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Liquid-Crystal Display (LCD) Screen Thermal Testing to Simulate Solar Gain

by Steven Callaway

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Computational and Information Sciences Directorate, ARL

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14. ABSTRACT

The Boland View Port 20 inch liquid-crystal display (LCD) monitor was tested in order to determine a solution to failures observed when the monitor was used outdoors. In direct sunlight, screen temperatures went beyond the maximum operational temperature, causing the image to “white out.” Tests were first performed to determine the monitor’s baseline operations and maximum screen temperature before failure. A temperature chamber and heat lamp were used to simulate worst-case conditions. The next tests were performed outdoors to determine possible solutions to problem. In separate tests, the metal frame and the screen of the monitor were shaded from the sun, eliminating the solar loading from each area. Results were the most promising when the screen was shaded from the sun. After observing this behavior Hot Mirror glass from Dicrotec Thin Films was tested. This glass uses a coating that passes visible light, but reflects infrared light, reducing the total heat transmitted to the monitor from the sun. Satisfactory results were achieved when a 1 inch air gap was maintained between the monitor and glass. These results lead to several design recommendations to eliminate the failures previously observed with the Boland monitor.

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Liquid crystal display, LCD, Solar, Thermal, Infrared

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Summary

Testing completed on the Boland View Port 20 inch liquid-crystal display (LCD) monitor was motivated by a customer request to solve a problem. The equipment to be tested was being used as a teleprompter screen in both indoor and outdoor settings. In both situations, the screen is positioned on its back, elevated roughly 9 inches from the ground. The area perpendicular to the screen is covered by a decorative shroud, used to obscure the screen during formal occasions. When the equipment is being used outdoors on hot summer days, ambient temperatures meet or exceed 90 °F. The monitor is subject to direct sunlight during the hottest part of the day as the sun is directly overhead. Under these conditions, the customer noted images would “white out,” making characters difficult to read. These malfunctions rendered the system unusable.

The testing performed set out to replicate these conditions and recommend an area of design improvement. A temperature chamber and heat lamp, as well as outdoor testing, were used to simulate thermal loading on the screen. Different configurations were then explored as solutions to help eliminate the solar loading on the monitor. For each test, various temperatures were recorded on the monitor using a Graphtec Midi Logger GL220 data logger. Internal exhaust fans on the monitor were set to high for each test, as they would be under normal warm weather conditions.

The first test involved placing the monitor in a heat chamber set to 90 °F. This was meant to simulate the operation of the monitor on a hot summer day in the absence of solar loading. It offered a baseline operation temperature for the system. The screen temperature was found to operate at an average of 1.70 °F above ambient.

The second test performed used a 250 W heat lamp suspended above the monitor to simulate solar loading. The test was performed on a lab bench at room temperature because of space constraints in the heat chamber. The screen developed a temperature 75 °F above ambient, averaged at 146.2 °F. Screen failure was observed at 140 °F, which set the maximum allowable temperature for the screen.

Test 3 was performed outdoors in direct sunlight. With an intermittent breeze and changing sunlight conditions, the screen reached an average temperature of 62.6 °F above ambient. This test provided baseline numbers for comparison to later results.

Test 4 was performed outdoors in direct sunlight with the metal frame of the monitor shielded from the sun. By comparing the results of this test to Test 3, the contributions of the solar gain through the monitor frame could be analyzed. The

screen reached an average temperature of 56.8 °F above ambient, 5.8 °F lower than the 62.6 °F rise over ambient observed without the frame shaded.

For Test 5 the monitor was again placed outside in direct sunlight, this time with the screen surface shielded from the Sun. By comparing the results of this test to Test 3, the contributions of the solar gain through the screen surface could be analyzed. The screen reached an average temperature of 23.3 °F above ambient, 39.3 °F lower than the 62.6 °F rise over ambient observed without the frame shaded.

With the results from Test 5, is was determined that shielding the screen from solar gains was the best way to avoid monitor failure. In order to accomplish this Hot Mirror glass from Dicrotec Thin Films was tested. The Hot Mirror glass features a glass substrate with a coating on one side that reflects infrared light and passes visible light. This allows the teleprompter image to be read clearly through the glass while the heat is reflected away from the monitor.

Test 6 examined the function of the Hot Mirror glass. The monitor was positioned on a lab bench with the 250 W heat lamp positioned above it to simulate solar loading. The Hot Mirror glass was placed on the top surface of the monitor. With this configuration screen failure was observed, as the screen temperature reached and exceeded 140 °F. This was due to the positioning of the Hot Mirror glass. With the glass placed directly on top of the monitor, it trapped any heat that was developed by the screen itself.

For Test 7 the Hot Mirror glass was spaced away from the monitor to leave a 1 inch air gap between the glass and screen. The monitor was again positioned on a lab bench with the 250 W heat lamp positioned above it to simulate solar loading. With this arrangement, heat developed by the monitor was able to convect out of the monitor and away from underneath the glass. The screen developed a 54.65 °F rise over ambient, approximately a 20 °F improvement over the results from Test 2.

Following the results of these tests several recommendations were made. An air gap needs to be maintained between the Hot Mirror glass and Boland monitor, fans should be used to prevent any heat from being trapped beneath the glass, and the glass needs to be thermally insulated from the fixture and monitor.

With these recommendations taken into account the issues with the Boland View Port 20 inch LCD monitor can be resolved.

1. Introduction

The motivation for the thermal testing performed in this report was brought on by customer difficulties with the failure of a Boland View Port 20 inch LCD monitor. The monitor is used outdoors as a teleprompter screen. The monitor is positioned face up on the floor of a stage, while the screen image is reflected to a viewing screen in front of the speaker.

Failure was only observed on hot summer days under direct sunlight. It was especially prevalent during the hottest part of the day, when the sun was at its highest point. The customer observed that the LCD screen began to "white out" and the characters became illegible.

Testing conditions set out to simulate these conditions in the most accurate way possible. A temperature chamber, heat lamp, and outdoor testing setup were all used in different configurations to perform 5 different tests. The test scenarios covered conditions in 90 °F ambient temperatures, screen failure under simulated solar loading, direct sunlight outdoors, conditions with the monitor frame shaded in direct sunlight, and conditions with the LCD screen shaded in direct sunlight.

Hot Mirror glass from Dicrotec Thin Films, which has a coating that passes visible light and reflects infrared light, was also tested as a possible solution to the problems experienced with the monitor.

2. Methods, Assumptions, and Procedures

In order to determine the mode of failure for the Boland monitor, several tests were performed. Several different configurations were used to simulate the normal working conditions of the monitor, including using a temperature chamber, using a heat lamp, and taking advantage of natural sunlight.

The View Port 20 inch HD/SD DayBrite Monitor (Model Number DHD 20W DB) features metal chassis measuring 19 inches x 11.63 inches x 2.25 inches. The chassis includes a 20 inch screen with a user adjustable 4:3 or 16:9 aspect ratio. The chassis is also equipped with 2 exhaust fans used to circulate and exhaust air from the chassis. The DayBrite Monitor features SDI, Composite, VGA, and DVI inputs to accommodate various configurations. Figures 1 and 2 show the front and rear views of the monitor.

Fig. 1 Front view of the View Port 20 inch HD/SD DayBrite Monitor

Fig. 2 Rear view of the View Port 20 inch HD/SD DayBrite Monitor

During each test, an image needed to be displayed on the screen to best simulate the function of a teleprompter. Figure 3 shows the image that was used. The use of a black background with white text was important in creating the worst-case scenario for the absorption of solar radiation.

Fig. 3 Test image used on Boland View Port 20 inch LCD monitor

To assess the performance and failure of the DayBrite Monitor, 7 tests were performed. They included running the monitor in 90 °F ambient temperature, under a 250 W heat lamp, outdoors in direct sunlight, outdoors in direct sunlight with the frame covered, and outdoors in direct sunlight with the screen covered. Hot Mirror glass was also evaluated as a possible solution to the problem. For each test, the monitor was positioned in a similar fashion with the internal fans set to high. This served to create consistency between the tests and to simulate real-world conditions. A Graphtec Midi Logger GL220 data logger was used for each test to record pertinent temperatures so that the result of each test could be compared and contrasted.

2.1 Test 1 – 90 °F Ambient Temperature

The first test performed was to place the monitor in a 90 °F ambient condition with no solar loading. This test determined the base line conditions of the monitor under worst-case ambient temperatures. Using a heat chamber, the temperature was set to hold at 90 °F after the monitor was in place.

