

## NEW COOPERATIVE OBSERVER NETWORKS AND INSTRUMENTATION DATA QUALITY

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### 1. INTRODUCTION

In the past few years, the advent of new cooperative volunteer networks such as the [Citizen Weather Observer Program](#) (CWOP) has raised the issue of whether the instrumentation in these networks is of high enough quality to be used for nowcasting, forecast models, and climate monitoring purposes. For the most part, these networks consist of “backyard” or personal weather stations (PWS). These weather stations are typically designed to be affordable for the weather hobbyist with the data presentation is designed to be entertaining rather than utilitarian. Since the data from this network are made available to research and operational meteorologists through the National Oceanic and Atmospheric Administration (NOAA) Global Systems Division Meteorological Assimilation Data Ingest System (MADIS) along with the Automated Surface Observing System (ASOS) and other operational networks for input to Numerical Weather Prediction Models (Citizen Weather Observer Program <http://www.cwop.net>), understanding the performance of PWS relative to “official” NOAA weather station performance is necessary to effectively utilizing the data from these stations in day to day operations. This study compares two types of shielded Davis Instruments weather stations to NOAA Cooperative Observer Network (COOP) passively shielded Maximum-Minimum Temperature System (MMTS).

Davis Instruments was approached a few years ago with the prospect of providing free equipment in exchange for comparison data. For the purpose of the MMTS comparison, the following Davis Instruments radiation products were used:

- Vantage Pro Temperature/Humidity Station, Product Number: 6380 (passive shield), Figure 1
- Vantage Pro Temperature/Humidity Station retrofitted with a Daytime Fan-Aspirated

Radiation Shield Kit, Product Numbers: 6380 & 7745, Figure 2. The Kit provides a fan that runs entirely on solar power, therefore the fan runs during the daytime to help mitigate the effects of insolation.

Both Davis Instruments’ systems and the MMTS system used their own temperature sensors, display and datalogging devices.



FIG. 1. Vantage Pro Temperature/Humidity Station with Anemometer



FIG. 2. Vantage Pro Temperature/Humidity Station retrofitted with a Daytime Fan-Aspirated Radiation Shield Kit

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## 2. INSTRUMENTATION SITING

The comparison was done at the COOP site at 2 miles southwest of downtown Sparta, Michigan, (43°8'34" N; 85°42'57" W; elevation 870 feet, 265 m) which is just north of Grand Rapids in the western part of the state. The grass is regularly mowed. All radiation shields were installed at the same height above the ground as the COOP MMTS shield (5 feet, 1.5 m). The various shields are spaced apart, so they do not shade or aspirate

each other's environment. A Davis Instruments anemometer was installed at this same height to measure the affects of wind speed on radiation shield effectiveness. A Davis Instruments Solar Radiation (insolation) sensor was also installed at the site to determine the daytime sky conditions, and therefore those effects on the radiation shields. Figure 3 shows the test bed with the Davis passive shield in the foreground right. The Davis "Daytime" shield is in the immediate background. The MMTS shield is on the left.



FIG. 3. Photograph of Test Location looking toward the southeast.

Figure 4 below is another view of the instrumentation siting configuration with the Davis passive shield to the left and the Davis "Daytime" shield to the right. The MMTS shield is in the center. The shield in the far background was for an unrelated test.

In this study, data were collected over a year from June 1, 2005 to June 30, 2006. Intermittent suspect readings have been observed by the NOAA COOP observer. In fact, the COOP observer later reported that the data cable from the MMTS shield to the display/datalogger had apparently been cut by utility service personnel and then poorly patched together using electrical tape and a sandwich bag. The cable has been

since properly spliced and weather-proofed. This should prevent future temporary failures of this type. This problem connection was fixed in October 2006. The affect that this had on the dataset and the subsequent removal of suspect data is discussed later.

This study compared the MMTS to the Davis Instruments passive shield and retrofitted daytime fan because it was believed that NOAA would be more likely to accept an installation where the radiation shield is separated from the rain collector. The most widely used weather station that Davis Instruments manufactures has a rain collector that is installed above the radiation shield.



FIG. 4. Photograph of Test Location looking toward the northeast.

### 3. RESULTS AND DISCUSSION

#### 3.1 *Daily Extrema*

The daily maximum and minimum temperatures for each Davis Instruments station and the MMTS were recorded. Both systems used local midnight as the start of each calendar day.

Figure 5 shows a scatter-plot of the daily maximum temperature readings. The line represents the MMTS readings and the dots the Davis readings. If the Davis shield readings were identical to the MMTS readings, they would fall exactly on the line. Dots below the line indicate the Davis shield read cooler than the MMTS, dots

above the line indicate where the Davis shield read warmer than the MMTS. As Figure 5 indicates, a majority of the Davis readings fell within a few degrees of those of the MMTS.

Figure 6 shows a scatter-plot of the daily minimum temperature readings in the same manner as shown in Figure 5. Figure 6 indicates a majority of the Davis readings fell within a few degrees of those of the MMTS. Table 1 lists the statistical measures of correlation between the MMTS and the Davis sensors for daily highs and lows. Although the MMTS is used as reference in this study, it is known that there are differences when comparing the MMTS to other “official” NOAA systems such as the US Climate Reference Network (USCRN) (Sun et al., 2005).

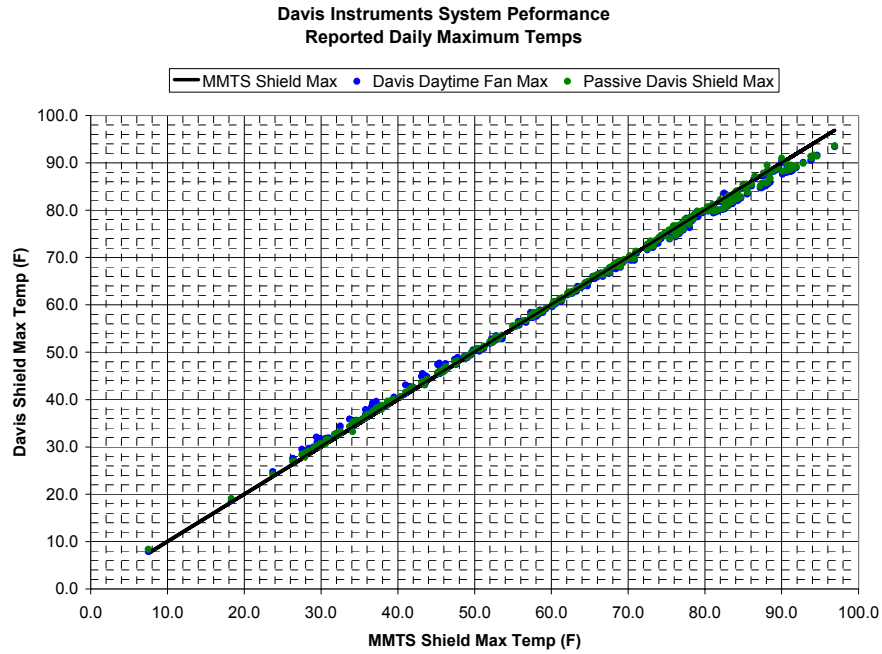


FIG. 5. Davis Instruments system performance for daily maximum temperature readings as compared to those of the MMTS

