Flux Mapping of Radiant Electric Heaters: Repeatability Considerations

June 2008

Directorate for Engineering Sciences
Randy Butturini, PE
Electrical Engineer

Mai Ngo
Electrical Engineer

Executive Summary

In 2007, U.S. Consumer Product Safety Commission (CPSC) staff conducted tests of portable electric heater samples to measure their radiant flux. Radiant flux measurements have the potential to be quicker, simpler, less expensive, and more sensitive than the draping tests currently used in the voluntary standards. The intrinsic variability of the draping materials is eliminated, and quantitative, rather than qualitative data is generated during the test.

This report summarizes radiant flux measurements made on four portable electric heaters with a simple test fixture. Good repeatability was achieved with heater-sensor alignment and positioning achieved by hand with tools no more sophisticated than a tape measure and a carpenter's square.

The report includes analyses of multiple data sets from each heater using three measures: position and magnitude of the maximum reading, the distribution of the differences between two data sets, and a measure of total relative difference between the data from repeated tests. Means to lower the observed variation are listed.

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1. Introduction

In 2007, U.S. Consumer Product Safety Commission (CPSC) staff conducted tests of portable electric heater samples to measure their radiant flux. A radiant electric heater is one whose primary means of heating is the emission of infrared radiation. Typically, the heating elements operate at 400 °C or greater in order to generate up to 1500 watts of infrared power. Underwriters Laboratories (UL) established a Task Group to investigate the utility of flux sensing for radiant electric heaters. Flux is defined as the radiant power per unit area, watts per square centimeter in our case. Prior CPSC staff reports[1,2] measured the flux necessary to ignite common combustibles. Flux measurements on radiant electric heaters were demonstrated in 2005[3].

Many of the performance tests in UL 1278 (*Movable and Wall- or Ceiling-Hung Electric Room Heaters*) and UL 2021 (*Fixed and Location-Dedicated Electric Room Heaters*) have practical inconveniences associated with them. The Vertical Wall Test (Section 42.6 in UL 2021 and Section 41.5 in UL 1278) may require several repetitions of a 7-hour test to establish the distance at which the maximum heating on the test material occurs. The materials used in draping tests may be difficult to obtain (such as cattle hair felt used in Section 42.10.1 of UL 2021 and Section 41.8.2 of UL 1278). Further, testing materials of different ages, stored in different locations, or manufactured by different suppliers, may perform differently when subjected to the same conditions. Lastly, the performance tests in UL 2021 and UL 1278 are qualitative in nature, and depend upon the tester discerning glowing, emission of embers, molten metal, or flaming. There is no way to determine "how close" a particular heater design comes to exceeding the limits in the standard.

Radiant flux measurements have desirable features from the standpoint of voluntary standards product evaluation. Flux sensors are readily available and not overly expensive. Mapping the radiant flux from a heater is a straightforward process that requires neither expensive fixtures nor long test times. Sensor calibration eliminates the variables associated with the test materials. Flux measurements are quantitative, allowing easy comparison to any numerical limits and quick determination of any margin between the highest measured value and a maximum allowed flux.

The 2005 study into radiant flux measurements reported measurements made on four heaters at 2, 5, and 10 cm from the heater face. A flux map for each heater was developed by measuring the radiant flux across the heater face at each distance. The intent of this study is to determine if there are practical difficulties involved in making repeatable flux measurements on radiant electric heaters. This follows up the earlier study that established that such measurements are possible. The objective of this study is to provide additional data to the UL Standards Technical Panel 1042 task group examining the potential uses of radiant flux measurements in voluntary standards development. The study intends to determine the relative ease by which repeatable measurements can be made. If a test were developed for inclusion into a voluntary standard that measured the flux of a candidate heater, the uncertainty of that measurement would need to be established. Demonstrating the repeatability establishes confidence that a single measurement rather than a series of measurements is sufficient for evaluation. CPSC staff intends to continue working with the task group in evaluating the utility of using flux measurements to evaluate electric heaters. This report examines flux measurements made at no clearance to the heater (0 cm from the heater face.

2. Method

2.1 Heater

Four portable electric heaters not used in the previous experiments were obtained for testing. Each heater model was listed to UL 1278 and had visibly-glowing heating elements when in use. All of the heaters (Heater A through Heater D) had a nominal power rating of 1500 watts. For heaters with fans, the fan is always on while the elements are energized.

The heaters chosen for testing were either ‘box-type’ horizontally-shaped units or a dish-style unit (Heater C). Vertical radiant heaters were not tested for practical reasons. The orientation of the heating element has no impact on its radiant emission. The limited vertical range of the sensor mounting would make testing of some vertical units incomplete. Further, vertical heaters tend to be taller (30 to 32 inches) than horizontal heaters are wide. That would tend to result in a lower flux magnitude spread out over a longer heating element to radiate the same amount of power.

Sometimes, the heater was raised on a wooden pedestal. This was to assure a larger range of vertical sensor positioning by allowing the sensor element to be placed below the heating elements during testing. Radiant electric heaters transfer the vast majority of their energy consumption into the environment as radiant electromagnetic waves, with a small amount of convective heat transfer through the heater exterior. Heat transfer through the heater’s feet is insignificant relative to the radiant flux.

The testing area was a large room with cubicle walls approximately 1.7 meters (5.5 feet) high. Thus, the heater output would quickly dissipate from the testing area and not noticeably affect the ambient temperature. The ambient conditions in the testing area were that of an ordinary office environment. Temperature and humidity were controlled by the central HVAC system. Other than possibly activating the heater’s thermostat and disconnecting electric power to the heating elements, ambient air temperatures have little effect on radiant power output.

Unconditioned electrical power was used to energize the heaters during testing. Typically, the voltage available for heater power was a little less than 125 VAC RMS. That tended to lower the total power consumption of the heater during testing. Each heater’s current was measured before testing. On some units, the nominal current changed during the testing period. Comparisons were only made between data sets in which the heater current was approximately the same. Because flux measurements were only examined for their repeatability and not for their magnitudes, input electrical power slightly below nominal was considered acceptable.

2.2 Sensor

A commercially-available radiant flux sensor was used for testing. The device consists of a Schmidt-Boelter element inside a metal housing. Two tubes for cooling water are located in the rear of the sensor. Schmidt-Boelter sensors depend upon a temperature difference between the portion of the face with high emissivity and the portion with low emissivity to measure radiant flux. Cooling water is used to keep the sensor from equilibrating thermally when placed in front of a heater. Figure 1 shows a picture of the heat flux sensor. In addition to the Schmidt-Boelter sensor, a thermocouple inside the housing was monitored to assure that the device body did not overheat during testing.

