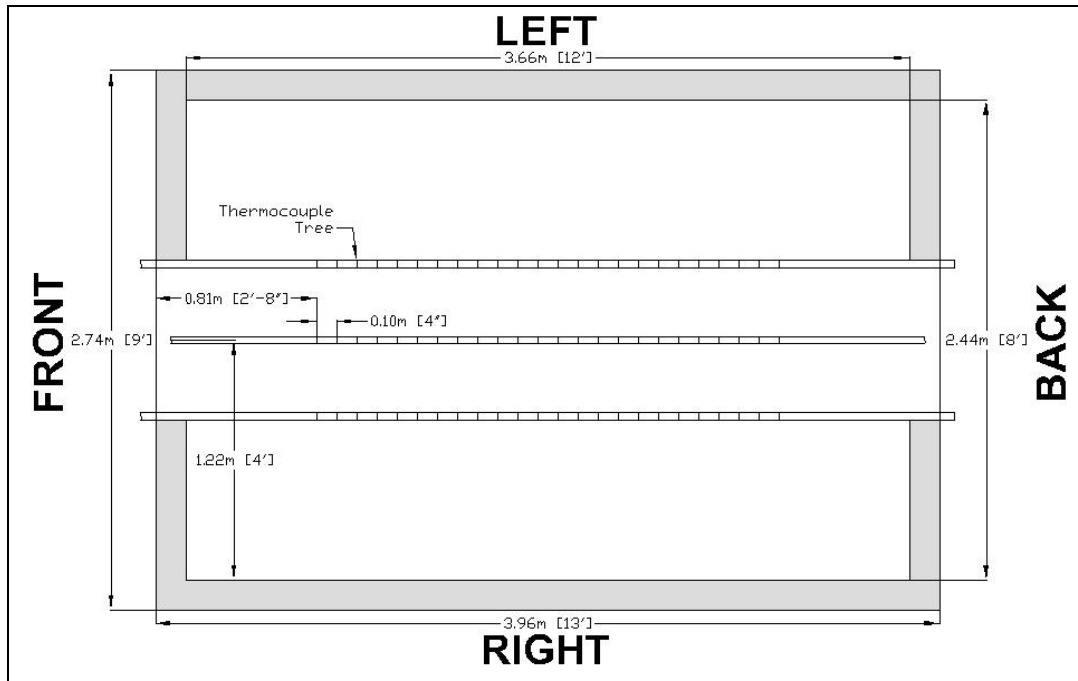


Figure 3-11: Plan view of thermocouple tree location



Figure 3-12: Thermocouple tree during testing

The thermocouples are Type K with a Chromega® and an Alomega® conductor which has a fiberglass insulation overall and on the conductors. The insulation is rated at 482°C which is exceeded during testing and deteriorates because of the extreme fire conditions. Several times during testing thermocouples were replaced due to insulation removal that caused the thermocouple to short out or give abnormal readings.



Figure 3-13: Bare bead thermocouple

The wooden support structure had six different levels for measurements. The first level is 0.46 m (18 in) from the floor of the test room; each level is spaced 0.30 m (12 in) apart. To collect temperature measurements the thermocouple tree is placed on either level one or six, if the first set of measurements began on the level one and ended on level six then the next set of measurements would begin on level six and would end on level one. If the temperature measurements were completed first, then the following day flux would be recorded then temperature. The order was switched to account for effects from the heating of the room.

Temperature measurements were collected continuously every second using the LabView program. When the thermocouple tree was placed below the fifth level, data collection would be stopped briefly while the thermocouple tree was moved, the burners were only reduced to the ignition setting while the thermocouple tree was moved up or down in levels. The burners were not reduced to the ignition setting because the thermocouple tree could be moved safely while minimizing the time of extreme fire conditions within the test room. Figure 3-14 shows the thermocouple tree being repositioned during testing on level four. Measurements on level five and six required the data collection to be stopped, the fire reduced to the ignition setting, the upper gas layer was allowed to dissipate from the room and then the thermocouple tree could be moved to a new position. This procedure took significantly longer because the burners

were increased to the test setting and conditions within the room had to reach near steady state conditions.



Figure 3-14: Thermocouple tree in the process of being repositioned during testing

4 Data Analysis

This section discusses the preliminary measurements taken to gain knowledge of the fire environment that different burner configurations create. The burners were first balanced visually. With the burners in configuration B a thermocouple tree was placed directly over the burners. The temperature measurements were used to adjust the burners so that the front and back were symmetrical. The left and right fires were balanced so that the fire would affect the mannequin equally. Flux profiles were created to verify that the fires were in equilibrium. The data analysis details the results collected for four different burner configurations.

4.1 Analysis Procedure

Current personnel protective clothing tests describe the fire environment in terms of temperature and flux. The analysis procedure discusses how outliers were removed from the measurements that were collected and the procedure used to determine the fire environment created. The data will then be used to compare existing test methods to the newly developed moving mannequin test.

4.1.1 Flux

The data analysis method mainly consisted of removing outlier data to improve the accuracy of the data set. To ensure that there were no discrepancies within the measurements, data were collected continuously, measurements were collected in one-second intervals. Breaks in the data were inserted using the *LabView* interface to add the location of the data measurement. The raw data was then entered into a Microsoft Excel spreadsheet, and each measurement was classified with a height, location and position.

The height values ranged between 1 and 6, which indicate the height above the floor, the first level being 0.41 m (16 in) above the floor of the room. Each level is separated by 0.30 m (12 in). Location was classified as front, middle or back; the front being 1.37 m (54 in) from the front wall, middle being 1.83 m (72 in), and back 2.29 m (90 in). Position is classified as the direction that the flux gage is facing, either left or right, each location the face of the gage is 0.91 m (36 in) from the wall.

Once the data was grouped, it was imported into Microsoft Access. Due to this method of data collection and control of the burners, the data contained several outliers. These outliers were recorded while the burners were inactive or while a gage was in the process of being moved. Each dataset for a measurement location was reviewed and outliers were ignored from the analysis. Additionally, a standard deviation was calculated and locations with extremes were reviewed to minimize differences within the measurements. The final dataset contained an average of nine continuous measurements for each location and day of testing.

	One Test Day	Both Test Days
Minimum	2	8
Maximum	40	56
Mean	9.27	20.8
Median	9	21
Standard Deviation	4.18	6.65

Table 4.1: Number of temperature measurements distribution

Once the outliers were removed, an average of the measurements were calculated then the graphs were created. The data was then averaged for each day, then the data from the two days was averaged. The graphs were created from at least eight measurements. Measurements were not collected in an even grid as to make an accurate

surface flux profile. Linear interpolations were completed so that there was a measurement every 0.15 m (6 in). The graphs have a label for height on each location where a measurement was completed.

The location of the flux measurements were determined to be located on the extreme side of the mannequin. With varying fire configurations this measurement is a minimum or maximum that would impinge on the mannequin. These issues concerning the configuration of each burner will be discussed.

4.1.2 Temperature

The design of the thermocouple tree was discussed in the methodology. The data was collected continuously every second and inserted into a text file that placed break marks within the data that noted the location of the measurements. The height was similar to the flux measurement, height levels of one to six. Level 1 was at 0.41 m (16 in) above the floor of the test room, each level was 0.30 m (12 in) above the previous level. The positions consisted of left, middle and right; the left and the right were the taken with the thermocouple tree against the edge of the doorway. There were 18 different measurement locations and the tree contained 24 thermocouples which allowed for the temperature to be measured in 432 locations. All directional assessments are based on looking at the front face of the room. The middle location was the centerline of the room, directly inline with the track system.

Once each measurement line was assigned a location the data was exported into Microsoft Access. The temperatures that were below zero or above 1200°C were

automatically ignored for the analysis as these were clearly erroneous measurements.¹

The resulting data set was used to determine surface temperature profiles. Queries were developed to calculate one, three, and five term averages, then maximums were found for each of the data points. A term average was used to remove sudden temperature fluctuations. A five term average was determined to be a valid calculation method because it averages the temperatures for five seconds and the mannequin when set at the design speed of the track system of 0.73 m/s (2.4 ft/s) the time the mannequin would be within the test room would be five seconds

4.2 Burner A

Burner configuration A, shown in Figure 4-1, is the original design and provides 0.61 m (2 ft) of direct flame exposure. The flames are floor to ceiling with all flames contained within the room. The fire conditions were designed to simulate a ruptured hydraulic or fuel line within a ship that would require a person to evacuate by passing through a flame front.

The temperature and flux measurements for burner configuration A were collected on October 21 and October 22, 2002. On October 21, 2002, the weather was clear and the temperature was between 1 and 10°C (34 and 50°F). The average wind was 9.5 mph from the west with gusts to 21 mph from the northwest. On October 22, 2002, the weather was mostly cloudy and the temperature was between -2 and 8°C (29 and 46°F). The average wind was 5.2 mph from the west with gusts to 10 mph from the west.

¹ When the thermocouples have problems or short circuit they give a reading of approximately 1247°C which is the upper limit which is set within *LabView*.



Figure 4-1: Burner configuration A fire conditions

4.2.1 Flux

Flux measurements were taken in 36 different locations. Flux measurement locations are shown in Figure 4-2, the triangles indicate the location and direction of the flux gage. With burner configuration A, the flux measurements recorded were a minimum that would affect the mannequin because in the middle of the flames the flux would be higher due to reradiation. The flux on the left side shown in Figure 4-3 is between 16 and 95 kW/m², while in Figure 4-4 the right side was between 15 and 108 kW/m². When the gage was in the front and back position, the measurements rapidly decreased since the gage was not directly in the flame front. The flux surface profiles differ from left to right because of issues with the exact location and angle of the Schmidt-Boelter gage and calibration of the burner flow rates.

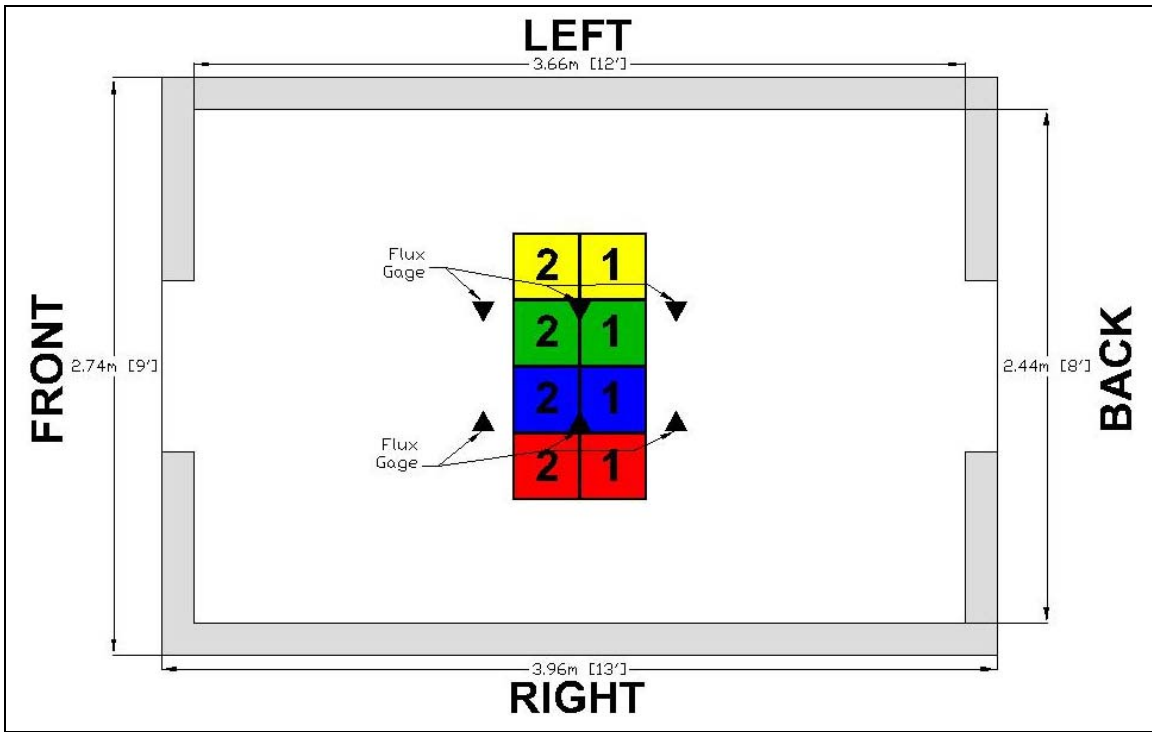


Figure 4-2: Plan view of burner configuration A flux gage measurement locations

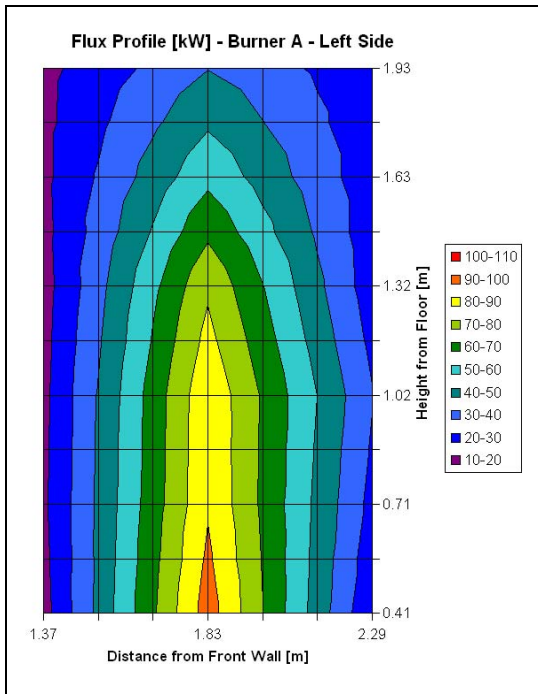


Figure 4-3: Flux Profile - Burner A - Left Side

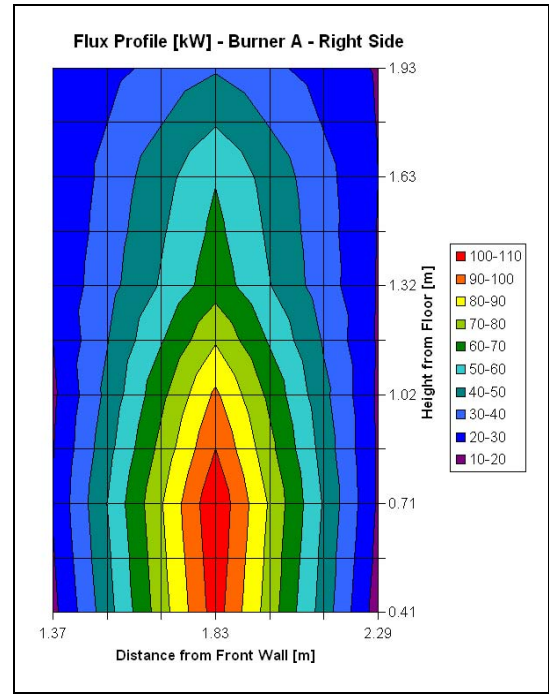


Figure 4-4: Flux Profile - Burner A - Right Side

4.2.2 Temperature

The overall temperature distribution for burner configuration A is evenly distributed over the pass through area of the mannequin. The left side maximum temperature profile in Figure 4-5 has values between 109 and 1004°C. The three-term average in Figure 4-6 has values between 101 and 986°C. The five-term average in Figure 4-7 has values between 100 and 977°C.

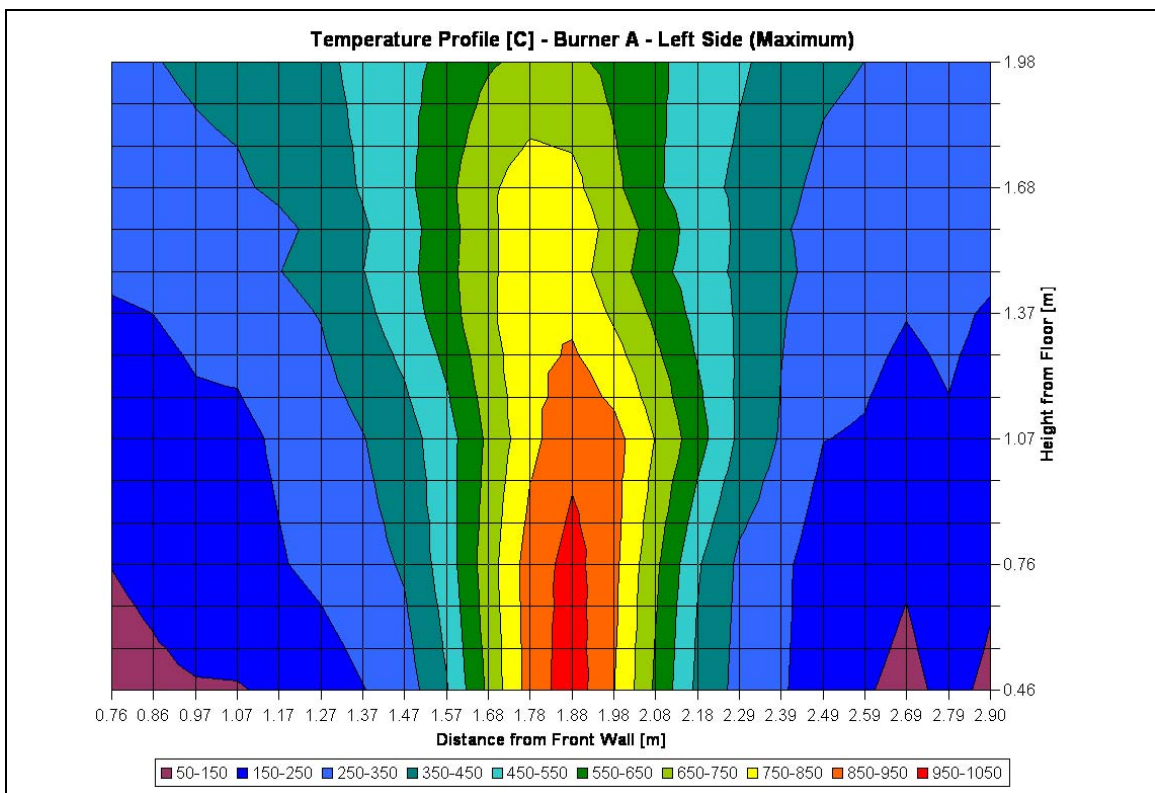


Figure 4-5: Temperature Profile - Burner A - Left Side - Maximum

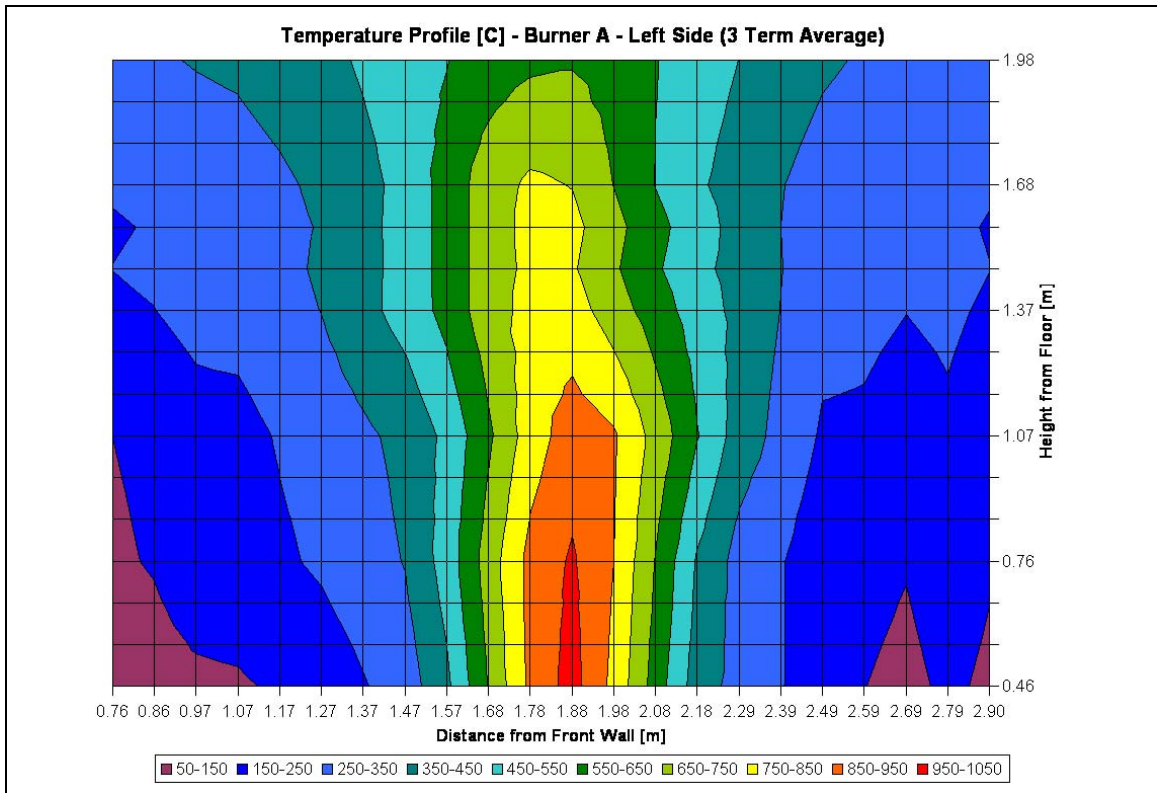


Figure 4-6: Temperature Profile - Burner A - Left Side – Three-term Average

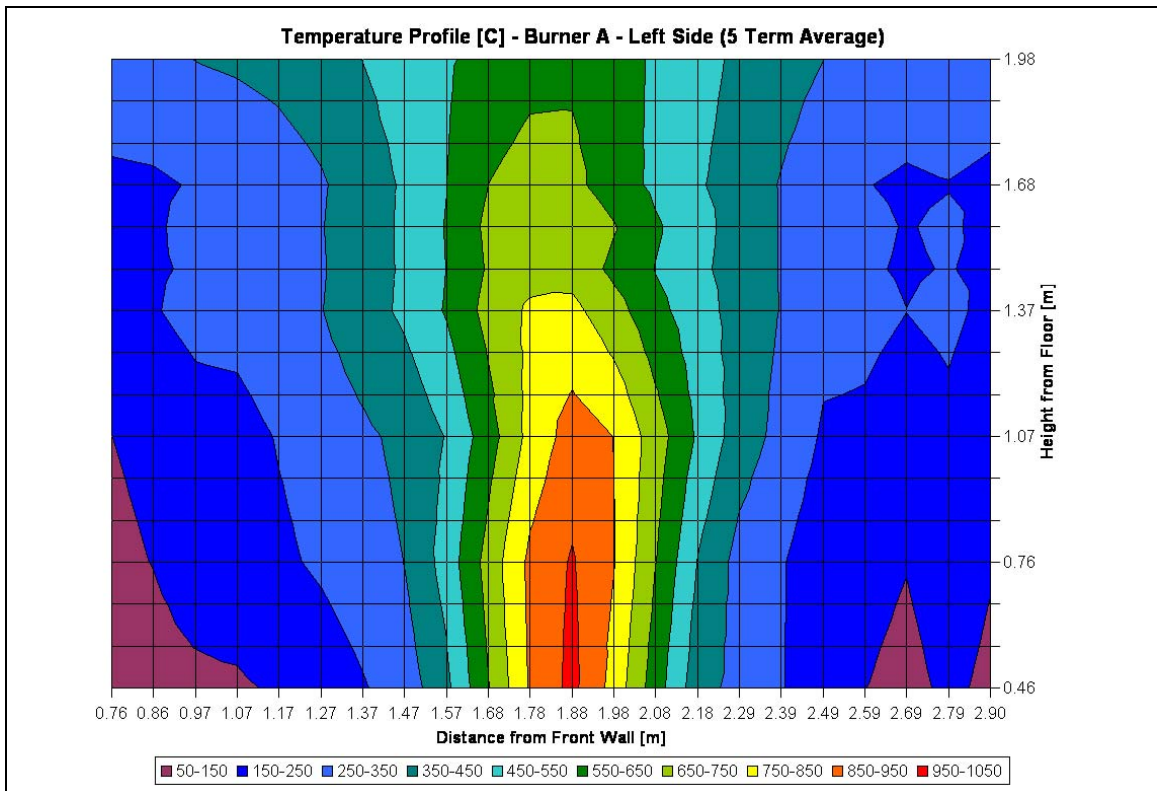


Figure 4-7: Temperature Profile - Burner A - Left Side – Five-term Average

The centerline maximum temperature profile in Figure 4-8 has values between 109 and 1003°C. The three-term average in Figure 4-9 has values between 104 and 989°C. The five-term average in Figure 4-10 has values between 103 and 971°C.