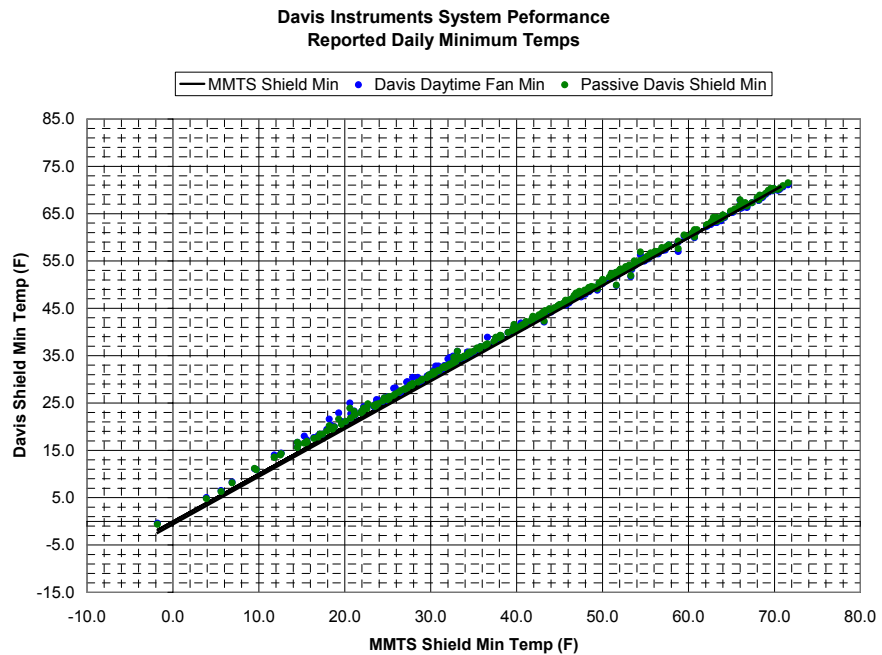


FIG. 6. Davis Instruments system performance for daily minimum temperature readings as compared to those of the MMTS

<b>Difference Statistics</b>				
	<b>Daytime Fan</b>		<b>Passive Shield</b>	
	<b>Daily Highs</b>	<b>Daily Lows</b>	<b>Daily Highs</b>	<b>Daily Lows</b>
<b>Maximum Difference</b>	+2.7°F (+1.5°C)	+4.4°F (+2.4°C)	+1.4°F (+0.8°C)	+3.3°F (+1.8°C)
<b>Average Difference</b>	-0.2°F (-0.1°C)	+0.7°F (+0.4°C)	-0.1°F (-0.1°C)	+0.8°F (+0.4°C)
<b>Minimum Difference</b>	-3.5°F (-1.9°C)	-1.8°F (-1.0°C)	-3.3°F (-1.8°C)	-1.7°F (-0.9°C)
<b>Standard Deviation</b>	1.2°F (0.7°C)	0.8°F (0.4°C)	0.9°F (0.5°C)	0.5°F (0.3°C)
<b>95% Confidence (2σ)</b>	2.4°F (1.3°C)	1.6°F (0.9°C)	1.8°F (1.0°C)	1.0°F (0.6°C)
<b>Correlation Coefficient</b>	0.9984	0.9988	0.9988	0.9993

TABLE 1. Davis radiation shield daily extrema differences statistics. Reference: MMTS

Overall, the daily lows had a greater average difference than the daily highs as referenced to the MMTS. The magnitude of the greatest positive differences was greater for the daily lows than those for the daily highs. Conversely, the magnitude of the greatest minimum differences was greatest for the daily highs. The temperature sensing accuracy requirement for the measurement of "Surface Weather Observations and Reports" is  $\pm 1.1^\circ\text{F}$  ( $\pm 0.6^\circ\text{C}$ ) (Office of the Federal Coordinator for Meteorological Services (OFCM) and Supporting Research, 2005). Assuming the MMTS read the "perfect" temperature, this indicates at the 95% confidence level, this requirement is exceeded by much more on reporting the daily highs than on reporting daily

lows. The Davis passive shield performance is a better match overall to the MMTS in this regard than the daytime fan shield is. However, the overall average difference of both daily high and low temperatures of both Davis shields falls within the OFCM requirement.

Table 2 provides a breakdown of the frequency of daily extrema observations with difference readings. As shown, a majority of the differences fell within the OFCM accuracy requirements. A significant minority fell within a multiple of twice this acceptable difference. Few differences were greater than this. The Davis passive shield performed better more often, and performance was better more often for recording daily lows.

<b>Frequency of Differences – Weather Forecasting Standards <math>\pm 1.1^\circ\text{F}</math> (<math>\pm 0.6^\circ\text{C}</math>)</b>				
	<b>Daytime Fan</b>		<b>Passive Shield</b>	
	<b>Daily Highs</b>	<b>Daily Lows</b>	<b>Daily Highs</b>	<b>Daily Lows</b>
<b>Differences <math>&gt; +3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	0.0%	1.0%	0.0%	0.0%
<b>Differences <math>&gt; +2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>) &amp; <math>\leq +3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	1.7%	3.0%	0.0%	1.3%
<b>Differences <math>&gt; +1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq +2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>)</b>	6.9%	17.5%	0.7%	15.2%
<b>Differences <math>\leq +1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\geq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	73.9%	77.2%	83.2%	82.2%
<b>Differences <math>\leq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>)</b>	8.9%	1.0%	11.6%	1.0%
<b>Differences <math>\leq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>) &amp; <math>\geq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	7.9%	0.0%	4.0%	0.0%
<b>Differences <math>\leq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	0.3%	0.0%	0.3%	0.0%

TABLE 2. Frequency of Davis radiation shield synoptic daily extrema differences. Reference: MMTS

<b>Frequency of Differences - Climate Monitoring Standards <math>\pm 0.5^\circ\text{F}</math> (<math>\pm 0.3^\circ\text{C}</math>)</b>				
	<b>Daytime Fan</b>		<b>Passive Shield</b>	
	<b>Daily Highs</b>	<b>Daily Lows</b>	<b>Daily Highs</b>	<b>Daily Lows</b>
<b>Differences <math>&gt;+1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	5.9%	11.9%	0.0%	5.6%
<b>Differences <math>&gt;+1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq+1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	5.3%	13.5%	0.7%	18.8%
<b>Differences <math>&gt;+0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\leq+1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>)</b>	11.2%	32.3%	17.2%	50.2%
<b>Differences <math>\leq+0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\geq-0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>)</b>	53.5%	40.3%	61.4%	23.8%
<b>Differences <math>\leq-0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>) &amp; <math>\geq-1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	6.6%	0.7%	5.0%	0.7%
<b>Differences <math>\leq-1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq-1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	2.3%	0.3%	4.0%	0.7%
<b>Differences <math>\leq-1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	15.2%	1.0%	11.9%	0.3%

TABLE 3. Frequency of Davis radiation shield climate daily extrema differences. Reference: MMTS

Table 3 provides a similar breakdown as Table 2, but with the accuracy requirements for climate based monitoring needs. For the purpose of this study, these are the stated accuracy specifications of the MMTS temperature sensor (National Weather Service Engineering Division, 1997). When subjected to the higher accuracy requirement, the Davis shields performed within specifications much less often than with the OFCM requirements. However, a majority of the time the shields still performed within specifications for recording daily highs. A significant minority of readings were a multiple of two to three times warmer than this standard.