To ensure even heating of the monitor, it was placed in the center of the floor of the chamber. Using Delrin blocks, the monitor was elevated 1 inch from the floor of the chamber. This allowed for air flow into and out of the monitor and prevented heat from conducting into the monitor from the walls of the chamber.

After the test was performed, the temperature rise over ambient of the screen was analyzed. This determined how much heat is generated by the monitor under normal operation.

2.2 Test 2 – Bench Test with a 250 W Heat Lamp

For Test 2, a 250 W heat lamp was used to simulate the solar loading from the sun on the monitor. The heat from the sun can be approximated using the solar constant, S_c,, which is an average measurement of the heat flux from the sun, measured by satellites outside of the Earth's atmosphere. As a rough approximation, it is assumed that 30% of the heat from the sun is reflected or absorbed by the Earth's atmosphere, and 70% of the heat travels to the Earth's surface.

To demonstrate the effect of the relationship of the location of the sun relative to the monitor, Lambert's Cosine Law is used. It says that there is a proportional relationship between the cosine of the angle of the normal vectors between 2 surfaces and the intensity of the radiation.[2] At the hottest part of the day, the angle between vectors normal to the surface of the sun and monitor is 0°, as shown in Fig. 4.

$$G_{S,O} = S_C \cdot \cos(\theta) \tag{1}$$

where $S_C = Solar\ Constant = 433.66\ \frac{Btu}{hr} ft^2$

$\theta = Angle\ of\ surface\ normal\ to\ Sun = 0^{\circ}$

$$G_{S,O} = 433.66\ \frac{Btu}{hr} ft^2 \cdot \cos(0^{\circ})$$

$$G_{S,O} = 433.66\ \frac{Btu}{hr} ft^2$$

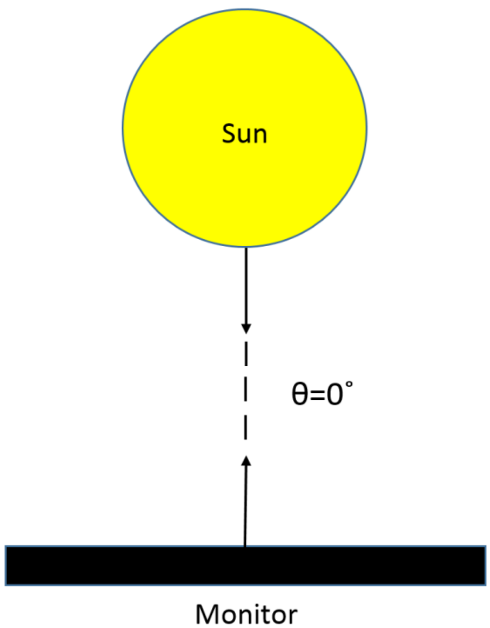


Fig. 4 Position of the sun relative to the monitor during the hottest part of the day

Assuming that 70% of the solar radiation penetrates the Earth's atmosphere,

$$q_{theoretical} = .70 \cdot G_{S,O} \cdot A_{screen} \quad (2)$$

$$where\ G_{S,O} = 433.66\ \frac{Btu}{hr} ft^2$$

$$A_{screen} = 11.75\ in\ x\ 19\ in = 223.25\ in^2 = 1.55\ ft^2$$

$$q_{theoretical} = .70 \cdot 433.66\ \frac{Btu}{hr} ft^2 \cdot 1.55\ ft^2$$

$$q_{theoretical} = 470.52\ \frac{Btu}{hr}$$

Once the theoretical solar loading on the monitor was obtained, it needed to be recreated in the lab setting. The 250 W heat lamp was positioned over the monitor so that it created an equivalent heat transfer rate. To determine this position, the view factor between the surface of the lamp and the surface of the monitor was calculated. The view factor (F_{ij}) is best described as the "fraction of the radiation leaving surface *i* that is intercepted by surface *j*".[1] Figure 5 shows the positioning and variables used to calculate the view factor.

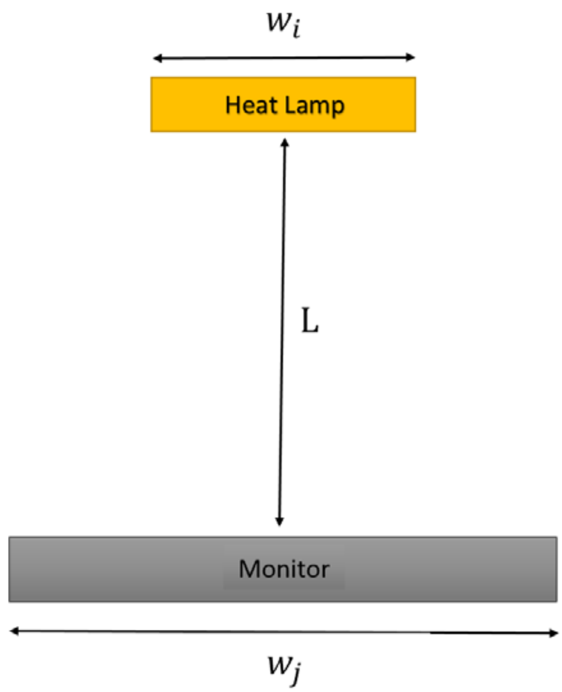


Fig. 5 View factor diagram

$$F_{ij} = \frac{\left((W_i+W_j)^2+4\right)^{\frac{1}{2}} - \left((W_j-W_i)^2+4\right)^{\frac{1}{2}}}{2W_i} \tag{3}$$

$$where\ W_i = \frac{w_i}{L} \quad and\ \ W_j = \frac{w_j}{L}$$

w_i = 4.875 in
w_j = 19.000 in
L = 14.221 in

$$F_{ij} = \frac{\left(\left(\frac{4.875\ in}{14.221\ in} + \frac{19.000\ in}{14.221\ in}\right)^2 + 4\right)^{\frac{1}{2}} - \left(\left(\frac{4.875\ in}{14.221\ in} - \frac{19.000\ in}{14.221\ in}\right)^2 + 4\right)^{\frac{1}{2}}}{2 \cdot \frac{4.875\ in}{14.221\ in}}$$

F_{ij} = .552

Multiplying the heat from the 250 W heat lamp (q_{lamp}) by the view factor (F_{ij}) gives the amount of heat transmitted to the screen:[1]

$$q_{screen} = q_{lamp} \cdot F_{ij} \tag{4}$$

$$where\ q_{lamp} = 250\ W = 853\ \frac{Btu}{hr}$$

$$F_{ij} = .552$$

$$q_{screen} = 853\frac{Btu}{hr} \cdot .552$$
$$q_{screen} = 470.856\ \frac{Btu}{hr}$$

It can be seen that the theoretical solar loading of the monitor and the loading due to the 250 W heat lamp are similar. By positioning the heat lamp 14.221 inches away from the monitor, the same heat transfer rate of $470.856\ \frac{Btu}{hr}$ is achieved.[3]

With the configuration determined, the monitor was placed on a lab bench with the same 1 inch Delrin blocks elevating the monitor from the table surface. The 250 W heat lamp was then positioned approximately 14.221 inches above the screen. This distance allowed the heat to be spread across the entire screen while still maintaining the necessary intensity. The test was performed outside of the heat chamber due to space constraints.

The temperature of the screen was closely monitored to determine the exact temperature at which the image began to fail.

2.3 Test 3 – Outdoors Under Direct Sunlight

Test 3 was performed outdoors in direct sunlight. The monitor was again placed on 1 inch Delrin blocks to allow for adequate airflow around the monitor. The test continued until the monitor reached a relatively steady-state, though this was difficult with changing sun throughout the day and an intermittent breeze.

The temperature rise of the screen over the ambient temperature was again analyzed. This dataset served as a baseline for comparison to later results.

2.4 Test 4 – Outdoors Under Direct Sunlight, Monitor Frame Covered

The fourth test performed on the monitor was completed outdoors in direct sunlight. A fixture was fabricated to shade the metal screen on the monitor from the sunlight, while leaving an adequate air gap for natural convection out of the frame. The monitor was placed on 1 inch Delrin blocks to allow for airflow around the monitor.

The data collected were compared to the results in Test 3 to determine if shading the monitor frame from the sun was a sufficient solution.

2.5 Test 5 – Outdoors Under Direct Sunlight, Monitor Screen Covered

Test 5 was performed in direct sunlight with the screen shaded from the sun. An air gap was left under the fixture to allow for convection at the screen. The monitor was again placed on 1 inch Delrin blocks to allow for airflow around the monitor.