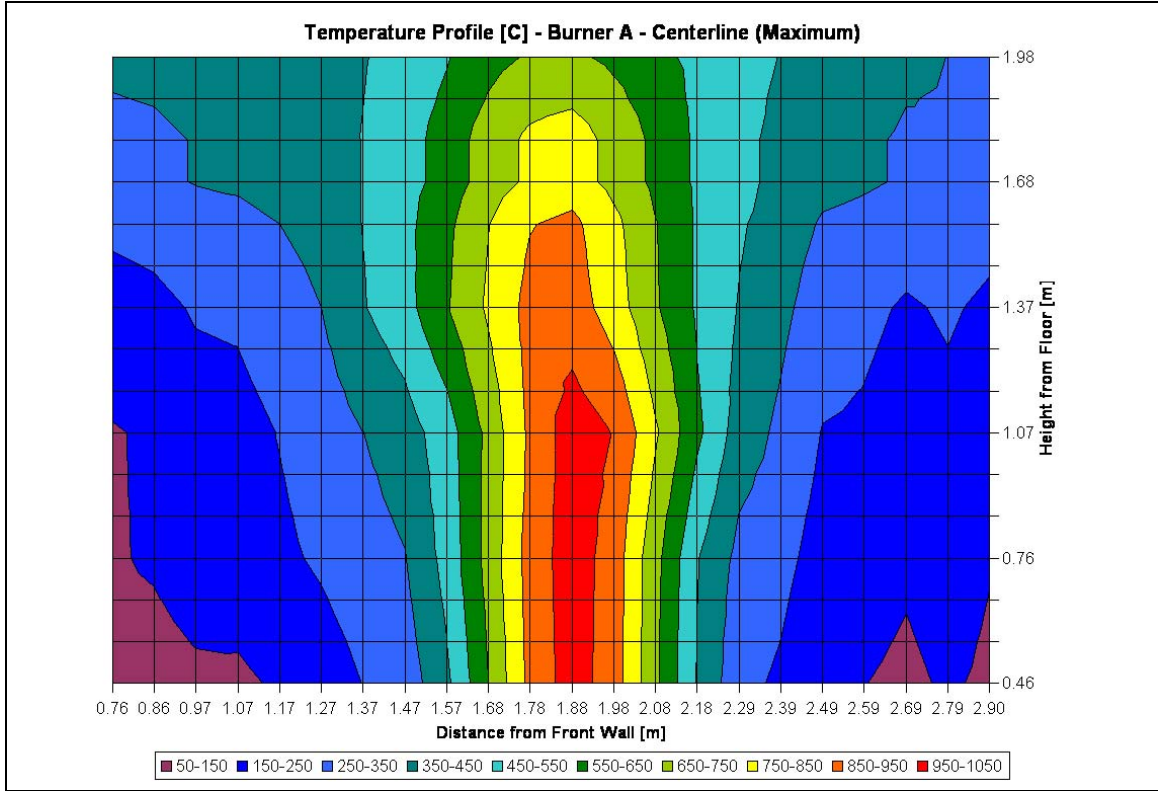


Figure 4-8: Temperature Profile - Burner A - Centerline - Maximum

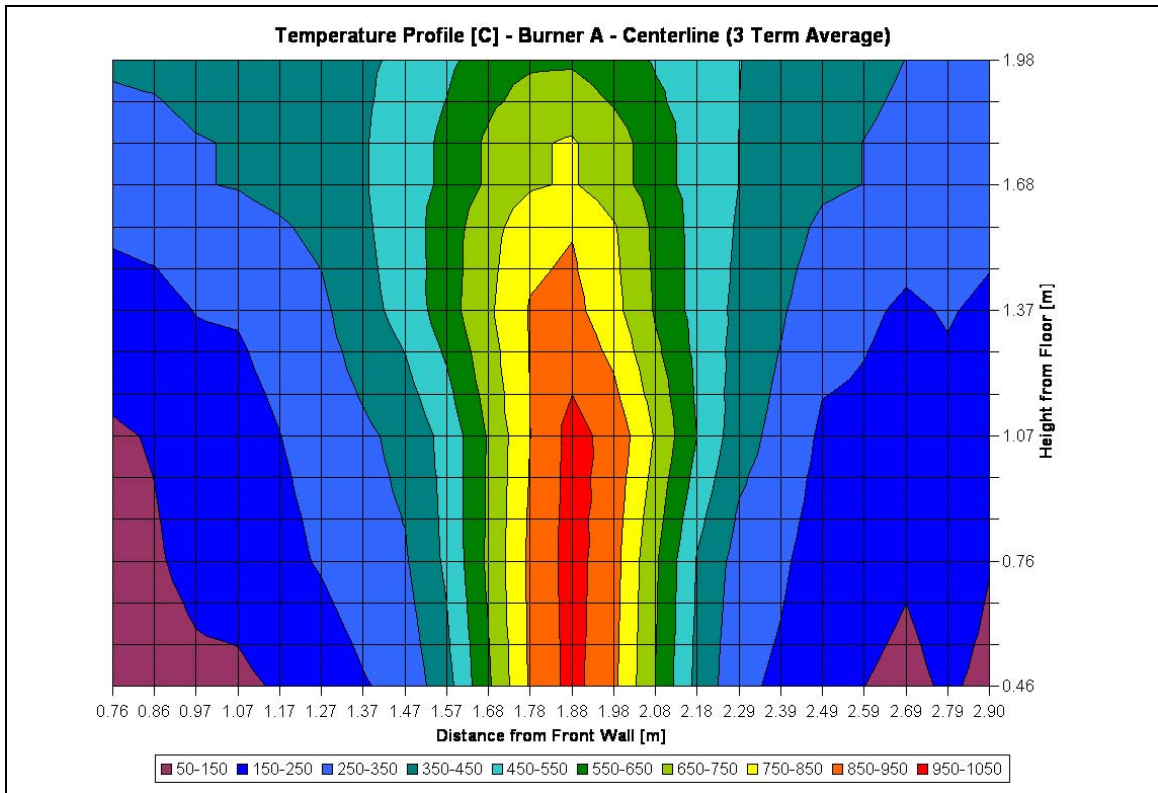


Figure 4-9: Temperature Profile - Burner A - Centerline – Three-term Average

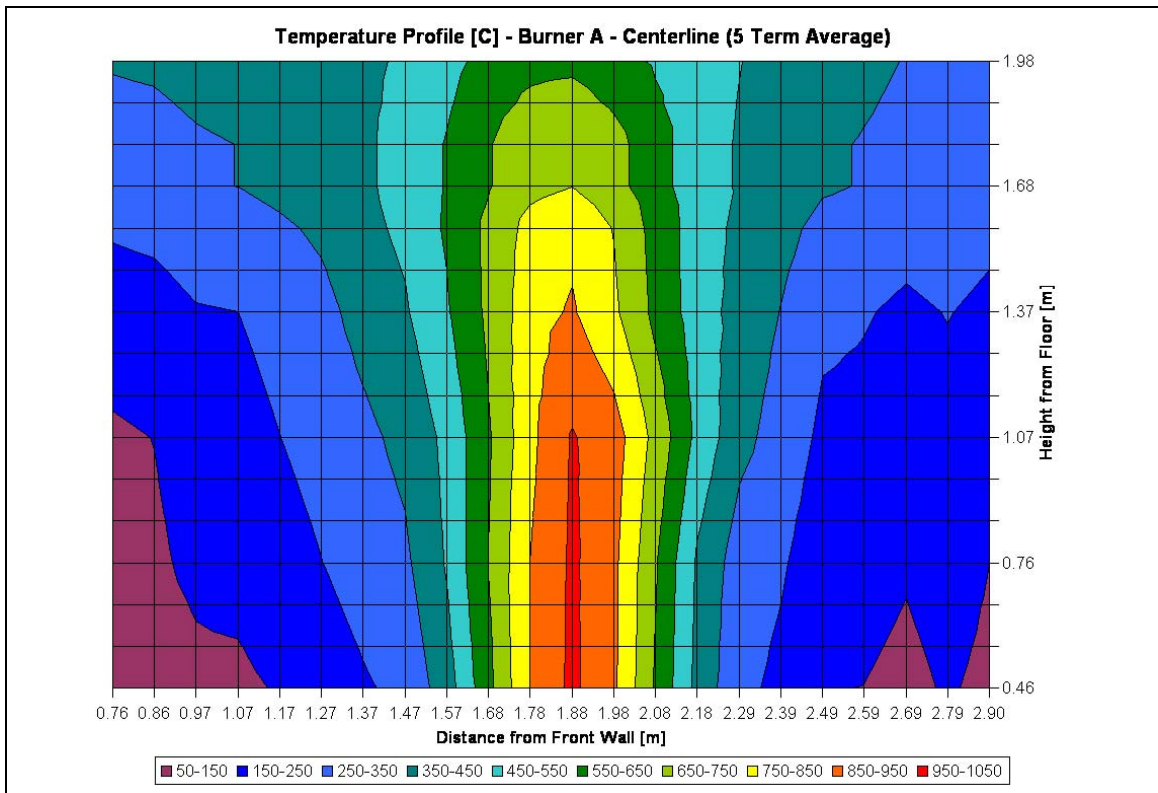


Figure 4-10: Temperature Profile - Burner A - Centerline – Five-term Average

The right side maximum temperature profile in Figure 4-11 has values between 97 and 988°C. The three-term average in Figure 4-12 has values between 89 and 963°C. The five-term average in Figure 4-13 has values between 82 and 928°C.

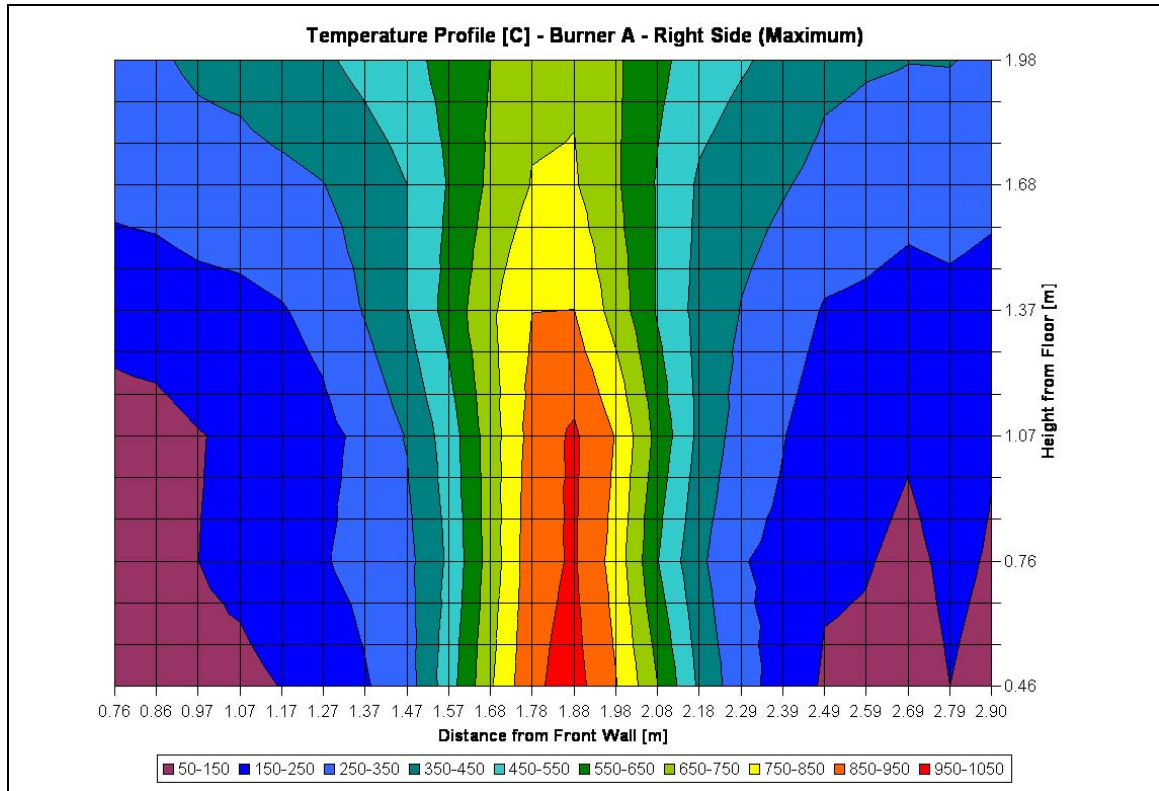


Figure 4-11: Temperature Profile - Burner A - Right Side - Maximum

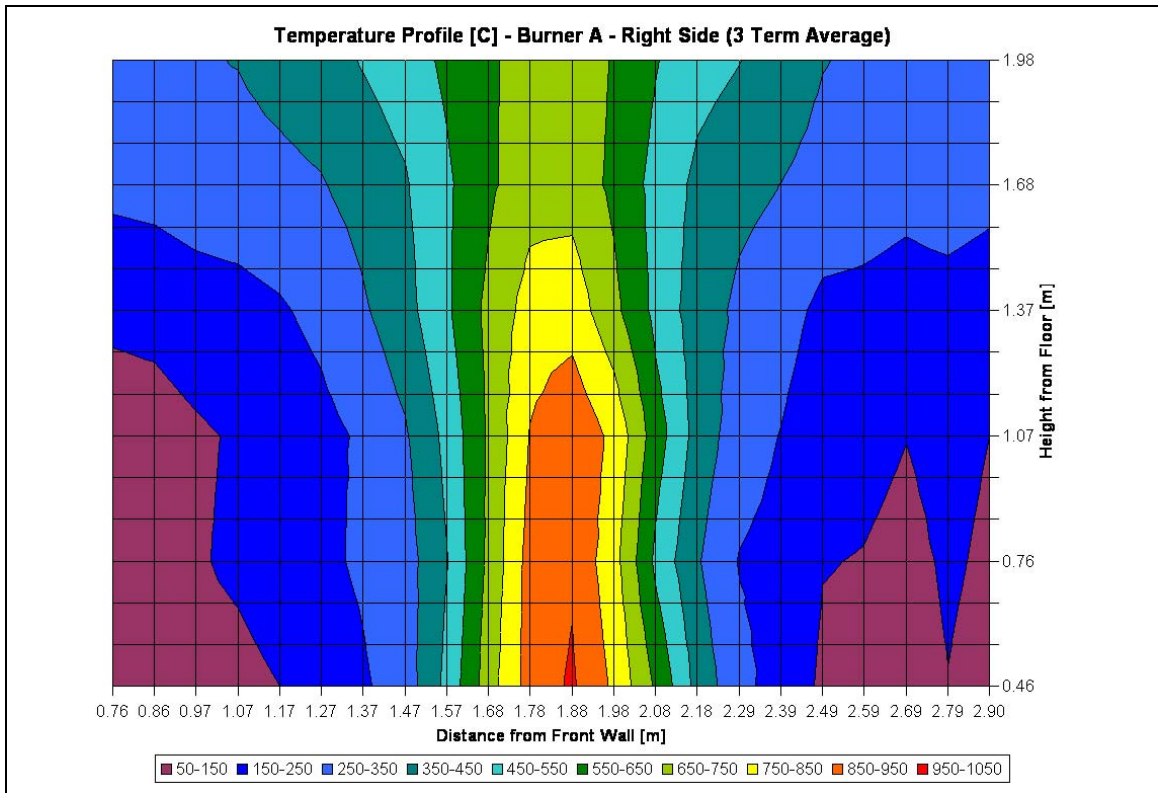


Figure 4-12: Temperature Profile - Burner A - Right Side – Three-term Average

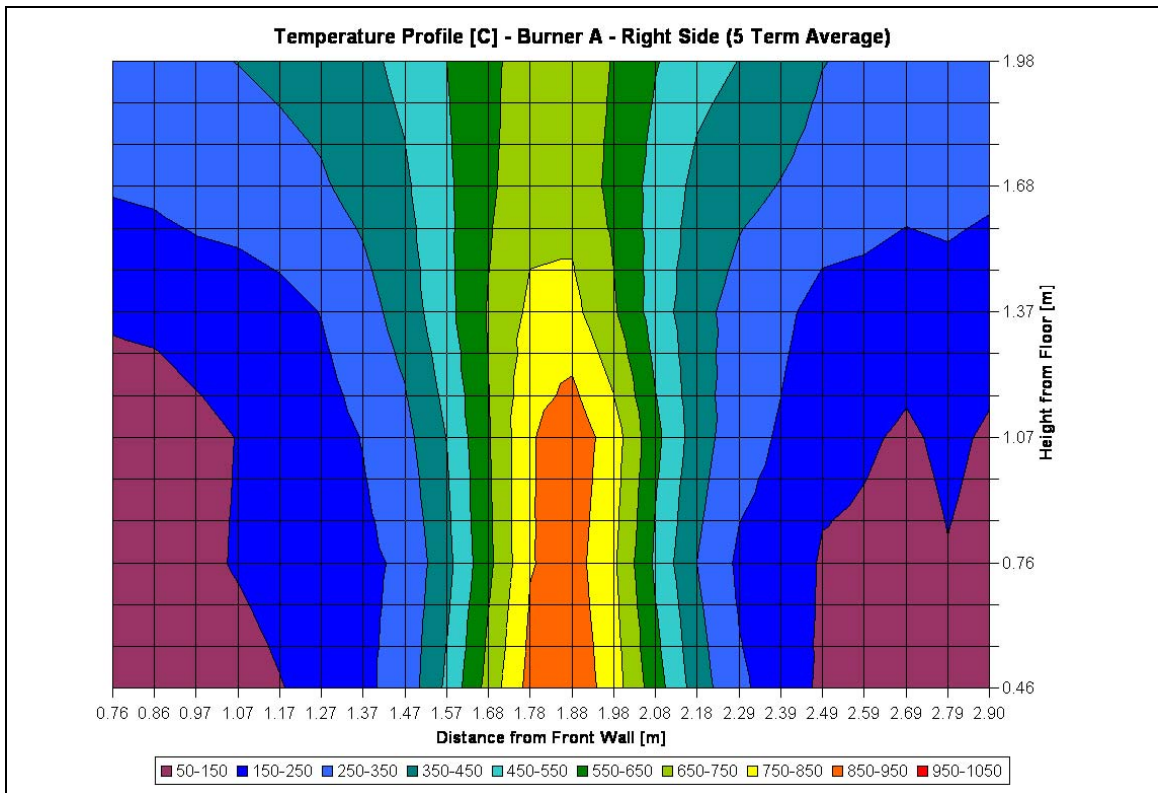


Figure 4-13: Temperature Profile - Burner A - Right Side – Five-term Average

4.3 Burner Configuration B

Burner configuration B was designed to apply indirect flame exposure to the mannequin. These fire conditions shown in Figure 4-14 could be experienced by a firefighter as they were passing flames that were blowing from a doorway or a window during an escape. This fire condition could be encountered while ship personnel attempted to evacuate in the situation where flames are impinging the exit path.

The temperature measurements for burner configuration B were collected on September 17 and September 20, 2002. Flux measurements were collected on October 1 and October 4, 2002. On September 17, 2002, the weather was partly cloudy and the temperature was between 14 and 23°C (57 and 73°F). The average wind was 5.7 mph from the north with gusts to 9 mph from the northwest. On September 20, 2002, the weather was partly cloudy and the temperature was between 14 and 23°C (58 and 74°F). The average wind was 13.3 mph from the southwest with gusts to 16 mph from the southwest. On October 1, 2002, the weather was clear and the temperature was between 13 and 24°C (56 and 75°F). The average wind was 14.3 mph from the southwest with gusts to 30 mph from the west. On October 4, 2002, the weather was cloudy with light rain and the temperature was between 10 and 18°C (50 and 64°F). The average wind was 7.6 mph from the east with gusts to 23 mph from the southwest.



Figure 4-14: Burner configuration B fire conditions

4.3.1 Flux

The flux measurements recorded are maximums that would impinge on the mannequin. The location of the Schmidt-Boelter gage in respect to the burners is depicted in Figure 4-15. The left side flux profile shown in Figure 4-16 ranged between 36 and 72 kW/m². While in Figure 4-17 the right side was between 27 and 68 kW/m². This burner configuration provides a very large area with a flux of between 40 and 70 kW/m².

