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Fact-Finding Report on Ambient Temperature Adjustment for Raceway and Cable Systems Exposed to Sunlight on Rooftops

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EXECUTIVE SUMMARY

The 2011 National Electrical Code® (NEC®) requires for circular raceways exposed to sunlight on rooftops, an adjustment temperature be added to the outdoor temperature when determining ambient temperature and associated correction factors for calculating the ampacity of conductors. This adjustment temperature adder for circular raceways exposed to sunlight on rooftops is to account for solar heating, and is needed to assure that no conductor is used in a manner such that its operating temperature exceeds that for which it is designed.

In preparing for the 2011 NEC, a proposal was submitted to include cables into the scope of this requirement. Although supporting documentation included a report of testing with MC cables, the Code Panel chose to reject this proposal since the term "cables" was too general, and that testing was insufficient since only MC cable in a single size was tested. Some of the Code Panel members also noted the need for a more comprehensive research project to determine the effects of sunlight on wiring systems in general when installed on rooftops.

This is a report of a Fact-Finding Investigation intended to provide technical data and other pertinent facts regarding the safety aspects of installing raceways and cables to direct sunlight on or above rooftops. The investigation included tests on 17 different types and sizes of wiring systems, each of which were installed at four different elevations above the roof at an outdoor test facility in Las Vegas, Nevada. In addition to temperature measurements on the wiring system conductors, outdoor ambient temperature, wind speed, and solar irradiance were also recorded during the summer months of 2011. By calculating the difference between the temperature on the wiring system conductors and the outdoor ambient temperature during the period of peak solar irradiance during selected days of full sun and minimum wind, inferences could be made about the effects of solar heating on these wiring systems.

A statistical analysis of the data also provided insights into how solar heating affects wiring systems in general when installed on or above a rooftop. For all wiring systems mounted directly on the roof, the maximum temperature rise above outdoor ambient with a 95% confidence interval would statistically be 62.2 ^{o}F. For all wiring systems mounted at a distance above the roof (1/2 inch and greater) the maximum temperature rise above outdoor ambient with a 95% confidence interval would statistically be 51.4 ^{o}F.

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GENERAL

A proposal was accepted for the 2008 National Electrical Code® (NEC®), which recommended that for conduits exposed to sunlight on rooftops, an adjustment temperature be added to the outdoor temperature when determining ambient temperature for the correction factors in Tables 310.16 and 310.18. The substantiation for this proposal noted that Section 310.10 required that no conductor shall be used in such a manner that its operating temperature exceeds that designated for the type of insulated conductor involved. It also cited testing that showed the air inside conduits in direct sunlight to be significantly hotter than the surrounding air. This proposal resulted in new Section 310.15(B)(2)(c) and new Table 310.15(B)(2)(c) for the 2008 NEC[1].

For the 2011 NEC, a similar proposal was submitted to include cables into the scope of this requirement. Although supporting documentation included a report of testing with MC cables, the Code Panel chose to reject this proposal since the term “cables” was too general, and that testing was insufficient since only MC cable in a single size was tested. Some of the Code Panel members noted the need for a more comprehensive research project to determine the effects of sunlight on conduits, MC cable, and cable in general when installed on rooftops.

[1] For the 2011 NEC, Sec. 310.10 became Sec. 310.15(A)(3), Sec. 310.15(B)(2)(c) became Sec. 310.15(B)(3)(c), and Table 310.15(B)(2)(c) became Table 310.15(B)(3)(c).

OBJECTIVE

The objective for this Fact-Finding Investigation is to provide technical data and other pertinent facts regarding the safety aspects of installing raceways and cables to direct sunlight on or above rooftops.

Travis Lindsey Consulting Services Inc. proposes to submit a public proposal to revise Section 310.15(B)(3)(c) of the 2011 NEC as follows:

> (c) *~~Circular~~ Raceways and Cables Exposed to Sunlight on Rooftops*. Where conductors ~~or cables~~ are installed in ~~circular~~ raceways or where in cables exposed to direct sunlight on or above rooftops, the adjustments shown in Table 310.15(B)(3)(c) shall be added to the outdoor temperature to determine the applicable ambient temperature for application of the correction factors in Table 310.15(B)(2)(a) or 310.15(B)(2)(b).

Table 310.15(B)(3)(c) Ambient Temperature Adjustment for ~~Circular~~ Raceways or Cables Exposed to Sunlight on or Above Rooftops

Distance Above Roof to Bottom of ~~Conduit~~ Raceway or Cable	Temperature Adder °C	Temperature Adder °F
0-13 mm (1/2 in.)	33	60
Above 13 mm (1/2 in.) - 90 mm (3-1/2) in.)	22	40
Above 90 mm (3-1/2 in.) - 300 mm (12 in.)	17	30
Above 300 mm (12 in.) - 900 mm (36 in.)	14	25

WIRING SYSTEMS AND ROOFTOPS

NEC Requirements

Wiring methods and materials are described in Chapter 3 of the NEC. Included in Chapter 3 are various Articles for different cable types and raceways for containing conductors for general wiring, including wiring that may be installed on a rooftop and exposed to sunlight. Although the “uses permitted” for these various cables and raceways do not specifically mention rooftops, it could be assumed that if permitted for outdoor use and/or wet locations, and resistant to sunlight, a particular wiring system could be installed on a rooftop exposed to sunlight. Tables 1 and 2 include the various cable and raceway systems from Chapter 3 that could typically be installed on or above rooftops exposed to sunlight as permitted by the NEC. Also included in these tables are the specific NEC Chapter 3 Article, the UL standard, and the range of sizes that would be permitted or could be listed.

Table 1 – Cables Suitable for Installation on Rooftops Exposed to Sunlight

Type	NEC Article	UL Standard	Wire Size Min	Wire Size Max	Comment
MV	328	1072	8	2000	If identified for use in direct sunlight, or as "MV or MC"
MC	330	1569	18	2000	
MI	332	1581	16	500	Max 4 AWG for 2 & 3 conductor; 6 AWG for 4 conductor; 10 AWG for a 7 conductor
UF	340	493	14	4/0	For use with PV (rooftop) systems; Max 6 AWG for multiple conductors. This can also include single conductor cable listed as PV wire.
TC	336	1277	18	1000	When marked "Sunlight Resistant"
SE	338	854	14	unspecified	

Table 2 – Conduits and Raceways Suitable for Installation on Rooftops Exposed to Sunlight

Type	NEC Article	UL Standard	Trade Size Min	Trade Size Max	Comment
IMC	342	1242	1/2	4	
RMC	344	6/6A	3/8	6	
LFMC	350	360	3/8	4	
PVC	352	651	1/2	6	
LFNC	356	1660	3/8	4	When listed as suitable for outdoors
EMT	358	797/797A	1/2	4	
Auxiliary Gutters	366	870			When listed for exposure to sunlight and wet locations
Cable Bus	370				When identified for outdoor use
Metal Wireways	376	870			When listed for wet locations
Nonmetallic Wireways	378	879/5A			When listed for wet locations

COMPREHENSIVE TEST PROGRAM TO ADDRESS WIRING SYSTEMS EXPOSED TO SUNLIGHT ON ROOFTOPS

Test Sample Selection

Various test samples were chosen because of their expected use on rooftops exposed to sunlight, and their similarity to other raceway and cable systems that were not tested, but considered to be representative of these other wiring systems for test purposes. For cables, Type MC cable was chosen to represent metal clad and metal sheathed cables and conduits (e.g. Type MC, MI, LFMC, etc.). Sizes 12 AWG, 1/0 AWG, and 500 kcmil were chosen to represent cables of the smaller, medium, and larger sizes. Type SE and TC cable was also chosen in the 1/0 AWG size to represent jacketed cables (e.g. Type SE, TC, MV, UF, etc.) For conduits and tubings, Type RMC and EMT were chosen to represent circular metal raceways (e.g. RMC, IMC, EMT, etc.). To represent the smaller sizes, trade size ½ was chosen for RMC, and trade size ¾ was chosen for EMT. For the medium and larger sizes, trade sizes 1-1/2 and 4 respectively were chosen. Type PVC was chosen to represent nonmetallic conduits and raceways. To represent the smaller sizes, trade size ¾ was chosen, and for the medium and larger sizes, trade sizes 1-1/2 and 4 respectively were chosen. For other metal wiring systems (e.g. metal wireways, gutters, etc.), metal raceway was chosen in the 4x4 inch and 8x8 inch sizes to represent smaller and larger raceways in general.

Table 3 is a summary of the proposed testing to consider a comprehensive research program to determine the effects of direct sunlight when conduit, MC cable, and wiring systems in general are installed on or above a rooftop.

Table 3 – Summary of Test Samples

Raceway/ Cable Type	Conductor Size*	Trade Size	Installed Conductor Size*	Number of Conductors
MC	12			3
MC	1/0			3
MC	500			3
SE	1/0			3
TC	1/0			3
RMC		1/2	12	7
RMC		1-1/2	1/0	4
RMC		4	500	3
PVC		3/4	12	3
PVC		1-1/2	1/0	3
PVC		4	500	3
EMT		3/4	12	3
EMT		1-1/2	1/0	5
EMT		4	500	3
Metal Raceway		4x4 in.	1/0	3
Metal Raceway		8x8 in.	500	3

* - AWG or kcmil (copper), Type THHN/THWN.

Test Considerations

Laboratory Site – The testing was conducted at an outdoor laboratory site located in Las Vegas, Nevada. This area was chosen for its broad range of days with higher solar radiation intensity.

Fig. 1 – Las Vegas, Nevada Outdoor Test Site

Roof - To support Table 310.15(B)(3)(c) from the 2011 NEC, each wiring system was tested directly on the roof, and at distances of 1/2, 3-1/2, and 12 inches above the roof[2]. For wiring systems tested directly on the roof and at 1/2 inch above the roof, the roof was asphalt painted black in color to account for additional heating from solar absorption on the roof. For wiring systems tested at distances greater than 1/2 inch above the roof, the roof surface was asphalt painted white in color to account for additional heating from solar reflection from the roof. Each roof structure was flat, approximately five feet off the ground, and measured 13-1/2 by 10 feet, with R19 fiberglass batt insulation under the roof deck.

Fig. 2 – Samples Mounted Directly on Black Roof

Fig. 3 – Samples Mounted 12 Inches off White Roof

Test Samples – Each test sample was 10 feet long exposed along the horizontal length of the roof surface. A thermocouple was secured to each conductor insulation midway along the length of the sample. The thermocouples were type T, No. 24 AWG, with welded junctions. For the Type MC cable samples, the thermocouple was secured near the conductor. For samples with more than three conductors, a maximum of three thermocouples were used. See Appendix A for a thorough description of each test sample. The ends of each wiring system were closed with surgical cotton to restrict air flow. The wires were not energized during the testing since the object of the testing was to obtain a measurement of the wiring system temperature increase due to the influence of exposure to the sun.

[2] Although the breakpoints in Table 310.15(B)(3)(c) are for distances of above (greater than) ½, 3-1/2, and 12 inches above the roof, the test samples were located at these breakpoint distances to represent a worst-case test condition.