### 3.2 Hourly Readings

Hourly temperatures for each Davis Instruments station and the MMTS station were recorded. The Davis station averaged temperature readings over the entire hour from discrete 10 to 12 second samples, while the MMTS display reported values at each hour boundary captured every 2 seconds. These differing sample rates can make a difference in the

resulting readings (Lin et al., 2005). In an attempt to compensate for this difference, the MMTS data were modified during analysis so that each data value represents an average between the current hour and the previous hour's reading. The reason for this modification is so that the data sets from both systems approximate an hourly average.

Figure 7 shows a scatter-plot of the hourly temperature readings for the daytime fan shield. As in Figure 5 & 6, the line represents the MMTS readings and the dots the Davis shield readings. If the Davis shield readings were identical to the MMTS readings, they would fall exactly on the line. Dots below the line indicate the Davis shield read cooler than the MMTS, dots above the line indicate where the Davis shield read warmer than the MMTS shield.

Figure 8 shows a scatter-plot of the hourly temperature readings for the Davis passive shield in the same manner as shown in Figure 7. Both Figures 7 and 8 indicate many of the Davis passive shield readings fell within a few degrees of those of the MMTS. Both Davis shields tended to read cooler above  $45^\circ\text{F}$  ( $7^\circ\text{C}$ ) and warmer below  $45^\circ\text{F}$  ( $7^\circ\text{C}$ ).

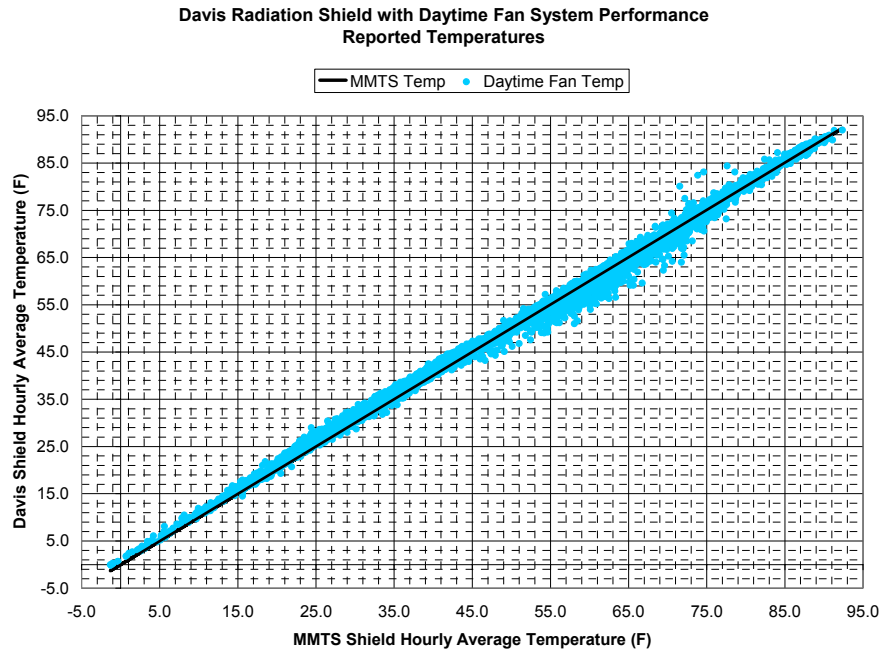


FIG. 7. Davis Instruments radiation shield with daytime fan system performance for hourly temperature readings as compared to those of the MMTS

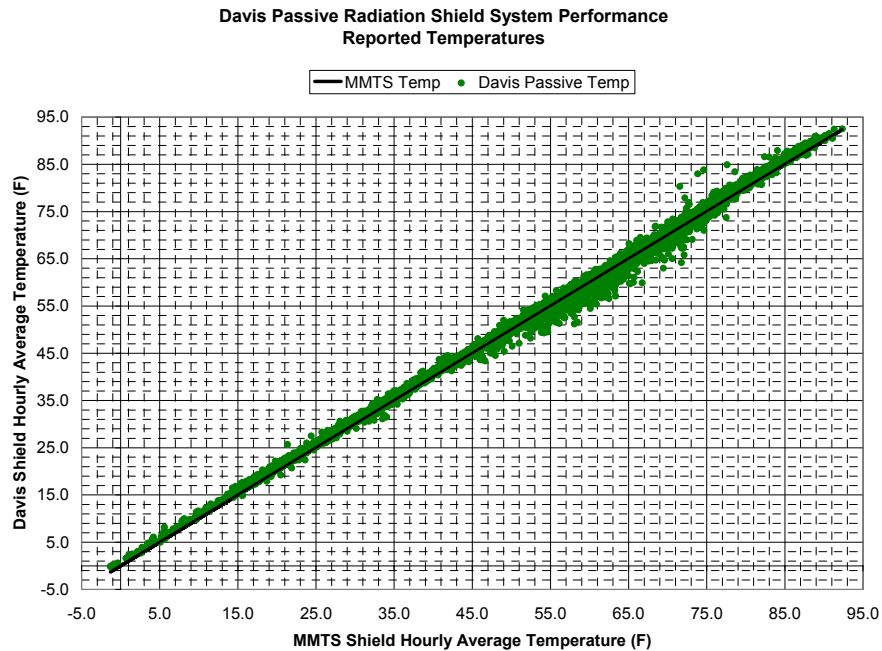


FIG. 8. Davis Instruments passive radiation shield system performance for hourly temperature readings as compared to those of the MMTS

Difference Statistics		
	Daytime Fan	Passive Shield
<b>Maximum Difference</b>	+8.6°F (+4.8°C)	+9.2°F (+5.1°C)
<b>Average Difference</b>	+0.5°F (+0.3°C)	+0.5°F (+0.3°C)
<b>Minimum Difference</b>	-7.8°F (-4.3°C)	-7.6°F (-4.2°C)
<b>Standard Deviation</b>	1.1°F (0.6°C)	0.9°F (0.5°C)
<b>95% Confidence (2σ)</b>	2.2°F (1.2°C)	1.8°F (1.0°C)
<b>Correlation Coefficient</b>	0.9973	0.9979

TABLE 4. Davis radiation shield hourly differences statistics. Reference: MMTS

On average, both Davis shields had the same, slightly positive difference as compared to the MMTS. The magnitude of the greatest positive differences was greater than those for the daily highs. Again, assuming the MMTS shield is a “perfect” reference, this indicates at the 95% confidence level, the OFCM requirement is exceeded by a multiple of nearly 4 times. However, the overall average difference of both daily high and low temperatures of both Davis shields falls within this requirement.