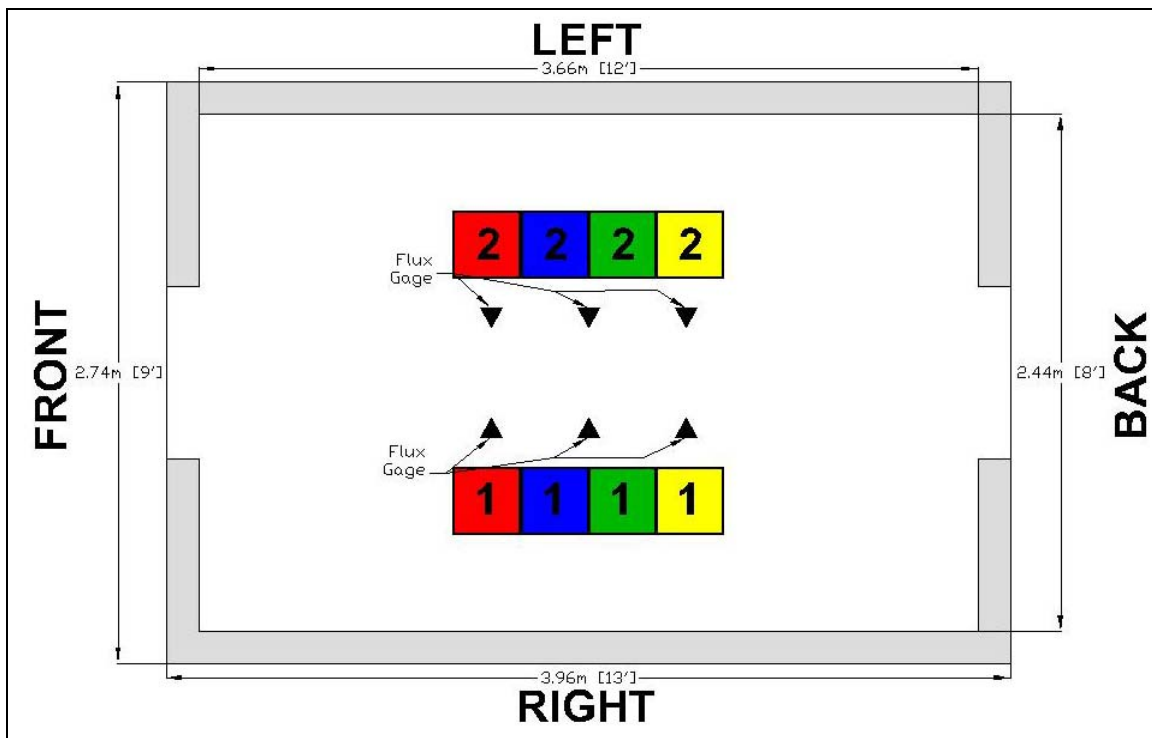


Figure 4-15: Plan view of burner configuration B flux gage measurement locations

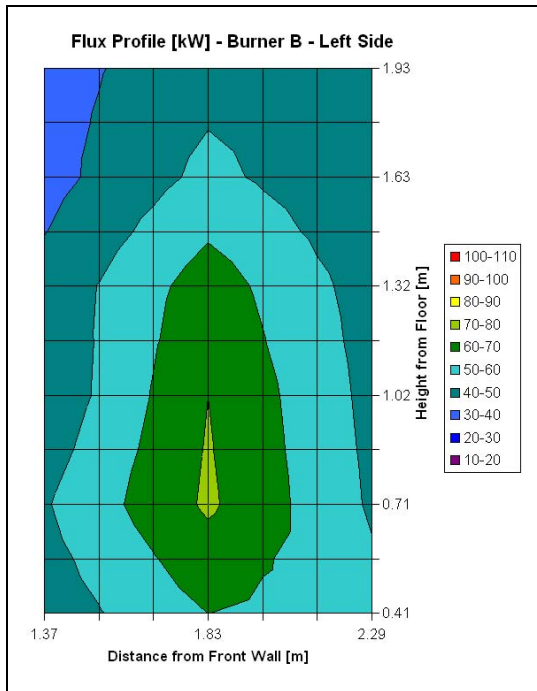


Figure 4-16: Flux Profile - Burner B - Left Side

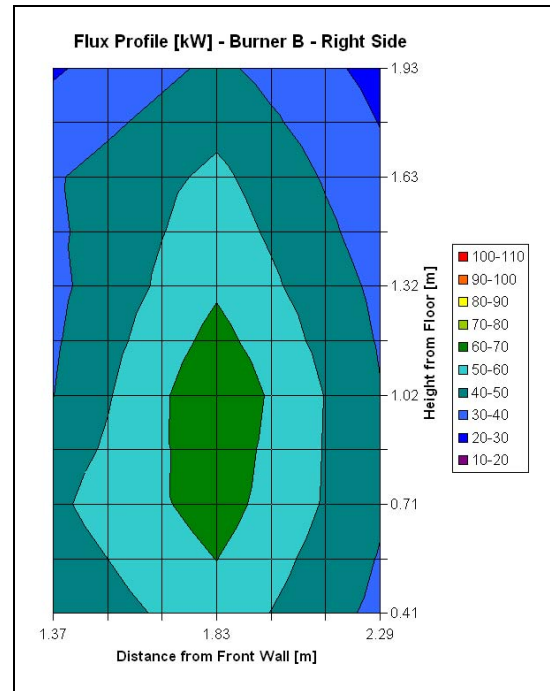


Figure 4-17: Flux Profile - Burner B - Right Side

4.3.2 Temperature

The temperature distribution for this burner configuration is similar on the left and right sides while the centerline is approximately 150°C cooler. The left side maximum temperature profile in Figure 4-18 has values between 173 and 847°C. The three-term average in Figure 4-19 has values between 170 and 779°C. The five-term average in Figure 4-20 has values between 169 and 750°C.

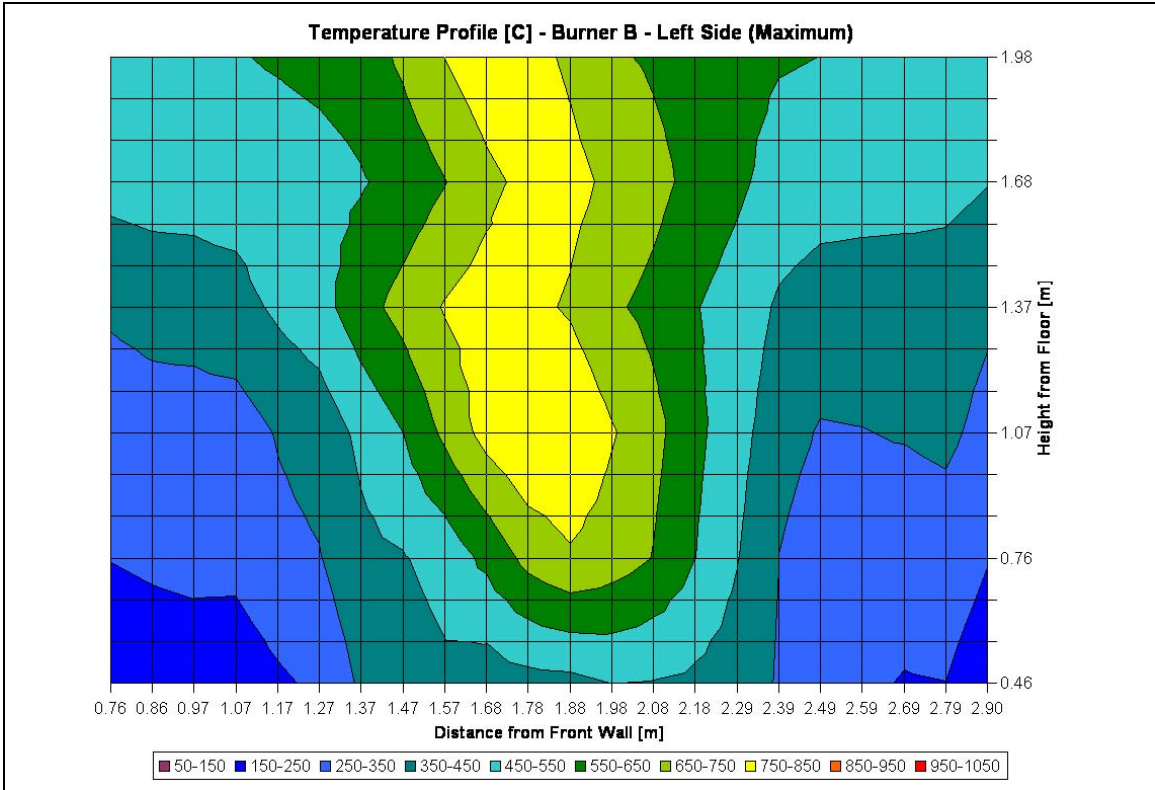


Figure 4-18: Temperature Profile - Burner B - Left Side - Maximum

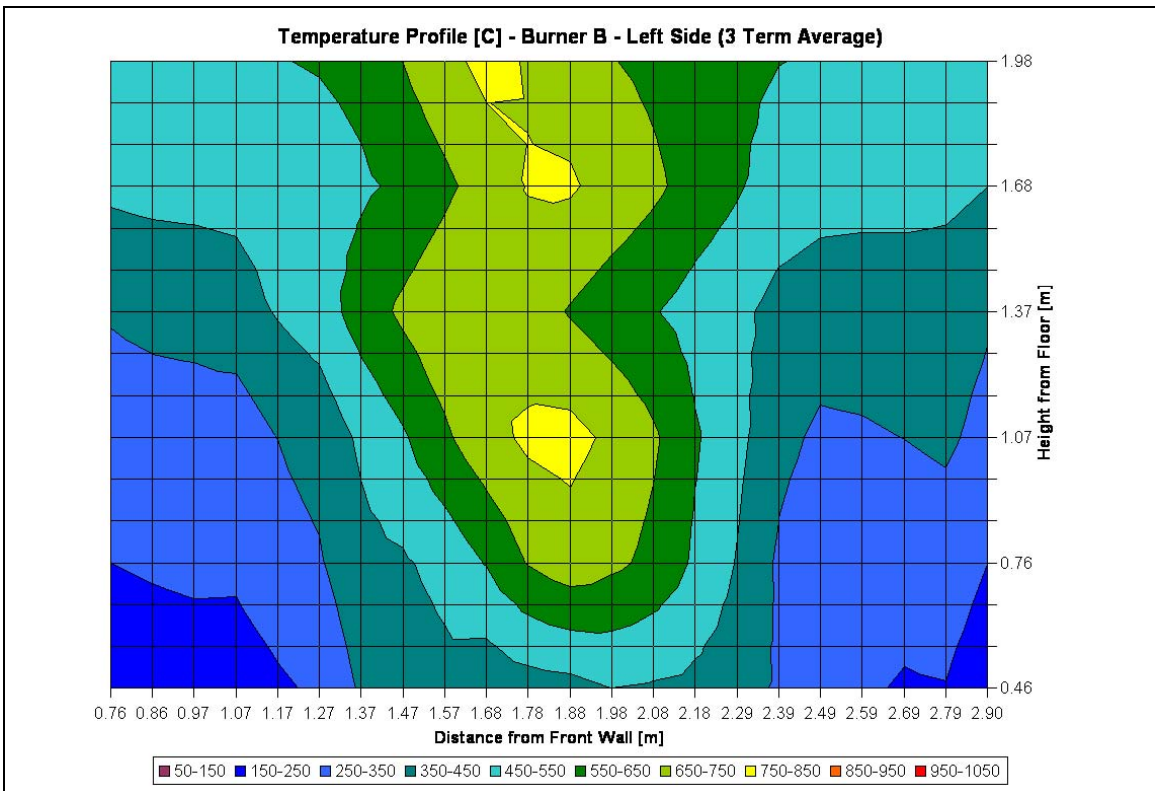


Figure 4-19: Temperature Profile – Burner B - Left Side – Three-term Average

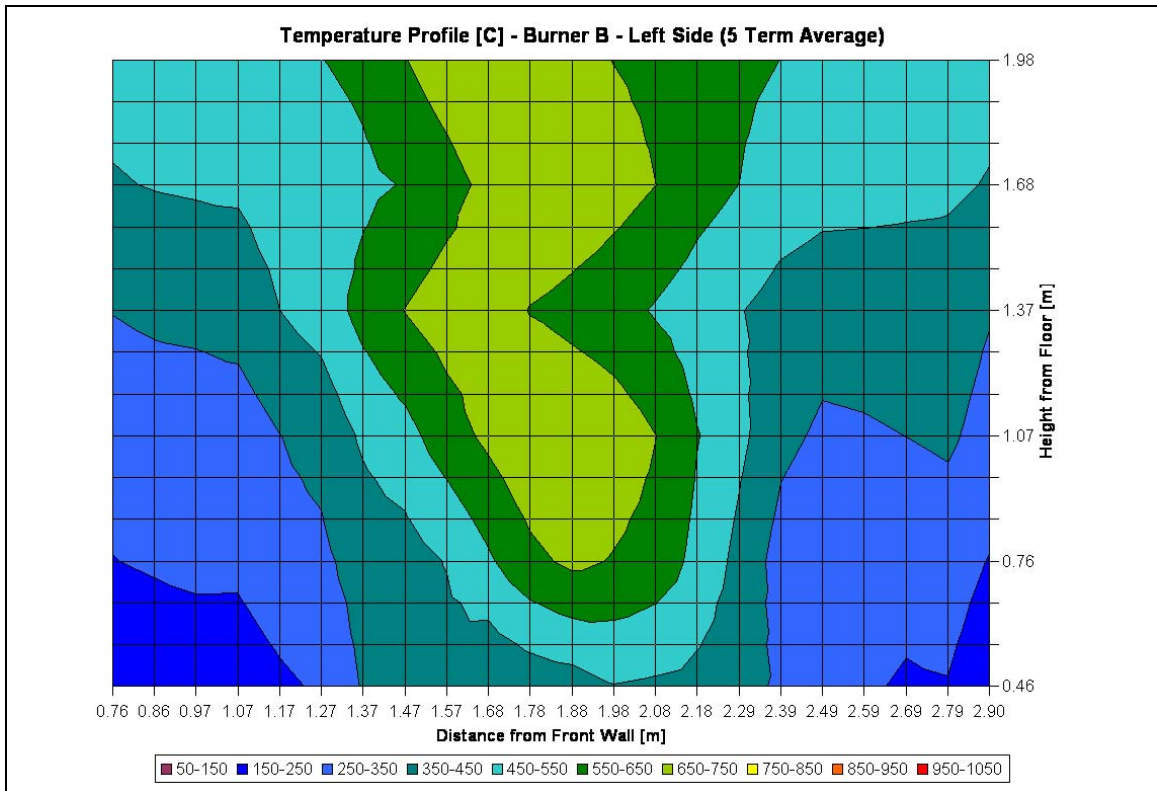


Figure 4-20: Temperature Profile - Burner B - Left Side – Five-term Average

The centerline maximum temperature profile in Figure 4-21 has values between 165 and 603°C. The three-term average in Figure 4-22 has values between 153 and 583°C. The five-term average in Figure 4-23 has values between 141 and 577°C.

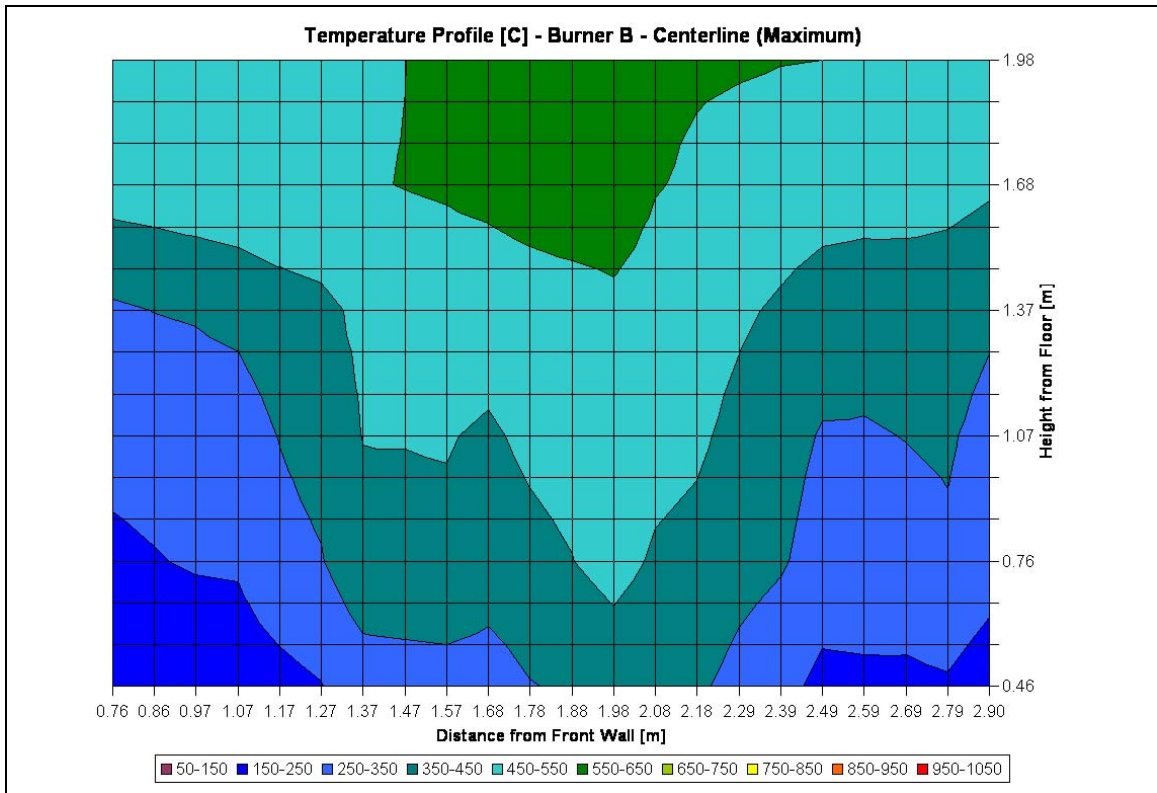


Figure 4-21: Temperature Profile - Burner B - Centerline - Maximum

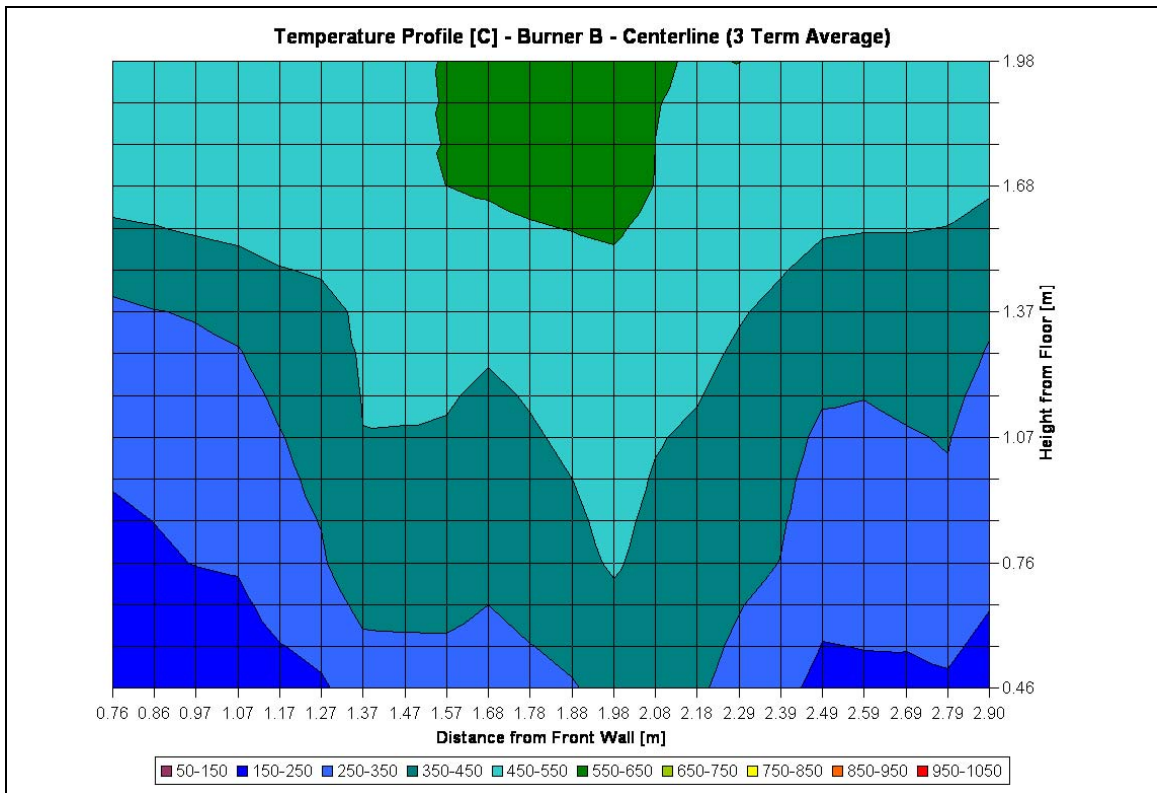


Figure 4-22: Temperature Profile - Burner B – Centerline – Three-term Average

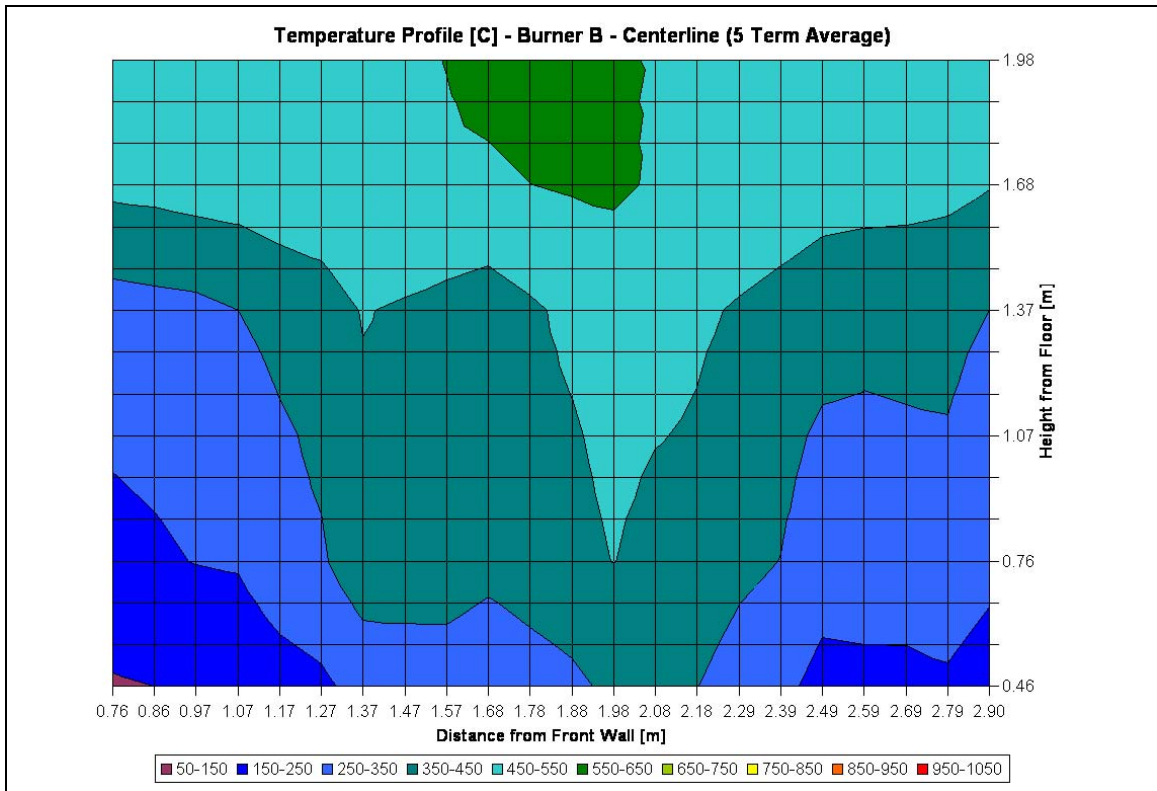


Figure 4-23: Temperature Profile - Burner B - Centerline – Five-term Average

The right side maximum temperature profile in Figure 4-24 has values between 188 and 847°C. The three-term average in Figure 4-25 has values between 182 and 781°C. The five-term average in Figure 4-26 has values between 173 and 765°C.