Fig. 4 – Thermocouples Installed on Conductors **Fig. 5 – Cotton Used to Close Ends of Wireways**

Data Measurements - Temperatures were measured at 1 minute increments throughout the day, and the maximum of the 1 minute increments for a 5 minute time period was recorded. This resulted in 12 recorded measurements per hour. In addition to the measurement of temperature of the conductor insulation of each test sample, the near-by outdoor air temperature was measured in two aspirated enclosures located approximately 8 feet and 13 feet above grade level in the vicinity of the roofs and test samples. Wind speed was similarly measured in the same vicinity using two anemometers. Solar irradiance was measured using a pyranometer located in the same plane as the roof surface.

Fig. 6 – Aspirated Enclosure for Outdoor Temperature **Fig. 7 – Anemometer for Wind Speed Measurement**

Solar irradiance and wind speed was recorded along with the test sample temperatures. Measurements were recorded during the months of June, July and August of 2011. Sufficient data was recorded to enable supportable and statistical inferences regarding expected ambient temperatures for raceway and cable systems exposed to sunlight on rooftops.

Solar Irradiance - Solar irradiance, or radiation from the sun, is measured as power density in Watts per square meter (W/m^2). This solar radiation reaching the earth can vary depending on several factors, including as time-of-day, time-of-year, atmospheric conditions such as clouds, haze, rain, etc., as well as geographical location. The maximum solar radiation reaching the earth's atmosphere can approach 1400 W/m^2, however, 1000 – 1200 W/m^2 is more typical of maximum surface irradiance on a sunny day in many parts of the United States, and can be less during the winter, and much less on cloudy days.

Solar photovoltaic (PV) modules are tested and rated under what is referred to as standard test conditions, or STC for short. These standard test conditions are solar irradiance of 1000 W/m^2 and air temperature of 25 ^oC.[3] In the NEC, PV system components, such as wire size and overcurrent protection, are based on these standard test conditions, with adjustment factors for periods of time where the maximum solar irradiance can exceed 1000 W/m^2.[4]

Figure 8 shows a graph of the solar irradiance at the test site incident to the test roofs on June 22, 2011. The day was full sun, maximum outdoor ambient temperature of 110 ^oF, and near the time of summer solstice. The solar irradiance that day exceeded 1000 W/m^2 for a three-hour period beginning at 11:10 am. The NEC defines in Article 100 a "continuous load" as a load where the maximum current is expected to continue for 3 hours or more.

[3] Underwriters Laboratories Inc., *UL Standard for Safety for Flat-Plate Photovoltaic Modules and Panels*, UL 1703. See Glossary Section 2.17 for definition of Standard Test Conditions.

[4] As an example, see NEC Sec. 690.8 where calculations for maximum circuit current and conductor ampacity involve multipliers of 125%.

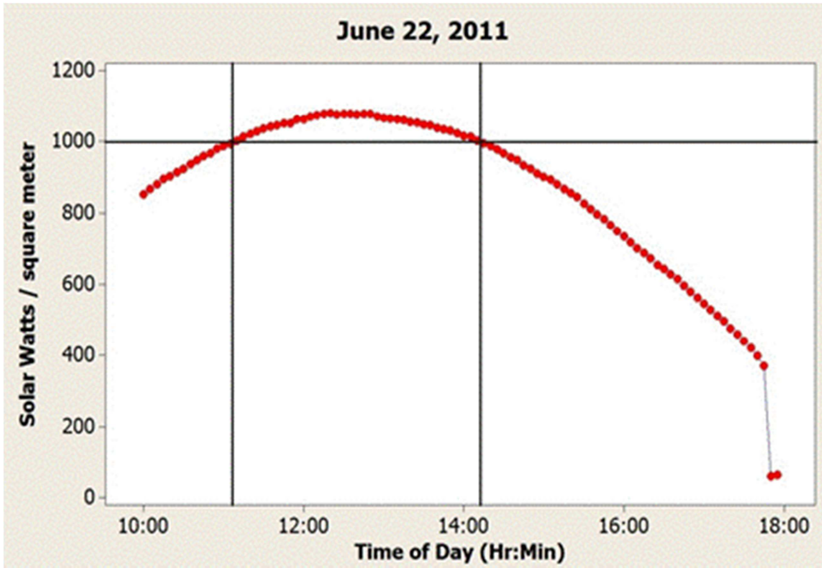


Fig. 8 – Solar Irradiance for June 22, 2011 at Las Vegas Test Site

Test Results

Data measurements were recorded during the months of June, July and August of 2011. This time of the year also produced many days of large amounts of solar radiation for the longest periods of time. During these months there were many days of full sun throughout the day where outside temperature exceeded 100 ^{o}F, and solar irradiance exceeded 1000 W/m^2. The solar irradiance for days of prolonged full sun peaked near solar noon, which occurred at about 12:45 pm in Las Vegas that time of year (daylight savings time). For analysis of results purposes, 10 days were chosen during this time period where that solar irradiance exceeded 1000 W/m^2 for a prolonged period of time. Although wind speed could not be controlled, these days were also chosen where the wind speed was minimized. This resulted in 5 days in late June, and 5 days in early August as shown in Table 4. For each of these 10 days, the temperature data were analyzed for the period of time that day were the solar irradiance was greater than or equal to 1000 W/m^2. Depending upon the day, this resulted in elapsed times of 3 hours and 5 minutes to 2 hours and 15 minutes as shown in the table. This table also includes the average wind speed and maximum outdoor ambient temperature for that period of time. See Appendix C for complete graphs of the daily outdoor ambient temperature, solar irradiance, and wind speed.

Table 4 – 10 Days of Analyzed Data

Day (2011)	Period of Solar Radiation ≥ 1000 W/m² (Hours:Minutes) Beginning	End	Elapsed Time	Avg Wind Speed (MPH)	Outdoor Ambient Deg F
June 21	11:15	14:05	2 hr 50 min	2.8	101
June 22	11:10	14:10	3 hr 00 min	3.1	109
June 23	11:20	14:15	2 hr 55 min	4.4	108
June 25	11:05	14:10	3 hr 05 min	3.1	103
June 26	11:10	14:15	3 hr 05 min	2.7	103
August 4	11:35	14:00	2 hr 25 min	6.0	105
August 5	11:30	14:05	2 hr 35 min	6.4	103
August 6	11:35	13:50	2 hr 15 min	5.7	102
August 8	11:35	14:00	2 hr 25 min	6.3	106
August 9	11:45	14:00	2 hr 15 min	5.5	106

For each test sample, the rise above outdoor ambient temperature for the three thermocouple temperatures were averaged for each five-minute increment to record the temperature rise above outdoor ambient of the test sample for that time measurement increment. An analysis of the variance for the three thermocouple readings of each test sample typically showed a variance of less than 1 ^{o}F, except for the tray cable (TC) samples, where the variance was greater because of the orientation of the three thermocouples around the circumference of the cable. For that reason, the maximum temperature of the three thermocouple readings for the tray cable was used for this test sample because of the importance of recording the hottest temperature being experienced by the cable.

For each of the ten chosen days, the maximum, minimum, 90th, 75th, and 50th percentile temperatures were calculated for each test sample at each elevation for the period of time that day when the solar irradiance was greater than or equal to 1000 W/m^2. For the accumulated ten days, the overall maximum, minimum, and averages of the 90th, 75th and 50th percentile temperatures were then tabulated. The tables below show that complied data.

Table 5

Maximum Temperature Rise Above Outdoor Ambient (°F)

		Distance Above Roof			
		1 Foot	3-1/2 inch	1/2 inch	On Roof
Circular Raceway - Metal	3/4" EMT	42.9	39.2	48.0	62.9
	1/2" RMC	34.2	35.1	38.7	66.5
	1-1/2" EMT	34.9	36.1	37.4	51.2
	1-1/2" RMC	48.5	47.0	34.8	55.7
	4" EMT	35.2	38.9	35.3	43.8
	4" RMC	45.7	48.1	40.9	47.5
Circular Raceway - Plastic	3/4" PVC	42.2	46.5	42.3	63.6
	1-1/2" PVC	43.1	47.3	43.9	58.5
	4" PVC	46.3	48.4	43.0	52.3
Square Raceway - Metal	4" DUCT	51.1	54.9	46.1	59.9
	8" DUCT	46.7	46.3	38.7	52.1
Cables	#12 MC	45.4	53.0	47.8	71.4
	#1/0 MC	52.8	55.1	50.7	66.6
	#1/0 SE	39.7	43.0	43.5	58.3
	Tray 1/0 SE	36.6	39.4	40.1	47.8
	Tray 1/0 TC	59.6	65.0	53.3	60.3
	#500 MC	55.1	58.3	51.8	62.2
	NEC Adder	25	30	40	60

Table 6

Minimum Temperature Rise Above Outdoor Ambient (°F)

		Distance Above Roof			
		1 Foot	3-1/2 inch	1/2 inch	On Roof
Circular Raceway - Metal	3/4" EMT	26.3	22.1	28.4	42.0
	1/2" RMC	21.2	22.3	23.2	39.8
	1-1/2" EMT	22.8	25.6	24.7	31.7
	1-1/2" RMC	30.9	31.3	20.1	31.0
	4" EMT	23.2	25.7	21.7	25.9
	4" RMC	29.3	30.3	23.4	25.7
Circular Raceway - Plastic	1/2" RMC	21.2	22.3	23.2	39.8
	1-1/2" PVC	29.9	33.7	27.0	35.7
	4" PVC	28.2	28.8	23.0	26.1
Square Raceway - Metal	4" DUCT	33.3	37.5	27.6	36.3
	8" DUCT	31.0	31.0	22.0	23.7
Cables	#12 MC	31.1	34.6	27.9	41.5
	#1/0 MC	36.9	39.5	33.8	42.7
	#1/0 SE	27.6	30.9	29.0	37.2
	Tray 1/0 SE	24.8	28.0	26.5	31.3
	Tray 1/0 TC	40.3	47.9	36.9	41.5
	#500 MC	36.3	37.9	31.2	35.3
	NEC Adder	25	30	40	60

Table 7

90th Percentile Temperature Rise Above Outdoor Ambient (°F)

		Distance Above Roof			
		1 Foot	3-1/2 inch	1/2 inch	On Roof
Circular Raceway - Metal	3/4" EMT	36.3	30.9	40.9	55.8
	1/2" RMC	29.2	29.9	33.0	56.0
	1-1/2" EMT	29.4	31.2	32.1	43.3
	1-1/2" RMC	40.0	39.5	28.3	45.0
	4" EMT	29.7	33.2	29.9	36.5
	4" RMC	38.7	40.7	33.9	39.9
Circular Raceway - Plastic	3/4" PVC	37.0	40.8	35.5	53.3
	1-1/2" PVC	37.4	41.3	36.9	49.4
	4" PVC	38.5	40.2	35.3	42.9
Square Raceway - Metal	4" DUCT	43.5	47.2	38.6	50.3
	8" DUCT	39.7	39.9	31.8	43.8
Cables	#12 MC	40.3	45.2	40.2	60.1
	#1/0 MC	46.3	48.5	43.7	56.8
	#1/0 SE	34.9	38.0	37.8	49.8
	Tray 1/0 SE	31.5	34.6	34.4	41.1
	Tray 1/0 TC	51.0	59.1	46.9	53.0
	#500 MC	47.6	50.6	43.9	52.7
	NEC Adder	25	30	40	60