Table 5 provides a breakdown of the frequency of hourly observations with difference readings. As shown, a majority of the differences fell within the OFCM accuracy requirements. A significant minority fell within a multiple of two times warmer than this acceptable difference. Few differences were greater than this. The Davis passive shield performance generally was a match to the MMTS more often.

Frequency of Differences – Weather Forecasting Standards $\pm 1.1^\circ\text{F}$ ( $\pm 0.6^\circ\text{C}$ )		
	Daytime Fan	Passive Shield
<b>Differences <math>&gt; +3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	0.2%	0.2%
<b>Differences <math>&gt; +2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>) &amp; <math>\leq +3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	2.9%	0.5%
<b>Differences <math>&gt; +1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq +2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>)</b>	14.1%	12.4%
<b>Differences <math>\leq +1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\geq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	77.2%	82.5%
<b>Differences <math>\leq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>)</b>	2.5%	2.1%
<b>Differences <math>\leq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>) &amp; <math>\geq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	1.7%	1.4%
<b>Differences <math>\leq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	1.4%	1.1%

TABLE 5. Frequency of Davis radiation shield synoptic hourly differences. Reference: MMTS

Table 6 provides a similar breakdown as Table 2, but with the accuracy requirements for climate observations. When subjected to these requirements, the Davis shields performed within

specifications only a minority of the time. A significant minority fell within a multiple of two to three times warmer than this acceptable difference.

Frequency of Differences - Climate Monitoring Standards $\pm 0.5^\circ\text{F}$ ( $\pm 0.3^\circ\text{C}$ )		
	Daytime Fan	Passive Shield
<b>Differences <math>&gt; +1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	8.9%	3.9%
<b>Differences <math>&gt; +1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq +1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	11.6%	13.9%
<b>Differences <math>&gt; +0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\leq +1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>)</b>	31.4%	48.8%
<b>Differences <math>\leq +0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\geq -0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>)</b>	38.8%	26.4%
<b>Differences <math>\leq -0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>) &amp; <math>\geq -1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	3.3%	2.2%
<b>Differences <math>\leq -1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq -1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	1.6%	1.3%
<b>Differences <math>\leq -1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	4.4%	3.5%

TABLE 6. Frequency of Davis radiation shield climate hourly differences. Reference: MMTS



Figure 9 shows a plot of the hourly temperatures from all the systems on the day (June 9, 2005) that the greatest daily maximum difference between the Davis shields and the MMTS was recorded. Hourly average wind speed is also plotted for comparison. What are most pronounced are the great variations in the MMTS temperature as compared to the Davis shields, which showed a more gradual warming and cooling than the MMTS shield and a more similar response to each other than to the MMTS shield.

The largest temperature difference between the two Davis shields on this day was +1.2°F (+0.7°C). The hourly wind speed never exceeded 3 mph (1.3 m/s) that day. At 09:00, the MMTS reading lowered significantly. At that time, the wind speed had been increasing since 08:00 from calm, but was consistent from 10:00 to 16:00 local time on that day, and the MMTS reading then began to rise rapidly. Therefore the fluctuation of the MMTS temperature cannot easily be explained by the wind speed.

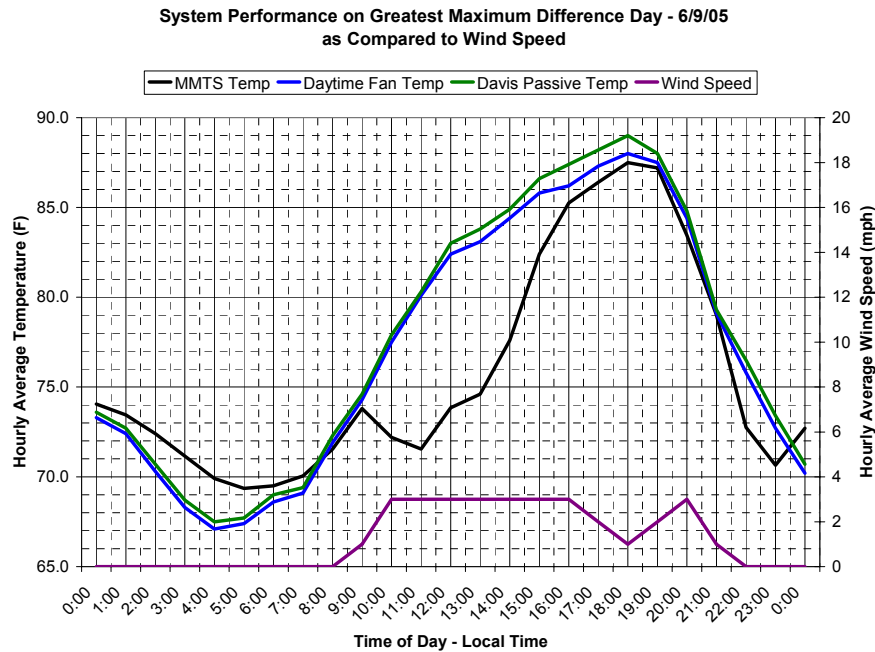


FIG. 9. System performance on day of greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to wind speed

Figure 10 shows the same day as Figure 9 except with data as compared to insolation. Since the insolation readings do not show a perfect cosine curve, this is indicative of clouds that day. It is possible that the dip in temperature of the MMTS was due to a fluctuation in cloud cover and the Davis shields have a much slower thermal

response to insolation. If this is true, then a clear sky day should have a more consistent response between the Davis shields and the MMTS. However, the insolation is increasing while the temperature as reported by the MMTS is decreasing.