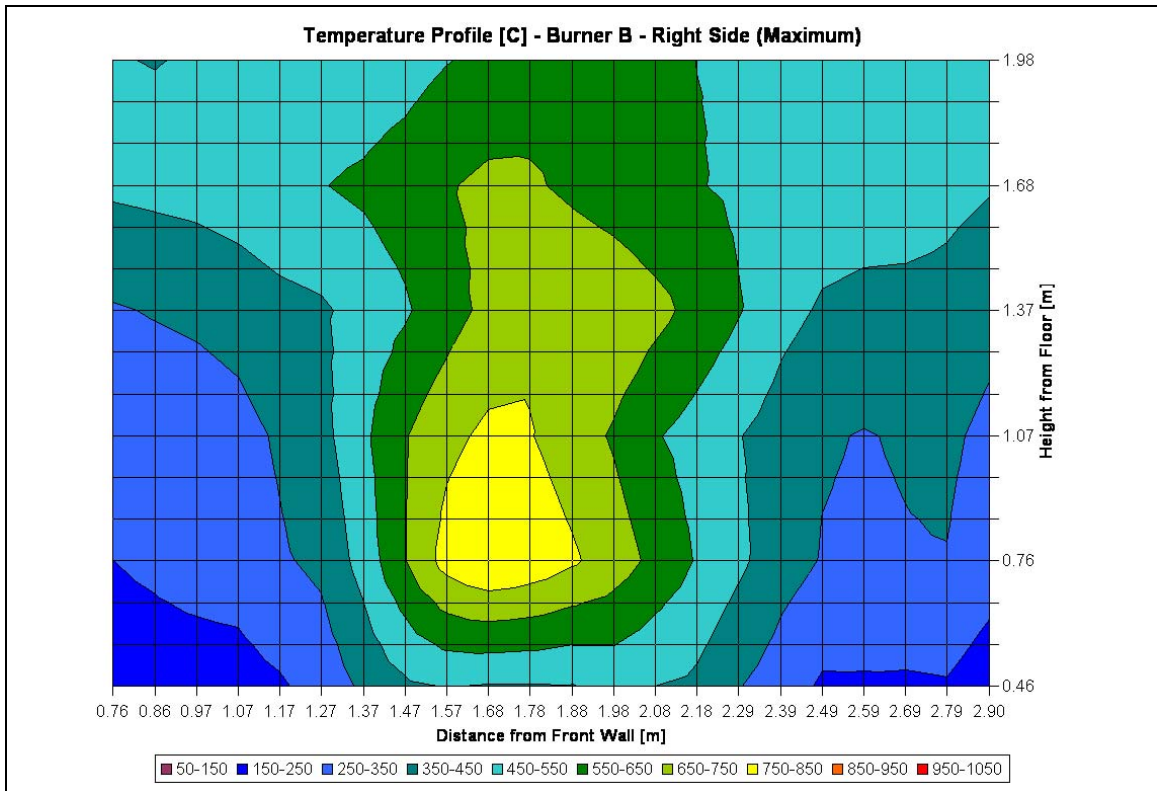


Figure 4-24: Temperature Profile - Burner B - Right Side - Maximum

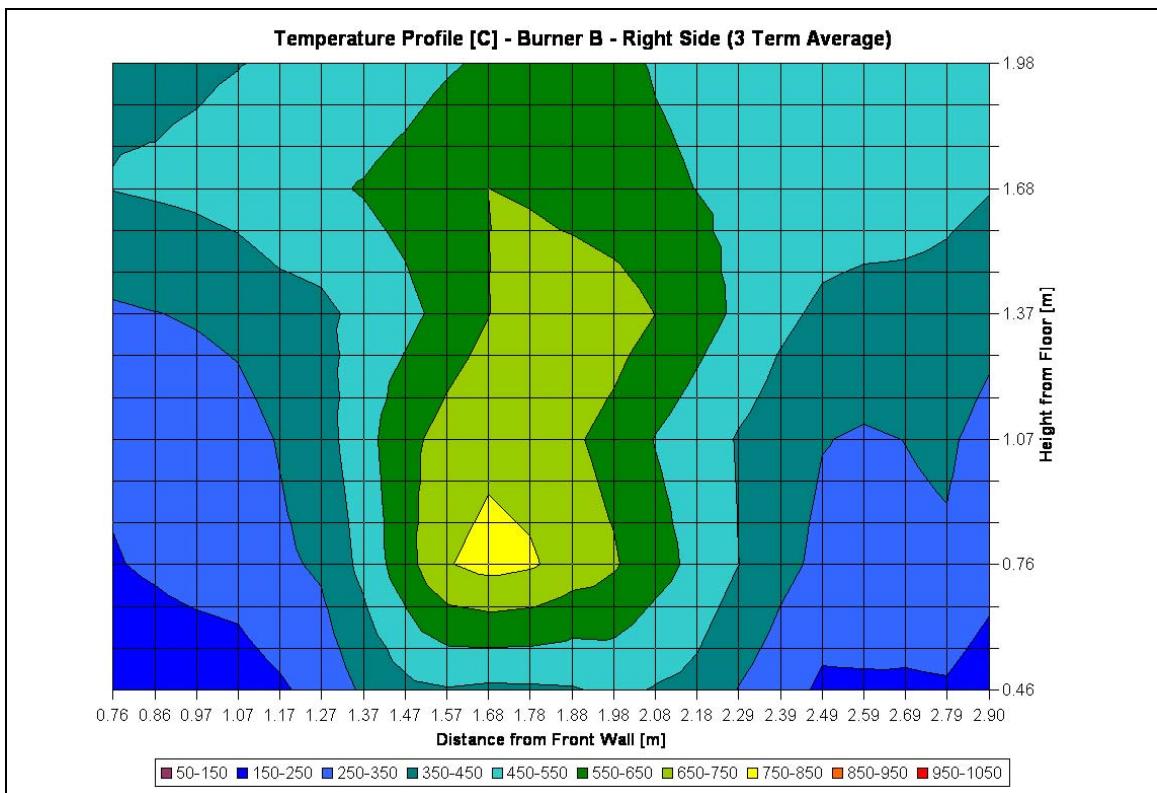


Figure 4-25: Temperature Profile - Burner B - Right Side – Three-term Average

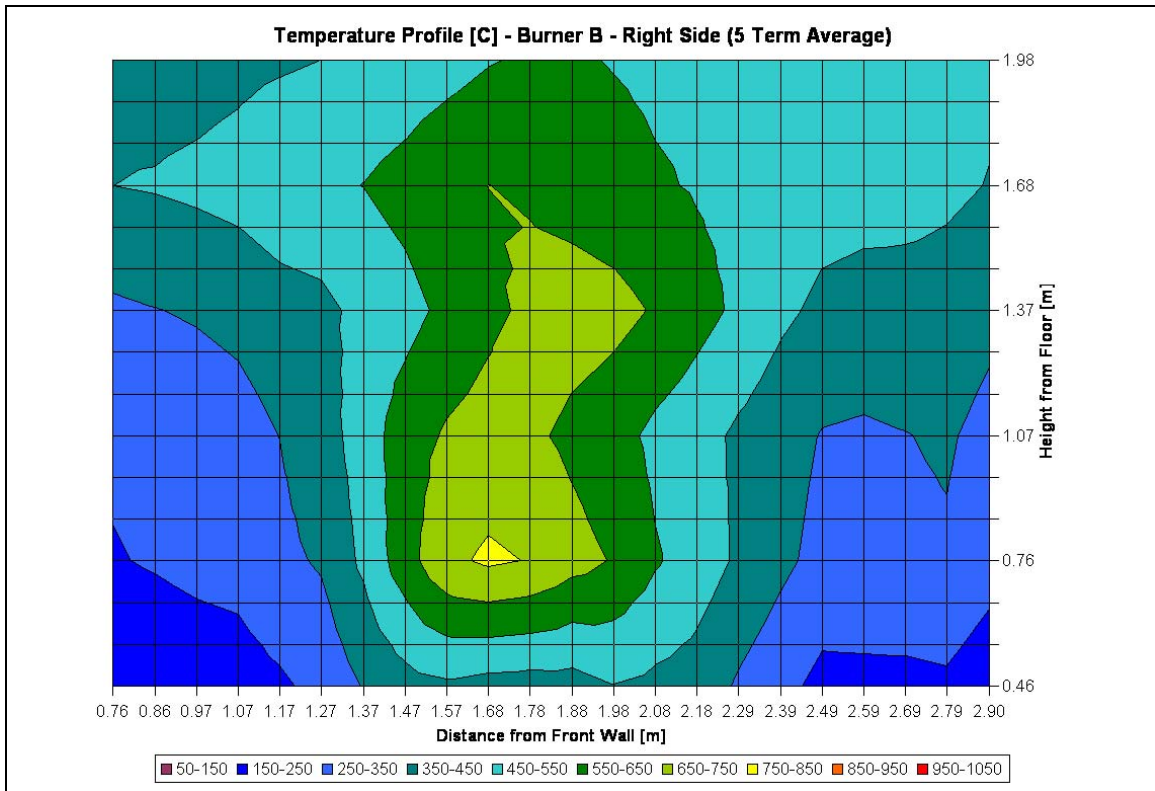


Figure 4-26: Temperature Profile - Burner B - Right Side – Five-term Average

4.4 Burner Configuration C

Burner configuration C is designed to be the worst-case fire scenario and simulates flashover conditions. Flames shown in Figure 4-27 consistently reach the ceiling and frequently exited the doorway.

The temperature and flux measurements for burner configuration C were collected on October 15 and October 17, 2002. Flux measurements were also collected on October 7, 2002. On October 7, 2002, the weather was mostly cloudy and the temperature was between 8 and 19°C (46 and 67°F). The average wind was 9.5 mph from the west with gusts to 30 mph from the west. On October 15, 2002, the weather was clear and the temperature was between 2 and 9°C (35 and 49°F). The average wind was 6.5 mph from the north with gusts to 9 mph from the south. On October 17, 2002, the weather was

partly cloudy and the temperature was between 5 and 14°C (41 and 58°F). The average wind was 11.6 mph from the west with gusts to 33 mph from the west.



Figure 4-27: Burner configuration C fire conditions

4.4.1 Flux

The flux profile shown in Figure 4-28 for the left side ranged between 31 and 91 kW/m², while the right side was between 17 and 63 kW/m². The large difference between flux measurements is because the gage measurement location is at the edge of the burner. During the data collection period, the flames had a slight lean to the left side due to issues concerning the unevenness of the air flow into the building.

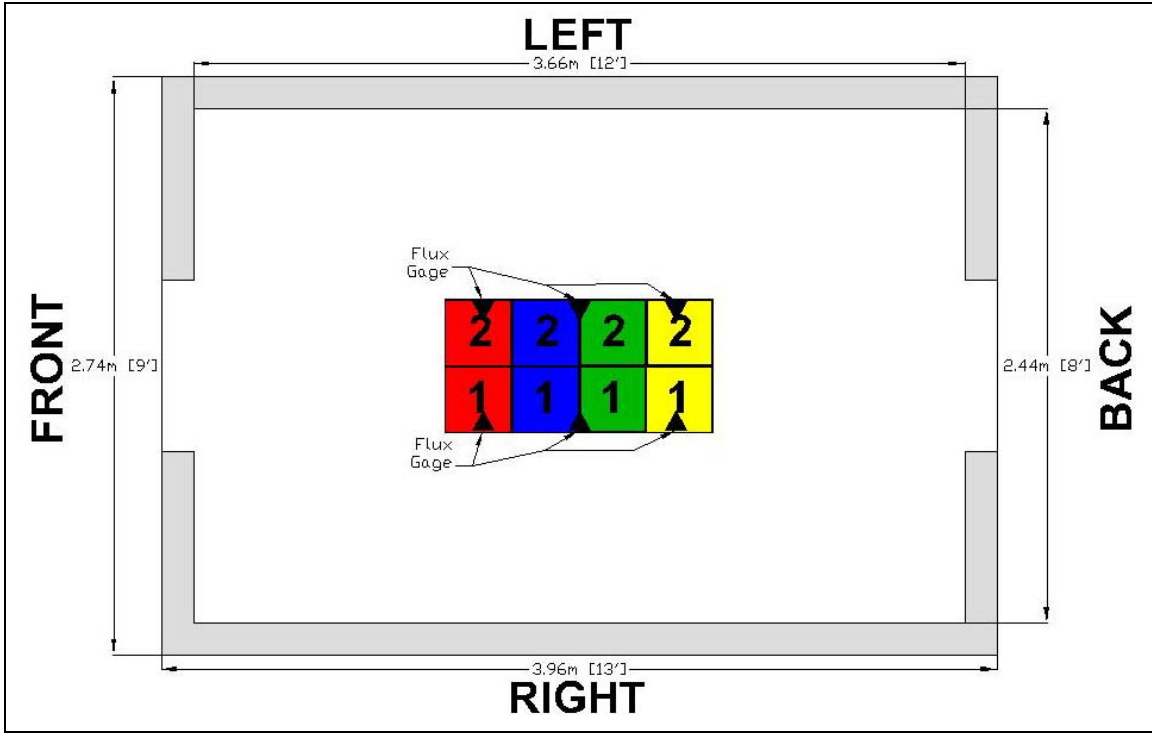


Figure 4-28: Plan view of burner configuration C flux gage measurement locations

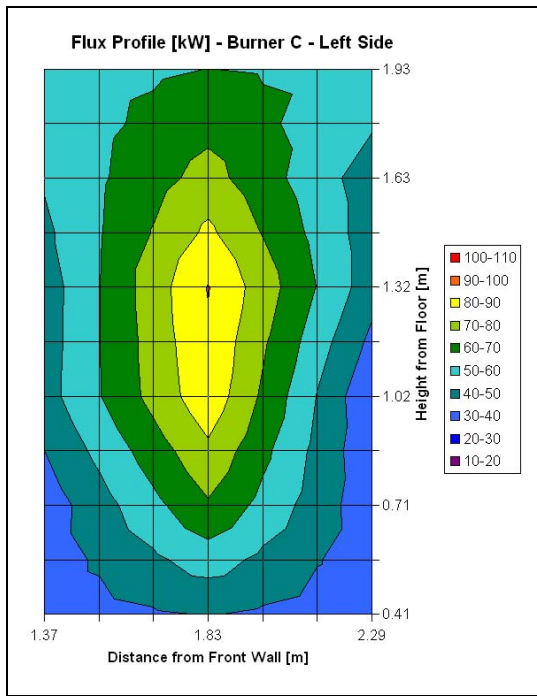


Figure 4-29: Flux Profile - Burner C - Left Side

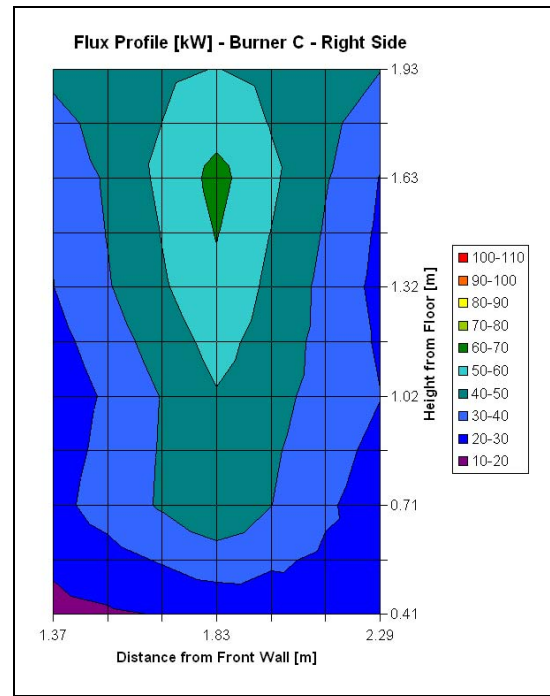


Figure 4-30: Flux Profile - Burner C - Right Side

4.4.2 Temperature

Burner configuration C has very extreme conditions, with temperatures approaching 1000°C over the entire travel path of the mannequin. The left side maximum temperature profile in Figure 4-31 has values between 157 and 1067°C. The three-term average in Figure 4-32 has values between 146 and 1039°C. The five-term average in Figure 4-33 has values between 135 and 1022°C.

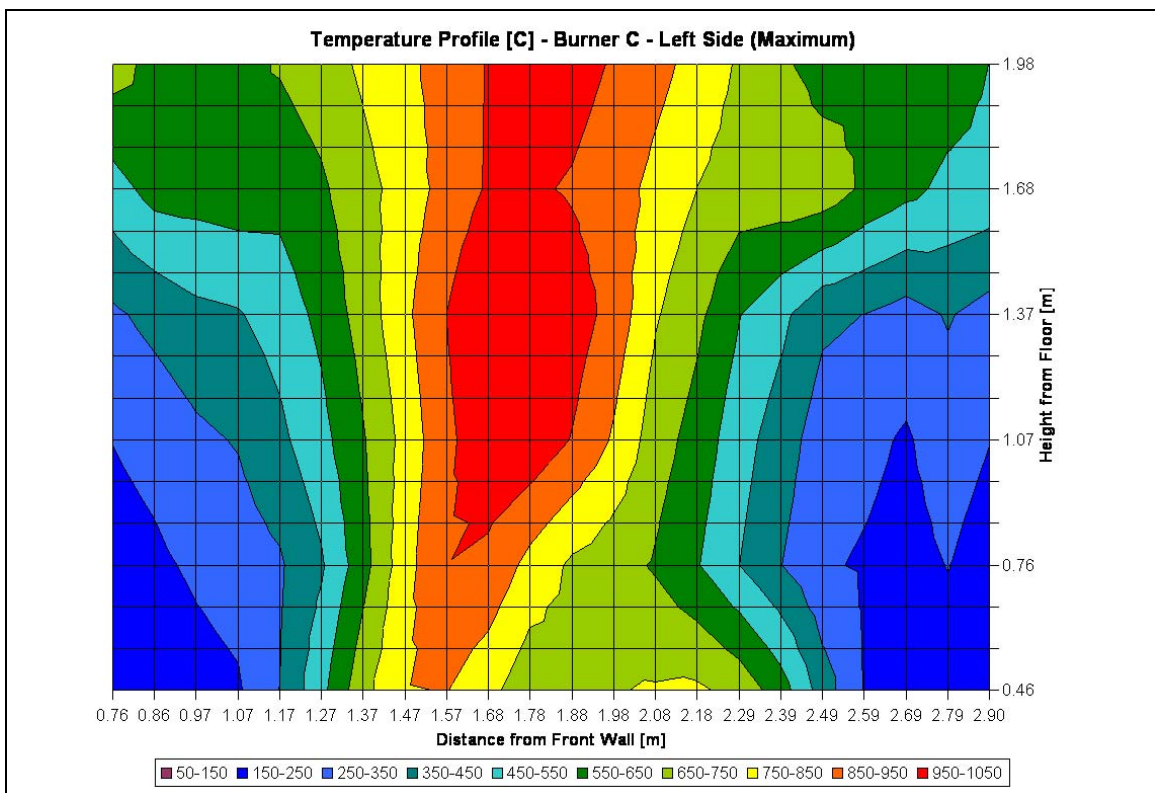


Figure 4-31: Temperature Profile - Burner C - Left Side - Maximum

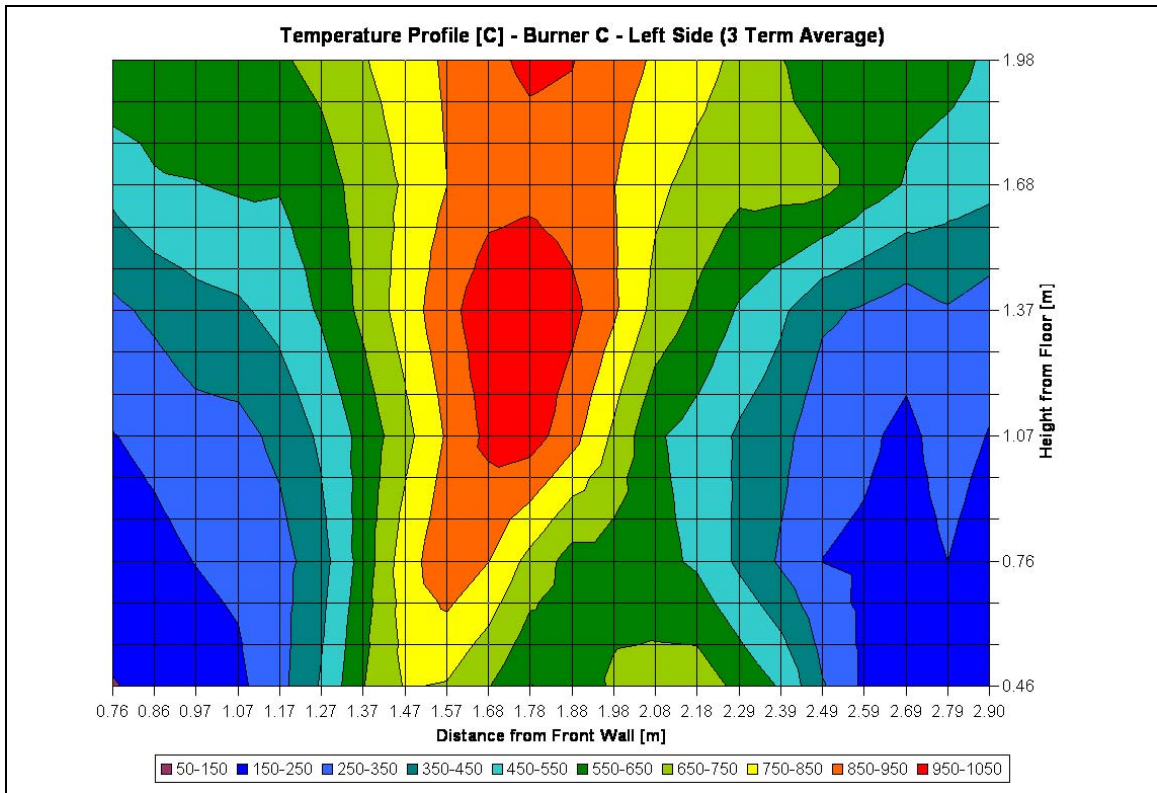


Figure 4-32: Temperature Profile - Burner C - Left Side – Three-term Average

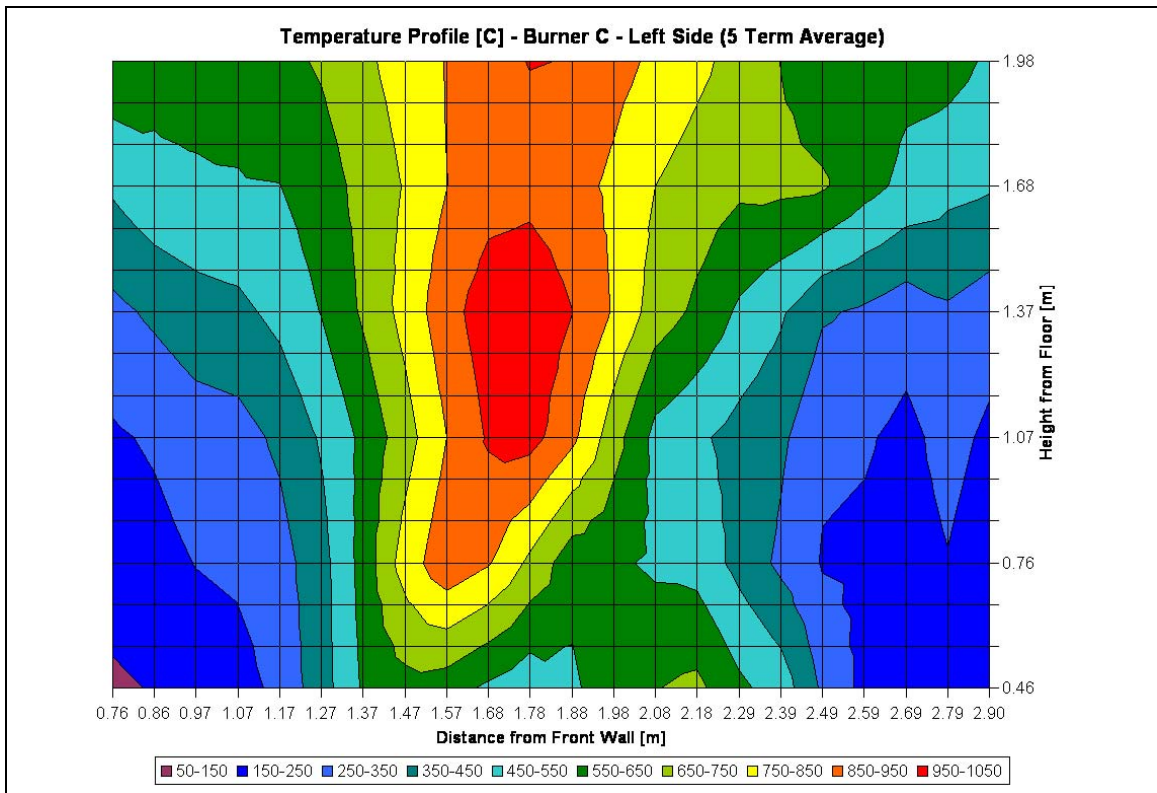


Figure 4-33: Temperature Profile - Burner C - Left Side – Five-term Average

The centerline maximum temperature profile in Figure 4-34 has values between 138 and 1035°C. The three-term average in Figure 4-35 has values between 135 and 1013°C. The five-term average in Figure 4-36 has values between 151 and 954°C. There is 0.5 m (20 in) of extreme temperatures near 1000°C exposure directly over the middle of the burners.