Table 8

75th Percentile Temperature Rise Above Outdoor Ambient (°F)

		Distance Above Roof			
		1 Foot	3-1/2 inch	1/2 inch	On Roof
Circular Raceway - Metal	3/4" EMT	35.1	29.9	39.7	54.5
	1/2" RMC	28.3	29.0	32.0	54.7
	1-1/2" EMT	28.9	30.7	31.5	42.6
	1-1/2" RMC	39.4	38.8	27.7	44.3
	4" EMT	29.1	32.5	29.3	35.8
	4" RMC	38.0	40.1	33.1	39.2
Circular Raceway - Plastic	3/4" PVC	36.2	39.9	34.5	52.1
	1-1/2" PVC	36.7	40.6	36.2	48.7
	4" PVC	37.9	39.6	34.6	42.2
Square Raceway - Metal	4" DUCT	42.7	46.5	37.8	49.6
	8" DUCT	39.0	39.2	31.0	43.1
Cables	#12 MC	39.2	44.2	39.1	58.9
	#1/0 MC	45.5	47.8	43.0	56.1
	#1/0 SE	34.2	37.3	37.2	49.1
	Tray 1/0 SE	30.9	34.0	33.7	40.4
	Tray 1/0 TC	50.0	58.3	46.3	52.3
	#500 MC	46.9	49.9	43.1	52.0
	NEC Adder	25	30	40	60

Table 9

50th Percentile Temperature Rise Above Outdoor Ambient (^{o}F)

		Distance Above Roof			
		1 Foot	3-1/2 inch	1/2 inch	On Roof
Circular Raceway - Metal	3/4" EMT	33.6	28.0	37.6	52.1
	1/2" RMC	27.1	27.9	30.6	52.3
	1-1/2" EMT	27.9	29.7	30.6	41.6
	1-1/2" RMC	38.2	37.7	26.8	43.1
	4" EMT	28.1	31.5	28.3	34.6
	4" RMC	36.6	38.6	31.7	37.1
Circular Raceway - Plastic	3/4" PVC	34.9	38.4	33.1	50.1
	1-1/2" PVC	35.6	39.6	35.2	47.4
	4" PVC	36.5	38.1	33.1	40.0
Square Raceway - Metal	4" DUCT	41.1	44.9	36.4	48.2
	8" DUCT	37.9	38.1	30.0	41.3
Cables	#12 MC	37.9	42.7	37.3	56.2
	#1/0 MC	44.2	46.6	41.8	54.8
	#1/0 SE	33.1	36.3	36.0	47.9
	Tray 1/0 SE	29.9	32.9	32.7	39.3
	Tray 1/0 TC	48.5	56.8	44.7	50.7
	#500 MC	45.5	48.2	41.7	50.0
	NEC Adder	25	30	40	60

Data Analysis

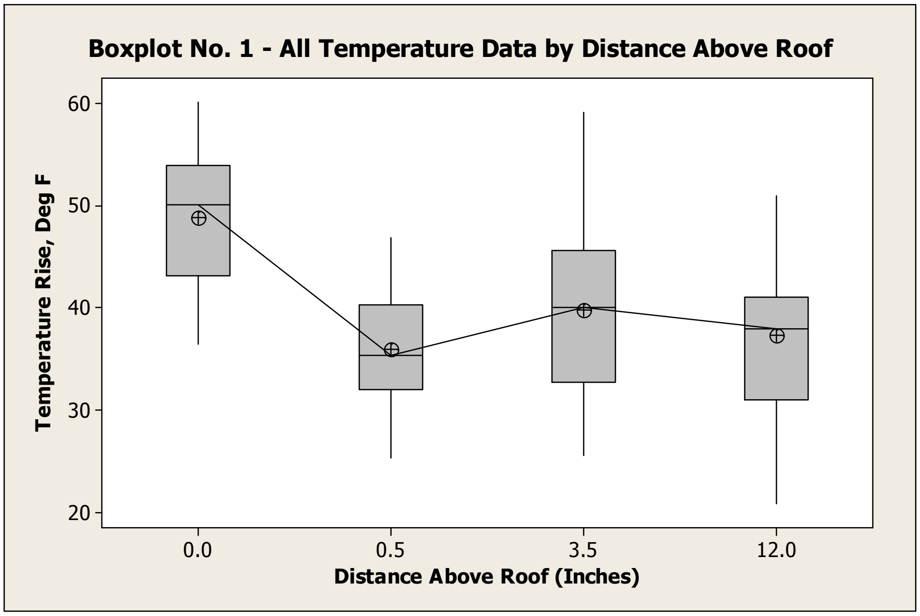
To analyze the differences between wiring systems at different distances from the roof, a compilation of all of the wiring system 90th percentile temperature rises (Table 7)[5] for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2 was made for each of the four elevations. This analysis is shown in Boxplot[6] No.1. Note that for the wiring systems at distances 0.0 and 0.5 inches above the roof, the roof color was black, and for distances 3.5 and 12.0 inches above the roof, the roof color was white. Previous research[7] had shown that at the 0.5 inch distance, there was no significant difference between the black and white roof colors affecting the temperature of the wiring systems. For that reason black was chosen for the color of the roof at that distance. However, this previous research was only conducted with smaller size raceways and cable. It is possible that larger size raceways and cables could have absorbed more of the reflected solar radiation off the roof had the roof been white. This could explain why the mean temperature rise for the wirings systems at 0.5 inches above the roof were less than those at 3.5 and 12.0 inches above the roof.

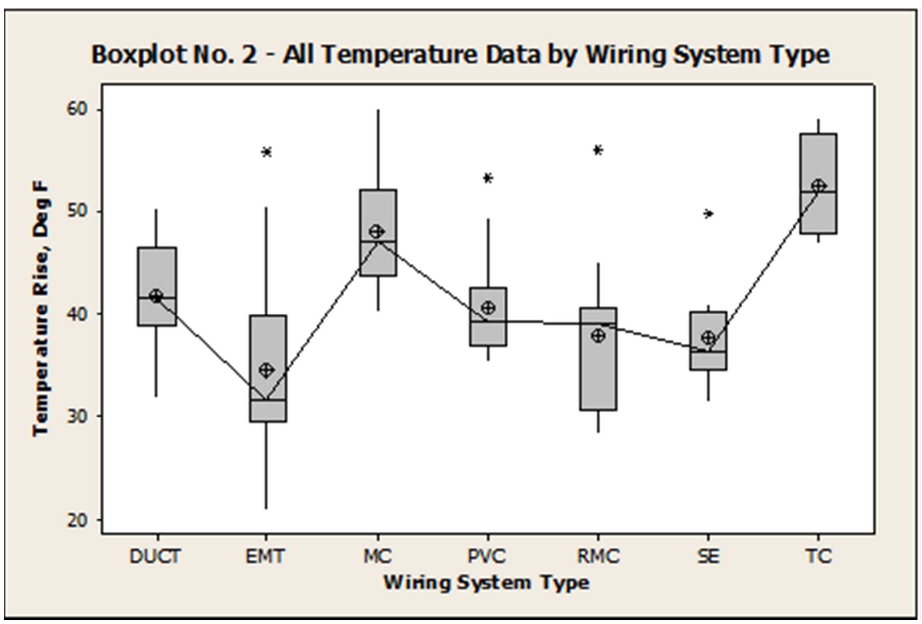
To analyze the differences between the different individual wiring systems, a compilation of all of the different wiring system 90th percentile temperature rises for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2 was made. This analysis is shown in Boxplot No.2. Note that the MC and TC cables were black in color, and the SE cable was light gray in color.

[5] The 90th percentile values were used to eliminate the maximum temperatures that were only being experienced for a very short period of time when the solar irradiance peaked for that day. Note however, there was typically only a few degrees F or less difference between the 90th and 75th percentile values. See Tables 7 and 8.

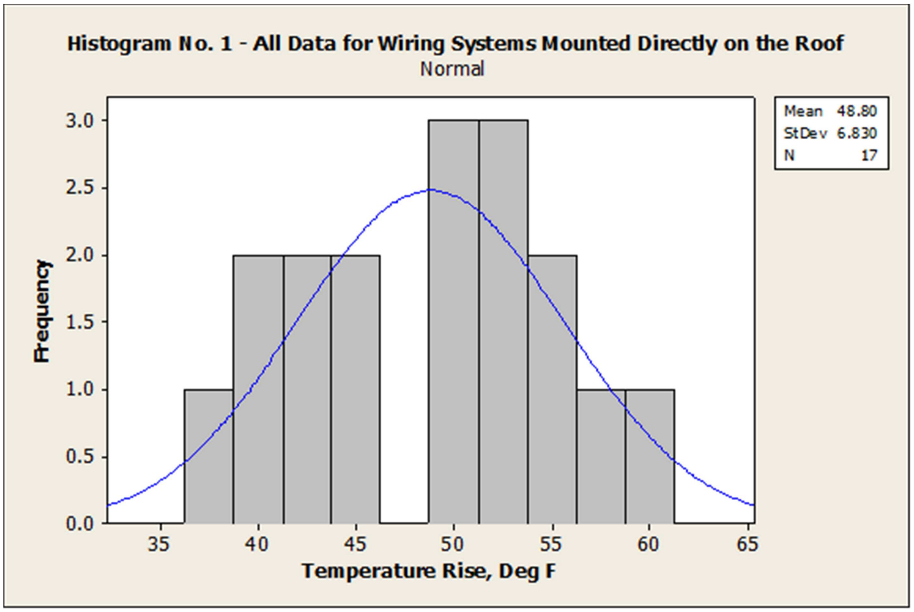
[6] See Appendix D for a description of boxplots.

[7] "*Effect of Rooftop Exposure on Cable Temperatures*," November 2008, by Travis C. Lindsey. Available for review at the National Fire Protection Association (NFPA) Headquarters, Quincy, MA. Reference Report on Proposals – June 2010, Proposal 6-66, Log #2751, NEC-P06. See Fig. 3, Temperature Rise as Function of Roof Color.

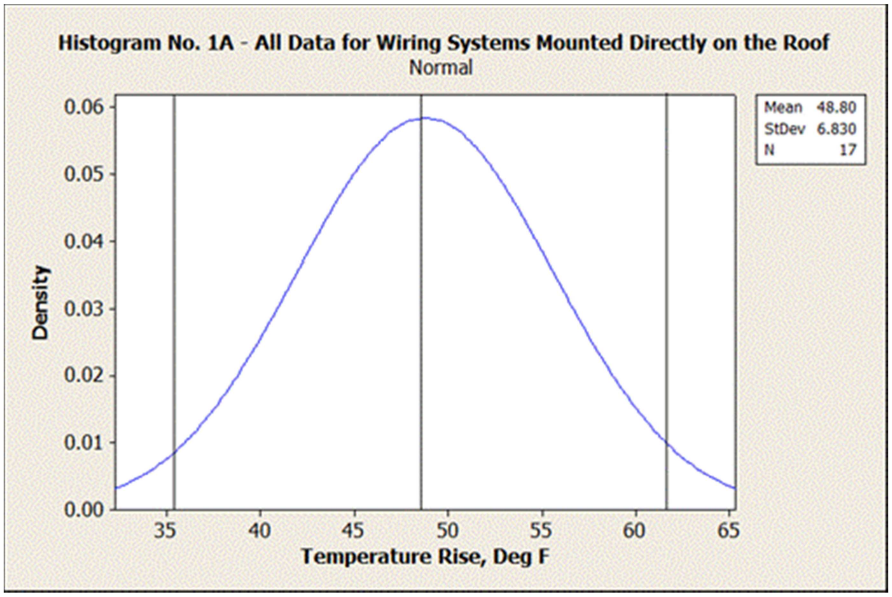

Boxplot No. 1 - All Temperature Data by Distance Above Roof
Temperature Rise, Deg F
60
50
40
30
20
0.0
0.5
3.5
12.0
Distance Above Roof (Inches)


Boxplot No. 2 - All Temperature Data by Wiring System Type
Temperature Rise, Deg F
60
50
40
30
20
DUCT
EMT
MC
PVC
RMC
SE
TC
Wiring System Type

Histogram No. 1 shows the 90th percentile temperature rise data for wiring systems directly on the roof for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2.