The data collected were compared to results from Test 3 to determine if shading the monitor screen from the Sun was a sufficient solution.

2.6 Test 6 – Bench Test with a 250 W Heat Lamp and Hot Mirror Glass

After the completion of Test 5, it was clear that in order to eliminate the solar loading that was causing the monitor to fail, the screen needed to be shielded from the sun. In order to accomplish this Hot Mirror glass from Dicrotec Thin Films was used. Hot Mirror glass consists of a glass substrate that is coated on 1 side. The coating passes visible light, but reflects the infrared component of the light back to its source. Infrared light, with a wavelength from about 700 nm to 1 mm, carries the majority of the heat that the Earth receives from the sun.

Figure 6 shows the spectral scan results of the Hot Mirror glass used. It can be seen that 90% to 95% visible light, which exists in the 300 and 700 nm range, is passed through the glass. However, from 700 to 1100 nm, the infrared light is almost completely reflected.

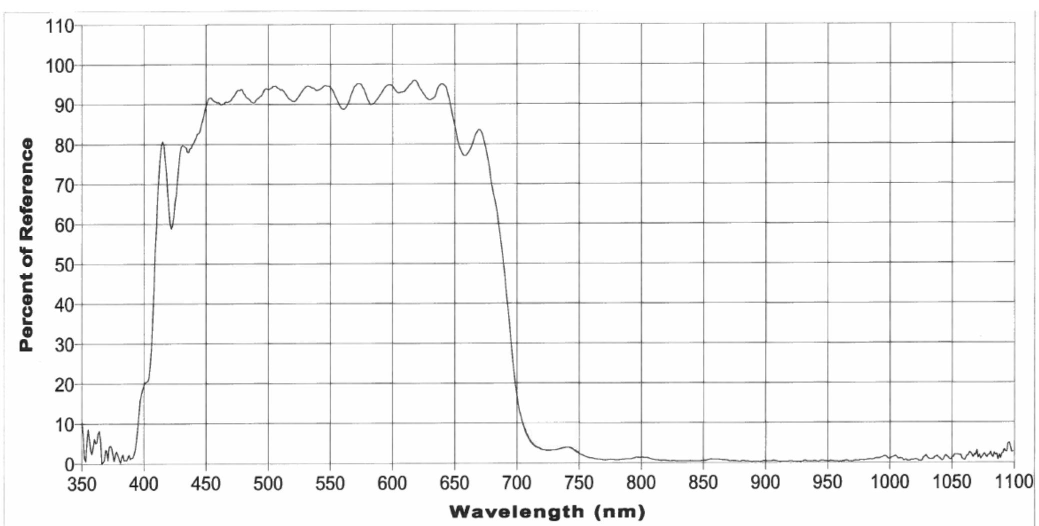


Fig. 6 Spectral scan results of Hot Mirror glass used from Dicrotec Thin Films

Test 6 was performed on a lab bench at room temperature. A 250 W heat lamp was used to simulate solar loading, positioned above the screen at a distance that allowed the heat to be spread across the entire screen while still maintaining the necessary intensity. A piece of the Hot Mirror glass large enough to cover the entire monitor was placed directly on the top side of the monitor in order to shield the monitor from the solar loading.

2.7 Test 7 – Bench Test with a 250 W Heat Lamp and Hot Mirror Glass, 1 Inch Air Gap

Test 7 was performed on a lab bench at room temperature. A 250 W heat lamp was used to simulate solar loading, positioned above the screen at a distance that allowed the heat to be spread across the entire screen while still maintaining the necessary intensity. A piece of the Hot Mirror glass large enough to cover the entire monitor was placed on the top side of the monitor with a 1 inch air gap between the monitor and glass. This configuration allowed for the infrared heat to be reflected away from the top side of the glass, while allowing heat generated by the monitor to escape from underneath the glass.

3. Results and Discussions

For each test thermocouples were positioned on the monitor as shown. Channel 1 was used to record the ambient temperature in each test. A graph was generated to show the steady state conditions for each test. The average temperature throughout that time period is also calculated.

3.1 Test 1, Environmental Chamber, 90 °F Ambient

The DayBrite Monitor was placed in a temperature chamber that maintained an ambient temperature of 90 °F. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the rear of the monitor, as well as along the front frame and at the center of the screen (Fig. 7). The temperature for each channel during the steady-state portion of the test can be seen in Fig. 8, and the average channel values can be seen in Table 1.

Thermocouple Locations:

1. Ambient

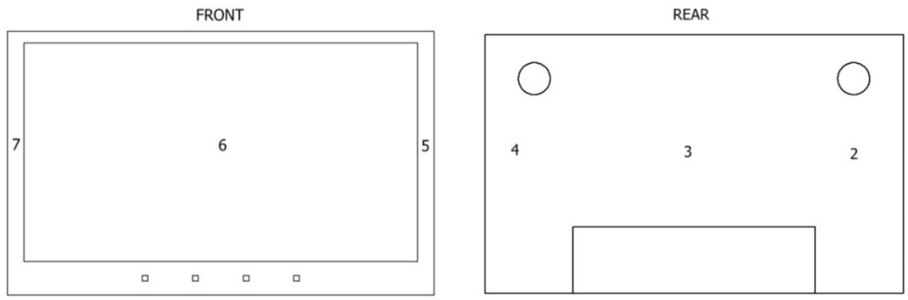


Fig. 7 Thermocouple locations for Test 1

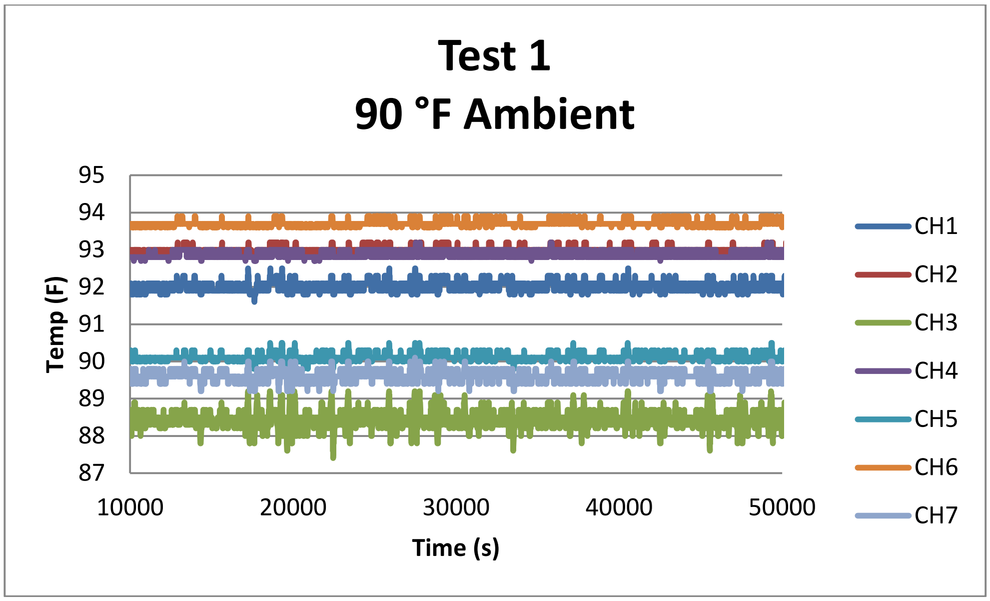
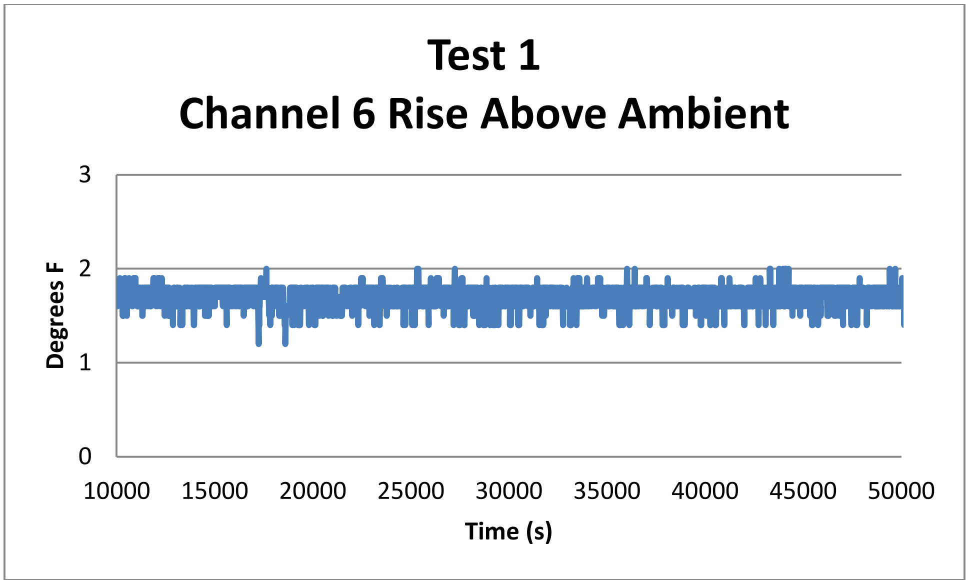


Fig. 8 Temperature vs. time for Test 1 during the steady state period of the test

Table 1 Channel averages for Test 1 during the steady state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7
92.0	93.0	88.4	92.9	90.1	93.7	89.6

The results show minimal heat generation by the monitor in the absence of solar loading. The temperature of the screen surface maintained an average rise of 1.70 °F above ambient during the steady-state period (Fig. 9).