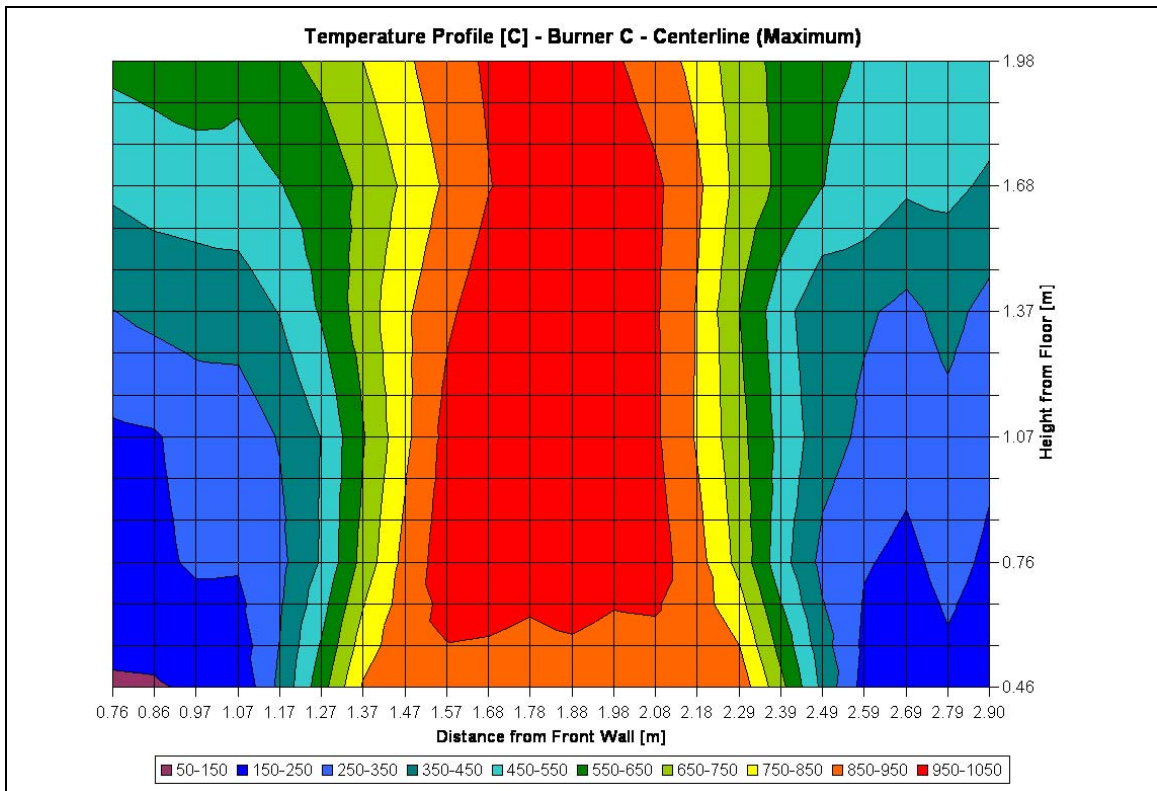


Figure 4-34: Temperature Profile - Burner C - Centerline - Maximum

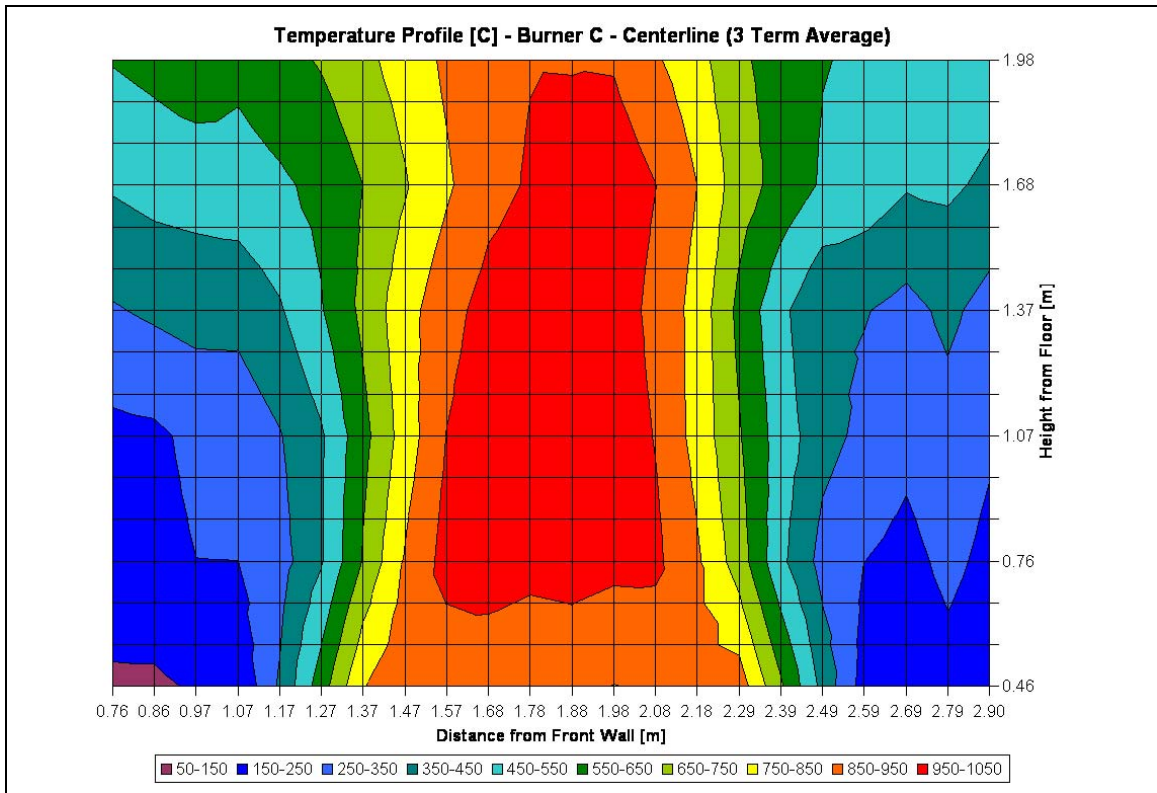


Figure 4-35: Temperature Profile - Burner C - Centerline – Three-term Average

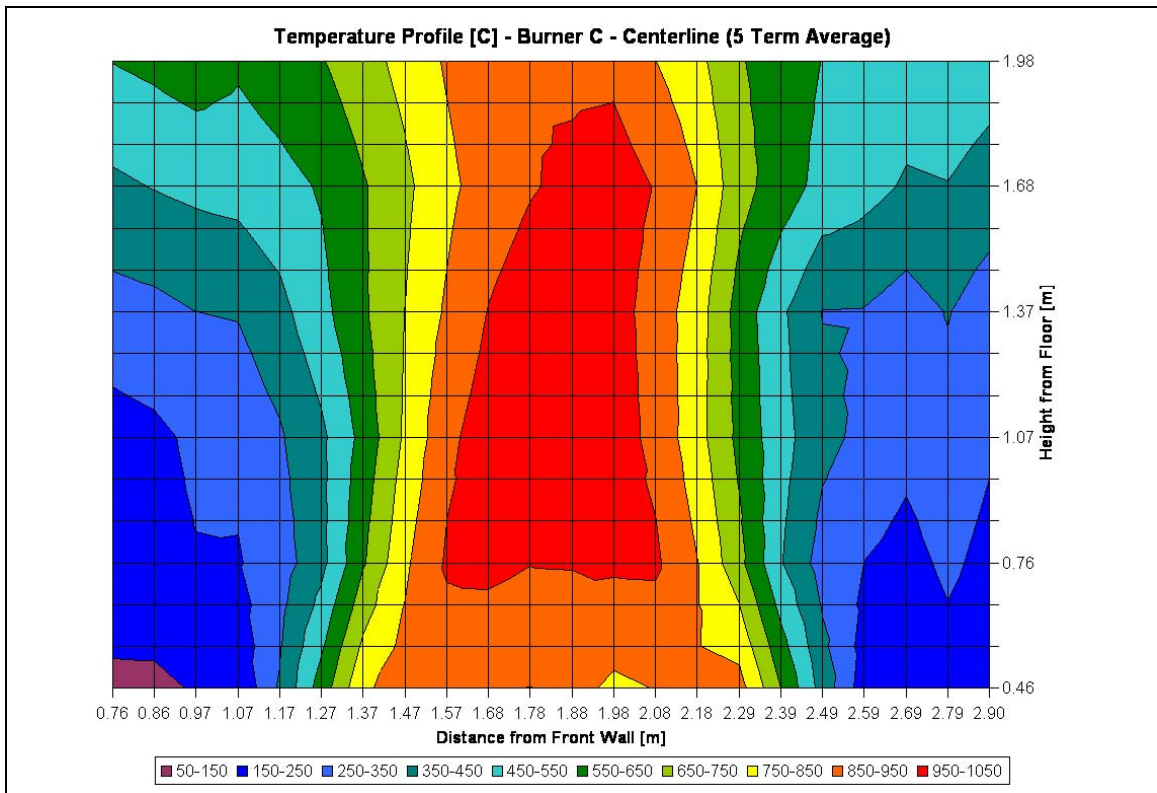


Figure 4-36: Temperature Profile - Burner C - Centerline – Five-term Average

The right side maximum temperature profile in Figure 4-37 has values between 151 and 954°C. The three-term average in Figure 4-38 has values between 145 and 917°C. The five-term average in Figure 4-39 has values between 139 and 901°C.

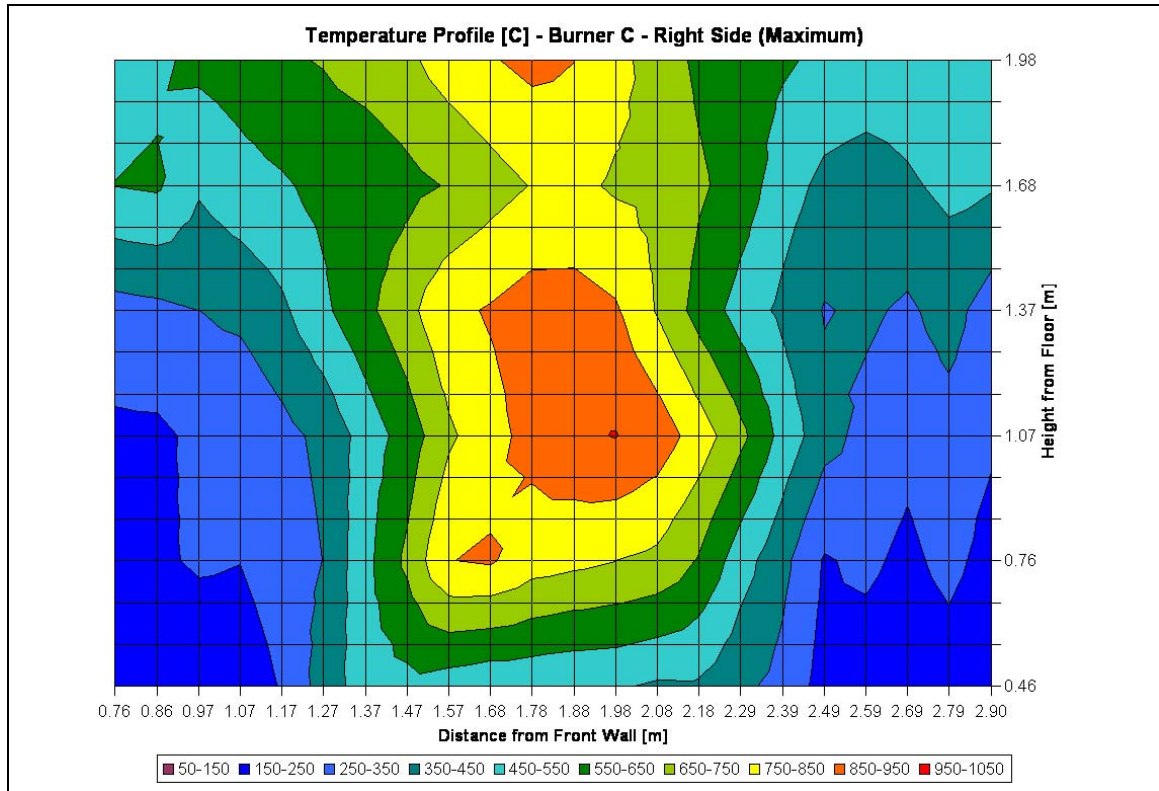


Figure 4-37: Temperature Profile - Burner C - Right Side - Maximum

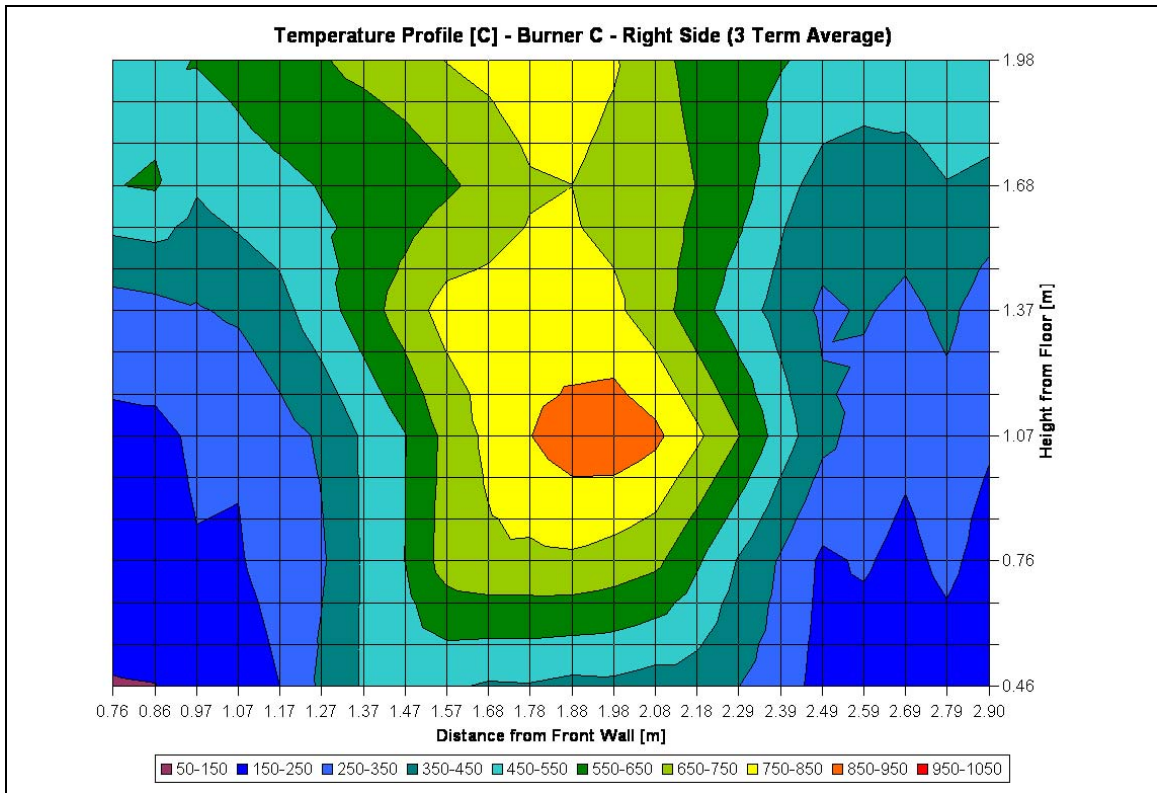


Figure 4-38: Temperature Profile - Burner C - Right Side – Three-term Average

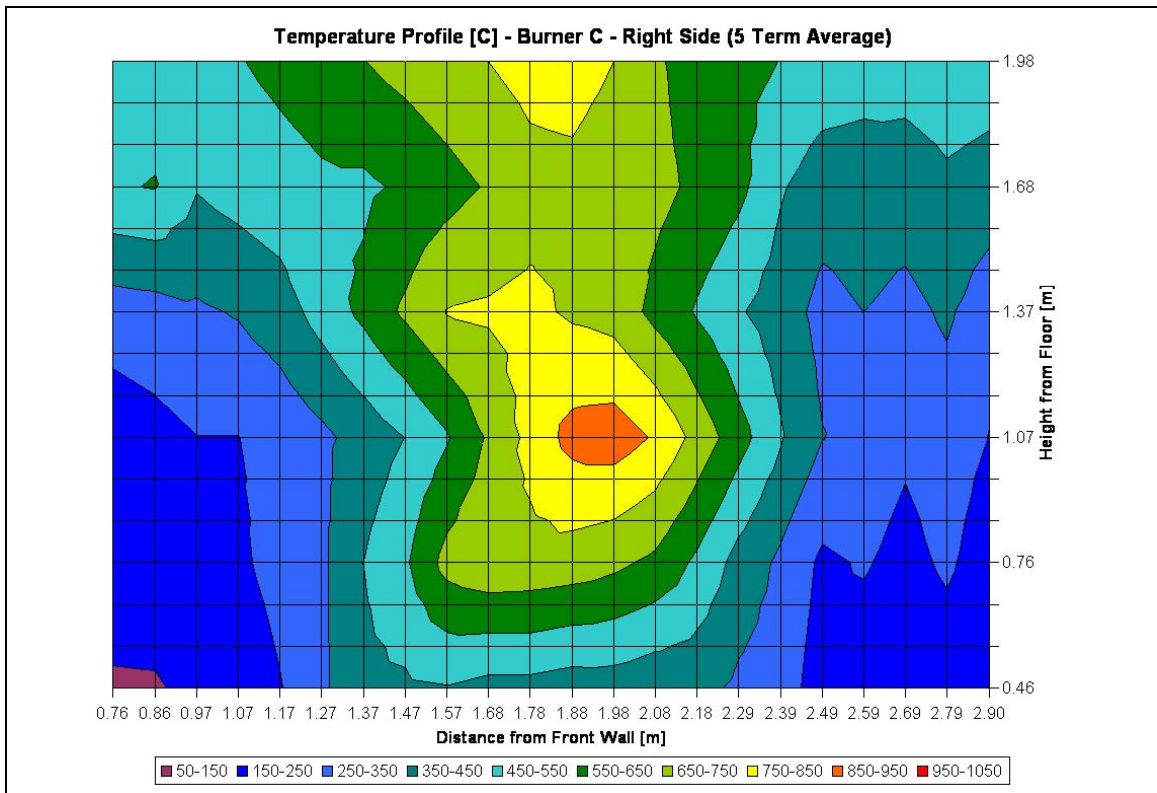


Figure 4-39: Temperature Profile - Burner C - Right Side – Five-term Average

4.5 Burner Configuration D

Burner configuration D was designed to simulate the conditions that would be experienced during a brush or wildfire scenario. As shown in Figure 4-40 this burner configuration produces flames approximately one meter (39.4 in) high.

The temperature and flux measurements for burner configuration D were collected on October 28 and October 29, 2002. On October 28, 2002, the weather was partly cloudy and the temperature was between -1 and 9°C (31 and 48°F). The average wind was 9.1 mph from the west with gusts to 17 mph from the west. On October 29, 2002, the weather was clear and the temperature was between -1 and 6°C (30 and 42°F). The average wind was 8.5 mph from the north with gusts to 23 mph from the northwest.



Figure 4-40: Burner configuration D fire conditions

4.5.1 Flux

The flux distribution on the left side shown in Figure 4-42 ranged between 11 and 63 kW/m² while the right side in Figure 4-43 was between 14 and 74.7 kW/m². The middle measurement is a maximum while the front and back are minimums impinge on

the mannequin which depicted in Figure 4-41.

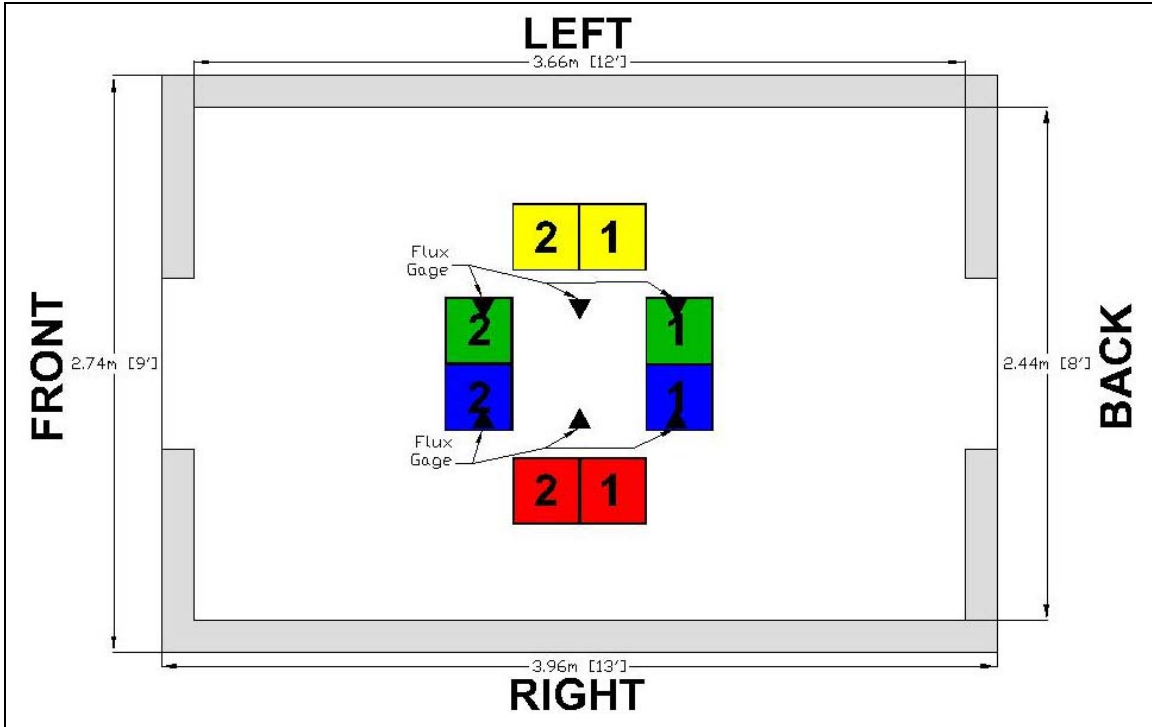


Figure 4-41: Plan view of burner configuration D flux gage measurement locations

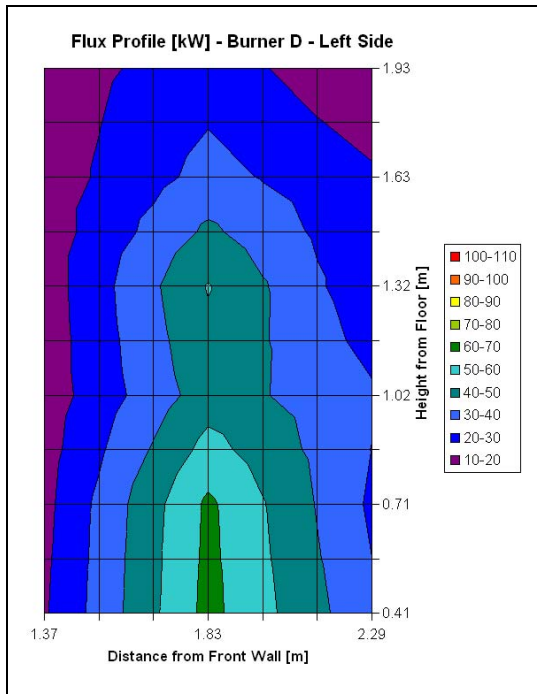


Figure 4-42: Flux Profile - Burner D - Left Side

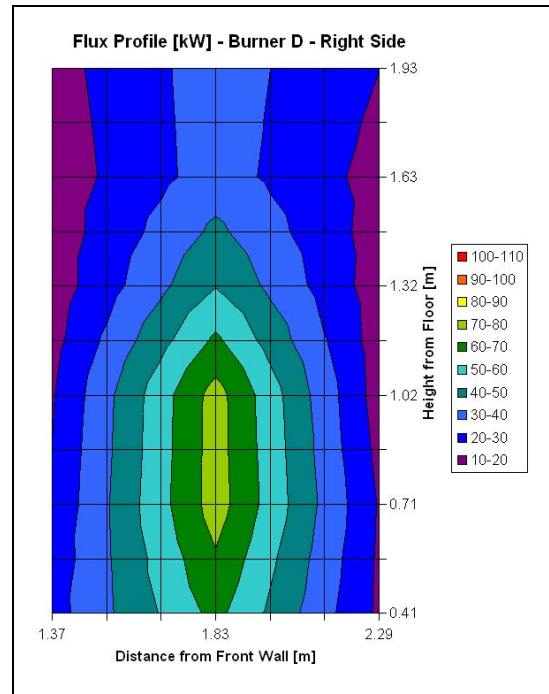


Figure 4-43: Flux Profile - Burner D - Right Side

4.5.2 Temperature

The higher temperatures are in the center of the room where the burners are not located and where there is no direct flame contact. The left side maximum temperature profile in Figure 4-44 has values between 80 and 916°C. The three-term average in Figure 4-45 has values between 74 and 883°C. The five-term average in Figure 4-46 has values between 74 and 857°C.