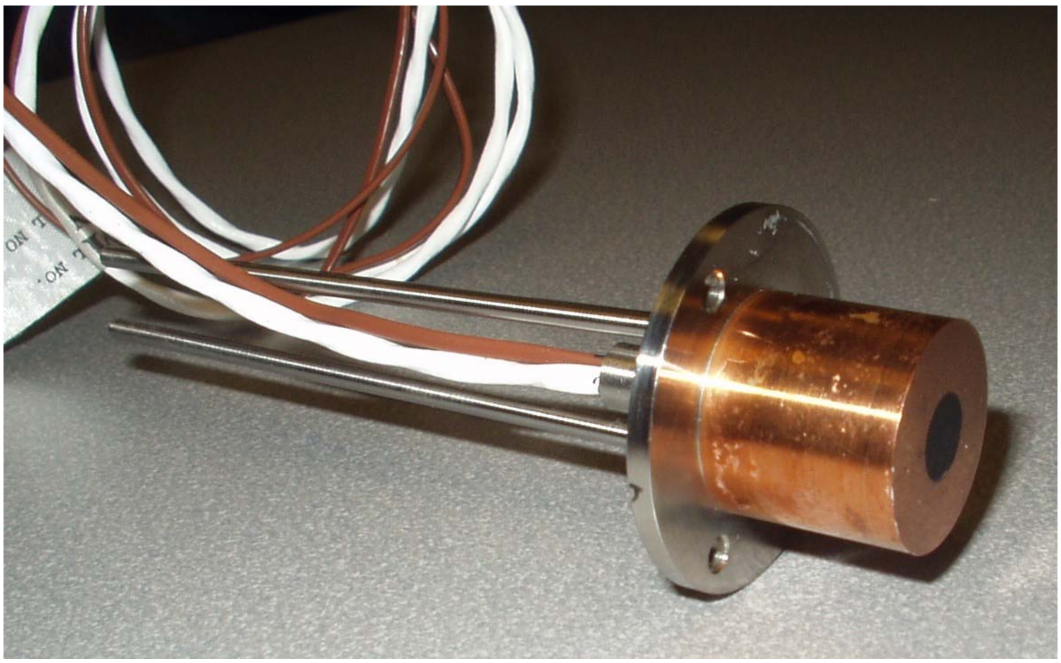

Figure 1: Heat Flux Sensor

2.3 Sensor Positioning

The radiant flux emitted from a heater was mapped with the sensor. This consisted of positioning the sensor at regularly-spaced positions in front of the heater (operating at steady-state conditions), and recording the sensor output. The readings were plotted with standard spreadsheet software to create a three-dimensional surface of flux magnitude vs. position.

Simplicity was emphasized in the development of the testing apparatus. A grid was drawn by hand on a sheet of plywood as a reference for X and Z measurements. "X" is the horizontal direction (left to right) across the front of the heater. "Z" is the distance away from the front of the heater. "Y" is the vertical distance (bottom to top). A test stand for force meters was adapted to hold the flux sensor. By turning the crank at the stand top, the sensor could be raised or lowered. A metric tape measure was used to measure vertical distances. A carpenter's square was employed to position the heater face parallel to the grid. Figure 2 illustrates the axis system.

Moving the heavy stand during data collection proved difficult during early testing. Thus, a set of painted metal rails was placed underneath the stand. The resultant low-friction interface allowed easy stand positioning in the X direction. In order to keep the sensor from rotating about the Y axis (Θ_y), a leveling bar was clamped to the plywood sheet parallel to the X grid lines. The bar was positioned such that, when the rear of the test stand base was placed against it, the sensor face would be at the Z = 0 cm position. For each heater, an arbitrary location was selected on the heater to define X = 0. The carpenter's square was used to align the X = 0 position on the heater with the X = 0 position on the grid. The Y = 0 position was selected such that the first readings would be below the heater grill. For every heater tested in the 2005 study, the magnitude of the radiant flux decreased with distance from the heater. Thus, the highest (and most interesting) flux values are at the closest distances. Also, since draping is a potential abnormal operating condition, voluntary standards tests are more likely to address the flux that might be experienced by a fire indicator at the grill surface. Thus the Z = 0 position was chosen for testing. The Z = 0 position was that at which the sensor would just clear the front face of the heater. Often, heater grills would bow slightly. The Z = 0 position was chosen so that the sensor face would not be touched by the furthest Z extension of the grill. Many heater grills tilt backwards so that the majority of the radiant flux is directed upwards as well as outwards. During testing, the sensor was moved vertically to acquire measurements at different "Y" positions (up and down). Thus, for a tilted grill, upper measurements in the "Y" direction increased the gap between the sensor and the grill. Generally, this would tend to lower the flux magnitude recorded. This effect can be seen in the flux maps where the higher magnitude readings are at the heater bottom.

Some testing was performed with the heater tilted forward so that the grill was vertical, and the distance from the grill to the sensor was kept constant. The recorded flux magnitudes were slightly higher at the upper "Y" positions than when the heater was in its nominal position. Tilting the heater forward is an abnormal operating condition. Testing results from heaters in this orientation were not included in the report. Figure 3 shows the full system setup.