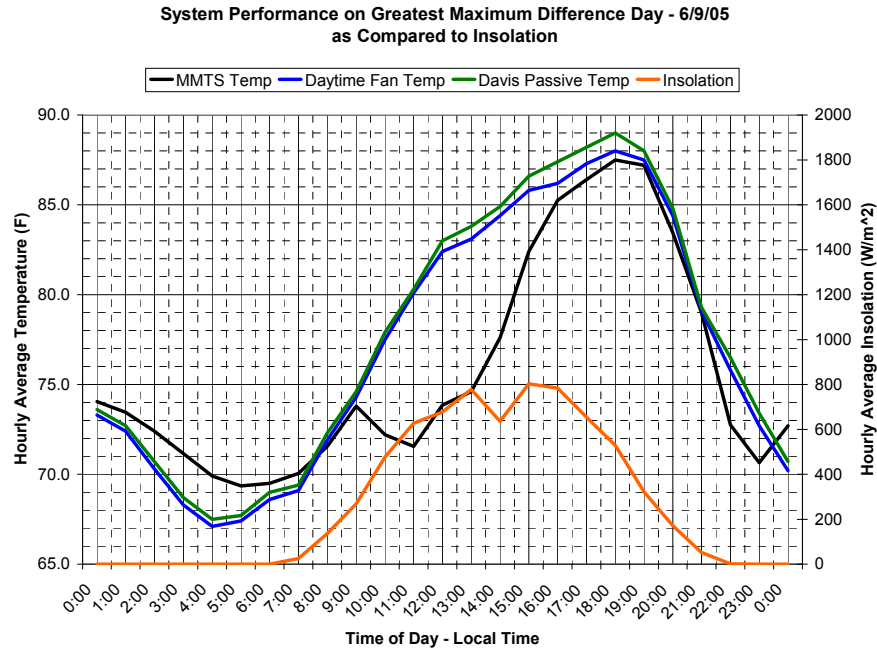


FIG. 10. System performance on day of greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to insolation

As mentioned previously, the COOP observer noted some suspect readings and a poor connection on the data cable. Therefore, it may be wise to consult a secondary source of data for this test. Figure 11 shows the same data as Figure 9, but with data from the nearest Automated Surface Observing System (ASOS) station to this COOP site added. As is shown,

excepting the period after 09:00 and before 16:00, the ASOS data tracks the COOP data fairly closely. The data tracking suggests this secondary source can be used as reasonable reality check and that the data during this suspect period probably represents a temporary failure mode on the part of the MMTS system.

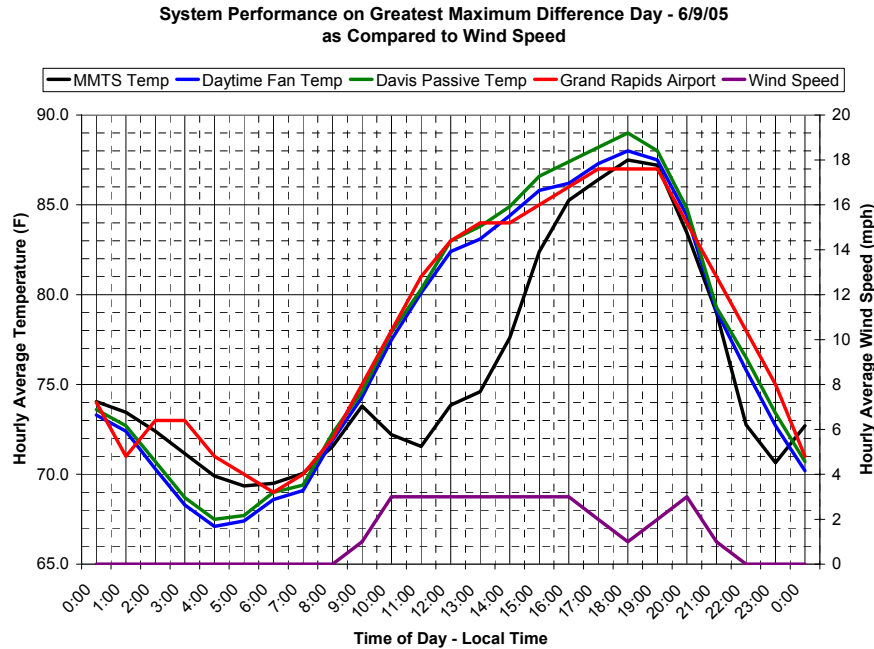


FIG. 11. System performance on day of greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to insolation with data from the nearest ASOS station (Grand Rapids Airport)

Difference Statistics		
	Daytime Fan	Passive Shield
<b>Maximum Difference</b>	+4.6°F (+2.6°C)	+4.8°F (+2.7°C)
<b>Average Difference</b>	+0.5°F (+0.3°C)	+0.5°F (+0.3°C)
<b>Minimum Difference</b>	-7.8°F (-4.3°C)	-7.6°F (-4.2°C)
<b>Standard Deviation</b>	1.0°F (0.6°C)	0.9°F (0.5°C)
<b>95% Confidence (2σ)</b>	2.0°F (1.1°C)	1.8°F (1.0°C)
<b>Correlation Coefficient</b>	0.9974	0.9980

TABLE 7. Davis radiation shield hourly differences statistics with suspect data removed. Reference: MMTS

Table 7 shows the hourly data statistics with these suspect data points removed. The main effect of removing the suspect data was to significantly lower the maximum difference value. The frequency tables remain relatively unchanged. A summary at the end of this paper illustrates the new values.

Pursuing the theory that cloud cover fluctuations result in a greater spread in the data, Figure 12 shows a clear sky day. It represents the best combination of high insolation and low average wind speed of all clear sky days during the study. The hourly average wind speed (not shown) did not exceed 3 mph (1.3 m/s) during this period. As is evident, there are no significant fluctuations in the thermal response of the MMTS as compared to the response of the Davis shields. Specifically, the largest temperature difference between the Davis shields and the MMTS was a much smaller +1.5°F (+0.8°C).

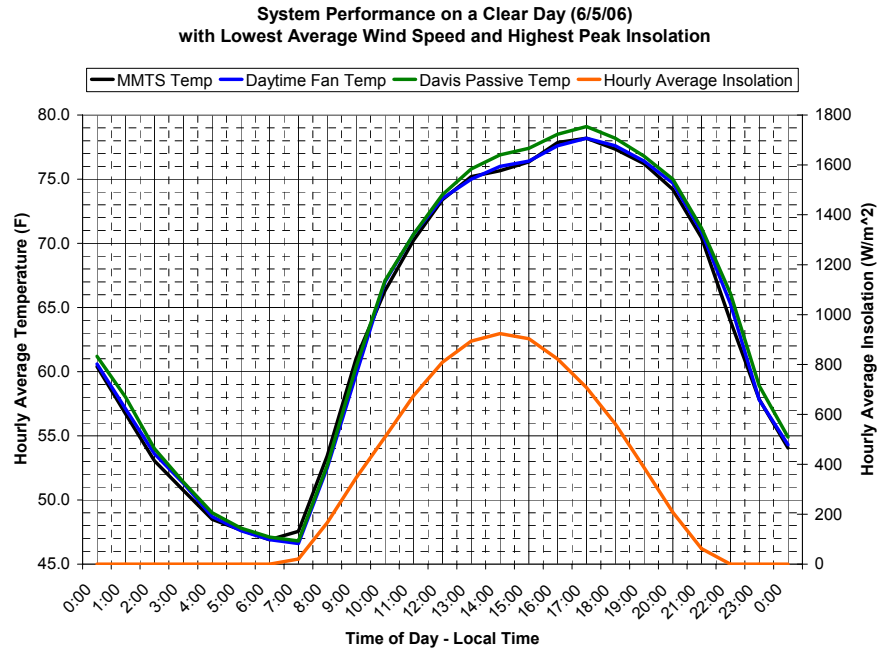


FIG. 12. System performance on a clear sky day with the combination of highest peak insolation and lowest wind speed during the study