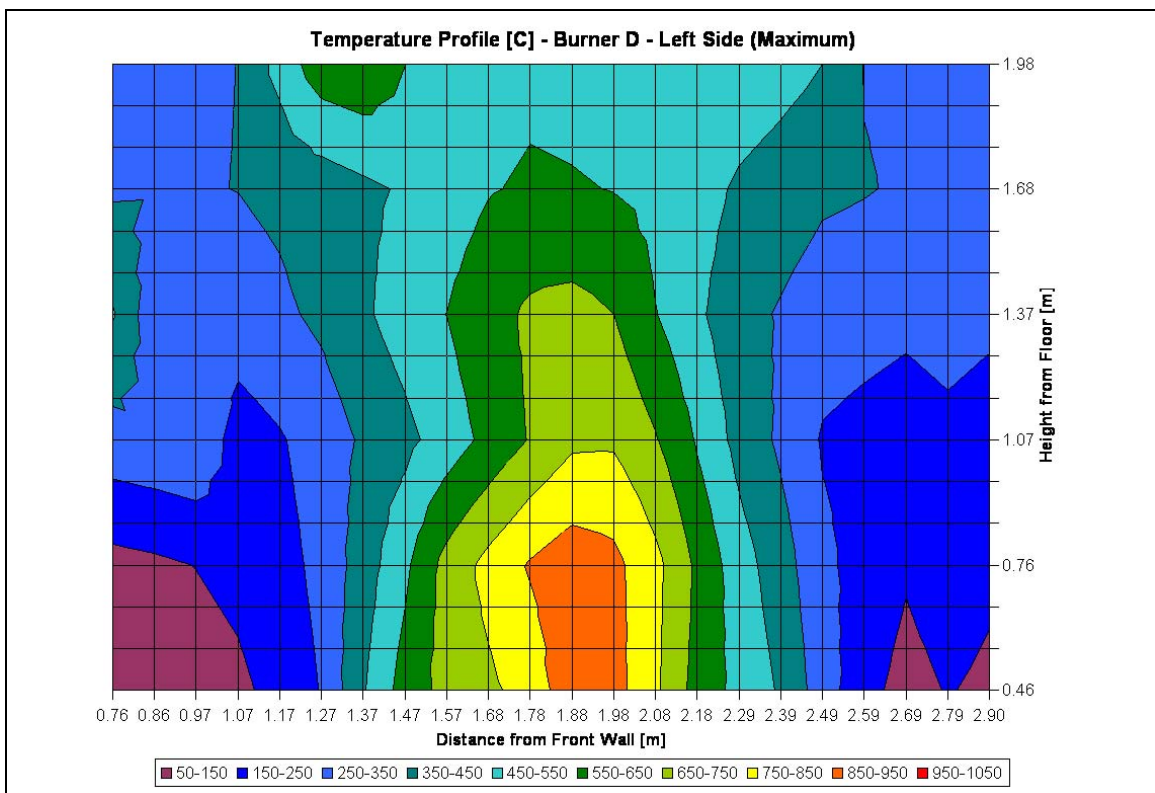


Figure 4-44: Temperature Profile - Burner D - Left Side – Maximum

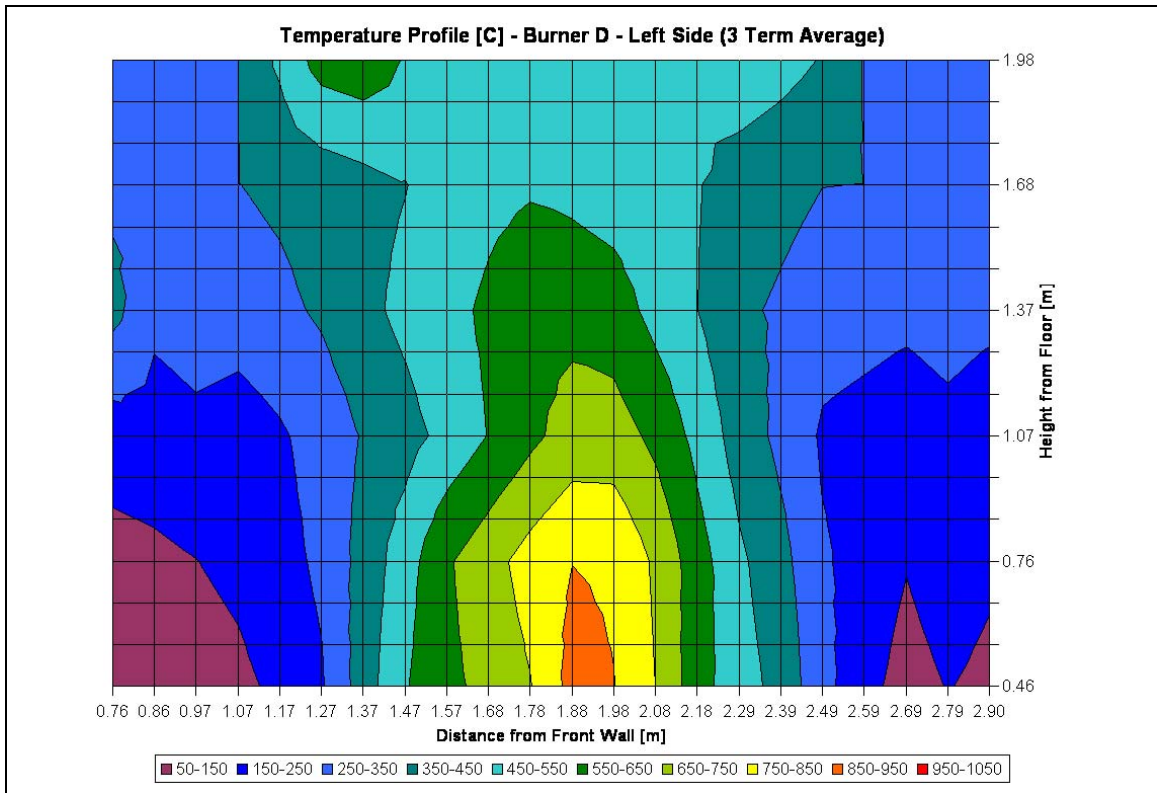


Figure 4-45: Temperature Profile - Burner D - Left Side – Three-term Average

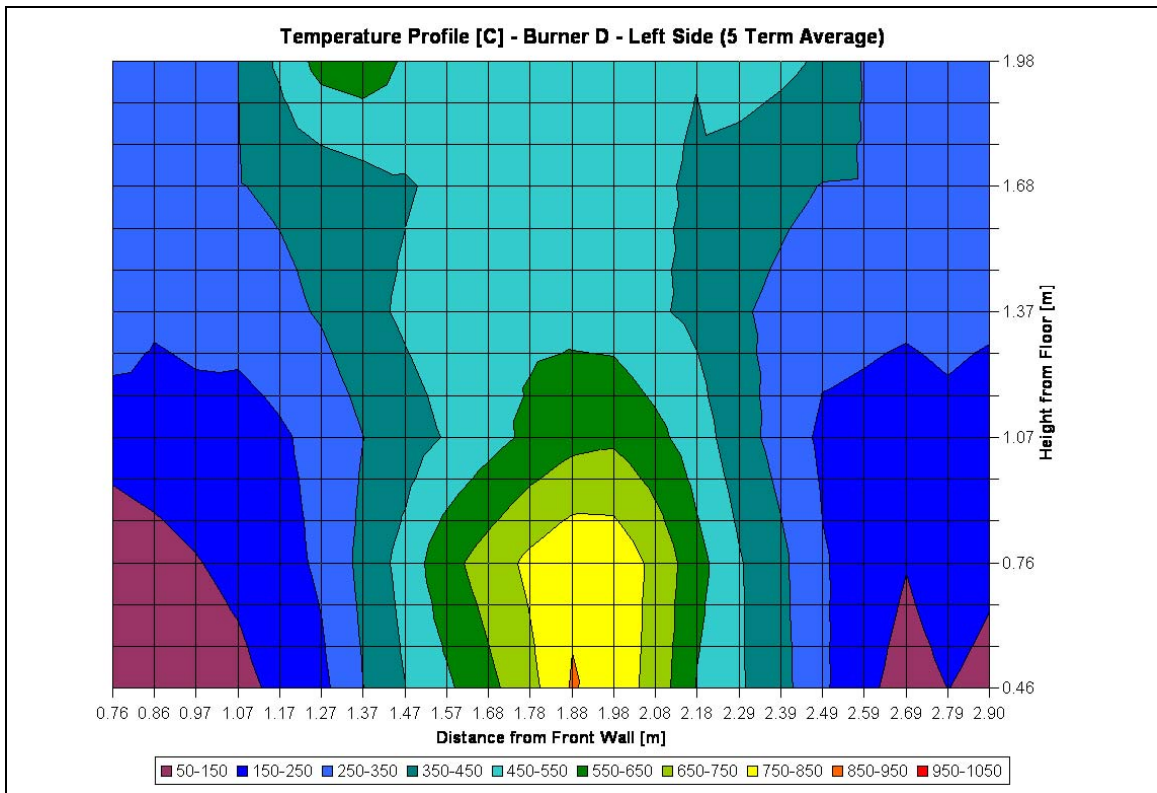


Figure 4-46: Temperature Profile - Burner D - Left Side – Five-term Average

The centerline maximum temperature profile in Figure 4-47 has values between 84 and 997°C. The three-term average in Figure 4-48 has values between 78 and 964°C. The five-term average in Figure 4-49 has values between 74 and 937°C.

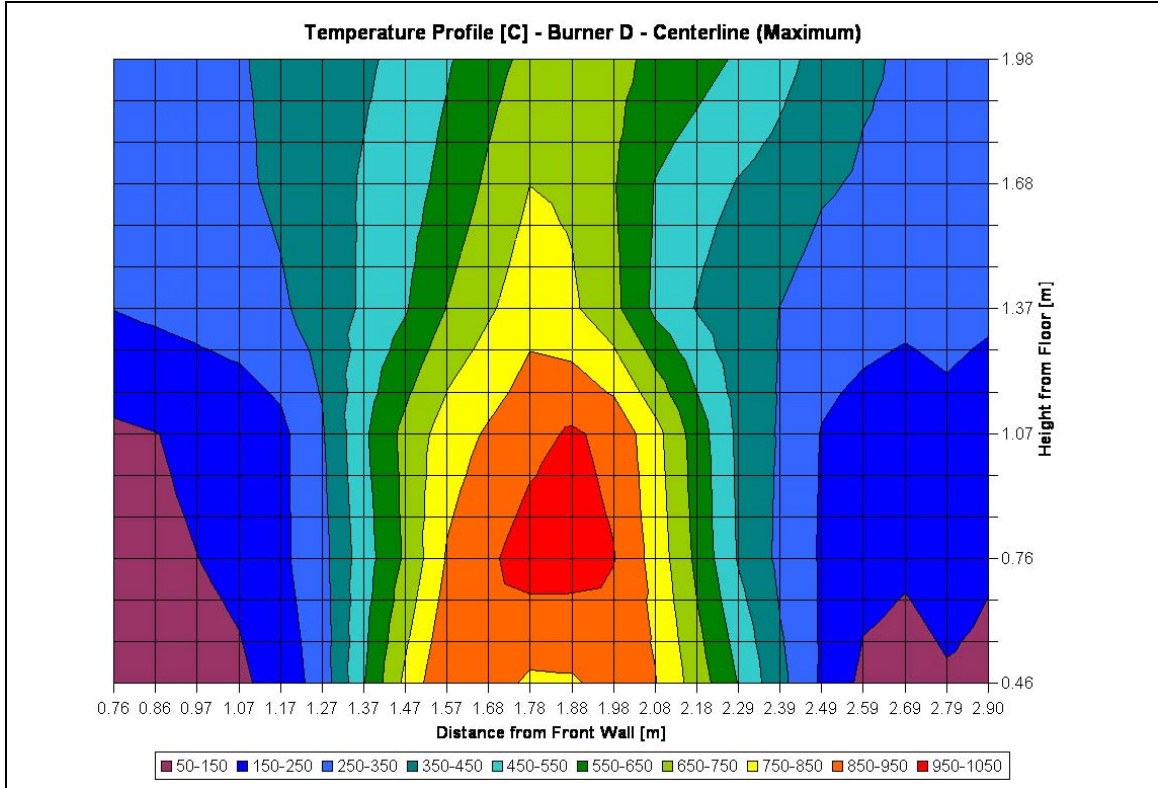


Figure 4-47: Temperature Profile - Burner D - Centerline - Maximum

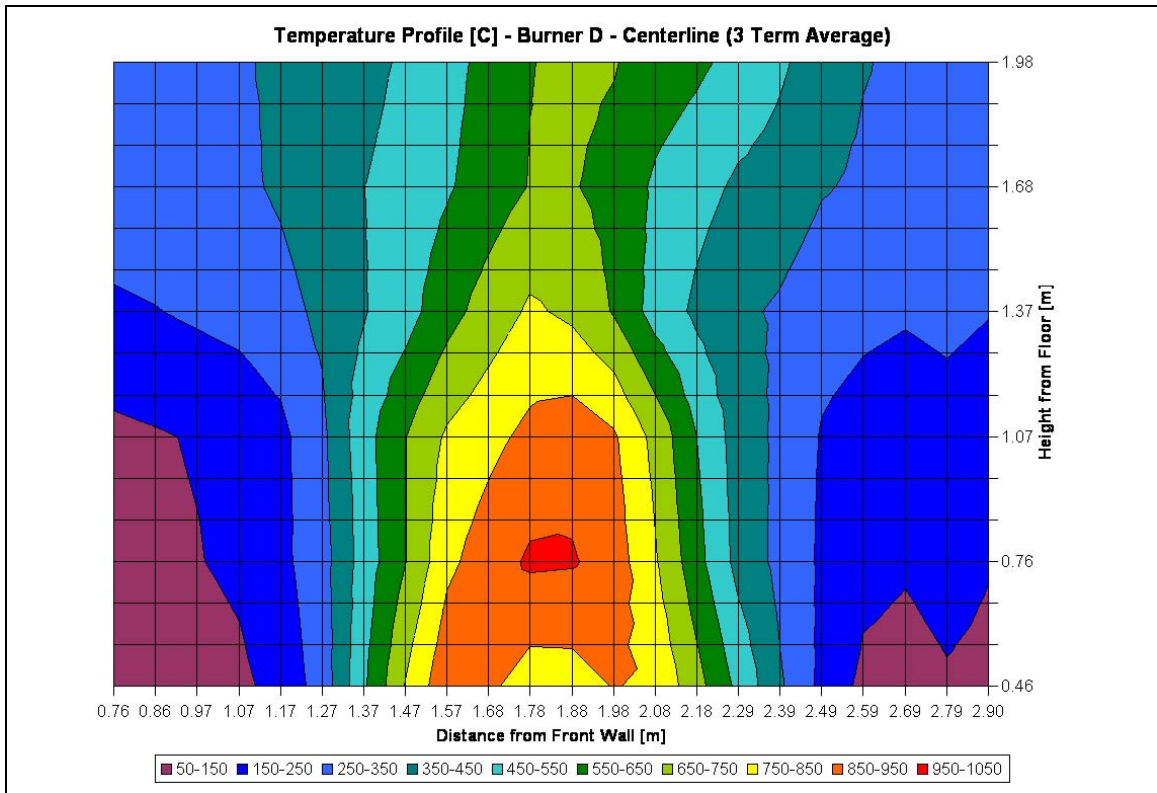


Figure 4-48: Temperature Profile - Burner D - Centerline – Three-term Average

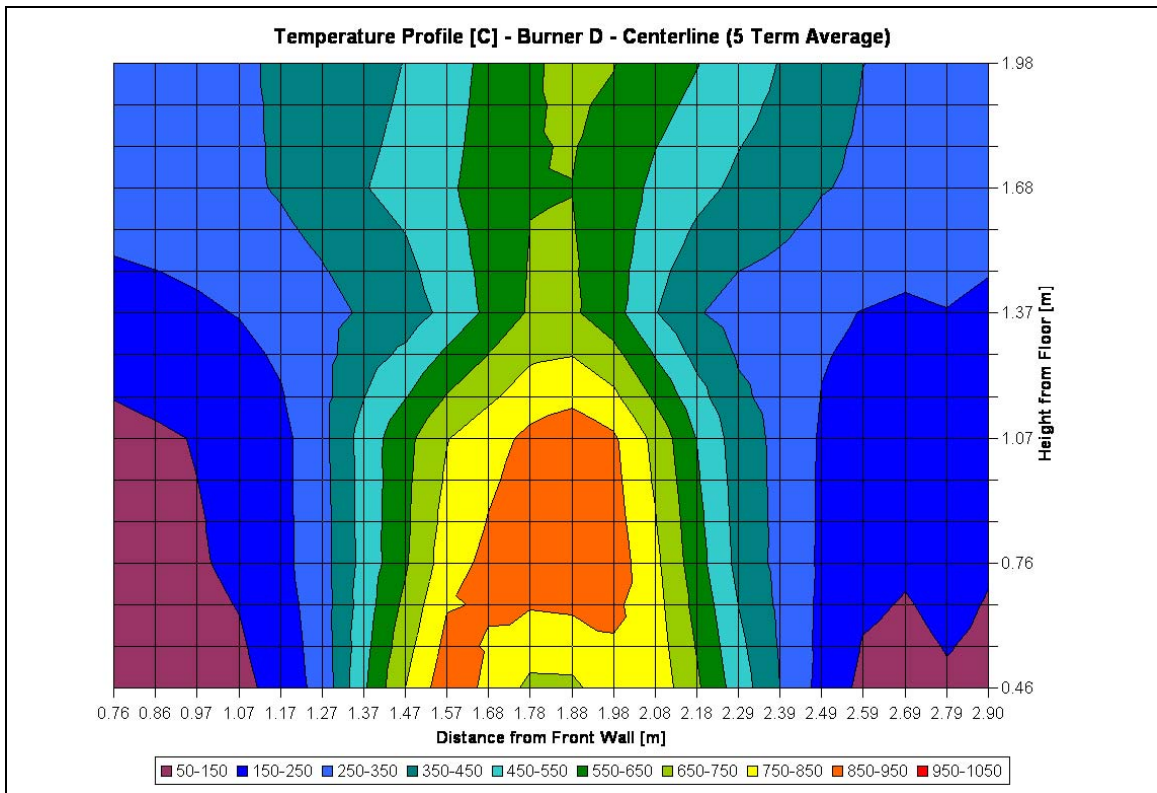


Figure 4-49: Temperature Profile - Burner D - Centerline – Five-term Average

The right side maximum temperature profile in Figure 4-50 has values between 79 and 911°C. The three-term average in Figure 4-51 has values between 72 and 887°C. The five-term average in Figure 4-52 has values between 69 and 888°C.