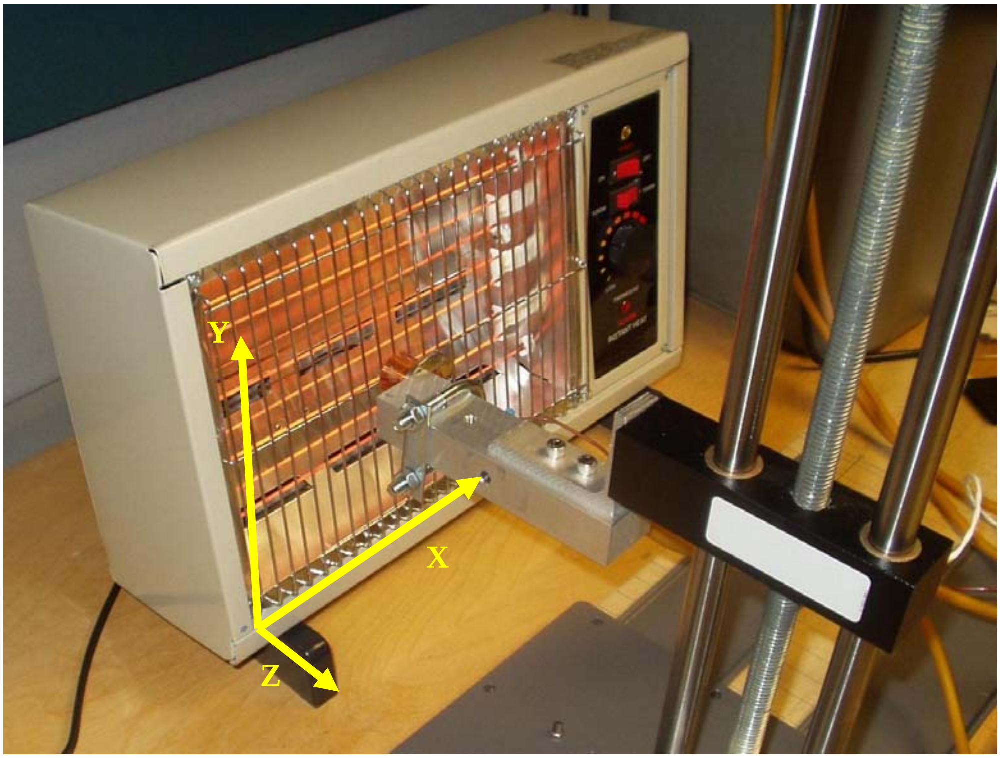

Figure 2: Axis System

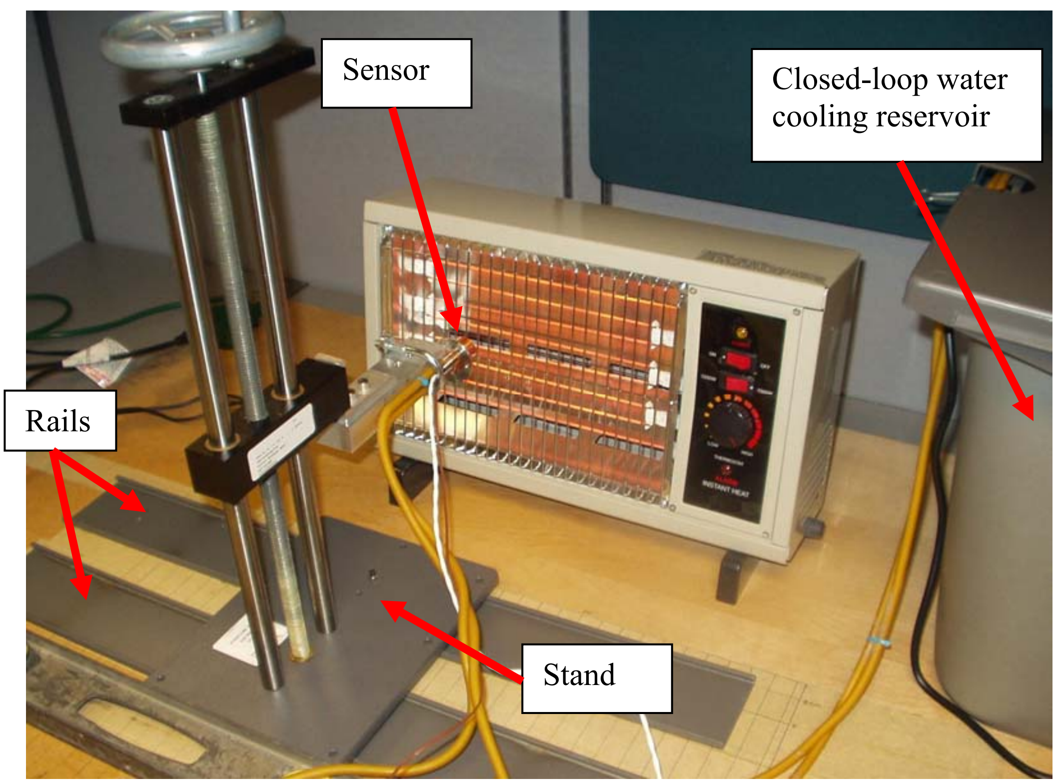

Figure 3: Sensor Test Setup

Sensor rotation about a horizontal, left-right axis, Θ_x, was constrained by the tight clearance between the vertical guides and their bearings in the test stand. The round-faced sensor output is insensitive to rotation about an axis passing through its body (Θ_Z). In these manners, with positioning only as precise as could be accomplished manually, or within the tolerance in the test stand, the six degrees of freedom of the sensor were controlled. For a given Z position, the sensor could be moved independently in X and Y without introducing appreciable sensor rotation on any axis.

2.4 Sensor Cooling

A plastic container and a submersible pump (commonly used for aquariums and small fountains) were used to provide cooling water to the sensor. A few gallons of water were put into the container with the pump. Rubber tubing connected the pump to the sensor and back to the reservoir (This is a closed-loop system.). The narrow diameter (0.125 inches) of the tubing required a relatively large pressure head to impel enough water through the sensor to keep its body cool. Occasionally, the tubes had to be cleaned by flushing with high-pressure tap water to insure adequate flow. Figure 4 shows a top view picture of the container and the pump.

Figure 4: Water Pump and Container

Preliminary experiments were performed where the sensor was positioned in front of an "on" heater and the water flow stopped. Continuous measurements showed a change in the sensor response as it was heated. Resumption of the water flow quickly brought the readings back to their original values. The reservoir volume has a high heat capacity relative to the flux impinging on the sensor. This large volume quickly "sinks" any heat in the water coming from the sensor (which was not even warm to the touch). The large reservoir and the generally short test time (about 30 minutes) kept the water from warming appreciably above the ambient temperature. Therefore, even at close positions, the radiant flux on the sensor was small enough that our pump and water supply were sufficient to assure consistent measurements.

3. Flux Measurements

3.1 Heater A

Heater A is a 1500-watt appliance with two quartz heating elements. The elements are positioned horizontally with a reflective metal wall to the rear. Directly behind the heating elements, the reflective wall curves in a semicircular shape to reflect energy emitted by the back side of the element out the heater front. Figure 5 shows a picture of the heater and an early sensor mount.

A power meter was used to measure the energy consumption of Heater A before the first set of measurements. The voltage was measured at 113 VAC, the current was 11.4 amperes, and the power was 1.29 kW.

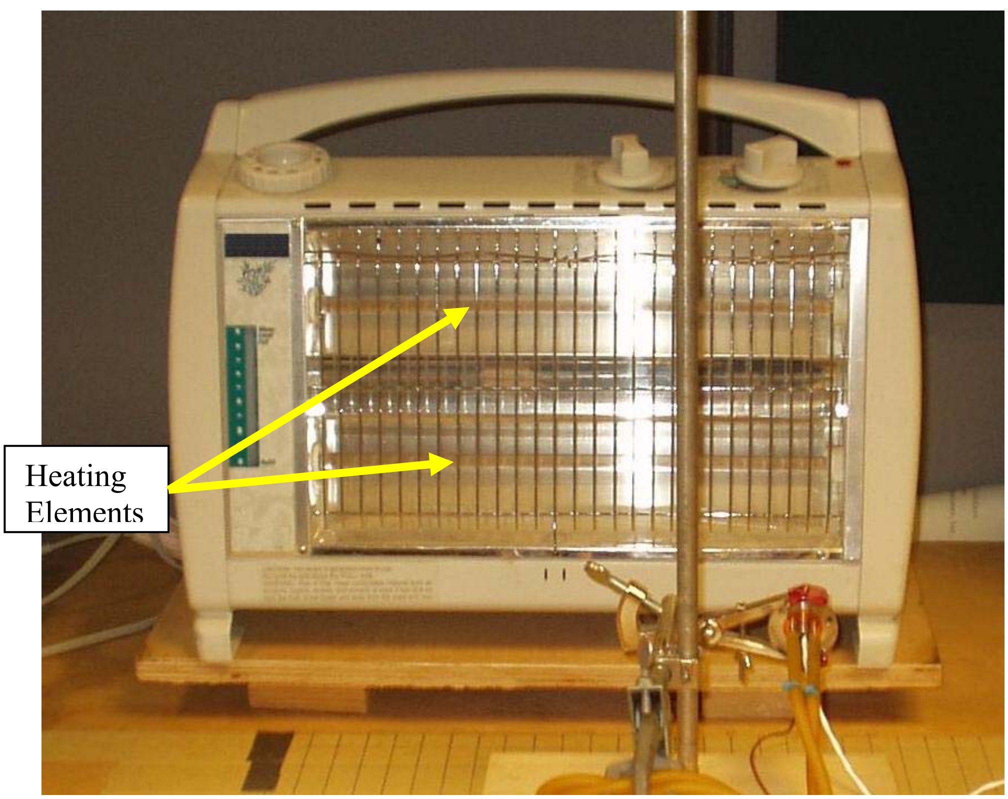

Figure 5: Heater A

Figure 6 shows the flux map of Heater A. The maximum radiant emission is from the lower portion of the heater. The maximum recorded flux was 1.8 W/cm^2. The flux is greater at positions slightly above and below the center of the heating elements. This is where radiant emission from the back of the element reflects off the shiny rear wall and adds to the radiant emission from the front of the heating element. The emission from the bottom portion of the heater has a greater magnitude than that from the top. This is because the heater face tilts back slightly from bottom to top. The flux sensor (which moves vertically up and down) is a little farther away from the heater face at the top. When the heater was tilted so that its front face was equidistant to the sensor at all vertical positions, the measured fluxes at the top and bottom were equivalent.