Average Difference: 1.70 °F

Fig. 9 Difference between screen temperature and ambient through the steady state period of Test 1

3.2 Test 2, Bench, 250 W Heat Lamp Above Screen

The DayBrite Monitor was placed on a lab bench with a 250 W heat lamp positioned above the screen. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the rear of the monitor, as well as along the front frame and at the center of the screen (Fig. 10). The temperature for each channel during the steady-state portion of the test can be seen in Fig. 11, and the average channel values can be seen in Table 2.

Thermocouple Locations:

1. Ambient

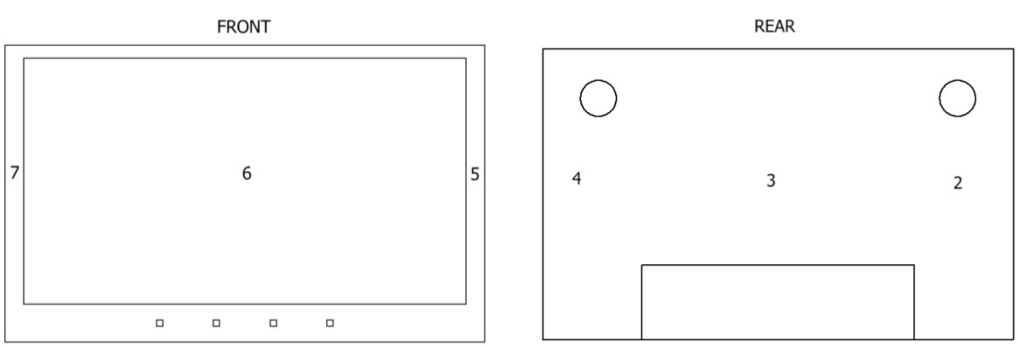


Fig. 10 Thermocouple locations for Test 2

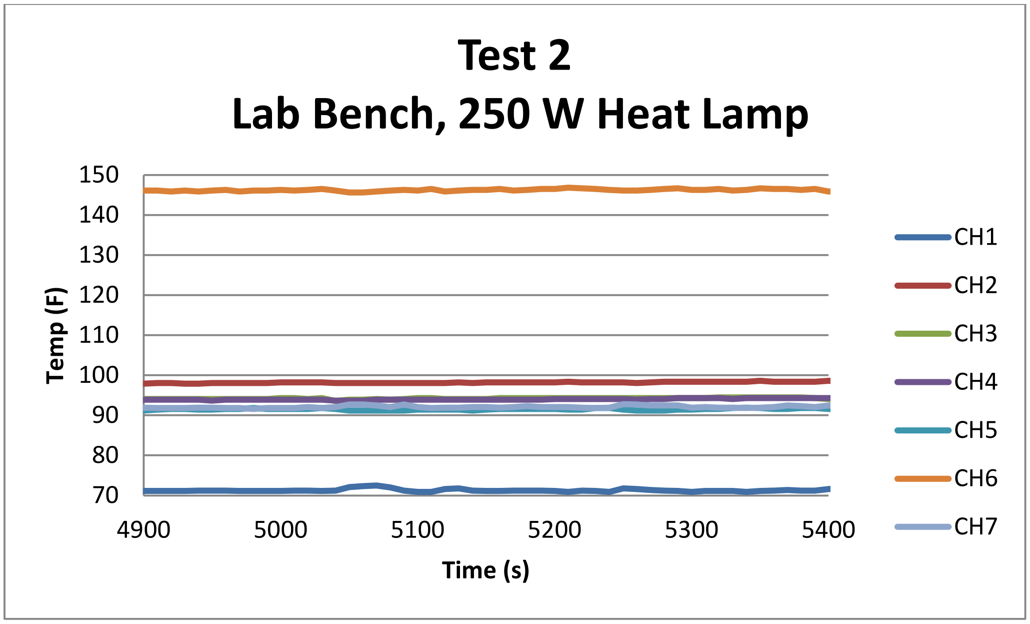
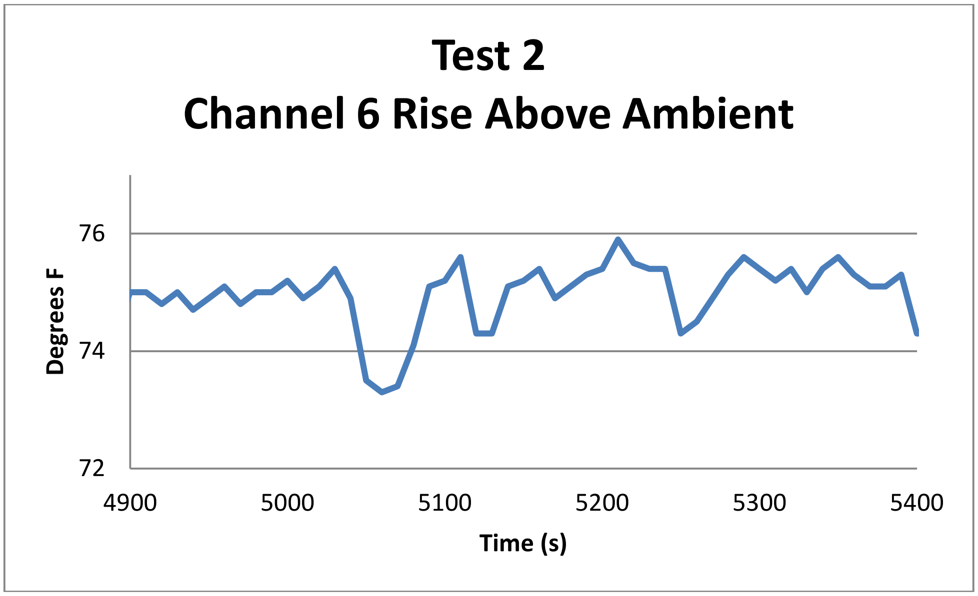


Fig. 11 Temperature vs. time for Test 2 during the steady-state period of the test

Table 2 Channel averages for Test 2 during the steady-state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7
71.3	98.2	94.2	94.0	91.5	146.2	92.1

The simulated solar loading created a 75.0 °F rise over ambient at the center of the screen (Fig. 12). Screen failure was observed at 140 °F.



Average Difference: 75.0 °F

Fig. 12 Difference between screen temperature and ambient through the steady-state period of Test 2

3.3 Test 3, Outdoors, Direct Sunlight

The DayBrite Monitor was placed outside in direct sunlight. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the rear of the monitor, as well as along the front frame and at the center of the screen. Thermocouple 9 was placed on the exhaust fan outlet on the rear of the monitor (Fig. 13). The temperature for each channel during the steady state portion of the test can be seen in Fig. 14, and the average channel values can be seen in Table 3.