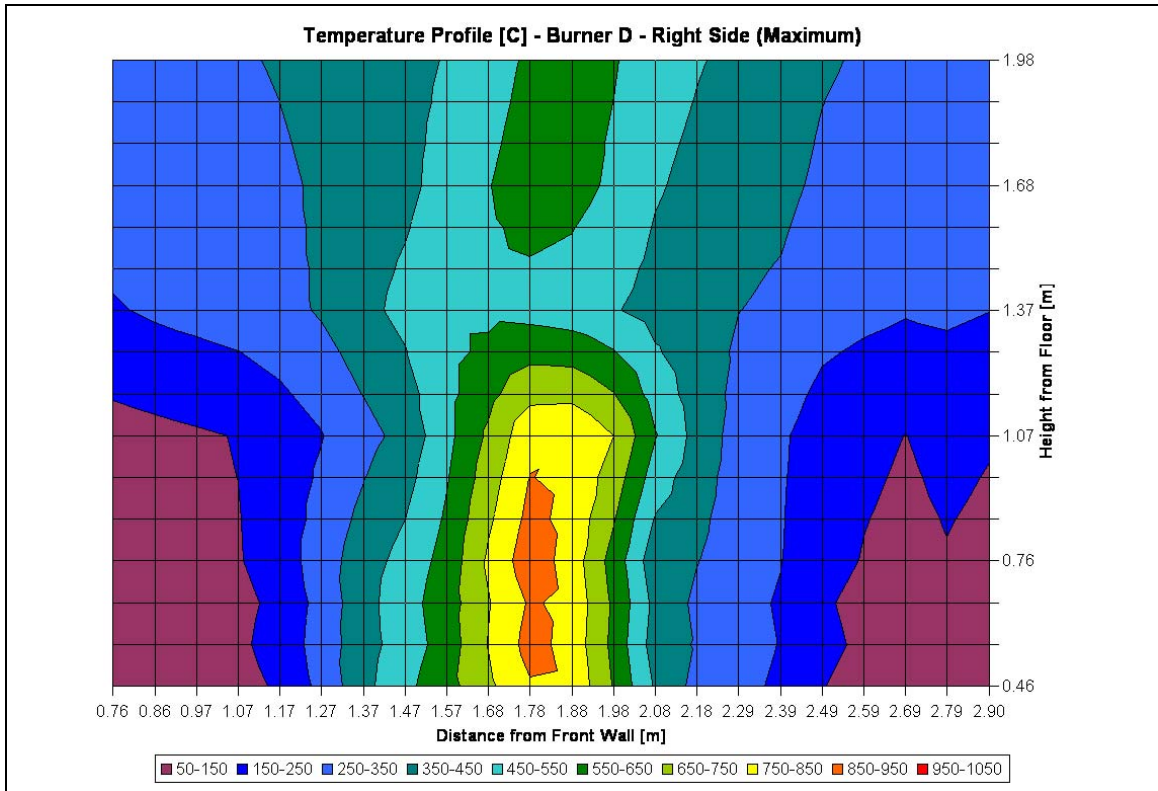


Figure 4-50: Temperature Profile - Burner D - Right Side – Maximum

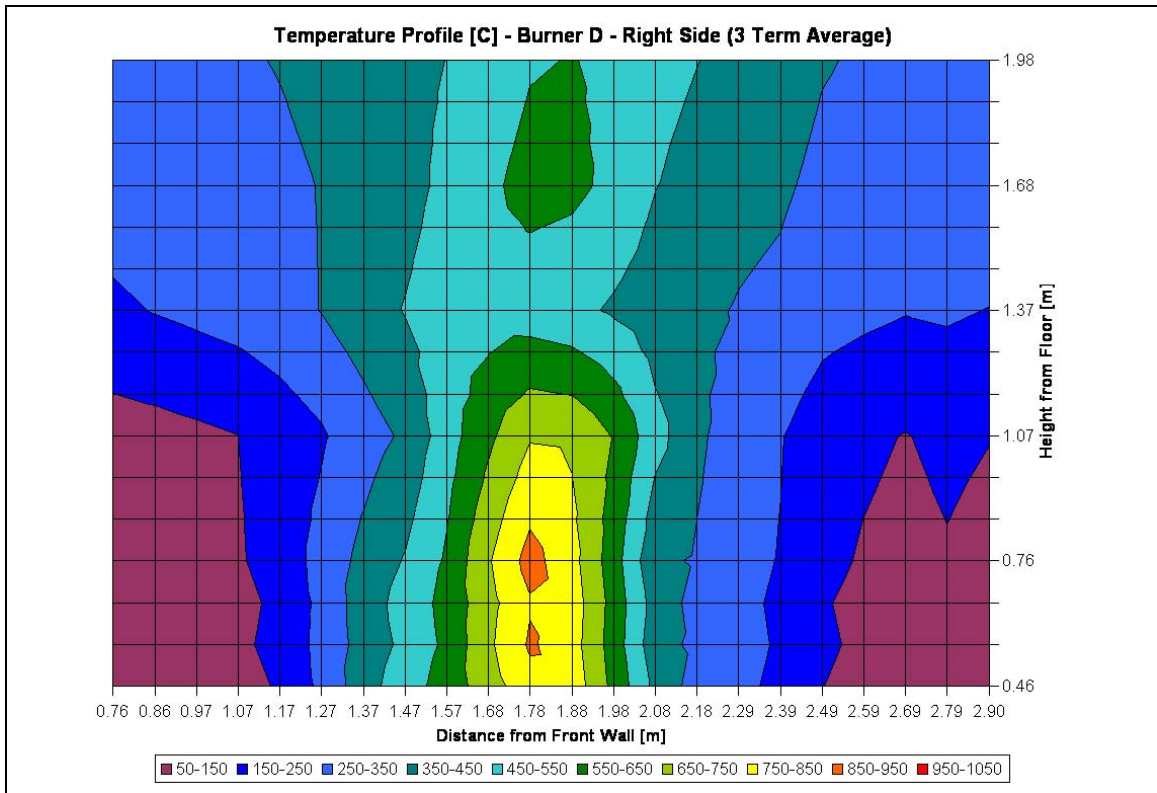


Figure 4-51: Temperature Profile - Burner D - Right Side – Three-term Average

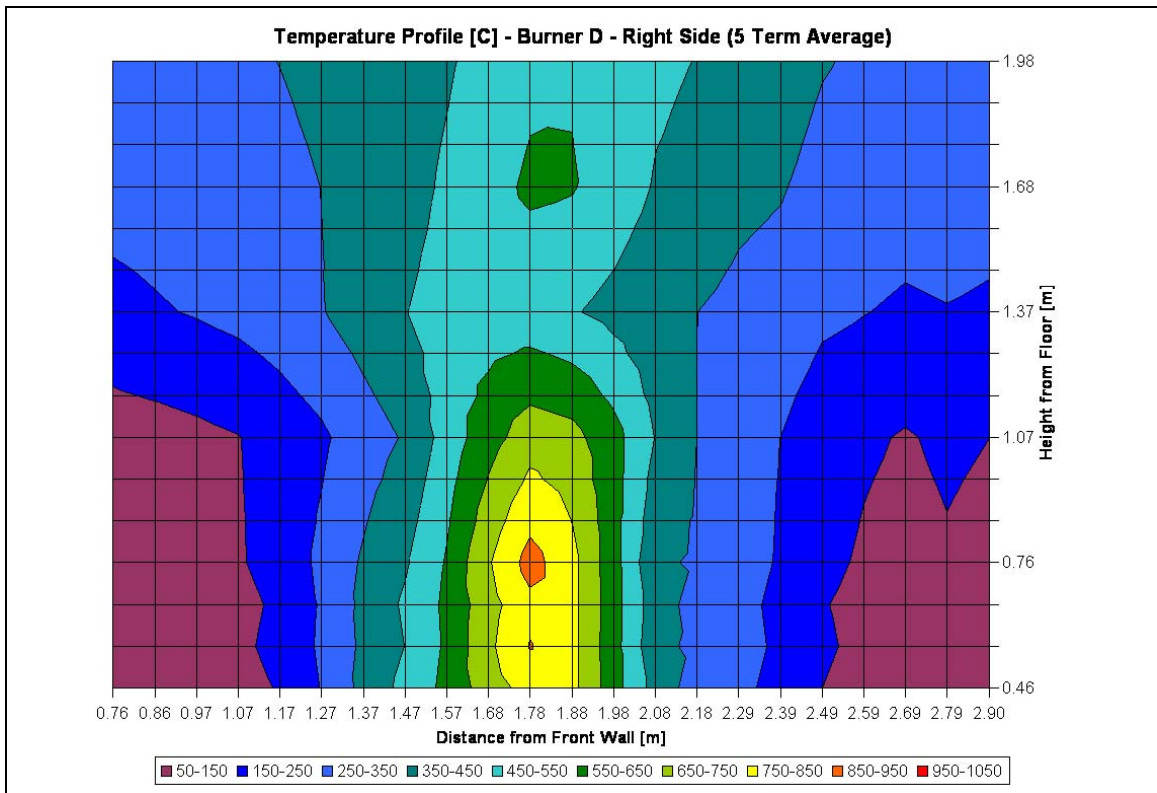


Figure 4-52: Temperature Profile - Burner D - Right Side – Five-term Average

4.6 Comparison

Once the data has been analyzed each burner configuration must be compared. Each scenario produces different fire environments that could be used to compare against existing test methods. The sections below outline the flux and temperature profiles for the four different burner configurations.

4.6.1 Flux

The left and right profiles have very similar characteristics and the measurements are within 10 kW/m^2 of each other on each side. This difference can be attributed to several issues, such as the position of the gage, the angle of the gage face and control of supply air. The gage was rotated by an apparatus so that each measurement was generally in the same position front to back within the burn room. The angle of the gage was nearly impossible to verify at some points. When the gage was directly in the flames, or completing the back measurement, the gage was usually not visible. This meant it could not be verified that the gage was parallel to the walls. There was a large requirement of supply air since the exhaust system exhausted $7.08 \text{ m}^3/\text{s}$ (15,000 cfm) each test day provided varying weather conditions. These varying weather conditions could of affected the differences since each data location was a point measurement.

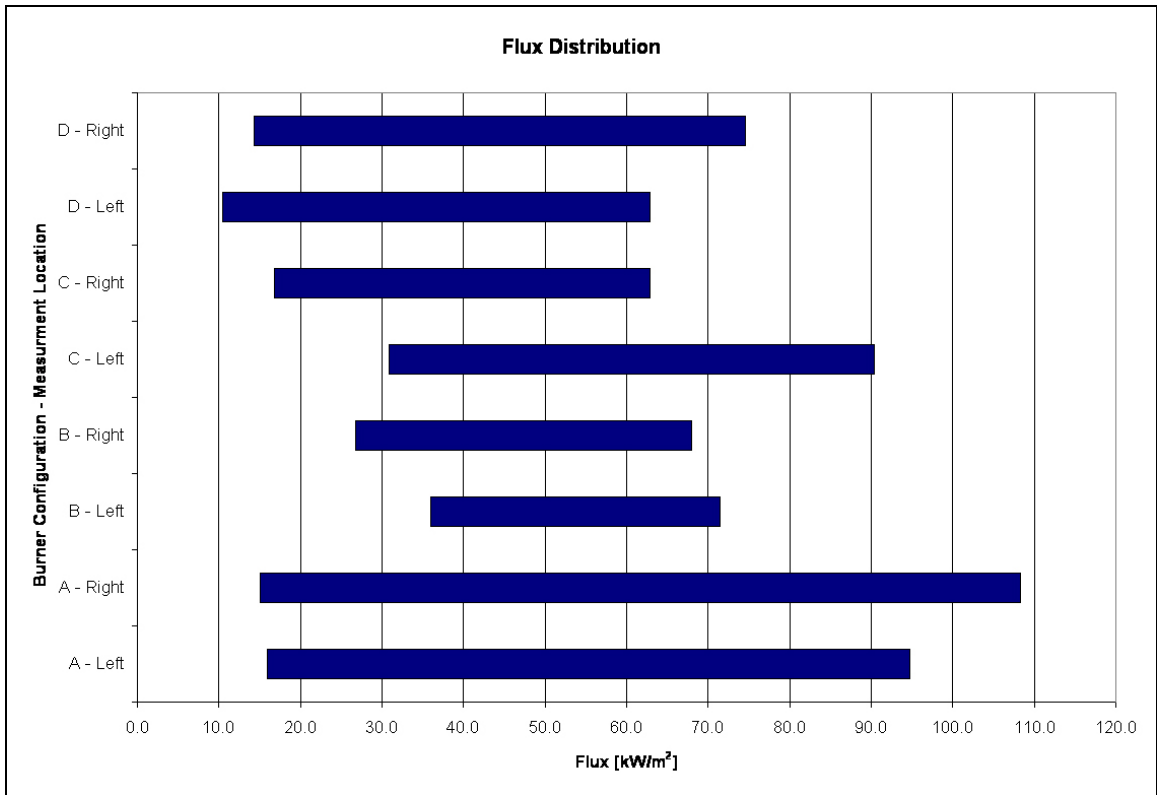


Figure 4-53: Flux Distribution, minimum and maximum limits

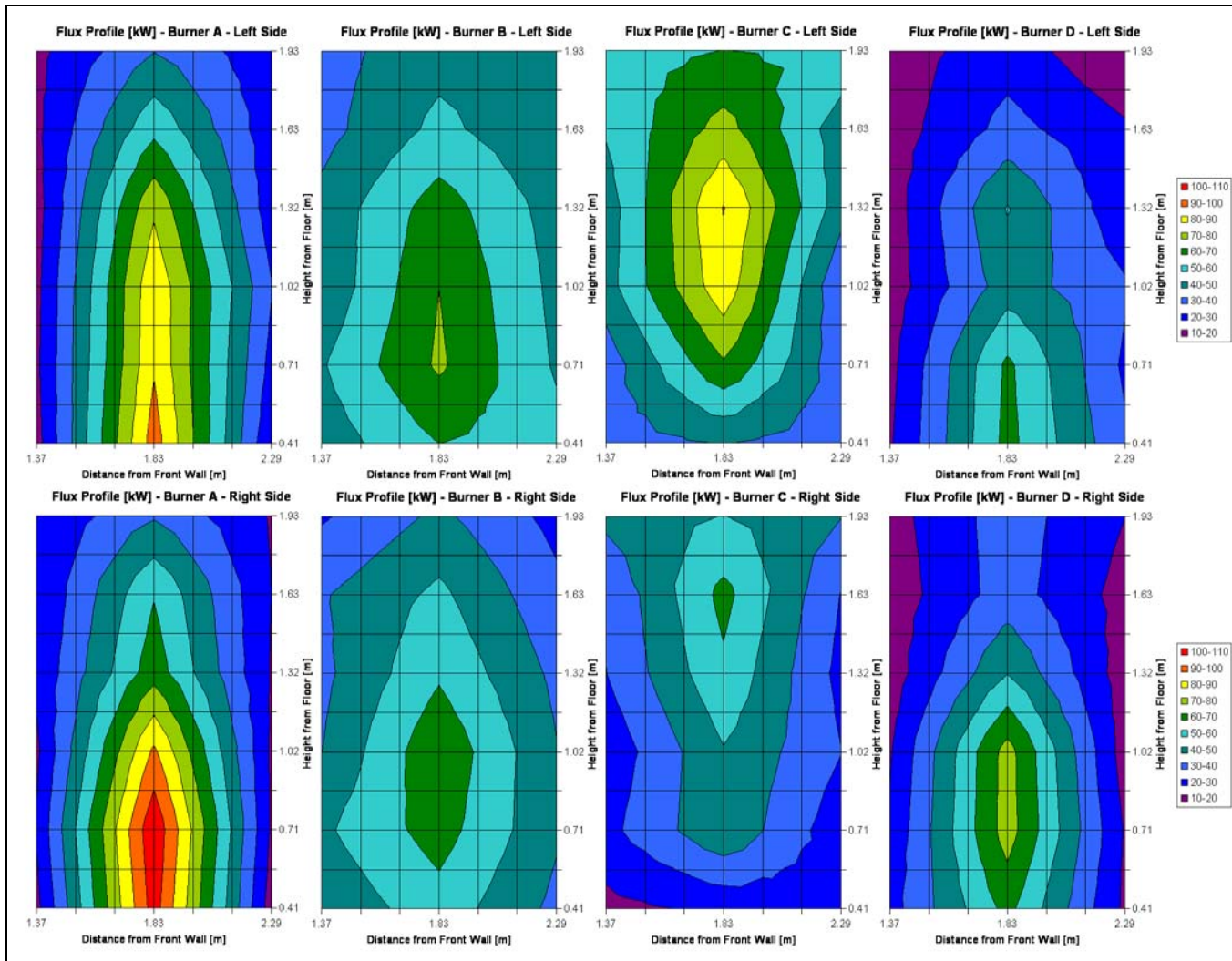


Figure 4-54: Comparison of flux distribution

4.6.2 Temperature

The temperature limits for burner configuration A, C and D are very similar, while the surface temperature profile is very different. Burner A has a 0.20 m (8 in) width that applies extreme temperatures over the travel path of the mannequin. Burner configuration B does not produce the extreme temperatures which are common to direct flame exposure. Burner configuration C produces the most extreme conditions and severe temperatures over 0.61 m (24 in). Burner configuration D produces temperatures that are balanced on the left and right while slightly higher along the centerline. These slight changes to burner positions greatly change the fire conditions while the gas flow remains constant.