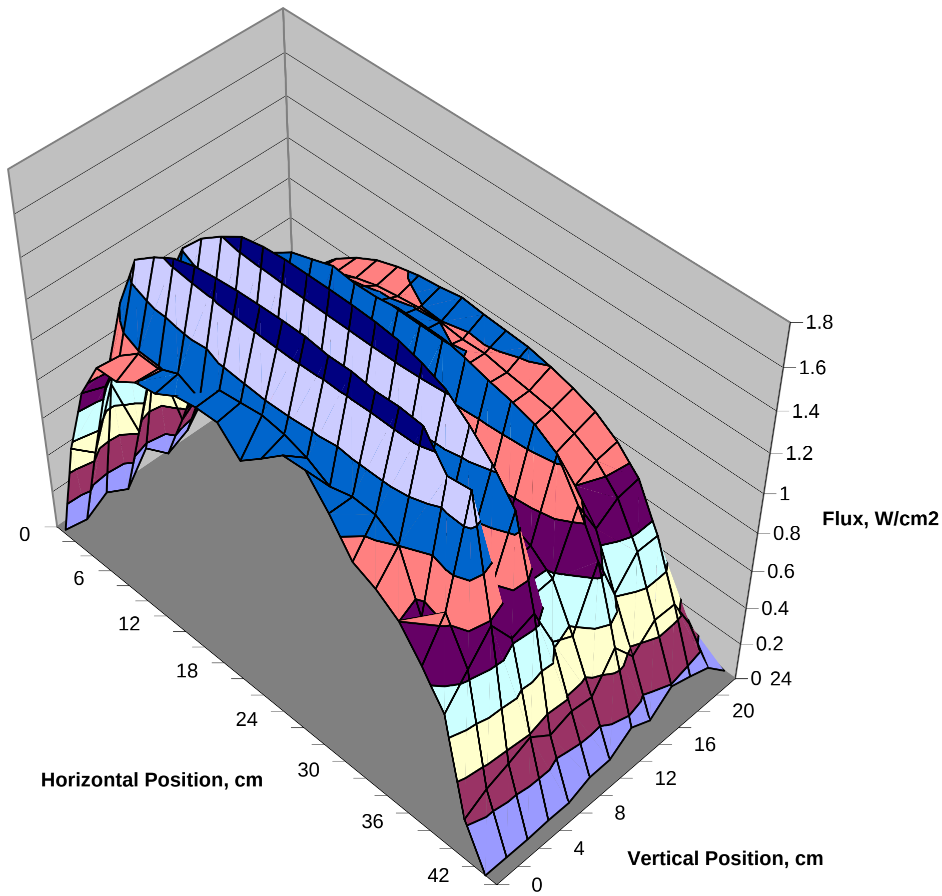

Figure 6: Heater A Flux Map at Z = 0 cm

3.2 Heater B

Heater B is a 1500-watt appliance with a ribbon heating element. The element zigzags across the face of the heater behind a grill integral with the front face of the heater. A fan blows air across the rear of the heater. Slots in the wall behind the heating element result in a small flow of hot air from the heater front. Figure 7 shows a picture of the heater.

A power meter was used to measure the energy consumption of Heater B. The voltage was measured at 108 VAC, the current was 11.4 amperes, and the power was 1.25 kW.

Figure 8 shows the flux map of Heater B. The vertical bars in the grill are seen as casting infrared "shadows," resulting in a drop in the recorded flux. The maximum radiant emission is from the upper left portion of the heater. The maximum recorded flux was 1.33 W/cm^2.

Figure 7: Heater B

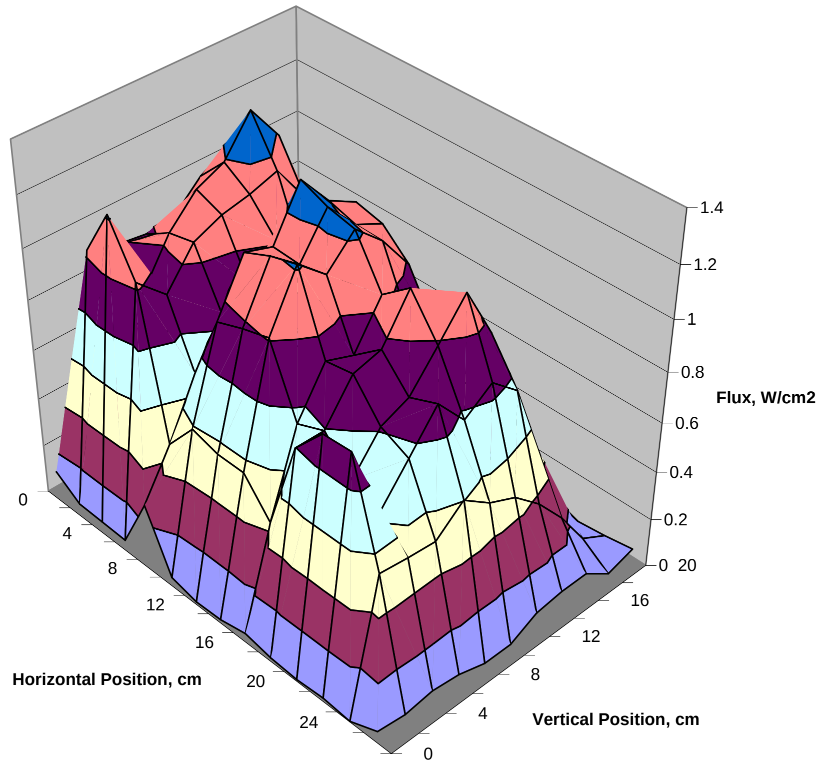

Figure 8: Heater B Flux Map at Z = 0 cm

3.3 Heater C

Heater C is a 1500-watt appliance with a coiled heating element wrapped around a central post. A curved reflector directs the infrared radiation out the heater front. Figure 9 shows a picture of the heater.

A power meter was used to measure the energy consumption of Heater C. The voltage was measured at 115 VAC, the current was 9.0 amperes, and the power was 1.03 kW.

Figure 10 shows the flux map of Heater C. Due to the geometry of the heating element and the reflector, there is a "cool spot" with little radiated energy in the center of the heater. The maximum radiant emission is from the lower portion of the heater. The maximum recorded flux was 1.04 W/cm^2.

It is possible that a reflector could focus the infrared energy at a point in front of the heater, creating a "hot spot" with a relatively high radiant flux. To investigate this possibility, the sensor was positioned at several X and Y positions in front of the heater, then moved in the Z direction (away from the heater), while the flux was monitored. In every case, the maximum flux was recorded at the lowest Z position (nearest the heater). The large size of the heating element relative to the reflector, and the reflector's simple construction (stamped metal), make it unlikely that such a focusing effect could be realized.