Difference Statistics		
	Daytime Fan	Passive Shield
<b>Maximum Difference</b>	+2.8°F (+1.6°C)	+2.9°F (+1.6°C)
<b>Average Difference</b>	+0.4°F (+0.2°C)	+0.7°F (+0.4°C)
<b>Minimum Difference</b>	-3.9°F (-2.2°C)	-3.7°F (-2.0°C)
<b>Standard Deviation</b>	0.8°F (0.4°C)	0.7°F (0.4°C)
<b>95% Confidence (2σ)</b>	1.6°F (0.9°C)	1.4°F (0.8°C)
<b>Correlation Coefficient</b>	0.9976	0.9980

TABLE 8. Davis radiation shield daytime, clear sky hourly difference statistics. Reference: MMTS

Table 8 shows statistics for only *daytime, clear sky* conditions. Eliminating days with clouds reduces the spread of differences significantly. Since the Davis shield data are hourly averages

derived from samples collected every 10 to 12 seconds, the Davis data will have any short-term rapid temperature changes smoothed out. The MMTS data is averaged, but only represent a sample of two, so the amount of smoothing of this data is minimal. Therefore, any deviation of the MMTS value at the hour boundary from the hourly average will show up in the difference statistics. These deviations are more likely when rapid changes in insolation occur on variably cloudy days.

Figure 13 illustrates a day with some degree of cloudiness as evident by the fluctuations in insolation. As is shown, other than minor differences from the MMTS reading (+1.6°F/+0.9°C for the passive shield and +1.1°F/+0.6°C for the daytime fan), the Davis shields tracked the MMTS rather closely. These differences are similar to the clear sky differences illustrated in Figure 12. This suggests that the difference statistics cannot be entirely explained by differences in performance in clear versus variably cloudy sky conditions.

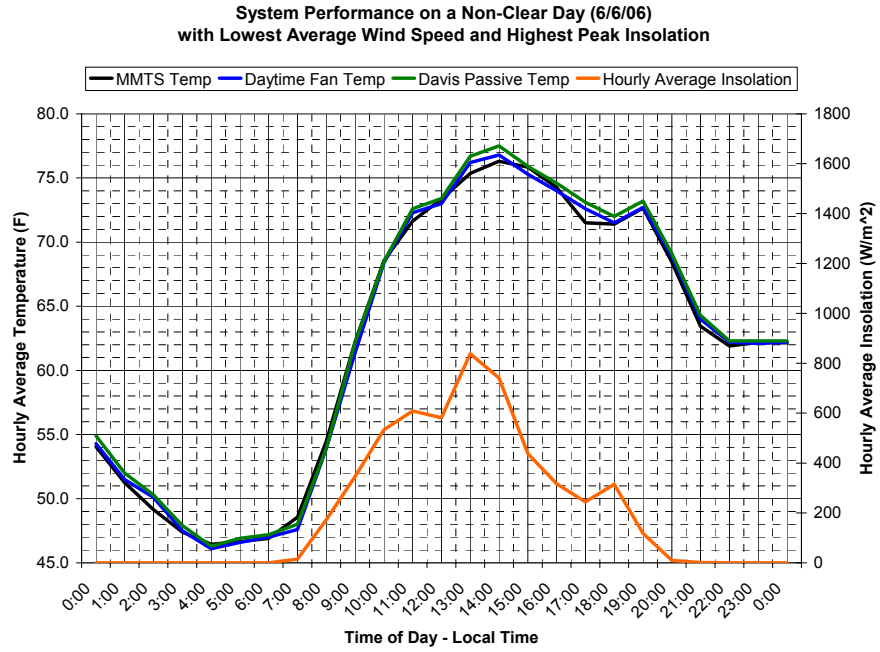


FIG. 13. System performance on a partly cloudy day during the same time of year as Figure 12.

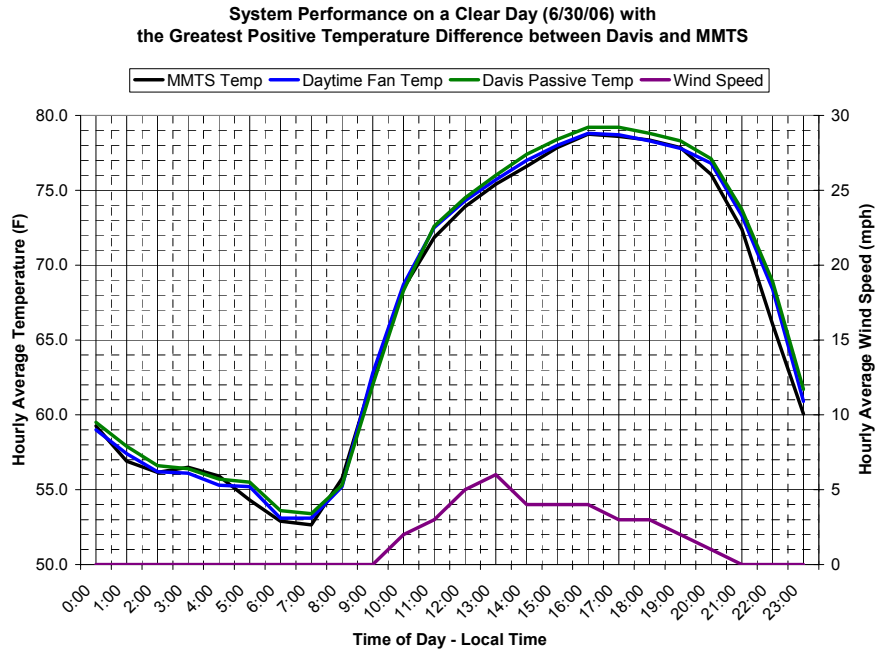


FIG. 14. System performance on a clear sky day with the greatest positive difference between the Davis shields and the MMTS

Figure 14 shows the *clear* day that the Davis shields had the greatest maximum difference. This difference occurred at 22:00 local time during the time of day when the temperature is cooling. This supports the suggestion that the Davis shields have more thermal inertia than the MMTS shield.

Further investigation examines when this greatest positive difference occurred. Each day was broken into three discrete periods: morning (warming), middle of the day (peak solar), and afternoon/evening (cooling). The morning period is up to and including 10:00. The middle of the day is after 10:00 and up to 14:00. The afternoon/evening period is after 14:00. The

greatest maximum differences all occur during the afternoon/evening period when the air temperature and radiation shields are cooling. Differences of +2.0°F (+1.1°C) or greater for the daytime shield and +1.9°F (+1.0°C) or greater for the passive shield all occurred during the afternoon/evening period.