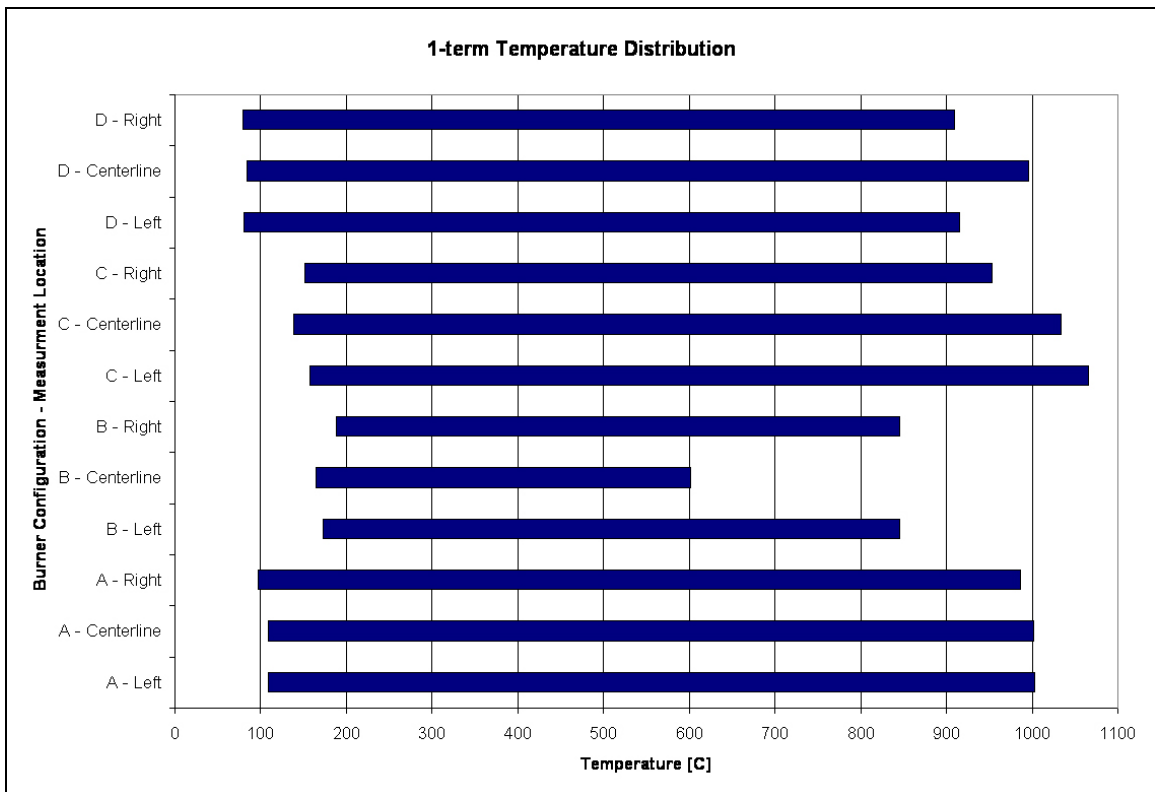


Figure 4-55: 1-term average temperature comparison, minimum and maximum limits

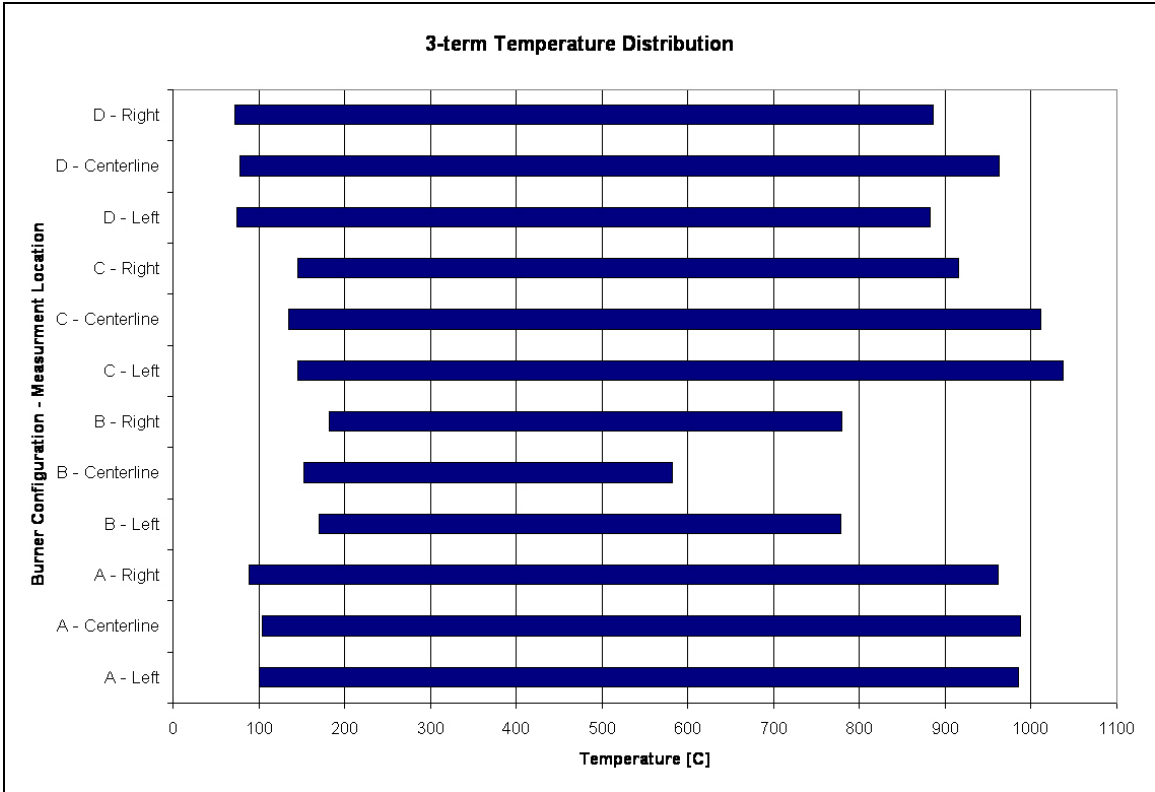


Figure 4-56: 3-term average temperature comparison, minimum and maximum limits

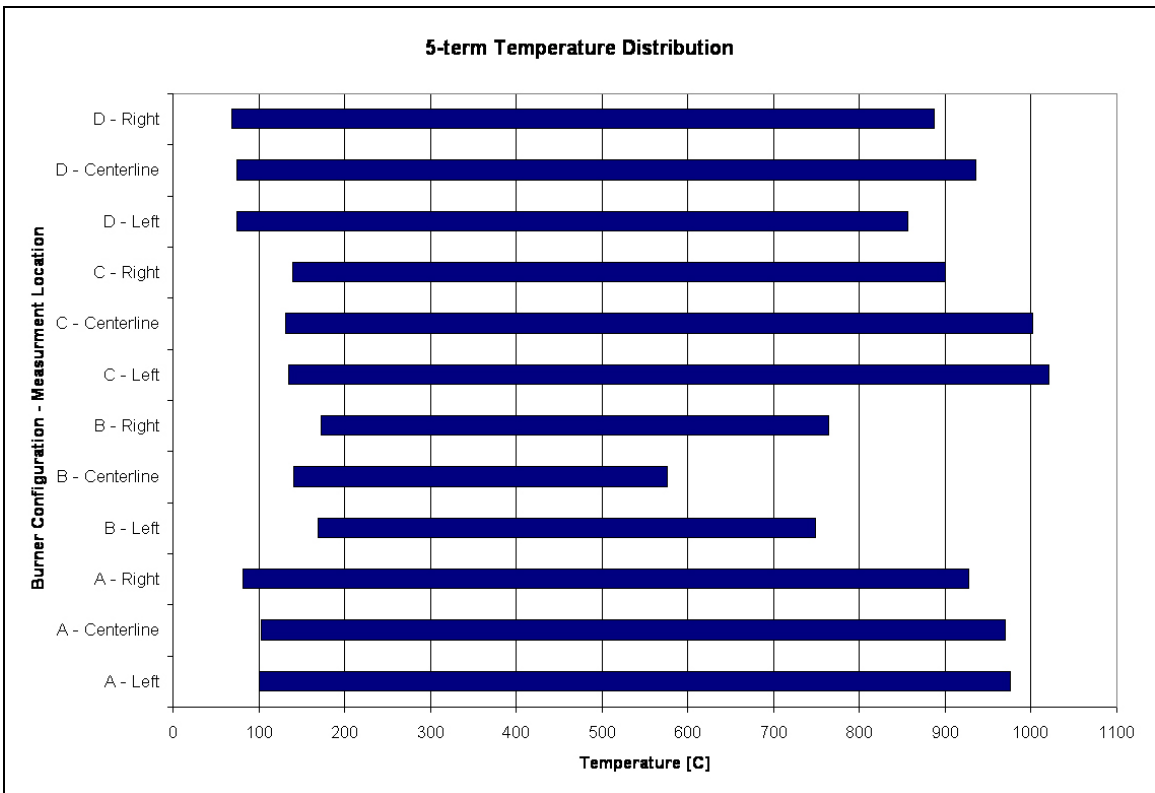


Figure 4-57: 5-term average temperature comparison, minimum and maximum limits

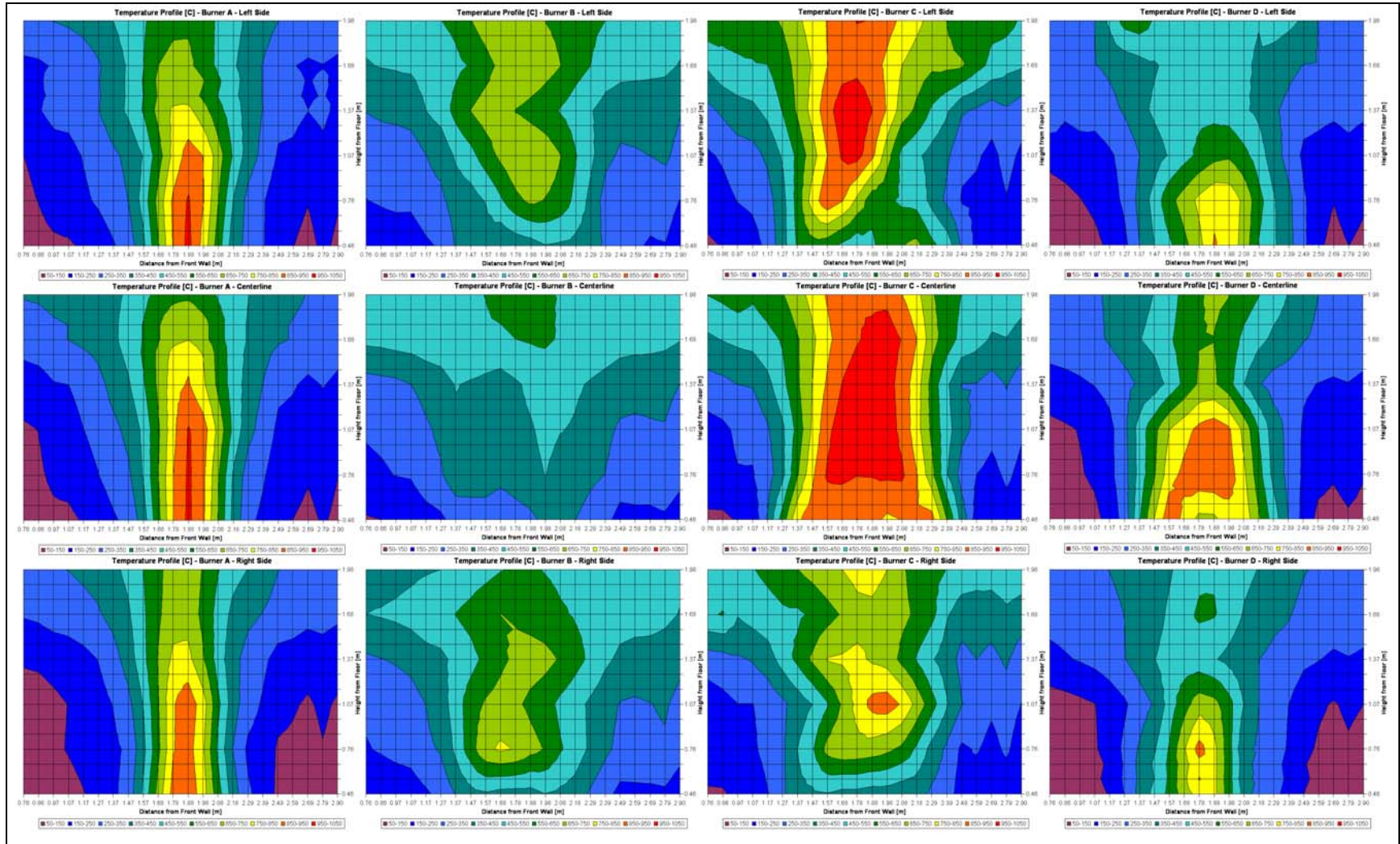


Figure 4-58: Temperature profile comparison

5 Conclusions

Data collected have shown that this prototype facility has the capabilities of simulating various fire scenarios that could be useful for testing the flammability of clothing. The fire scenarios were tested with the same propane flow rate and produced very different temperature and flux environments. The point flux measurements show that some of the fire environments tested are capable of producing the required average flux of 84 kW/m^2 , which will allow direct comparison to an existing standard. Burner configurations that did not produce this high flux could be adjusted by increasing the flow rate, so the flux would meet this requirement.

The major issue observed was the effect of propane pressure on the actual fire environments. Propane pressure is affected by temperature that was between 2 and 19°C (36 and 66°F) during testing. These temperature variations resulted in pressures between 59 and 102 psi. According to Richard Wojtaszek of the NCTRF, this is an issue at similar testing facilities, and has proven unavoidable. Any concern with the large fluctuation of pressure could be reduced by installing an underground propane tank or computer operated flow controllers.

The next step in evaluating the utility of the test facility would be to wire the mannequin with thermocouples and perform several tests with the mannequin clothed with clothing that has been tested with other test methods (ASTMF1930). This will allow for a comparison to existing standard tests. This preliminary testing may show flaws in existing test methods (Thermo-man and PyroMan) and design of clothing, which

would lead the way towards the implementation of this new testing method.

Hopefully this work will be used to develop a new test method for clothing flammability. This moving mannequin test is a more accurate representation of actual fire conditions that could be encountered while a person was escaping a life threatening fire situation. This testing method could also be used as a performance method of evaluation and comparison of products available to protect firefighters. The implementation of this full ensemble test will increase testing and certification costs but may reduce fire ground fatalities and injuries that are caused by burns.

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Appendix-A: Operation Manual – Contact Information

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Appendix-B: Operation Manual – Test Personnel Roles

- **Supervisor**
The supervisor of the testing would be a person familiar with the facility and be responsible for testing process
- **Operator**
The operator is stationed at the control station and opens and closes the propane flow valves.
- **Safety**
Positioned outside and watches the conditions on the rear of the room. If something does appear to be wrong this person immediately shuts down valve B. This person also inspects all personnel to verify that they are wearing appropriate safety equipment.
- **Igniter**
This person ignites the burners with cardboard and also monitors the conditions of the fire within the room. This person should be wearing complete thermal protective equipment and have an understanding of fire dynamics and basic knowledge of propane.
- **Data Collector / Aid**
This role performs a wide range of tasks, during ignition this person watches the igniter to ensure their safety. During testing this person operates the computer and monitors data collection.

Appendix-C: Operation Manual – Spring Start Up

1 Charging sprinkler system

- Close the garden hose and main sprinkler valve
- Remove water meter pit cover
- Close drain valve in meter pit
- Open buried water valve outside slowly (quarter turn ball valve, will need pipe with notch to reach valve)
- Stretch garden hose to outside drain
- Open garden hose valve
- Open main sprinkler water valve slowly
- When water pressure equalizes shut main sprinkler valve and allow water to drain from piping
- Repeat this process of filling sprinkler piping and allowing to drain until the water from the garden hose is clean

2 Propane gas delivery system

- Calibrate MSA Ultima Gas Sensor
 - Calibration kit is available from campus fire lab
 - Do not proceed until Gas Sensor reports 0 % LFL
- Inspect all propane hoses for damage or wear
- Connect propane tanks to supply hoses
- Connect nitrogen tank to regulator
- Leak check propane delivery system to 150 psi
 - Close all valves on control panel
 - Close Valve C (counter clockwise)
 - Close Valve B

- Open Valves A1, A2, A3 & A4
- Loosen (counter clockwise) nitrogen pressure regulation valve so there is no gas flow
- Open nitrogen tank valve
- Screw in (clockwise) nitrogen pressure regulation valve so that the pressure gauge at the top of the outside manifold is 150 psi
- Apply soapy water solution with brush to all fittings on the pressure side of Valve B
- Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
- Open Valve B
- Apply soapy water solution to connections at Valve B
- Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
- Apply soapy water solution to all fittings on the pressure side of Valve C
- Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
- Open Valve C
- Apply soapy water solution to all fittings on the pressure side of control panel
- Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
- Close valve on nitrogen tank
- Open Valve A5 to allow nitrogen to be removed from the system
- Loosen (counter clockwise) nitrogen pressure regulation valve so there is no pressure on diaphragm
- Close Valves C, B, A1, A2, A3, A4 & A5

3 Verify Operation of Equipment

- Ensure the test enclosure doors open freely

- Turn on Blower and verify proper operation
- Turn on Vaporizer and verify proper operation

Appendix-D: Operation Manual – Daily Testing Procedure (temperatures >4°C (40°F))

1 Record Test Information

- Date / Time: _____ / _____ / _____ : _____ AM / PM
- Test Goals: _____

2 Test Team

- Supervisor: _____
- Operator: _____
- Safety: _____
- Igniter: _____
- Data Collector / Aid: _____
- Visitors: _____

3 Record Weather Conditions

- Weather: Sunny Partly Cloudy Mostly Cloudy Rain Other: _____
- Temperature: _____ °F
- Wind: _____ MPH Direction: _____

4 Pre Test Procedures

- Remove combustibles from around test enclosure
- Sweep area around test room if needed
- Check radios to ensure proper operation
- Record MSA Ultima Gas Sensor _____ % LFL (should be zero)
- Turn on Vaporizer briefly to verify operation
- Leak check propane delivery system with 100 psi of Nitrogen
 - Close all valves on control panel
 - Close Valve C (counter clockwise)
 - Close Valve B
 - Open Valves A1, A2, A3 & A4
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no gas flow
 - Open nitrogen tank valve
 - Screw in (clockwise) nitrogen pressure regulation valve so that the pressure gauge at the top of the outside manifold is 100 psi
 - Apply soapy water solution with brush to all fittings on the pressure side of Valve B
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Open Valve B
 - Apply soapy water solution to connections at Valve B
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Apply soapy water solution to all fittings on the pressure side of Valve C
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Open Valve C

- Verify that the pressure gauge at the vaporizer is 100 psi
 - Apply soapy water solution to all fittings on the pressure side of control panel
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Close valve on nitrogen tank
 - Open Valve A5 to allow nitrogen to be removed from the system
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no pressure on diaphragm
 - Close Valves C, B, A1, A2, A3, A4 & A5
- Lay and charge garden hose
 - Charging propane delivery system
 - Open one propane tank slowly
 - Check to make sure there are no leaks
 - Open the valves on the other three propane tanks
 - Allow for the tanks to equalize
 - Open Valve B
 - Record pressure on the outside manifold: _____ psi
 - Turn on vaporizer and allow temperature to reach set point
 - Call ADT at (888) 238-2666
 - System Phone Number: (508) 831-5967
 - Place the system on test mode until: _____ : _____ AM / PM
 - Open the garage doors on the North and West side of the building
 - Check that the trap is closed to ensure that the air flow is evenly dispersed
 - Setup video camera and monitor so that the operator can see the fire
 - Verify operation of track system

- Verify data collection system
- All personnel must wear appropriate safety equipment
 - All personnel should wear firefighters coat and pants, gloves, boots, and head and eye protection
- Proceed with test once vaporizer has reached set point

5 Test Procedures

- Ignition sequence
 - Open Valve C
 - Ignite a piece of cardboard in each group of burners
 - The fire will only light burners that are touching
 - Use a propane torch to ignite cardboard
 - When igniter exits the room the operator then opens the ignition valve for each burner that has a piece of burning cardboard
 - If cardboard extinguishes before propane is ignited the ignition valve for that burner should be turned off
 - Once other burners are ignited the igniter must enter the room and ignite another piece of cardboard
 - Once the burners with cardboard are ignited the other burners ignition valve may be opened
- Perform desired test
 - Open test valves allow the room to reach steady state
 - Close test valves when testing is not in operation

6 Post Test Shutdown

- Shut down propane delivery system
 - Close valves on tanks
 - Allow fires to decrease in size

- Open test valves on control panel
 - Open the nitrogen tank
 - Set the nitrogen regulator to 5 psi
 - Open valves A1, A2, A3 & A4
 - Allow lines to be purged of propane (bluish flames will flicker when the propane is almost purged)
 - When flames are out close nitrogen tank
 - Close all control valves
 - Close valves C, B, A1, A2, A3 & A4
- Turn off vaporizer
 - Open doors to the test room and allow room to cool
 - Open garage and allow smoke to dissipate
 - Allow the room is cool and smoke has dissipated from the warehouse
 - You should be able to hold your hand on the gypsum wall board inside the room
 - Shut down exhaust system
 - Discharge and store garden hose
 - Close test room doors
 - Close warehouse garage doors
 - Close and lock propane storage shed

Appendix-E: Operation Manual – Daily Testing Procedure (temperatures <4°C (40°F))

1 Record Test Information

- Date / Time: _____ / _____ / _____ : _____ AM / PM
- Test Goals: _____

2 Test Team

- Supervisor: _____
- Operator: _____
- Safety: _____
- Igniter: _____
- Data Collector / Aid: _____
- Visitors: _____

3 Record Weather Conditions

- Weather: Sunny Partly Cloudy Mostly Cloudy Rain Other:

- Temperature: _____ °F
- Wind: _____ MPH Direction: _____

4 Pre Test Procedures

- Remove combustibles from around test enclosure
- Sweep area around test room if needed
- Check radios to ensure proper operation
- Record MSA Ultima Gas Sensor _____ % LFL (should be zero)
- Turn on Vaporizer briefly to verify operation
- Leak check propane delivery system with 100 psi of Nitrogen
 - Close all valves on control panel
 - Close Valve C (counter clockwise)
 - Close Valve B
 - Open Valves A1, A2, A3 & A4
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no gas flow
 - Open nitrogen tank valve
 - Screw in (clockwise) nitrogen pressure regulation valve so that the pressure gauge at the top of the outside manifold is 100 psi
 - Apply soapy water solution with brush to all fittings on the pressure side of Valve B
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Open Valve B
 - Apply soapy water solution to connections at Valve B
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Apply soapy water solution to all fittings on the pressure side of Valve C
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Open Valve C

- Verify that the pressure gauge at the vaporizer is 100 psi
 - Apply soapy water solution to all fittings on the pressure side of control panel
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Close valve on nitrogen tank
 - Open Valve A5 to allow nitrogen to be removed from the system
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no pressure on diaphragm
 - Close Valves C, B, A1, A2, A3, A4 & A5
- Lay and charge garden hose
 - Charging propane delivery system
 - Open one propane tank slowly
 - Check to make sure there are no leaks
 - Open the valves on the other three propane tanks
 - Allow for the tanks to equalize
 - Open Valve B
 - Record pressure on the outside manifold: _____ psi
 - Turn on vaporizer and allow temperature to reach set point
 - Call ADT at (888) 238-2666
 - System Phone Number: (508) 831-5967
 - Place the system on test mode until: _____ : _____ AM / PM
 - Open the garage doors on the North and West side of the building
 - Check that the trap is closed to ensure that the air flow is evenly dispersed
 - Setup video camera and monitor so that the operator can see the fire
 - Verify operation of track system

- Verify data collection system
- All personnel must wear appropriate safety equipment
 - All personnel should wear firefighters coat and pants, gloves, boots, and head and eye protection
- Proceed with test once vaporizer has reached set point

5 Test Procedures

- Ignition sequence
 - Open Valve C
 - Ignite a piece of cardboard in each group of burners
 - The fire will only light burners that are touching
 - Use a propane torch to ignite cardboard
 - When igniter exits the room the operator then opens the ignition valve for each burner that has a piece of burning cardboard
 - If cardboard extinguishes before propane is ignited the ignition valve for that burner should be turned off
 - Once other burners are ignited the igniter must enter the room and ignite another piece of cardboard
 - Once the burners with cardboard are ignited the other burners ignition valve may be opened
- Perform desired test
 - Open test valves allow the room to reach steady state
 - Close test valves when testing is not in operation

6 Post Test Shutdown

- Shut down propane delivery system
 - Close valves on tanks
 - Allow fires to decrease in size

- Open test valves on control panel
 - Open the nitrogen tank
 - Set the nitrogen regulator to 5 psi
 - Open valves A1, A2, A3 & A4
 - Allow lines to be purged of propane (bluish flames will flicker when the propane is almost purged)
 - When flames are out close nitrogen tank
 - Close all control valves
 - Close valves C, B, A1, A2, A3 & A4
- Turn off vaporizer
 - Open doors to the test room and allow room to cool
 - Open garage and allow smoke to dissipate
 - Allow the room is cool and smoke has dissipated from the warehouse
 - You should be able to hold your hand on the gypsum wall board inside the room
 - Shut down exhaust system
 - Close test room doors
 - Close warehouse garage doors
 - Close and lock propane storage shed
 - Drain sprinkler system
 - Shut off garden hose
 - Stretch garden hose outside and remove garden hose
 - Close 2-inch ball valve for the sprinkler system
 - Open garden hose valve allow water to drain from the system
 - Disconnect and store garden hose

- Leave the valve for the garden hose open
- Plug in heat tape for sprinkler system

Appendix-F: Operation Manual – Changing Propane Tanks

- 1 Changing Propane tanks
 - Verify propane gas system was shut down properly
 - Disconnect regulator from Nitrogen tank
 - Disconnect hoses from propane tanks (the fittings are reverse threaded)
 - Remove empty tanks
 - Place full tanks into place
 - Connect hoses to propane tanks
 - Reconnect regulator to Nitrogen tank
 - Leak check propane delivery system with 100 psi of Nitrogen to Valve B
 - Close Valve B
 - Open Valves A1, A2, A3 & A4
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no gas flow
 - Open nitrogen tank valve
 - Screw in (clockwise) nitrogen pressure regulation valve so that the pressure gauge at the top of the outside manifold is 100 psi
 - Apply soapy water solution with brush to all fittings on the pressure side of Valve B
 - Look for expanding soap bubbles and listen for an hissing to indicate a leak, repair if leak exists
 - Close valve on nitrogen tank
 - Open Valve A5 to allow nitrogen to be removed from the system
 - Unscrew (counter clockwise) nitrogen pressure regulation valve so there is no pressure on diaphragm

- Close Valves A1, A2, A3, A4 & A5

Appendix-G: Operation Manual – Fall Winterization

- 1 Disconnect Propane Delivery System
 - Verify propane gas system was shut down properly
 - Disconnect regulator from Nitrogen tank
 - Disconnect hoses from propane tanks
 - Hang hoses to relieve stress
- 2 Winterize Sprinkler System
 - Close buried valve
 - Use pipe with notch and vice grips
 - The valve is a ball valve and needs a quarter turn to close
 - Run garden hose outside and allow system to drain
 - Open drain valve in meter pit to allow water to drain
 - Leave valve open all winter
- 3 Computer
 - Disconnect power to computer
 - Place plastic over computer incase water leaks
- 4 General
 - Remove all supplies that must be kept above freezing
 - Store in a location that will be heated
 - Perform general clean up of facility

Appendix-H: Operation Manual – Relining Procedure

- All personnel must wear head and eye protection
- Cover burners with scrap plywood
- Remove outer layer of gypsum wall board from the soffits
- Lower Track System
 - Place support braces at the front and back of the room
 - Place scrap piece of 2x4 under track
 - Remove the six supporting bolts
 - Two at the front of the room
 - Two are at the back of the room
 - One is a third of the way from the front
 - One is two thirds of the way from the front
 - Lift track and remove scrap 2x4 piece from each support to lower track
- Remove the outer layer of gypsum wall board
- Clean up and remove old gypsum wall board from area
- Verify that all screws have been removed
- Cut gypsum wall board to the following dimensions
 - Two sheets lengthwise so there are four pieces that measure 2'x8'
 - Cut one sheet into quarters so there are four pieces that measure 2'x4'
- Install gypsum wall board on the left and right walls
 - Use 2-1/2" coarse thread drywall screws
 - Install two cut pieces on the back end of the room
 - Install two full sheets of gypsum wall board one on each side of the room

- Install two cut pieces on the front end of the room
- Install gypsum wall board on the ceiling with the seams tight on the left and right walls
 - Use 2-1/2" coarse thread drywall screws
 - Install two cut pieces on the ceiling on the back of the room
 - Install two full sheets of gypsum wall board on the ceiling
 - Install two cut pieces on the ceiling on the front of the room
- Tape and fill seams with joint compound
- Cover screws with joint compound
- Let joint compound harden overnight
- Raise track and bolt into place
 - Lift track and place scrap 2x4 piece support track in place
 - Replace and tighten the six supporting bolts
 - Two at the front of the room
 - One is a third of the way from the front
 - One is two thirds of the way from the front
 - Two are at the back of the room
 - Remove support braces at the front and back of the room
- Install gypsum wall board on the front and back walls
 - Use 2-1/2" coarse thread drywall screws
 - Install the four soffits
 - Install the four doors
- Verify the doors open freely
- Tape and fill seams with joint compound
- Cover screws with joint compound

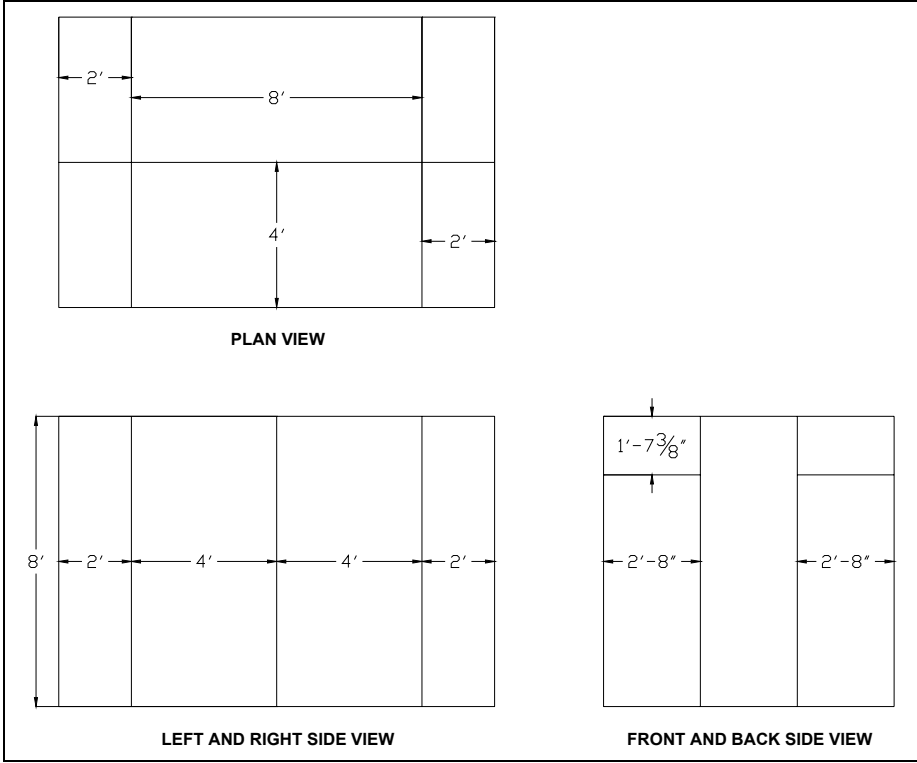


Figure H-1: Layout of installation of gypsum wall board