Figure 9: Heater C

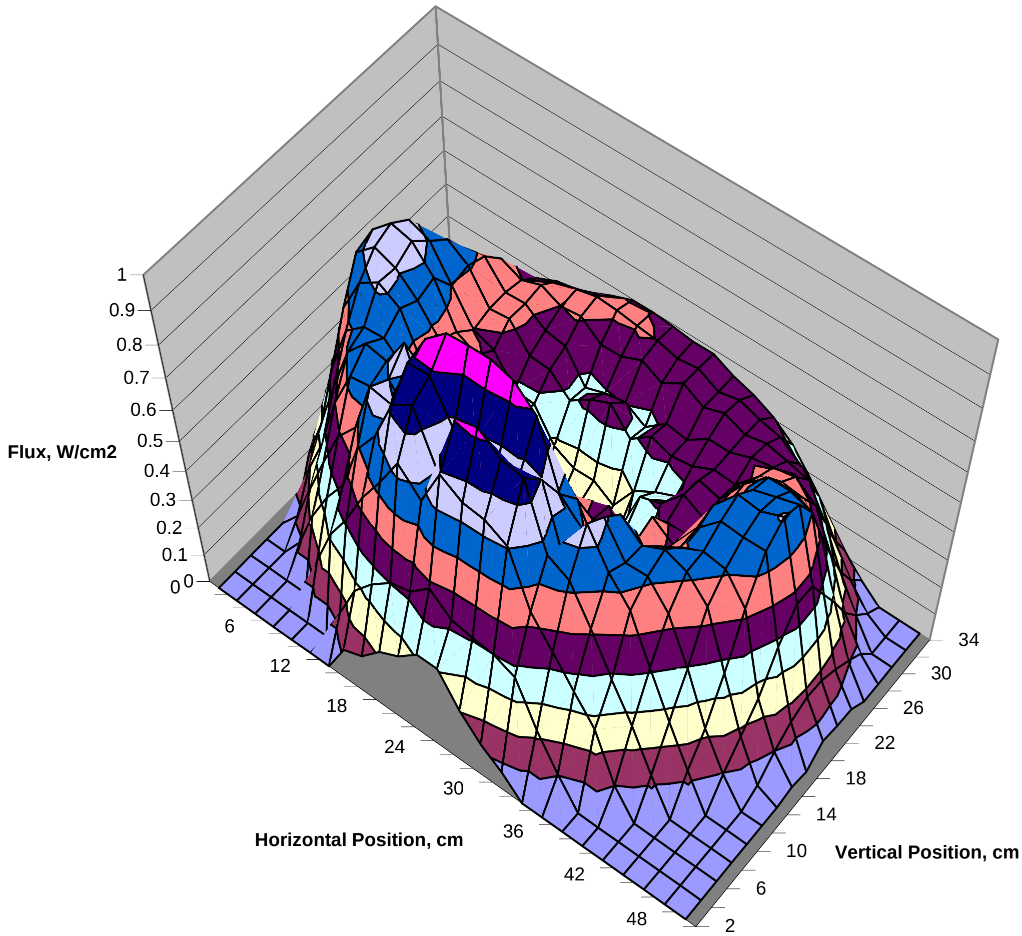

Figure 10: Heater C Flux Map at Z = 0 cm

3.4 Heater D

Heater D is a 1500-watt appliance with a ribbon heating element. The element wraps around ceramic posts on either end of the element chamber. Figure 11 shows a picture of the heater and the flux sensor. A small fan blows air across the rear of the element chamber, out the slots in the chamber walls, and across the heating element.

A power meter was used to measure the energy consumption of Heater D. The voltage was measured at 107 VAC, the current was 11.1 amperes, and the power was 1.20 kW.

Figure 12 shows the flux map of Heater D. Similar to Heater A, the front face of this heater tilts back slightly. Consequently, the maximum measured radiant emission is from the lower portion of the heater. The maximum recorded flux was 1.42 W/cm^2.

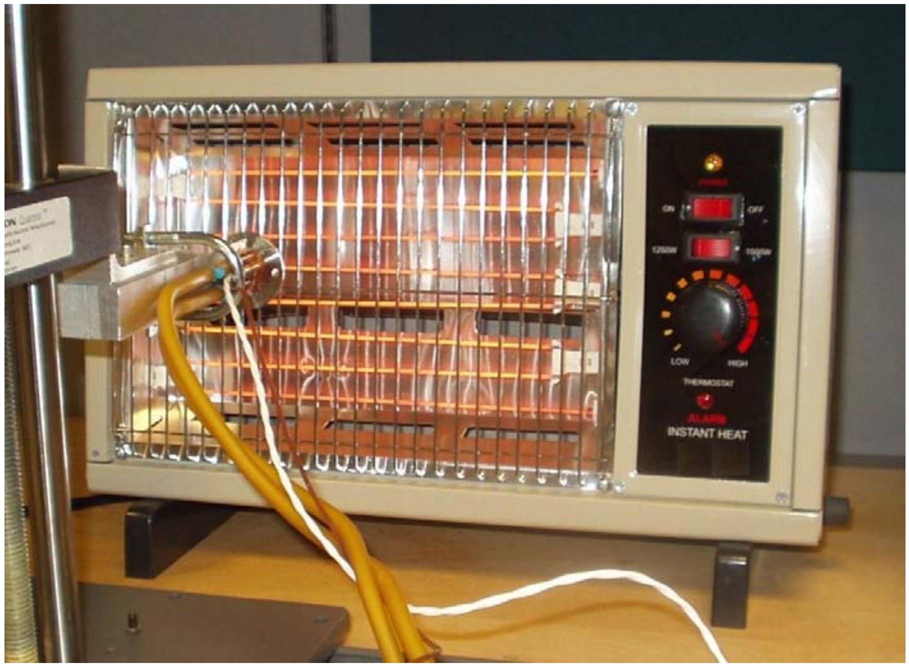

Figure 11: Heater D

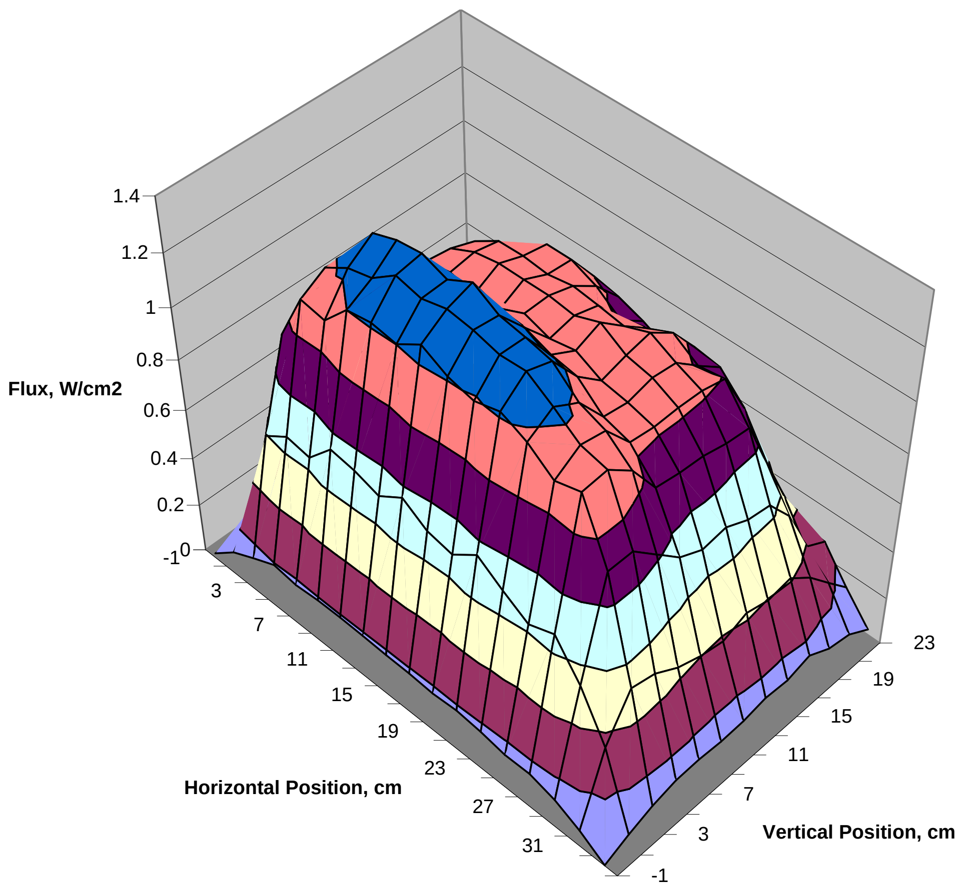

Figure 12: Heater D Flux Map at Z = 0 cm

4. Repeatability

The repeatability of the measurement procedure was assessed by repeating the setup and acquisition of flux data for each heater, then comparing the two data sets. For each data collection session, the heater-under-test was re-installed, and re-aligned relative to the measurement grid used to position the flux sensor. The sensor was aligned to the arbitrary zero position on the heater, and data was collected using manual sensor positioning and a simple computer program. Thus, measurement differences related to positioning, rotation, lack of perpendicularity, etc., would be reflected in the two data sets.