Thermocouple Locations:

1. Ambient

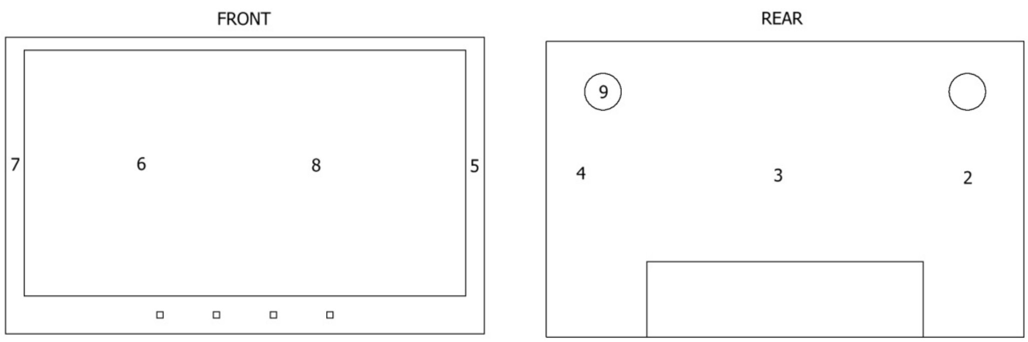


Fig. 13 Thermocouple locations for Test 3

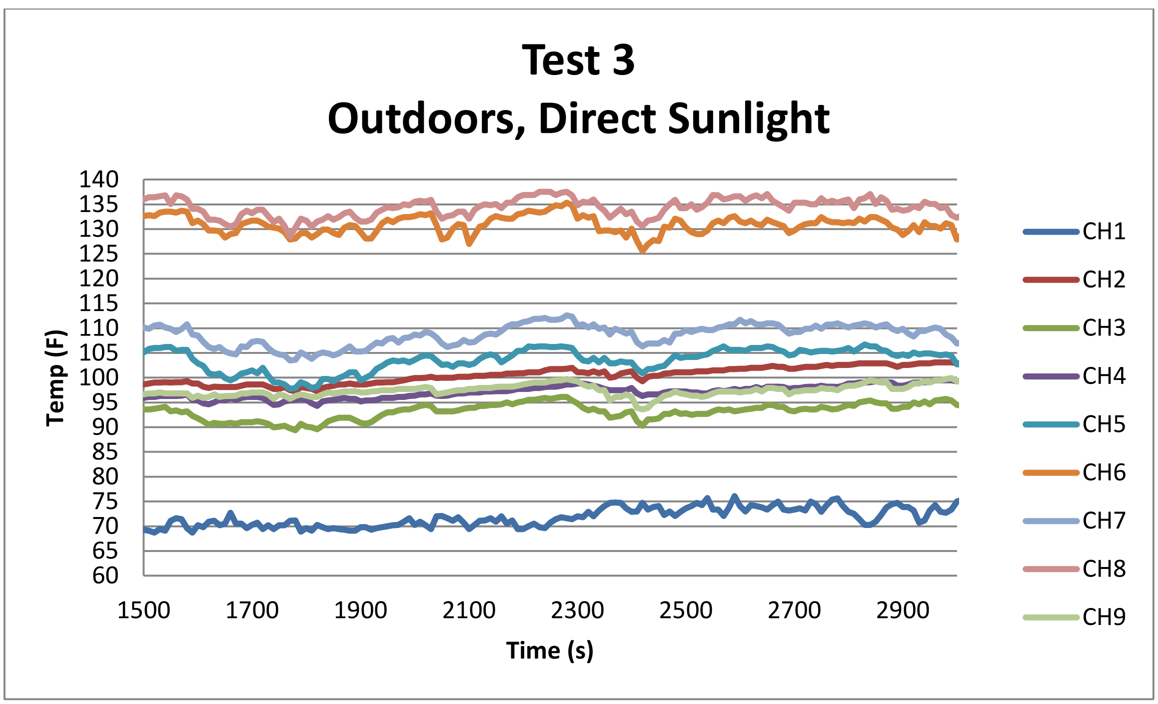
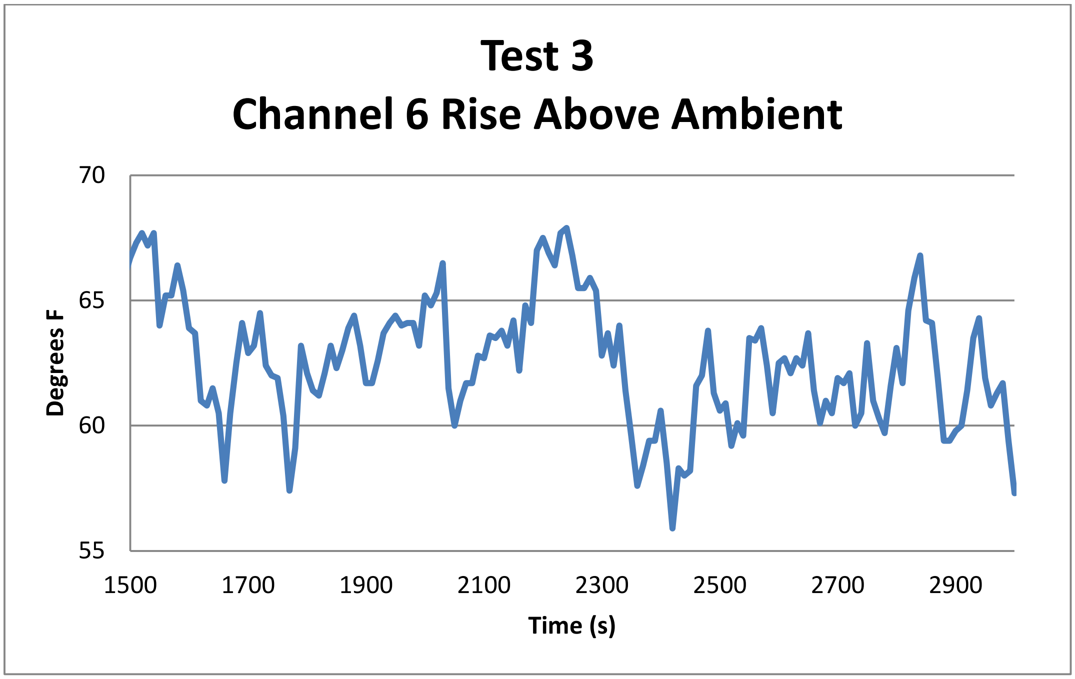


Fig. 14 Temperature vs. time for Test 3 during the steady-state period of the test

Table 3 Channel averages for Test 3 during the steady-state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9
71.8	100.5	93.2	97.1	103.6	130.9	108.7	134.4	97.4

At the conclusion of the test, a 62.6 °F rise over ambient was observed at the screen (Fig. 15). It should be noted that the test was performed during September, a time of the year when the sun is not at its most intense. There was also a slight breeze, which contributed to lower screen temperatures.



Average Difference: 62.6 °F

Fig. 15 Difference between screen temperature and ambient through the steady-state period of Test 3

3.4 Test 4, Outdoors, Direct Sunlight, Frame Covered

The DayBrite Monitor was placed outside in direct sunlight. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the rear of the monitor, as well as along the front frame and at the center of the screen. Thermocouple 9 was placed on the exhaust fan outlet on the rear of the monitor (Fig. 16). The front frame of the monitor was shaded from the sun to analyze the contribution of the solar gains through the monitor frame to the screen temperature. The temperature for each channel during the steady-state portion of the test can be seen in Fig. 17, and the average channel values can be seen in Table 4.

Thermocouple Locations:

1. Ambient

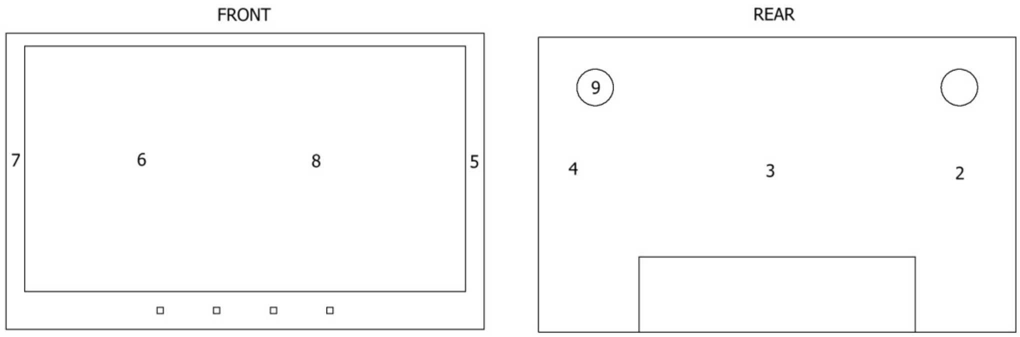


Fig. 16 Thermocouple locations for Test 4

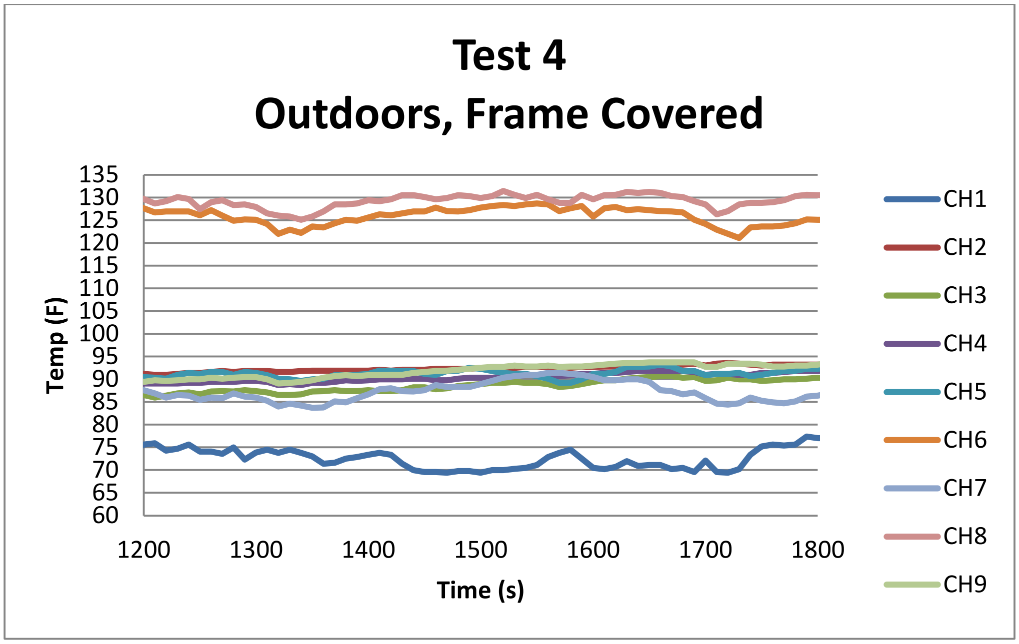
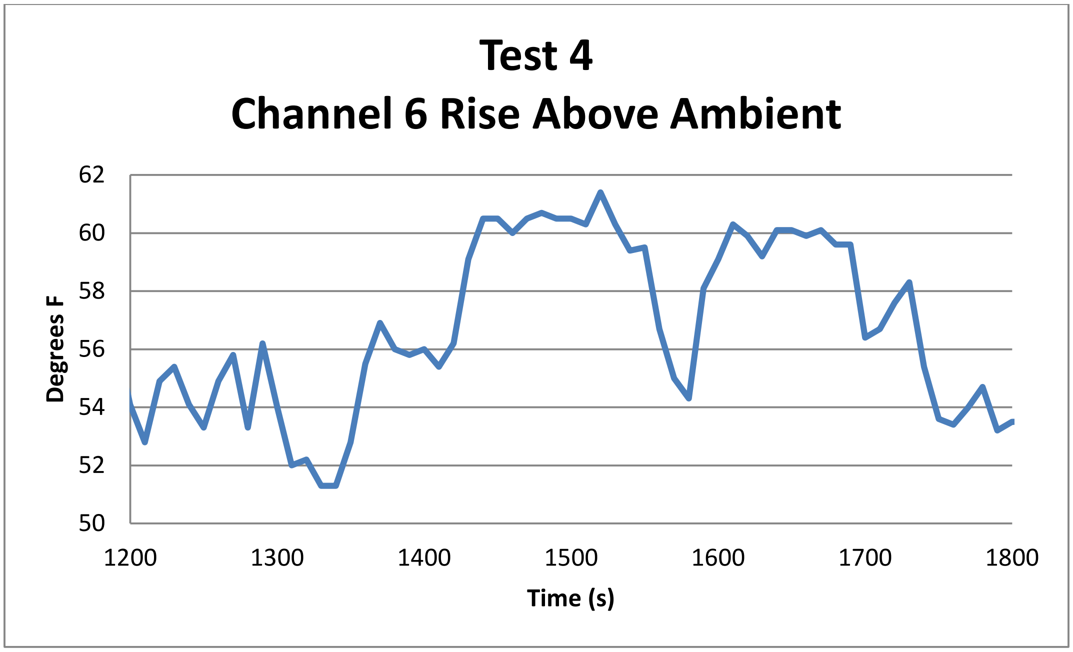


Fig. 17 Temperature vs. Time for Test 4 during the steady-state period of the test

Table 4 Channel averages for Test 4 during the steady-state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9
72.5	92.4	88.5	90.4	91.3	125.9	87.3	129.2	91.8

At the conclusion of the test, an average rise over ambient of 56.8 °F was observed at the screen (Fig. 18). It should be noted that the test was not performed during a part of the year that the sun was at its most intense. There was also a slight breeze, which contributed to lower screen temperatures. When compared to the results of Test 3, where a 62.6 °F rise over ambient was observed in direct sunlight, it can be seen that the solar gains through the monitor frame have a small contribution to the overall temperature of the screen.



Average Difference: 56.8 °F

Fig. 18 Difference between screen temperature and ambient through the steady state period of Test 4

3.5 Test 5, Outdoors, Direct Sunlight, Screen Covered

The DayBrite Monitor was placed outside in direct sunlight. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the rear of the monitor, as well as along the front frame and at the center of the screen. Thermocouple 9 was placed on the exhaust fan outlet on the rear of the monitor (Fig. 19). The screen was shaded from the sun to analyze the contribution of the solar gains through the screen to its overall temperature. The temperature for each channel during the steady-state portion of the test can be seen in Fig. 20, and the average channel values can be seen in Table 5.

Thermocouple Locations:

1. Ambient

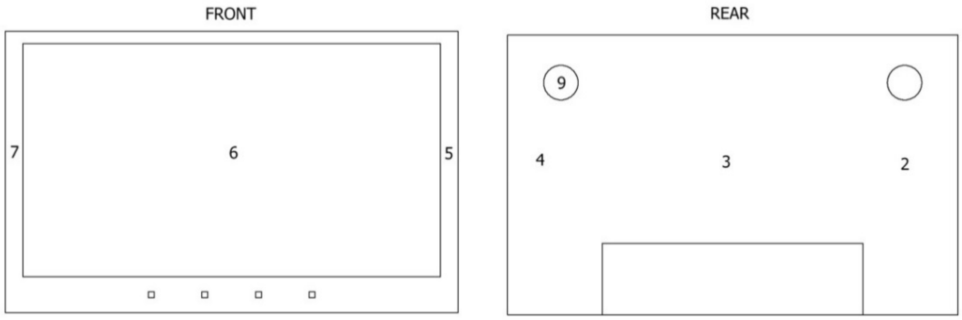


Fig. 19 Thermocouple locations for Test 5

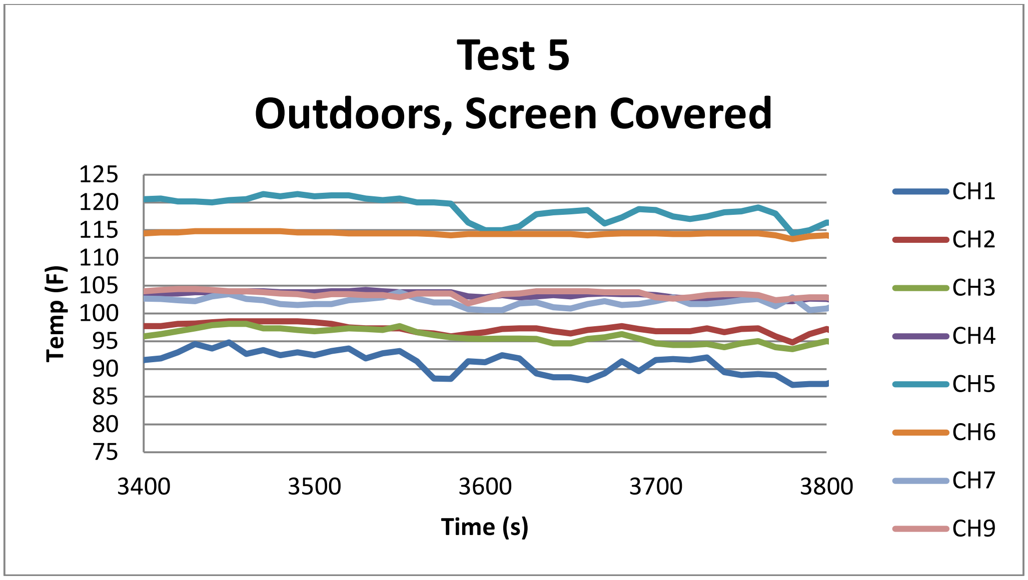
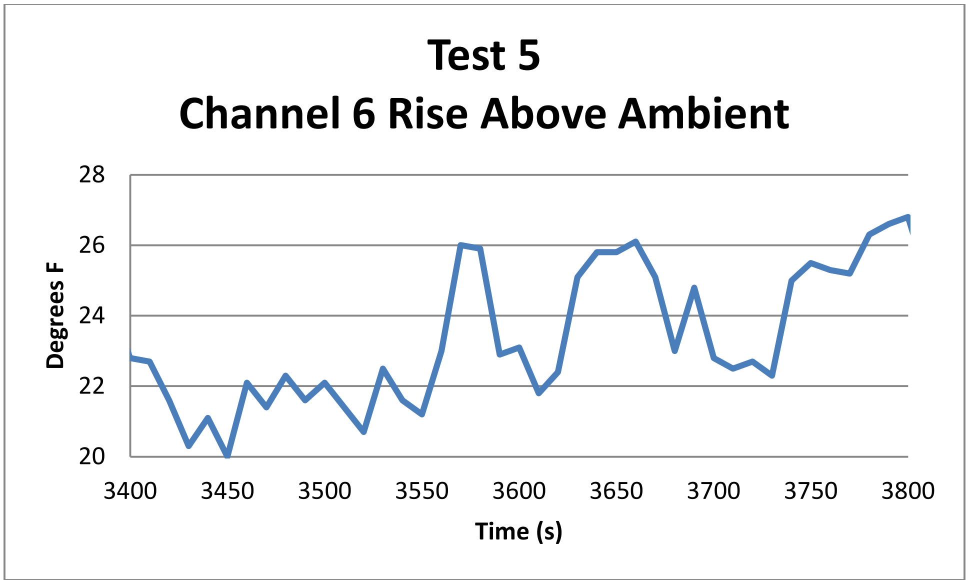