This analysis shows that for all of the 17 test samples of wiring systems mounted directly on the roof, the mean (average) temperature rise was 48.8 ^{o}F with a standard deviation of 6.83 ^{o}F. Confidence intervals (C.I) are often used as a statistical estimate to bracket data parameters with a known degree of certainty. A 95% C.I. is suggested as an appropriate safety factor to represent the true population of the data from the sampled population (tested samples). A 95% C.I. is calculated (two-sided) as the mean plus/minus 1.96 times the standard deviation. For this case, maximum temperature rise for all wiring systems mounted directly on the roof with a 95% C.I. would be 62.2 ^{o}F. Histogram 1A shows a representation of this with vertical lines at the mean and 95% C.I. points.



An observation from Boxplot No. 1 appears to show that there is little difference between mean temperature rises for test samples of wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof. Neglecting any heat convection or reradiation from the surface of the roof, this would be expected since the distance from the sun to the surface of the earth is large as compared to the distance between the three wiring systems. To verify this, an analysis of variance (ANOVA) was conducted with this data for the three distances from the roof. This analysis, shown in Fig. 9, demonstrates there is little difference between the mean temperature rises for all test data from each of the three wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof. This is exemplified by the low value for R_{sq}, which shows that varying the distance from the roof between 0.5 and 12.0 inches does not have any significant effect on the temperature rise within the raceway or cable. It is expected that distances greater than 12.0 inches will also show this minimal difference.

One-way ANOVA: 90th Percentile Data versus Distance from Roof (0.5, 3.5, and 12.0 inches)

Source	DF	SS	MS	F	P
Distance	2	137.6	68.8	1.62	0.209
Error	48	2043.1	42.6		
Total	50	2180.8			

S = 6.6   R-Sq = 6.31%   R-Sq(adj) = 2.41%

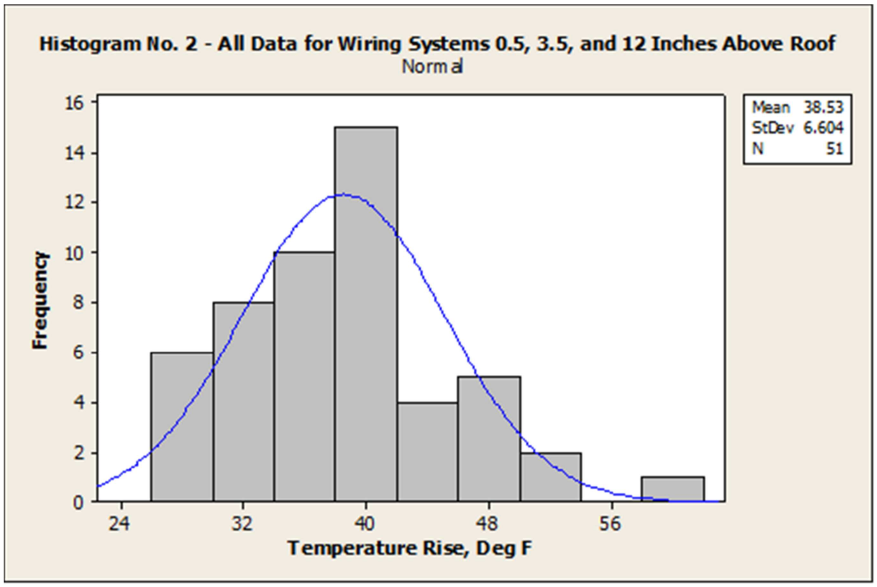
DF = Degrees of Freedom
SS = Sum of squares
MS = Mean square
S = Standard deviation
F = F ratio
P = p-value
R = Correlation coefficient

Individual 95% C.I.s for Mean Based on Pooled Standard Deviation of 6.6

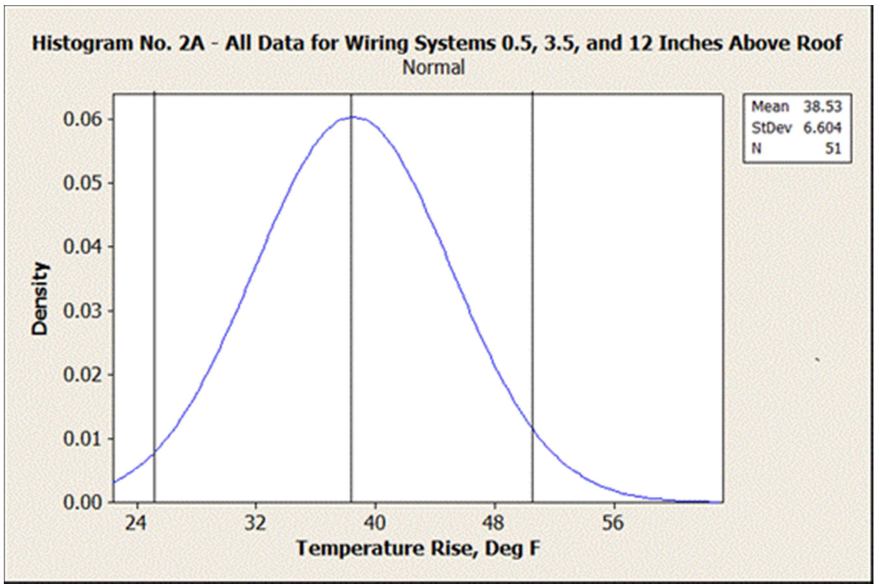
```
Level   N    Mean  StDev  --------+---------+---------+---------+-
 0.5   17  36.640  5.186  (---------*----------)
 3.5   17  40.644  7.769              (---------*----------)
12.0   17  38.297  6.359       (----------*---------)
                          --------+---------+---------+---------+-
                              36.0      39.0      42.0      45.0
```

Fig. 9 – Analysis of Variance for Wiring Systems Mounted Off Roof

Histogram No. 2 shows the 90th percentile temperature rise data for all wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2.



This analysis shows that for all of the 51 test samples of wiring systems mounted off the roof (0.5, 3.5, and 12.0 inches), the mean temperature rise was 38.5 ^{o}F with a standard deviation of 6.60 ^{o}F. The maximum temperature rise for all wiring systems mounted off on the roof with a 95% C.I. would be 51.4 ^{o}F. Histogram 2A shows a representation of this with vertical lines at the mean and 95% C.I. points.



SUMMARY

1. Of the 17 different wiring systems tested, nine are currently addressed by the 2011 NEC Sec. 310.15(B)(3)(c) requirement for circular raceways exposed to sunlight on rooftops, *e.g.*, EMT, RMC, and PVC, and eight are not, *e.g.*, square raceway and cables. Using the maximum temperature rises from Table 5:
    a. All of the wiring systems mounted 12 inches from the roof and 3-1/2 inches from the roof exceeded the NEC Table 310.(B)(3)(c) temperature adders of 25 ^{o}F and 30 ^{o}F respectively. For wiring systems mounted 12 inches from the roof, this ranged from 34.2 to 59.6 ^{o}F, and for wiring systems 3-1/2 inches from the roof this ranged from 35.1 to 65.0 ^{o}F.
    b. For wiring systems mounted ½ inch off the roof, all of the cables, and the 4 inch square metal duct exceeded the 40 ^{o}F NEC temperature adder. Five of the nine circular raceways also exceeded this 40 ^{o}F adder. The range in temperature rises for wiring systems mounted ½ inch off the roof was 34.8 to 53.3 ^{o}F.
    c. For wiring systems mounted on the roof, four of the cables exceeded the 60 ^{o}F temperature adder, and three of the circular raceways also exceeded this 60 ^{o}F adder. The range in temperature rises for wiring systems mounted on the roof was 43.8 to 71.4 ^{o}F.

2. In general, the smaller size wiring systems reached a hotter temperature than wiring systems of the same type but larger. This was especially true of the metallic wiring systems, and when the wiring systems were mounted directly on the roof. This was expected because the larger wiring systems had a larger ratio of surface area to mass, and thus took longer to heat up and cool down. This greater mass could also absorb the radiated heat from the sun (and the conducted heat from the roof) over a greater volume. See Tables 5 – 9.

3. The 1/0 SE cable operated much cooler than the similar sized 1/0 MC and 1/0 TC cables. This was expected due to the black outer jacked of the 1/0 MC and 1/0 TC cables having greater absorption properties, *e.g.*, higher emissivity, than the lighter colored SE cable. See Boxplot No. 2.

4. Wiring systems mounted 3-1/2 inches off the white roof usually operated hotter than similar wiring systems mounted ½ inch off the black roof. This was likely because of the solar reflection off the white roof producing additional solar power that could be absorbed by the underside of the wiring system 3-1/3 inches from the roof. These results may have been different had the wiring systems mounted ½ inch off the roof been tested with a white roof. However, wiring systems mounted directly on the roof most always operated significantly hotter than wiring systems of the same type mounted off the roof. See Boxplot No. 1.

5. For all wiring systems mounted directly on the roof, the 90th percentile mean temperature rise above outdoor ambient for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2 was 48.8 ^{o}F with a standard deviation 6.8. For this case, maximum temperature rise above outdoor ambient for all wiring systems mounted directly on the roof with a 95% confidence interval (C.I.) would be 62.2 ^{o}F.

6. A statistical analysis of variance of the data for temperature rise above outdoor ambient showed that all test data from wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof were not affected significantly by distance. Therefore, distances greater than 0.5 inches above the roof can be considered far from the roof and roof distance does not need to be a consideration in calculating temperature rise. For all wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof, the 90th percentile mean temperature rise above outdoor ambient for the period of time each day where the solar irradiance was greater than or equal to 1000 W/m^2 was 38.5 ^{o}F with a standard deviation 6.6. For this case, maximum temperature rise above outdoor ambient for all wiring systems mounted off on the roof with a 95% confidence interval (C.I.) would statistically be 51.4 ^{o}F.

Report by:

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APPENDIX A

Test Samples

1. Metal-Clad Cable, Type MC, No. 12 AWG/3 with No. 12 AWG ground. Aluminum interlocked armor with black PVC jacket. Copper THHN/THWN conductors.

2. Rigid Metal Conduit, Type RMC, Trade Size ½. Metallic silver in color. Seven No. 12 AWG copper conductors, Type THHN/THWN installed.

3. Rigid Polyvinyl Chloride Conduit, Type PVC, Trade ¾. Natural gray in color. Three No. 12 AWG copper conductors, Type THHN/THWN installed.