Three factors were chosen to assess the repeatability of a heater's flux measurements. First, the position and magnitude of the maximum flux reading was chosen because the maximum flux is the most significant measurement in a data set. Whether an electric heater is capable of igniting common combustibles is dependent on its maximum flux value. For the second measure of repeatability, a flux map was made of the absolute value of the differences between the two data sets. Each map was examined for systemic errors or large amplitudes. A 95% confidence interval was computed on the sample mean of the differences between the two data sets using the following formula: [4]

$$\text{95\% Confidence Interval} = \overline{x} \pm 1.96\ S/\sqrt{n-1}$$

Where: $\overline{x}$ = Sample mean
S = Sample standard deviation
n = Number of samples

If the confidence interval included zero, it would be reasonable to conclude that the two data sets have no systemic differences. The third measure of repeatability was to divide the sum of the magnitudes of the differences by the sum of the measurements of one data set. This would generate an overall measure of the differences compared to the data readings.

With multiple data sets, other measures could be used to evaluate the repeatability of the test procedure, from an analysis of variance between the data sets to a root sum square of the difference between a data set and a spline curve fit across the two dimensional surface.

4.1 Position and Magnitude of the Maximum Flux Reading

The flux maps shown in Figures 6, 8, 10, and 12 show strikingly different distributions of radiant energy emission. Simply looking at a heater and surmising the area of maximum flux would be problematic. Therefore, creating a map of the heat flux (for a given Z distance) is probably necessary to assure that the position with the maximum emission is identified. For heaters with very smooth flux distributions, a maximum (or near maximum) value may be recorded at several positions. Table 1 contains the X and Y positions, and the amplitude of the maximum flux recorded for each heater's two data sets.

		X position	Y Position	Amplitude	Amplitude % difference
Heater A	Data Set 1	22	8	1.80	6%
	Data Set 2	22	4	1.70	
Heater B	Data Set 1	4	12	1.33	0.2%
	Data Set 2	6	6	1.33	
Heater C	Data Set 1	22	8	1.04	7%
	Data Set 2	22	10	0.97	
Heater D	Data Set 1	6	14	1.42	1.8%
	Data Set 2	6	14	1.40	

Table 1: Heater Maximum Flux

Heater A's two data sets positioned the maximum flux at the same X position and 4 cm apart (2 sampling positions) for the Y position. If you examine Figure 6, it appears that the maximum reading "hopped" from one peak area to another. These high areas in radiant flux are positioned slightly above and below the center of the heating element, and combine the flux from the element front with the reflection from the element's rear surface. The two maximums differ by 0.1 W/cm^2. This amplitude is near the practical lower limit of the sensor's resolution.

Heater B has different locations for its maximum flux in both the X and Y positions. Interestingly, this heater has the least difference in amplitude for its maximum flux reading.

Heater C's maximum flux readings are one sample distance apart. These two data sets have the highest percentage difference in maximum flux amplitude; however, this difference is only 0.07 W/cm^2.

Heater D's maximum flux readings are at the same X and Y positions, and differ by only 0.02 W/cm^2.

4.2 Flux Maps of Differences

Maps were constructed of the magnitudes of the differences between the two data sets for each heater. If there were a systemic error (such as a positional shift between the first and second set of readings), the difference map would highlight that error. If a large majority of the differences were either positive or negative, that might indicate a change in heater operation between the two data sets. If the differences were large in the areas of high flux and lower in the areas of low flux, a magnitude-dependent sensitivity may be present. The same vertical scale was used for the difference maps as the flux maps to show the relative amplitude of the differences.

4.2.1 Heater A

Heater A shows a relatively flat difference graph in Figure 13. The largest amplitudes are seen at the edges of the data set, where the flux readings are the smallest. The largest difference, 0.35 W/cm^2, is at position X=40, Y=8. This is where the flux changes rapidly with position. A small change in measurement position would result in a large change in measured flux. When the differences were examined, 55% of the readings were positive, and 45% were negative. The 95% confidence interval on the sample mean is from -0.0038 to 0.018 W/cm^2. Since this interval includes zero, there is probably no systemic difference between the two data sets.

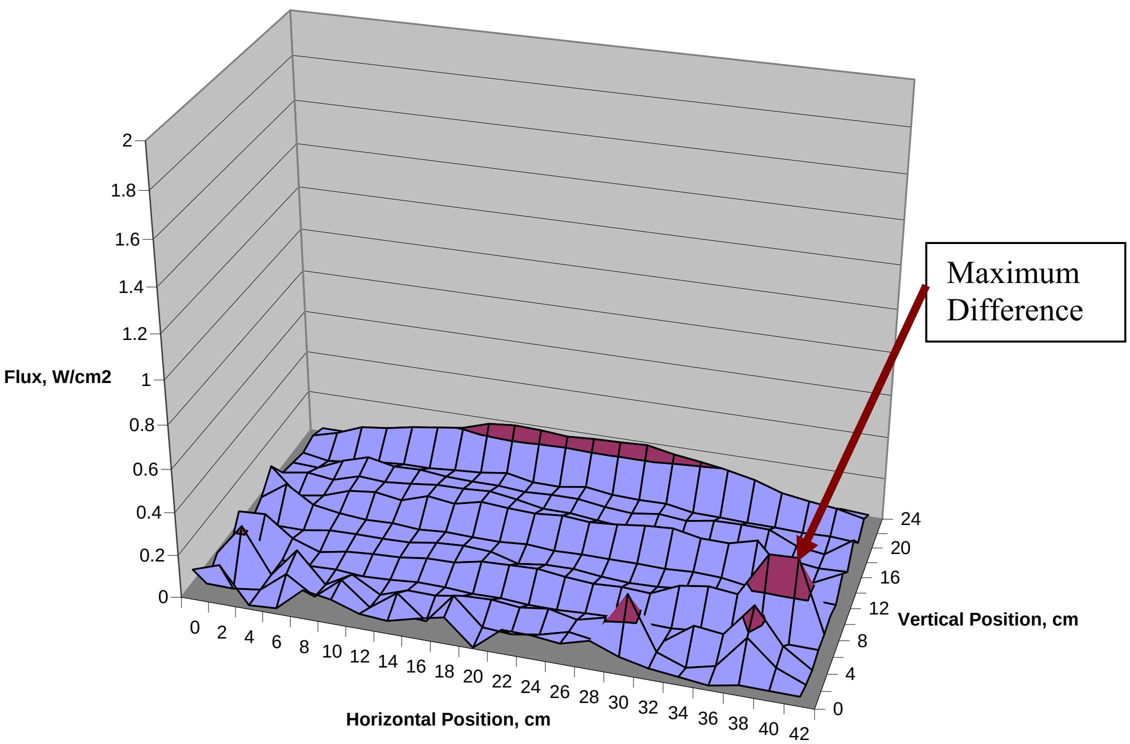

Figure 13: Heater A Difference Magnitudes

4.2.2 Heater B

Heater B also shows a relatively flat difference graph in Figure 14. There are four data points with amplitudes above 0.2 W/cm^2. The largest difference, 0.29 W/cm^2, is at position X=20, Y=6. When the data are examined, 73% of the differences are positive. The 95% confidence interval on the sample mean is from 0.00034 to 0.020 W/cm^2. The lower value is effectively zero. Even though a relatively high percentage of differences are positive, the inclusion of zero (albeit at one end of the confidence interval) in the confidence interval suggests that it would be difficult to conclude that a systemic change in operation occurred between the two tests.