Figure 15 examines the day with the greatest daytime, clear sky, *negative* difference. This value of -3.9°F (-2.2°C) for the daytime fan shield and -3.7°F (-2.0°C) for the passive shield both occurred during the morning at 07:00 local time. To determine whether this difference represents a failure in the MMTS, ASOS data is also shown.

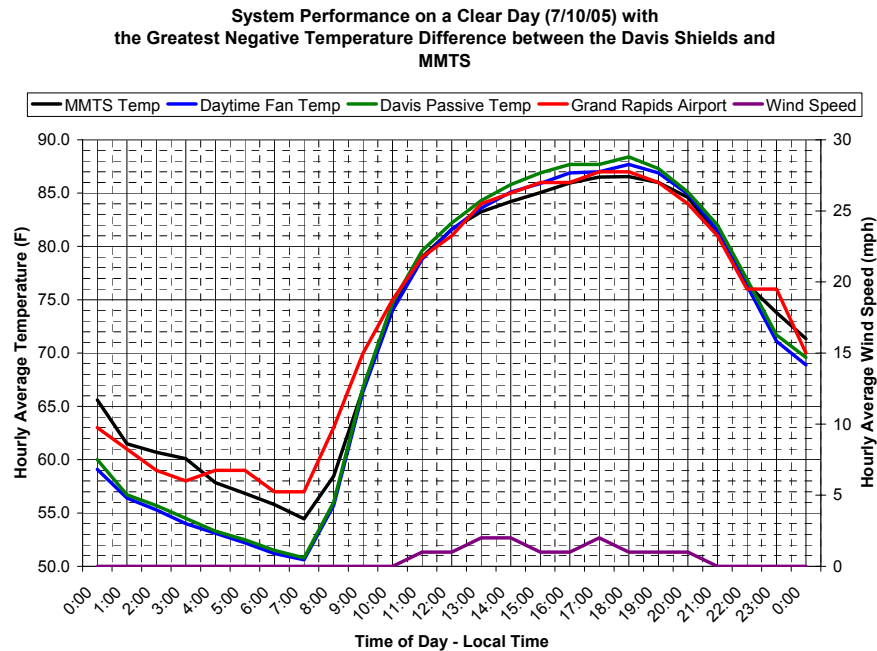


FIG. 15. System performance on a clear sky day with the greatest negative difference between the Davis shields and the MMTS

Further, the greatest negative differences overall occurred during the morning period, with differences of -3.9°F (-2.2°C) or more negative for the daytime fan shield and -3.7°F (-2.0°C) or more negative for the passive shield. Since the ASOS and MMTS data track each other more closely than the Davis data, it must be concluded

that this data represents normal MMTS performance. These results suggest that negative differences are primarily related to nighttime cooling since this worst case, negative difference occurred right before the temperature began to rise.

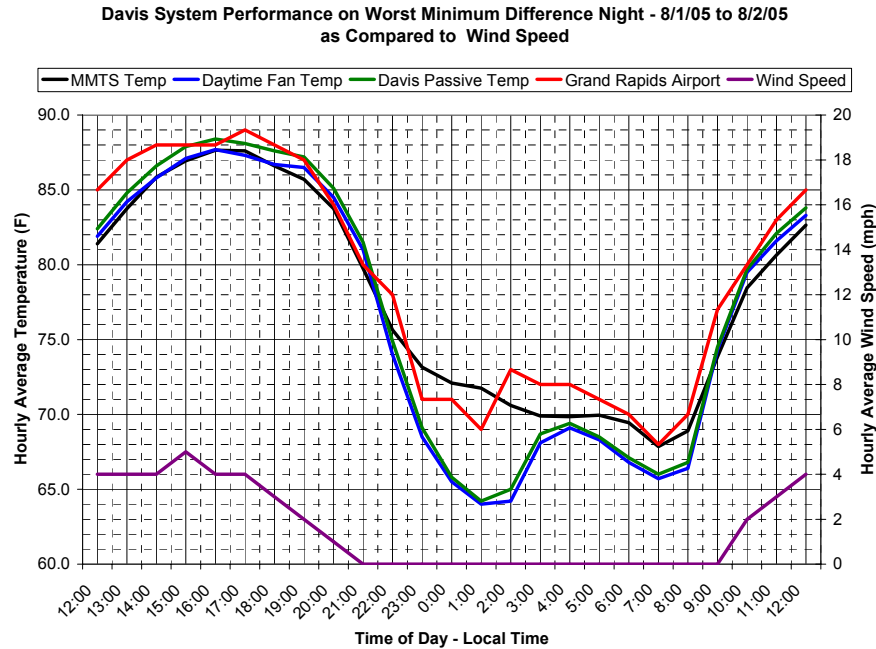


FIG. 16. System performance on a mostly clear sky **night** with the greatest negative difference between the Davis shields and the MMTS

So, the greatest overall negative differences between the Davis shields and the MMTS ( $-7.8^{\circ}\text{F}/4.3^{\circ}\text{C}$  for the daytime fan shield and  $-7.6^{\circ}\text{F}/4.2^{\circ}\text{C}$  for the passive shield) for the entire dataset are examined. These events occur during the nighttime and also happen to correspond with days with relatively clear skies. Figure 16 illustrates the day (Aug. 2, 2005) of this occurrence. The August event occurred at 01:00 local time. As is shown, winds were essentially calm during both events. Again, the MMTS and ASOS data track more closely than the MMTS and

Davis data, so the MMTS data cannot be considered invalid.

### 3.3 Daily Extrema Results as Compared to Hourly Results

Table 9 summarizes the statistics with the daily maximum and minimum statistics combined. Excepting minimum differences, the data are similar, particularly for the daytime fan performance. The passive shield daily maximum difference is considerably better than the hourly maximum difference.

Difference Statistics				
	Daytime Fan		Passive Shield	
	Daily	Hourly	Daily	Hourly
<b>Maximum Difference</b>	+4.4°F (+2.4°C)	+4.6°F (+2.6°C)	+3.3°F (+1.8°C)	+4.8°F (+2.7°C)
<b>Average Difference</b>	+0.7°F (+0.4°C)	+0.5°F (+0.3°C)	+0.7°F (+0.4°C)	+0.5°F (+0.3°C)
<b>Minimum Difference</b>	-3.5°F (-1.9°C)	-7.8°F (-4.3°C)	-3.3°F (-1.8°C)	-7.6°F (-4.2°C)
<b>Standard Deviation</b>	1.1°F (0.6°C)	1.0°F (0.6°C)	0.9°F (0.5°C)	0.9°F (0.5°C)
<b>95% Confidence (2σ)</b>	2.2°F (1.2°C)	2.0°F (1.1°C)	1.8°F (1.0°C)	1.8°F (1.0°C)
<b>Correlation Coefficient</b>	0.9988	0.9974	0.9991	0.9980