Fig. A1 – No. 12 MC (1), ½ RMC (2), ¾ PVC (3)

4. Electrical Metallic Tubing, Type EMT, Trade Size ¾. Metallic silver in color. Three No. 12 AWG copper conductors, Type THHN/THWN installed.

5. Metal-Clad Cable, Type MC, No. 1/0 AWG/3 with No. 6 AWG ground. Aluminum interlocked armor with black PVC jacket. Copper THHN/THWN conductors.

6. Service-Entrance Cable, Type SE, No. 1/0 AWG/3 with No. 2 AWG ground. Sunlight resistant with light gray jacket. Copper THHN/THWN conductors.

7. Rigid Metal Conduit, Type RMC, Trade Size 1-½. Metallic silver in color. Four No. 1/0 AWG copper conductors, Type THHN/THWN installed.

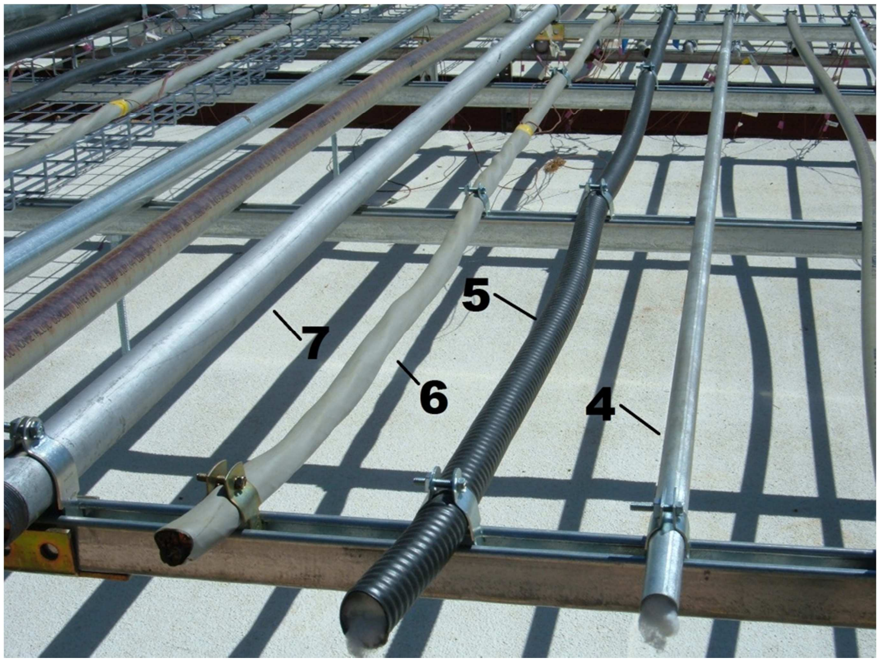


Fig. A2 – ¾ EMT (4), No. 1/0 MC (5), No. 1/0 SE (6), 1-1/2 RMC (7)

8. Rigid Polyvinyl Chloride Conduit, Type PVC, Trade1-1/2. Natural gray in color. Three No. 1/0 AWG copper conductors, Type THHN/THWN installed.

9. Electrical Metallic Tubing, Type EMT, Trade Size 1-1/2. Metallic silver in color. Five No. 1/0 AWG copper conductors, Type THHN/THWN installed.

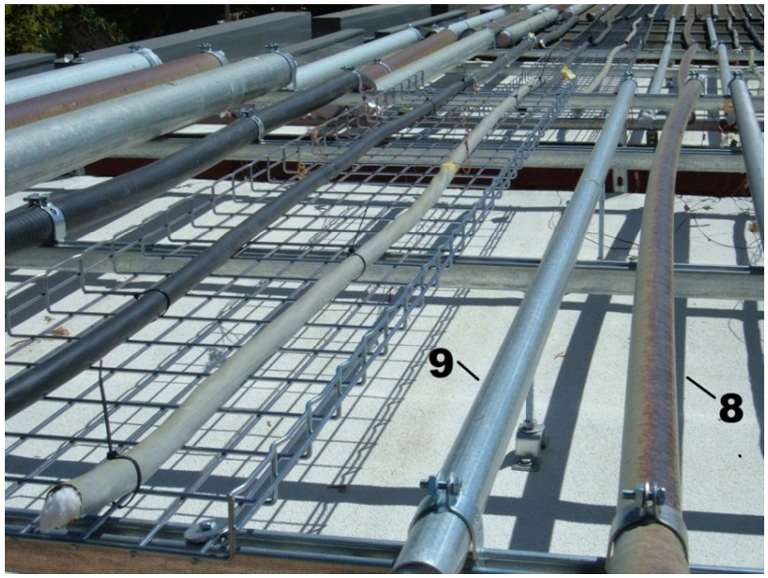


Fig. A3 – 1-1/2 PVC (8), 1-1/2 EMT (9)

10. Service-Entrance Cable, Type SE, No. 1/0 AWG/3 with No. 2 AWG ground. Sunlight resistant with light gray jacket. Copper THHN/THWN conductors. Installed in a cable tray, basket type.

11. Power and Control Tray Cable, Type TC, No. 1/0 AWG/3 with No. 6 AWG bare ground. Sunlight resistant with black jacket. Copper THHN/THWN conductors. Installed in a cable tray, basket type.

Fig. A4 – No. 1/0 SE (10), No. 1/0 TC (11), Installed in Cable Tray

12. Metal-Clad Cable, Type MC, No. 500 kcmil/3 with No. 2 AWG ground. Aluminum interlocked armor with black PVC jacket. Copper THHN/THWN conductors.

13. Rigid Metal Conduit, Type RMC, Trade Size 4. Metallic silver in color. Three No. 500 kcmil copper conductors, Type THHN/THWN installed.

Fig. A5 – No. 500 MC (12), 4 RMC (13)

14. Rigid Polyvinyl Chloride Conduit, Type PVC, 4. Natural gray in color. Three No. 500 kcmil copper conductors, Type THHN/THWN installed.

15. Electrical Metallic Tubing, Type EMT, Trade Size 4. Metallic silver in color. Three No. 500 kcmil copper conductors, Type THHN/THWN installed.

Fig. A6 – 4 PVC (14), 4 EMT (15)

16. Metal Wireway, 4 in. by 4 in., 16 gauge steel. Gray in color. Three No. 1/0 AWG copper conductors, Type THHN/THWN installed.

17. Metal Wireway, 8 in. by 8 in., 14 gauge steel. Gray in color. Three No. 500 kcmil copper conductors, Type THHN/THWN installed.

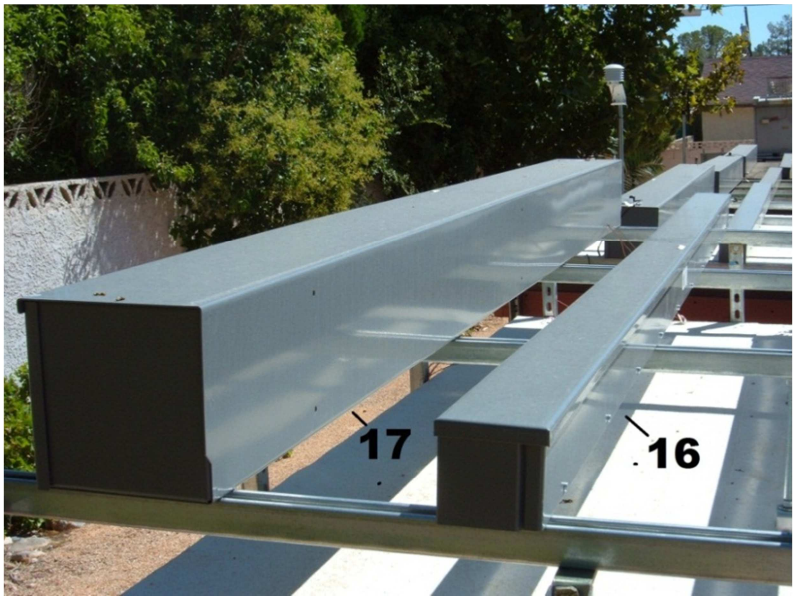


Fig. A7 – 4 In. Duct (16), 8 In. Duct (17)

APPENDIX B

Test Instrumentation

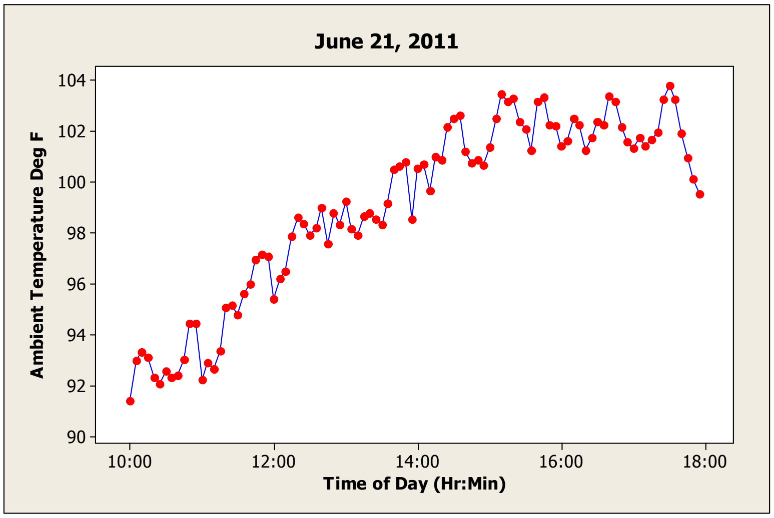
Pyranometer – Campbell Scientific, CS300 apogee silicon pyranometer.

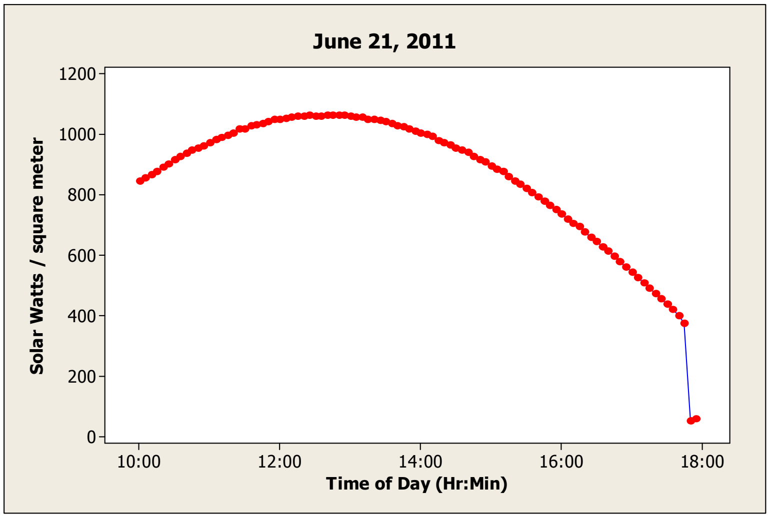
Anemometer - Campbell Scientific, 03101 three-cup anemometer.