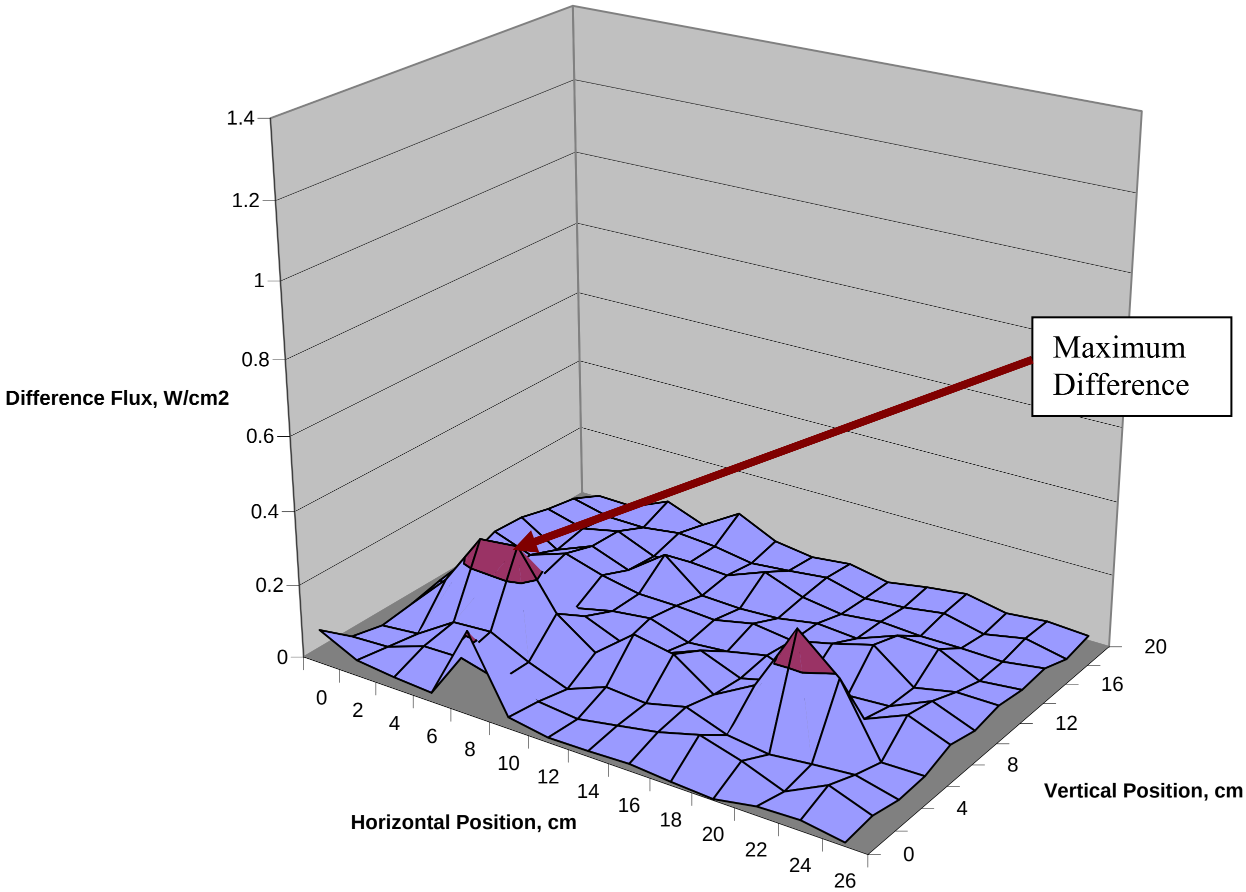

Figure 14: Heater B Difference Magnitudes

4.2.3 Heater C

Heater C also shows a flat difference graph with two peaks, seen in Figure 15. There are six data points with amplitudes above 0.2 W/cm^2. The largest difference, 0.36 W/cm^2, is at position X=22, Y=12. This is in an area with a strong sensitivity of flux on position. When the data are examined, 39% of the differences are positive. The 95% confidence interval on the sample mean is from -0.0014 to 0.0045 W/cm^2. Since this interval includes zero, there is probably no systemic difference between the two data sets.

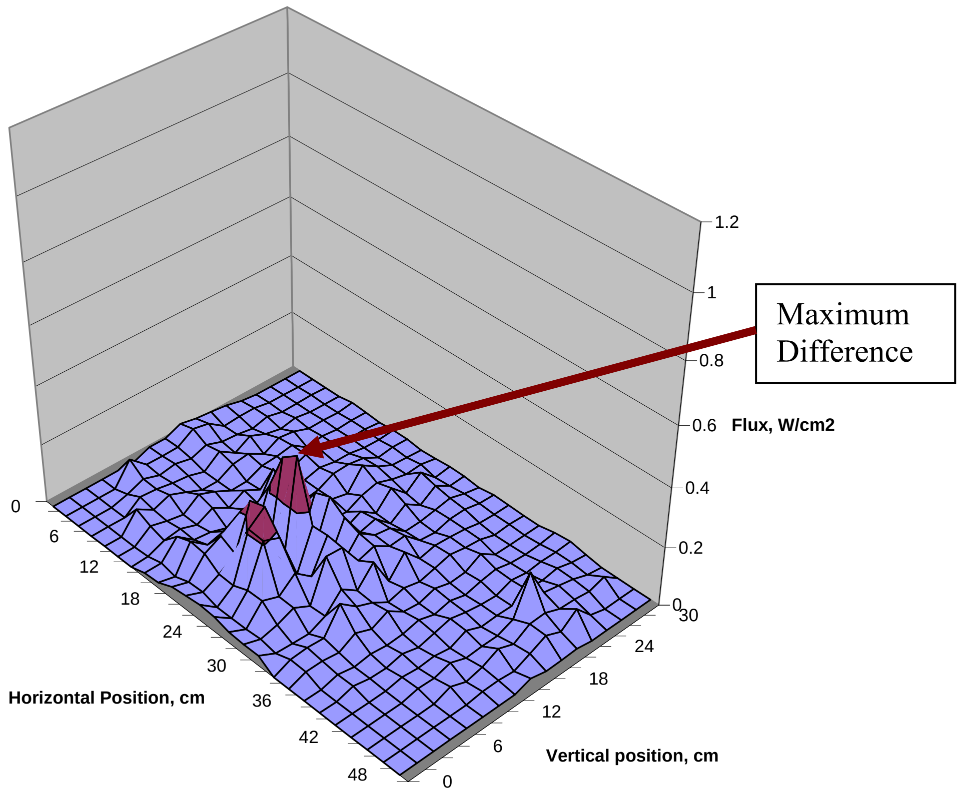

Figure 15: Heater C Difference Magnitudes

4.2.4 Heater D

Heater D shows the flattest difference graph of the four heaters, and is seen in Figure 16. The largest difference, 0.24 W/cm^2, is at position X=12, Y=2. This is near the edge where the flux changes rapidly with position. When the data are examined, 64% of the differences are positive. The 95% confidence interval on the sample mean is from -0.0019 to -0.007 W/cm^2. Even though the percentage of positive reads is not highly skewed, the confidence interval excludes zero and implies that a systemic change in operation may have occurred between the two tests.