TABLE 9. Davis radiation shield differences statistics summarized. Reference: MMTS

Frequency of Differences - Weather Forecasting Standards $\pm 1.1^\circ\text{F}$ ( $\pm 0.6^\circ\text{C}$ )				
	Daytime Fan		Passive Shield	
	Daily	Hourly	Daily	Hourly
<b>Differences <math>&gt;+3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	0.5%	0.1%	0.5%	0.1%
<b>Differences <math>&gt;+2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>) &amp; <math>\leq +3.3^\circ\text{F}</math> (<math>+1.8^\circ\text{C}</math>)</b>	2.3%	2.9%	1.5%	0.5%
<b>Differences <math>&gt;+1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq +2.2^\circ\text{F}</math> (<math>+1.2^\circ\text{C}</math>)</b>	12.3%	14.1%	9.1%	12.4%
<b>Differences <math>\leq +1.1^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\geq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	75.8%	77.3%	80.5%	82.6%
<b>Differences <math>\leq -1.1^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>)</b>	5.0%	2.5%	6.3%	2.1%
<b>Differences <math>\leq -2.2^\circ\text{F}</math> (<math>-1.2^\circ\text{C}</math>) &amp; <math>\geq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	4.0%	1.7%	2.0%	1.4%
<b>Differences <math>\leq -3.3^\circ\text{F}</math> (<math>-1.8^\circ\text{C}</math>)</b>	0.2%	1.4%	0.2%	1.1%

TABLE 10. Frequency of Davis radiation shield differences summarized. Reference: MMTS

Frequency of Differences - Climate Monitoring Standards $\pm 0.5^\circ\text{F}$ ( $\pm 0.3^\circ\text{C}$ )				
	Daytime Fan		Passive Shield	
	Daily	Hourly	Daily	Hourly
<b>Differences <math>&gt;+1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	8.9%	8.9%	2.8%	3.8%
<b>Differences <math>&gt;+1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>) &amp; <math>\leq +1.5^\circ\text{F}</math> (<math>+0.8^\circ\text{C}</math>)</b>	9.4%	11.6%	9.7%	13.9%
<b>Differences <math>&gt;+0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\leq +1.0^\circ\text{F}</math> (<math>+0.6^\circ\text{C}</math>)</b>	21.8%	31.4%	33.7%	48.8%
<b>Differences <math>\leq +0.5^\circ\text{F}</math> (<math>+0.3^\circ\text{C}</math>) &amp; <math>\geq -0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>)</b>	46.9%	38.8%	42.6%	26.5%
<b>Differences <math>\leq -0.5^\circ\text{F}</math> (<math>-0.3^\circ\text{C}</math>) &amp; <math>\geq -1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>)</b>	3.6%	3.3%	2.8%	2.2%
<b>Differences <math>\leq -1.0^\circ\text{F}</math> (<math>-0.6^\circ\text{C}</math>) &amp; <math>\geq -1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	1.3%	1.6%	2.3%	1.3%
<b>Differences <math>\leq -1.5^\circ\text{F}</math> (<math>-0.8^\circ\text{C}</math>)</b>	8.1%	4.4%	6.1%	3.5%

TABLE 11. Frequency of Davis radiation shield differences summarized. Reference: MMTS

Table 10 summarizes the frequency of differences for synoptic standards and Table 11, for climate standards. When comparing the relative performance of the Davis shields when examined on a daily maximum and minimum basis against an examination of the hourly readings, the

Davis shields' performance is similar in both instances. The differences are more visible when using the more stringent "climate" standards. The daily values meet these standards more often than the hourly values do.



Table 12 compares the daily statistics to the hourly statistics with cloudy daytime conditions removed. The data with cloudy, daytime

conditions (i.e., days with sharp increases and decreases in insolation) removed shows better performance excepting minimum differences.

	Difference Statistics			
	Daytime Fan		Passive Shield	
	Daily	Hourly	Daily	Hourly
<b>Maximum Difference</b>	+2.7°F (+1.5°C)	+3.3°F (+1.8°C)	+1.9°F (+1.0°C)	+2.9°F (+1.6°C)
<b>Average Difference</b>	0.0°F (0.0°C)	+0.1°F (+0.1°C)	+0.3°F (+0.2°C)	+0.4°F (+0.2°C)
<b>Minimum Difference</b>	-3.0°F (-1.7°C)	-7.8°F (-4.3°C)	-2.6°F (-1.4°C)	-7.6°F (-4.2°C)
<b>Standard Deviation</b>	1.0°F (0.6°C)	1.3°F (0.7°C)	0.8°F (0.4°C)	1.2°F (0.7°C)
<b>95% Confidence (2σ)</b>	2.0°F (1.1°C)	2.6°F (1.4°C)	1.6°F (0.9°C)	2.4°F (1.3°C)
<b>Correlation Coefficient</b>	0.9990	0.9945	0.9992	0.9951

TABLE 12. Davis radiation shield summarized differences statistics with cloudy daytime conditions removed. Reference: MMTS

## 4. CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

### 4.1 Conclusions

The data results suggest that, if properly sited, the Davis Instruments weather stations perform well enough on reporting the daily maxima and minima to meet the requirements of NOAA for surface observations, and therefore, in most cases, can be used for daily observations, forecast model input and forecast verification. The larger hourly differences did not occur during the time of daily highs and lows. This may be due, in part to the greatest hourly differences occurring during transition periods between daytime and nighttime conditions.

The Davis system data showed great variability under some conditions of highly variable insolation as compared to the MMTS. With data now being collected by the Davis system in similar fashion to the MMTS, it will be possible to see if this variation is truly environment or a function of the data collection differences. It is suggested that the greater spread in differences in the hourly readings may represent the difference between hourly average values and values at the hour boundary rather than the differences in system

performance. The smaller spread in differences in the daily extrema values reinforces this argument. Since the minimum difference is relatively unaffected by conditions, this may suggest an area of design improvement.

### 4.2 Suggestions for Further Study

Two more MMTS systems will be added to give guidance whenever MMTS data is suspect. The Davis systems will be upgraded to the equivalent Vantage Pro2 version to better represent current product and facilitate easier data collection. Any radiation shield design modifications will also be tested at this site.

Further studies could include other COOP sites where the ground cover is different from this Michigan location, and therefore, the infrared radiation properties of the ground are vastly different. These types of climates would include those that receive more or less snowfall and greater or lesser snow cover during the year or semi-arid or arid areas. Other test locations could include locations in the southern tier of the United States that receive higher levels of insolation. These studies might indicate whether Davis Instruments radiation shield performance varies significantly in environments with different solar and infrared radiation properties. Such studies will require other COOP observers to volunteer their

sites, their recorded information, and to some extent, their time and effort, to setup and sustain a viable test.

The results presented here do not represent a final conclusion of the effectiveness of Davis Instruments radiation shields and how they compare to the MMTS shield. These results are presented to encourage similar evaluations by other interested parties.

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