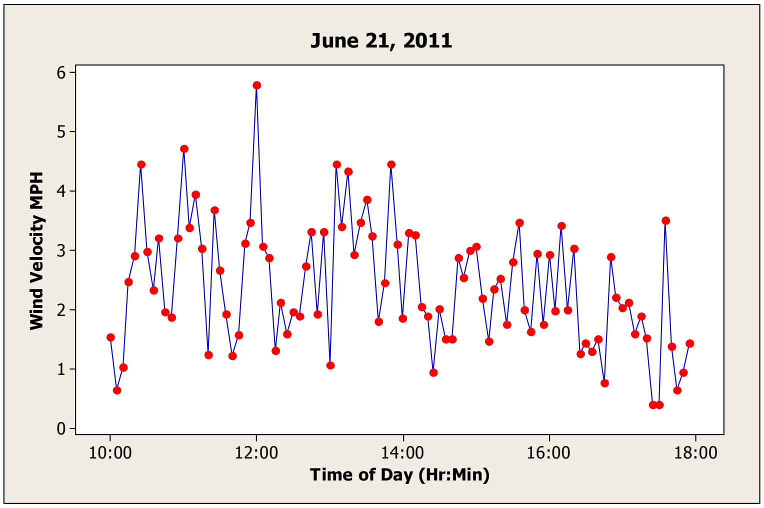
Data Acquisition System - Campbell Scientific, CR5000 Measurement and Control System. Serial No. 1315. Date of last calibration, April 15, 2011, by Campbell Scientific (A2LA accredited).

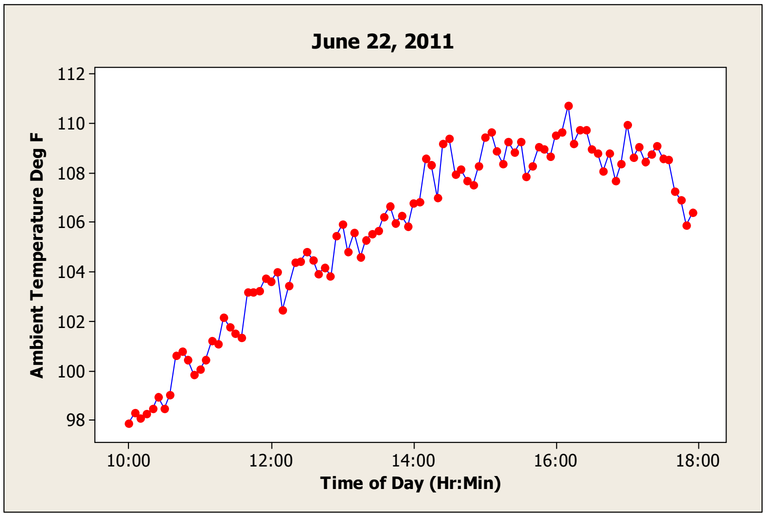
APPENDIX C

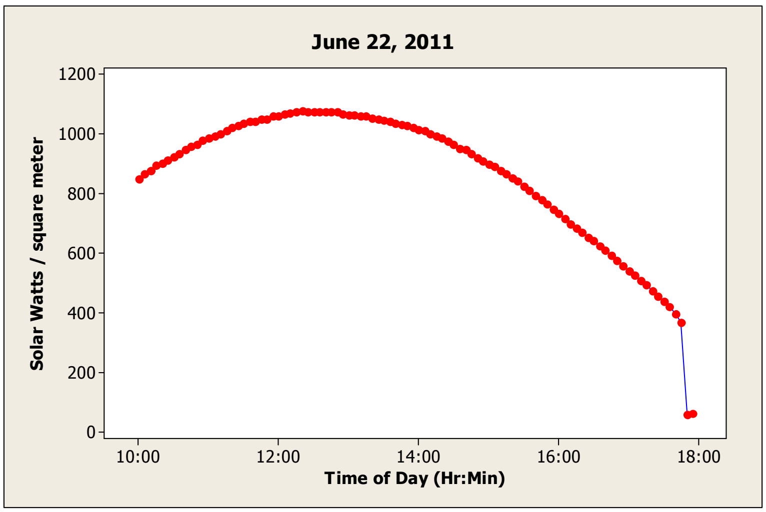
Graphs of Daily Outdoor Ambient Temperature, Solar Irradiance, and Wind Speed

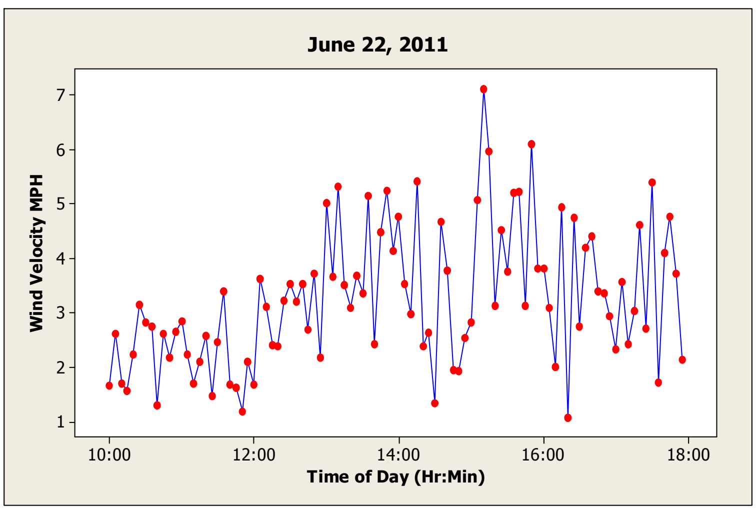

June 21, 2011
Ambient Temperature Deg F
104
102
100
98
96
94
92
90
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

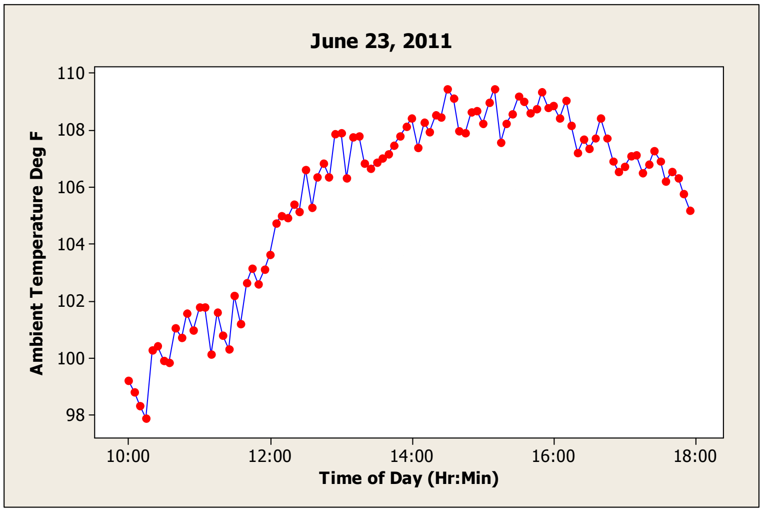

June 21, 2011
Solar Watts / square meter
1200
1000
800
600
400
200
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

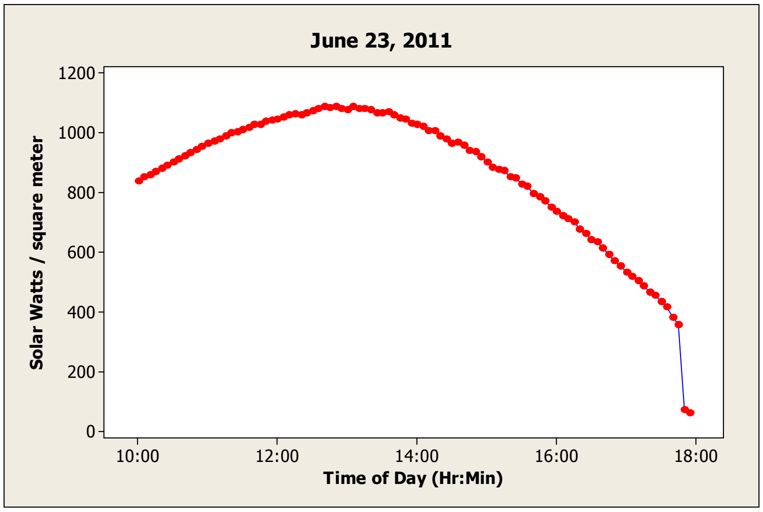

June 21, 2011
Wind Velocity MPH
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

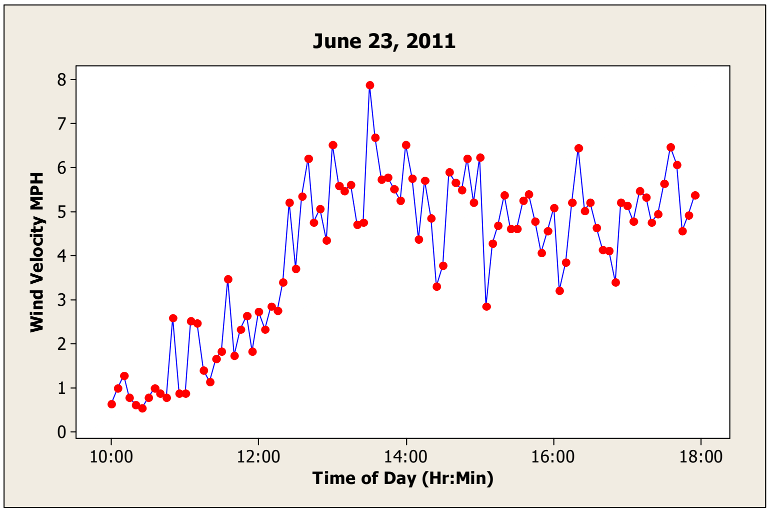

June 22, 2011
Ambient Temperature Deg F
112
110
108
106
104
102
100
98
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

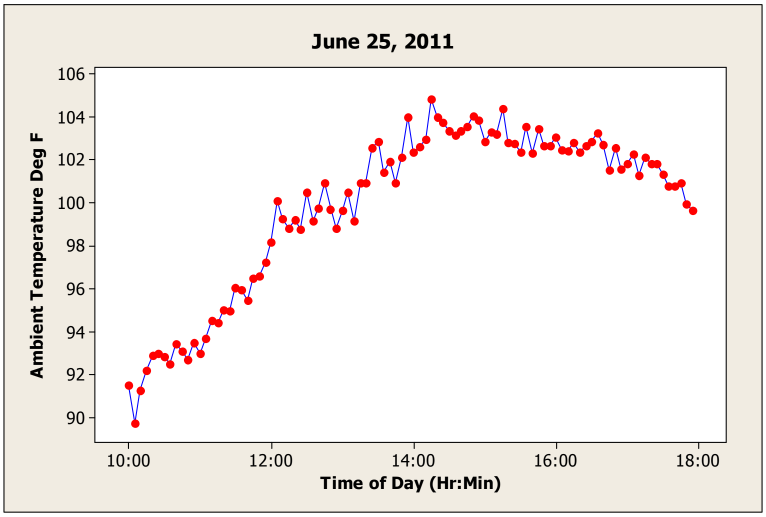

June 22, 2011
Solar Watts / square meter
1200
1000
800
600
400
200
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