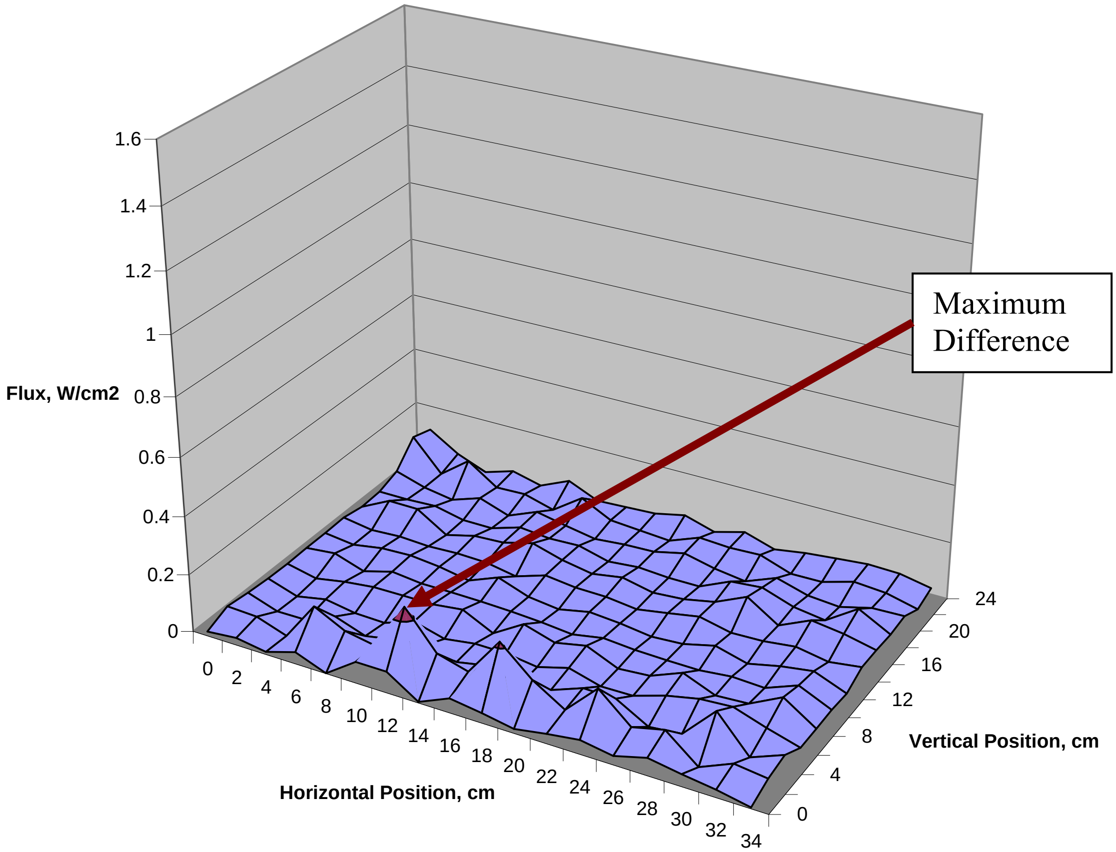

Figure 16: Heater D Difference Magnitudes

4.3 Relative Differences

For each heater, the magnitudes of all the differences were summed. That sum was divided by the sum of all the flux readings from a data set (the first data set was chosen for each heater). The result is presented as a percentage. Table 2 contains the results of the calculation.

	Summed Differences Relative to Total Flux
Heater A	8.0%
Heater B	8.1%
Heater C	7.6%
Heater D	4.6%

Table 2: Relative Differences to Total Flux

For all the heaters, the relative difference is less than 10%. That is, the recorded differences in the flux readings, independent of sign, changed by less than 10% between the first and second data sets. This data was recorded in an environment where the sensor was positioned by hand, input AC power was not conditioned, and the ambient temperature was controlled only to office levels.

5. Discussion

Measuring the flux emitted from radiant electric heaters proved to be a straightforward task. Using no more location precision than that achieved with a tape measure and a carpenter's square, a heater could be positioned such that a flux map could be reliably generated. With the flux sensor output connected to an A/D converter and using data acquisition software, all the readings necessary to construct a flux map could be obtained in less than 1 hour.

The simple techniques involving hand positioning of the heater and the sensor during data acquisition yielded repeatability within 10% for 2 trials on each of 4 heaters. Some of the known sources of variability in the readings are listed below.

- The input AC power was not conditioned or filtered. Changes in the RMS voltage would have a linear effect on power and a fourth-order effect on the temperature of the heating element. The testing showed that heater input voltage is an important variable to control
- The positioning of the heater could have an effect on the readings. Each heater showed a strong drop in radiant flux with distance from the heater grill (moving in the Z direction). If the heater face is not parallel to the motion of the sensor (in the X direction), readings on one side may be slightly lower than they should because of the increased distance between the elements and the sensor. Some heaters had large gradients in radiant flux with position. For repeatability purposes, accurately positioning the sensor is important.
- Section 4.2 of the project report examined the differences between sets of hundreds of readings taken on each heater. The greatest differences between data sets occurred at XY positions at which the flux varies strongly with position. Repeated measurements with the present sensor positioning setup would have the effect of measuring the repeatability of sensor positioning rather than flux measurement. Any actual test incorporated into a voluntary standard would have to attain positional repeatability beyond this report's hand positioning method.
- The perpendicularity of the sensor to the heater face could have an effect on the reading taken. If the sensor face is not perpendicular to the heater, the signal detected by the sensor could decrease by the cosine of the angle between the sensor and the heater. However, small offsets from perpendicularity are not significant. A 10 degree misalignment should decrease the reading by less than 2%.
- The temperature of the test area was not controlled beyond that provided by the building HVAC system. Higher or lower ambient temperatures could have an

effect on the radiant flux only to the extent that the surfaces on which the flux impinges are warmer. For normal office temperature ranges, this is not considered significant.

- Most of the heaters tested were new. There may be a "burn-in" period where the heater output changes from its initial condition. On one heater, the current decreased by over one-third of an ampere after it was first energized. This represents about a 7% change in power consumption. Any test procedures developed for heater evaluation would need to consider a heater's operational stability.

Careful control of sensor-heater positioning and using conditioned AC power could reduce the relative differences in heater readings and increase the precision of the data collected.

The flux maps for heaters A-D are mostly smooth in their contours. This is not unexpected as a large heating element combined with enclosures designed mostly to keep the interiors from overheating is unlikely to focus energy in any one point. Heater C, with its curved reflector, did not tend to focus the radiant flux, but tended to direct it forward. Several tests were conducted where the sensor was positioned at an XY position, then moved away from the heater in the Z direction, while monitoring the flux. In every case, whether moving perpendicular to the middle of the heater, or perpendicular to the curved face at a position offset from the middle, the flux decreased as the sensor moved back from the heater front.

Two-centimeter resolution is probably the largest practical step size needed to map the flux from a heater. On each heater, measurements were conducted at fixed X and Z positions, and moving vertically in the Y direction. The measurements in these flux "slices" were made at 0.5 cm resolution. The data showed more detail than the 2 cm maps, but did not reveal a maximum flux above that measured with 2 cm resolution.

6. Conclusions

An unsophisticated test fixture was constructed and used to measure the radiant flux from four electric heaters. Using simple tools and hand-positioning, the flux was measured to a repeatability of a few percent. Variables affecting the repeatability of the measurements were identified. Means to control those variables can be simply implemented for greater accuracy in flux measurements.

These tests show that it is not difficult to obtain radiant flux data from an electric heater and that simple techniques can yield repeatable data. Using flux measurements for heater evaluation eliminates the performance variables and reduces the testing time associated with draping materials. In addition, quantitative data is generated, as opposed to the qualitative and somewhat subjective judgment of whether there is emission of embers or glowing of the combustible material during the test. The quantitative data can be used to judge "how close" a sample heater comes to igniting combustible materials, and can be employed to adjust the flux distribution without affecting total heat output.

Radiant flux measurements on an electric heater are simple, inexpensive, repeatable, and generate quantitative data. Combined with a determination of the maximum acceptable flux for a radiant electric heater, the techniques used in this set of experiments can be used to evaluate the acceptability of electric heaters for voluntary standards purposes.

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