Fig. 20 Temperature vs. time for Test 5 during the steady-state period of the test

Table 5 Channel averages for Test 5 during the steady-state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH9
91.0	97.3	95.9	103.4	118.8	114.4	102.0	103.5

At the conclusion of the test, an average rise over ambient of 23.3 °F was observed at the screen (Fig. 21). It should be noted that the test was not performed during a part of the year that the sun was at its most intense. There was also a slight breeze, which contributed to lower screen temperatures. When compared to the results of Test 3, where a 62.6 °F rise over ambient was observed in direct sunlight, it can be seen that the solar gains through screen are significant.



Average Difference: 23.3 °F

Fig. 21 Difference between screen temperature and ambient through the steady state period of Test 5

3.6 Test 6, 250 W Heat Lamp, Glass on Monitor

The DayBrite Monitor was placed on a lab bench with a 250 W heat lamp positioned above the screen. A piece of Hot Mirror glass was placed across the monitor so that its entire surface was covered. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the front frame of the monitor and at the center of the screen. Temperatures were also monitored on the top and bottom sides of the glass (Fig. 22). The temperature for each channel during the test can be seen in Fig. 23.

Thermocouple Locations:

1. Ambient

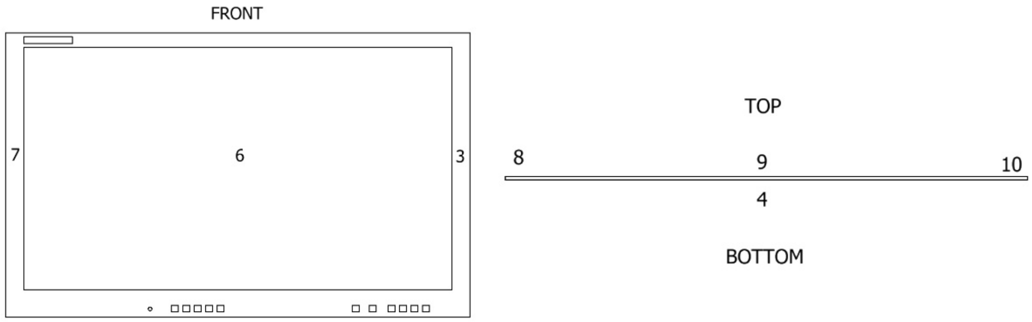


Fig. 22 Thermocouple locations for Test 6

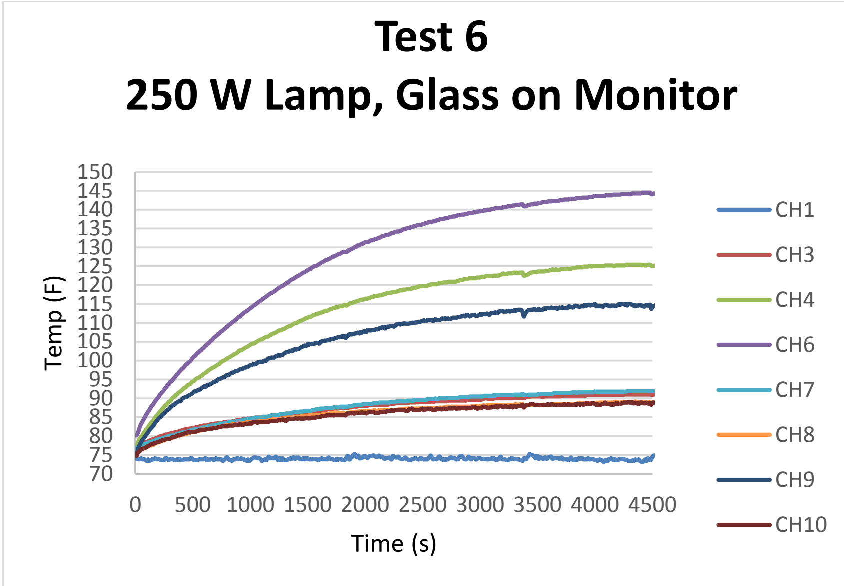


Fig. 23 Temperature vs. time for Test 6

After approximately 3000 s, the screen temperature reached 140 °F. As the temperature continued to climb without reaching steady-state, the test was aborted.

3.7 Test 7, 250 W Heat Lamp, Glass with 1 Inch Air Gap

The DayBrite Monitor was placed on a lab bench with a 250 W heat lamp positioned above the screen. A piece of Hot Mirror glass was placed across the monitor so that its entire surface was covered. The glass was spaced 1 inch above the surface of the monitor to allow heat produced by the monitor to escape. With the internal fans set to high, the monitor was positioned to allow for adequate airflow around the monitor. Thermocouples were placed along the front frame of the monitor and at the center of the screen. Temperatures were also monitored on the top and bottom sides of the glass (Fig. 24). The temperature for each channel during the steady state portion of the test can be seen in Fig. 25, and the average channel values can be seen in Table 6.

Thermocouple Locations:

1. Ambient

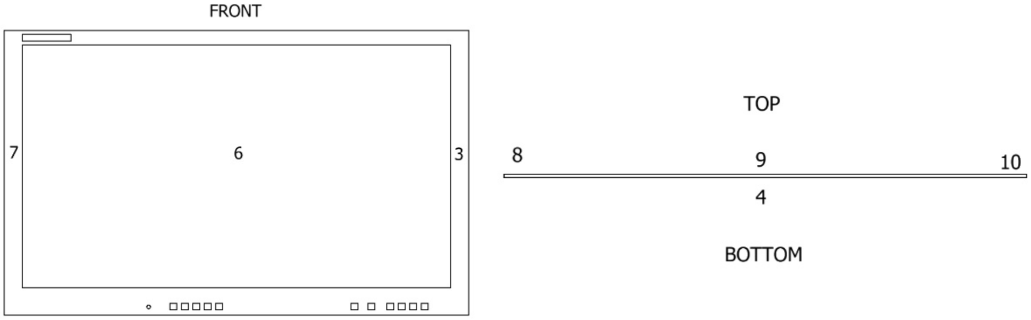


Fig. 24 Thermocouple locations for Test 7

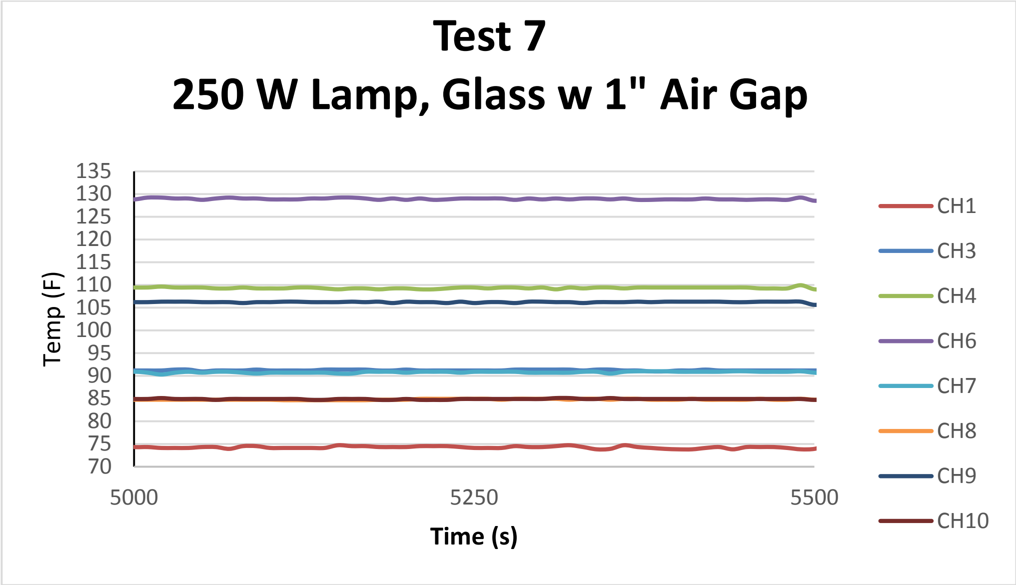
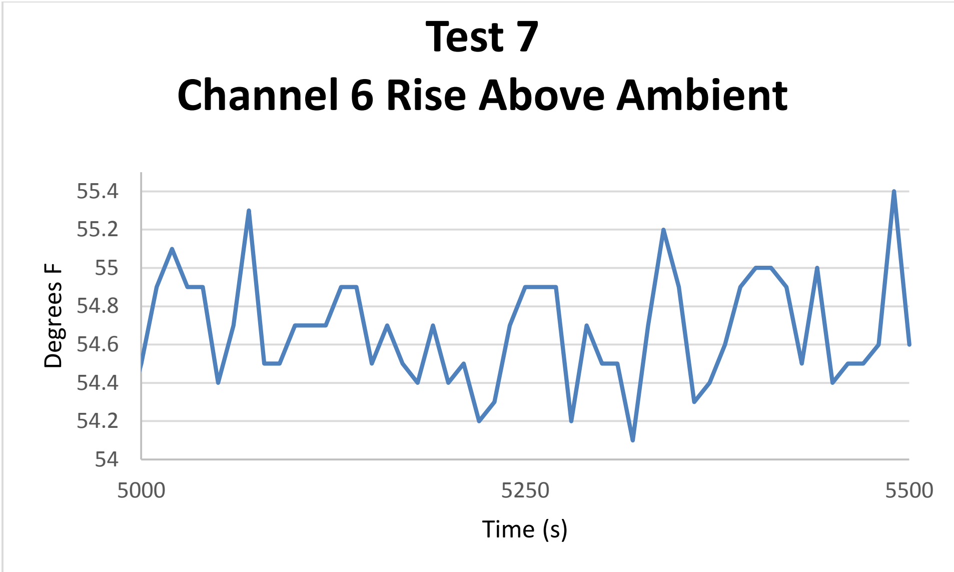


Fig. 25 Temperature vs. time for Test 7 during the steady-state period of the test

Table 6 Channel averages for Test 7 during the steady-state period of the test

CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH9
74.22	91.25	109.30	128.90	90.81	84.75	106.21	84.88

The screen temperature developed a steady-state average of 54.65 °F over ambient (Fig. 26). When compared to the results of Test 2, which produced a 75.0 °F rise over ambient at the screen, it can be seen that the Hot Mirror glass eliminated approximately 20 °F of temperature rise due to the simulated solar gain.



Average Difference: 54.65 °F

Fig. 26 Difference between screen temperature and ambient through the steady state period of Test 7

4. Conclusions and Recommendations

Table 7 summarizes the test results. Detailed conclusions and recommendations follow.

Table 7 Test result overview

Test	Description	Average Degrees Above Ambient (F)
Test 1	90 °F ambient temp in chamber	1.70
Test 2	Bench Test, 250 W heat lamp	75.0
Test 3	Outdoors, Direct Sunlight	62.6
Test 4	Outdoors, Frame Covered	56.8
Test 5	Outdoors, Screen Covered	23.3
Test 6	Bench Test, 250 W heat lamp, hot mirror glass on monitor	Screen failure
Test 7	Bench Test, 250 W heat lamp, hot mirror glass w 1” air gap	54.65

For Test 1 the environmental chamber was set to 90 °F to simulate a summer day in the shade. The monitor was placed in the chamber and allowed to come to steady-state. Various chassis temperatures as well as the screen temperature were recorded. The test showed that without solar loading the screen operates slightly above ambient temperature, with an average screen temperature 1.70 °F above ambient.

For Test 2 the monitor was placed on a lab bench with a 1 inch air gap below the body of the monitor. A 250 W heat lamp was placed 14.221 inches above the center of the screen to simulate intense solar loading. Various chassis temperatures and the screen temperature were again recorded. The screen image began to “white out” when the screen surface temperature rose above 140 °F. With the threshold for screen failure determined at 140 °F, the maximum operating conditions can be specified. Assuming an ambient temperature of 90 °F thermal loading can only cause a 50 °F rise before the monitor will fail.

The monitor was then set outside in direct sunlight to determine natural solar loading with a more even distribution than a heat lamp can supply. The test resulted in a 62.6 °F average increase over ambient. Failure was not observed during either test, as the screen temperature only reached an average temperature of 130.9 °F. This can be attributed to a slight breeze outside as well as a reduced intensity of the sun because of the time of year.

The results while shading the metal frame from the sun were then tested. Average screen temperatures of 56.8 °F over ambient were observed. Screen temperatures averaged at 125.9 °F. These results would be very close to the threshold for failure on a hot summer day, especially if the increased intensity of the summer sun is considered.

The next scenario tested shielded the screen from the sun. Average screen temperatures of 23.3 °F over ambient was observed at an average screen temperature of 114.4 °F. This scenario offers the most promising results.

With these results Hot Mirror glass from Dicrotec Thin Films was then tested as a method to shield the screen from solar loading. The Hot Mirror glass uses a glass substrate with a coating on 1 side that passes visible light, but reflects infrared light. This eliminates the heat component of light from the sun while still maintaining the function of the teleprompter.

The first test performed with the glass used the monitor on a lab bench with the 250 W heat lamp positioned above it. The Hot Mirror glass was placed directly on top of the monitor in an attempt to shield the screen from the simulated solar loading. This test produced unsatisfactory results. With the Hot Mirror glass located on the top of the monitor, heat from the 250 W heat lamp was reflected away from the monitor. However, any heat that passed through the glass or that was generated by the monitor was trapped beneath the Hot Mirror glass by the same principle. This caused the screen to fail, as temperatures climbed above 140 °F.

In order to mitigate this problem, the glass was then placed on top of the monitor with a 1 inch air gap. The air gap allows any heat generated by the monitor to escape, instead of being trapped underneath the glass. This test produced more satisfactory results, with an average rise of 54.65 °F over ambient at the screen.

These test results lend themselves to several design recommendations: maintaining an air gap between the Hot Mirror glass and the monitor, using fans to evacuate any heat trapped under the glass, and thermally insulating the glass from the monitor.

The results of Test 6 show that it is essential to maintain an air gap between the Hot Mirror glass and the monitor. The same characteristics of the glass that allow it to reflect solar gain also allow it to trap heat between the monitor and the glass. With an air gap between the glass and monitor, the heat will have an avenue of escape from the monitor and screen surface.

Using a small fan will also ensure that heat accumulated between the glass and monitor will not cause a failure. If placed inside the air gap between the monitor and glass, a series of small fans can be used to evacuate heat that may remain trapped underneath the glass. A multitude of small and quiet low voltage fans are available from commercial vendors.

The results of Test 7 showed a substantial influx of heat in the Hot Mirror glass. The top side of the center of the glass reached a steady-state temperature of 106.21 °F, approximately 32 °F above the average ambient temperature. The bottom side of the center of the glass reached a steady-state temperature of 109.30 °F, approximately 35 °F above the average ambient temperature (see Table 6). With these results in mind, the glass needs to be thermally insulated from the fixture that holds it, as well as from the monitor itself. Otherwise, the heat will simply conduct from the glass to the monitor.

With these recommendations taken into account, the issues caused by solar loading on the Boland View Port 20 inch LCD monitor can be resolved.

5. References

1. Incropera Frank P, Dewitt David P, Bergman Theodore L, Lavine Adrienne S. Fundamentals of heat and mass transfer. 6th ed. Hoboken: John Wiley & Sons, 2007.

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