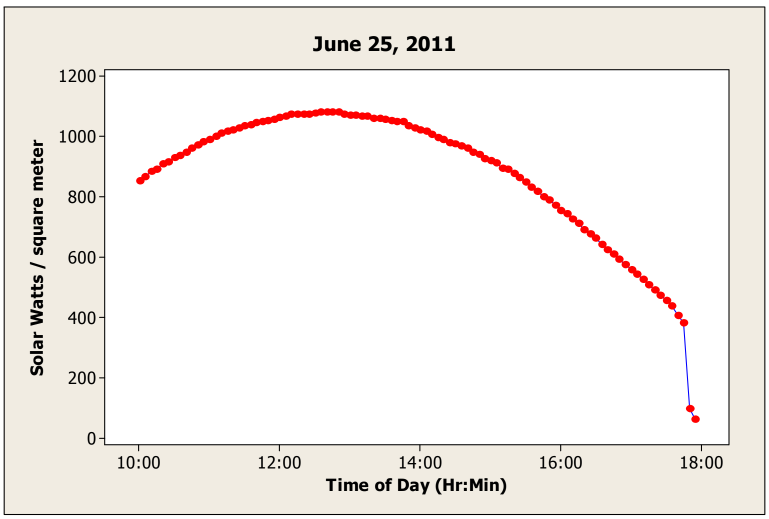

June 22, 2011
Wind Velocity MPH
7
6
5
4
3
2
1
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

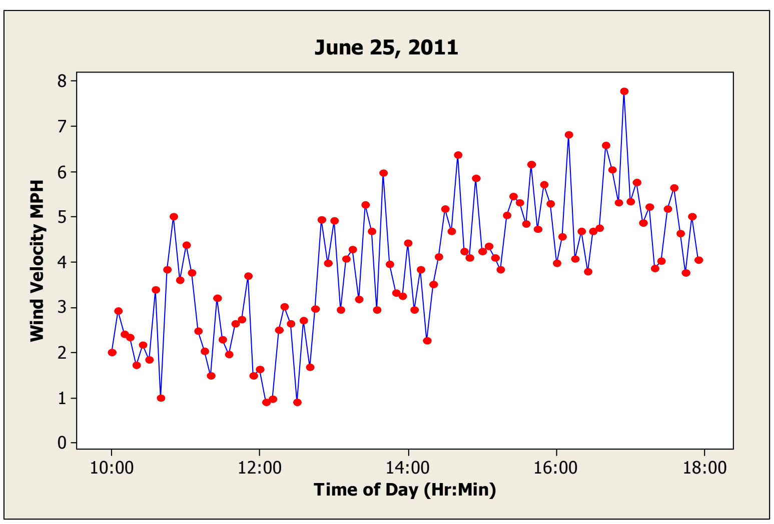

June 23, 2011
Ambient Temperature Deg F
Time of Day (Hr:Min)
110
108
106
104
102
100
98
10:00
12:00
14:00
16:00
18:00

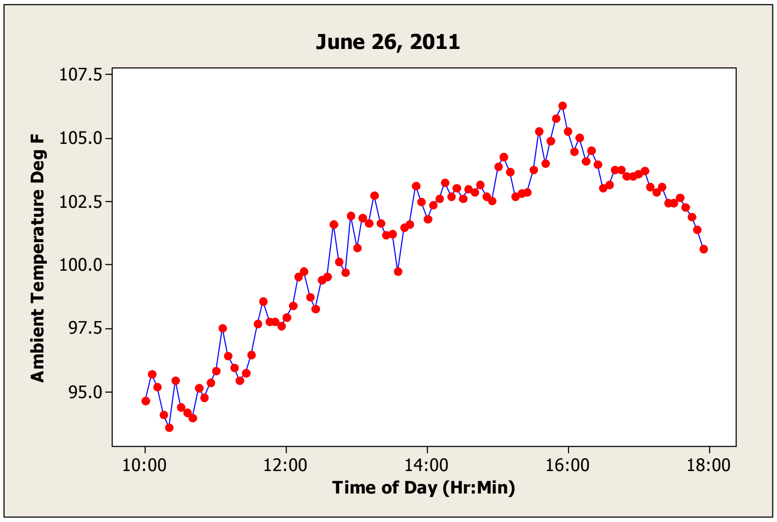

June 23, 2011
Solar Watts / square meter
Time of Day (Hr:Min)
1200
1000
800
600
400
200
0
10:00
12:00
14:00
16:00
18:00

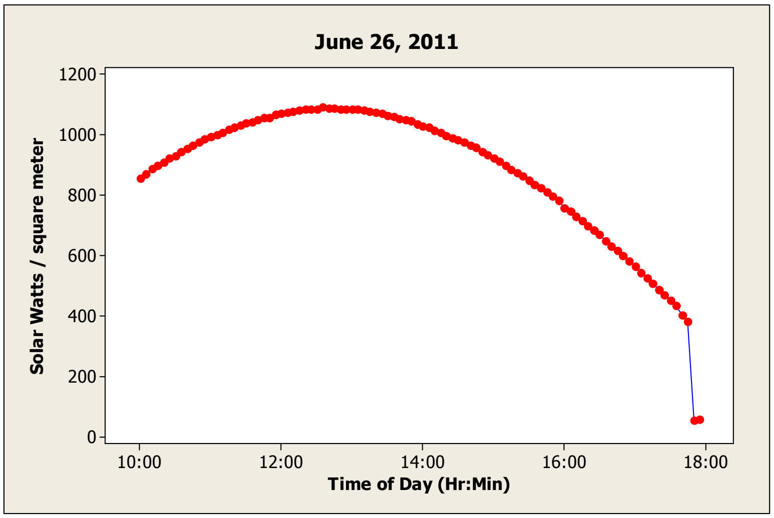

June 23, 2011
Wind Velocity MPH
Time of Day (Hr:Min)
8
7
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00

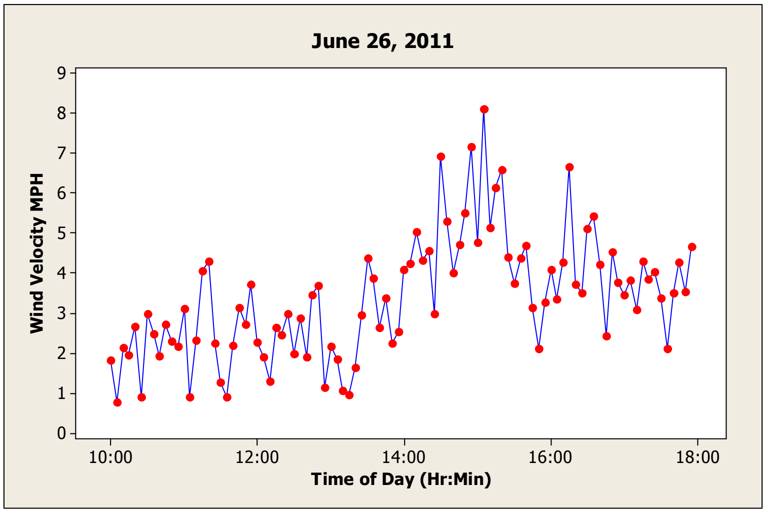

June 25, 2011
Ambient Temperature Deg F
106
104
102
100
98
96
94
92
90
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

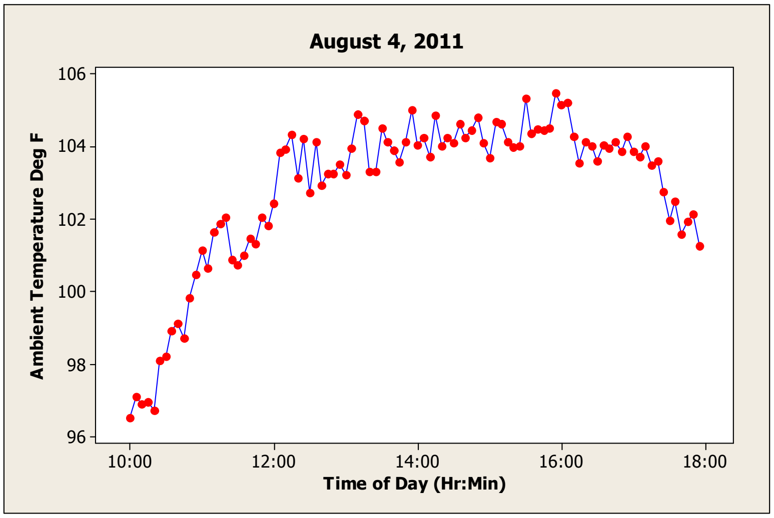

June 25, 2011
Solar Watts / square meter
1200
1000
800
600
400
200
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

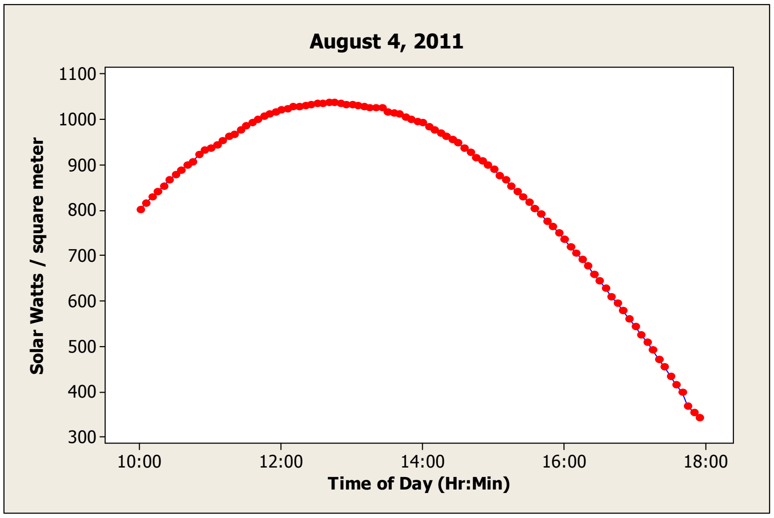

June 25, 2011
Wind Velocity MPH
8
7
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

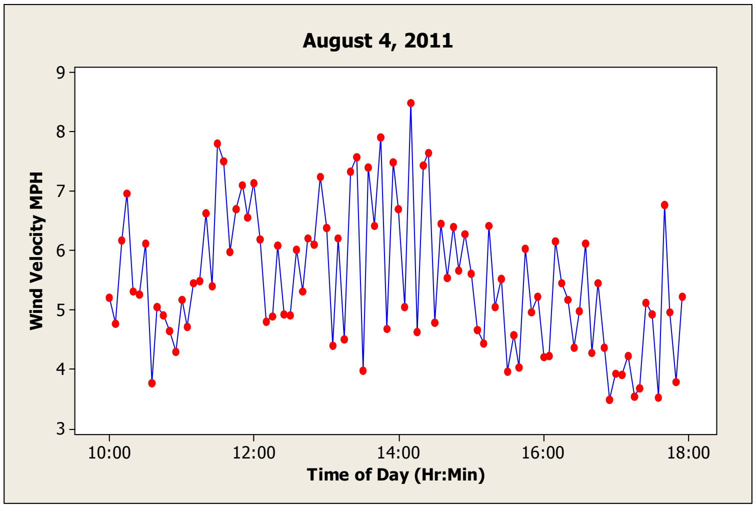

June 26, 2011
Ambient Temperature Deg F
107.5
105.0
102.5
100.0
97.5
95.0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

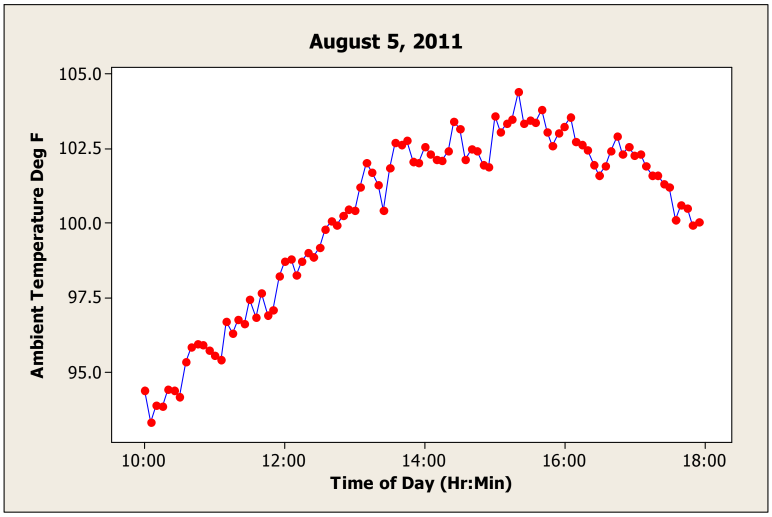

June 26, 2011
Solar Watts / square meter
1200
1000
800
600
400
200
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


June 26, 2011
Wind Velocity MPH
9
8
7
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 4, 2011
Ambient Temperature Deg F
106
104
102
100
98
96
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 4, 2011
Solar Watts / square meter
1100
1000
900
800
700
600
500
400
300
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 4, 2011
Wind Velocity MPH
9
8
7
6
5
4
3
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 5, 2011
Ambient Temperature Deg F
105.0
102.5
100.0
97.5
95.0
10:00
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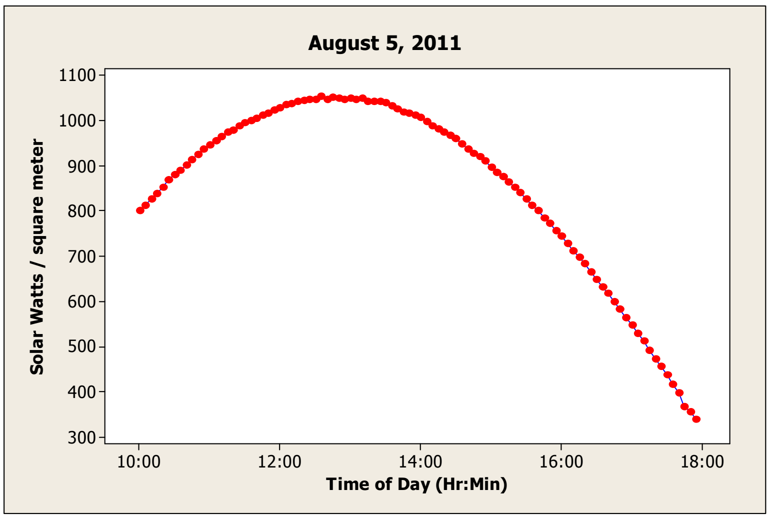
14:00
16:00
18:00
Time of Day (Hr:Min)


August 5, 2011
Solar Watts / square meter
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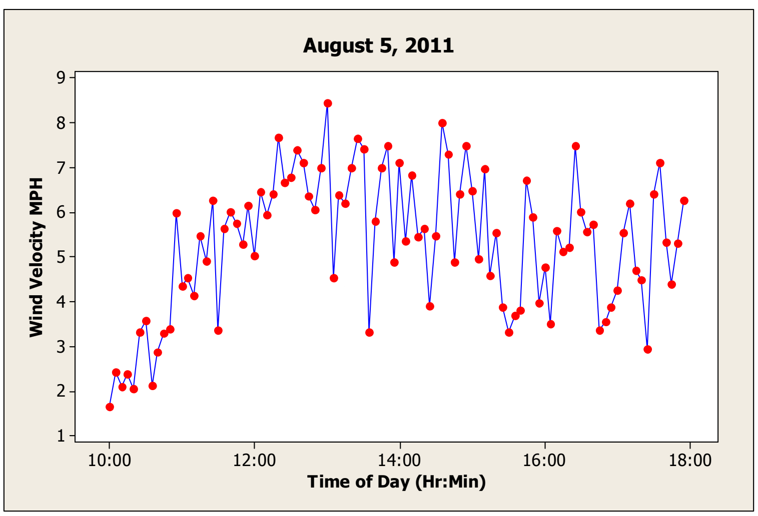
1000
900
800
700
600
500
400
300
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 5, 2011
Wind Velocity MPH
9
8
7
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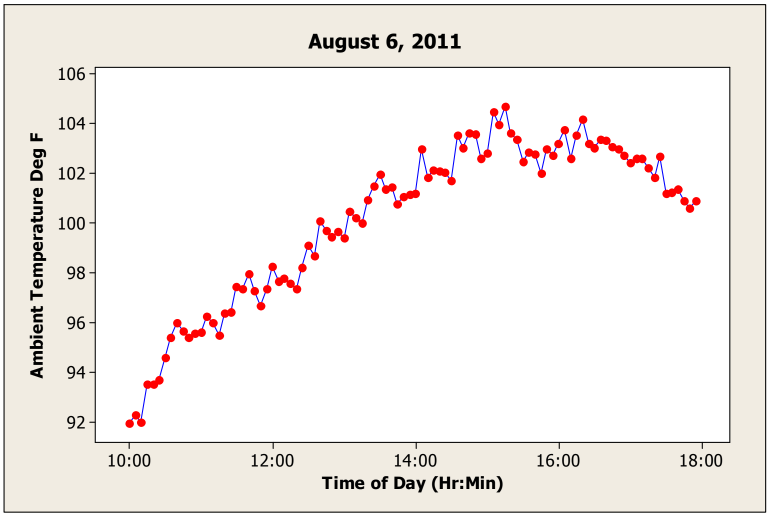
4
3
2
1
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 6, 2011
Ambient Temperature Deg F
106
104
102
100
98
96
94
92
10:00
12:00
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16:00
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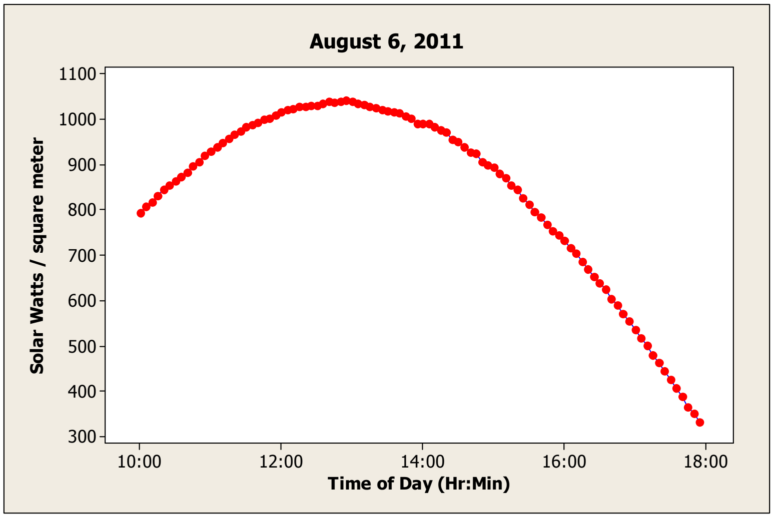
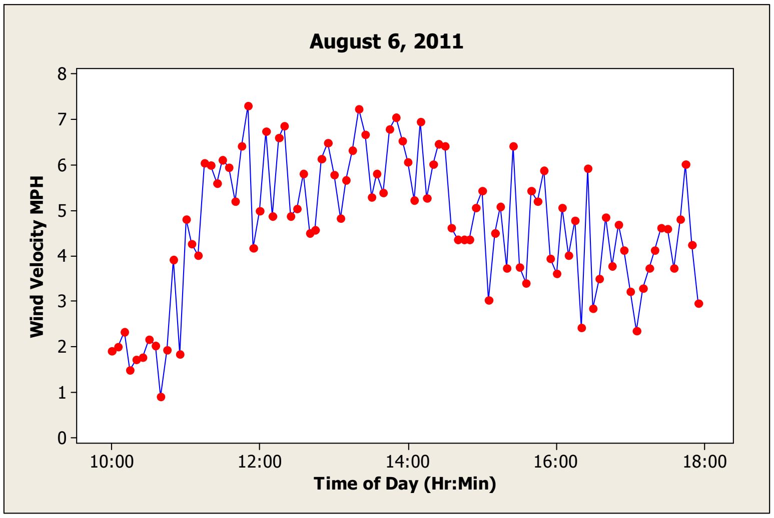
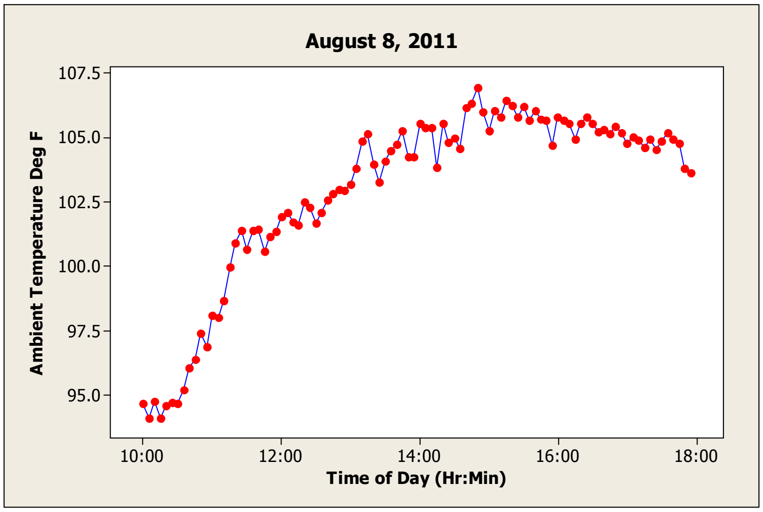
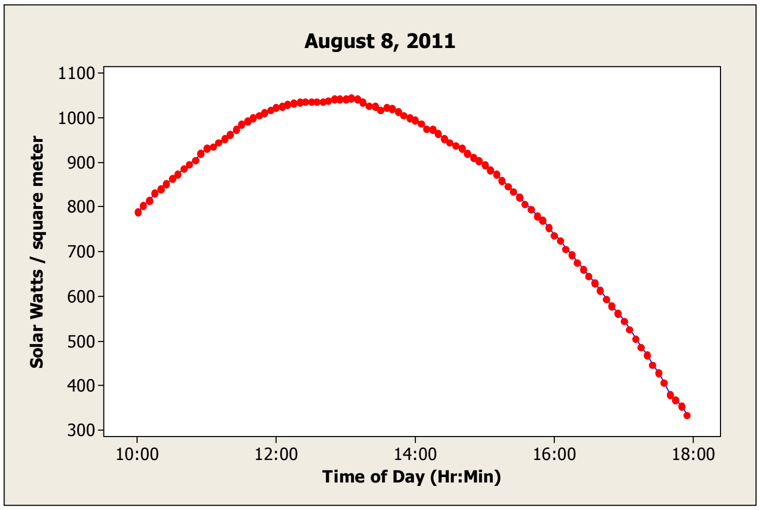
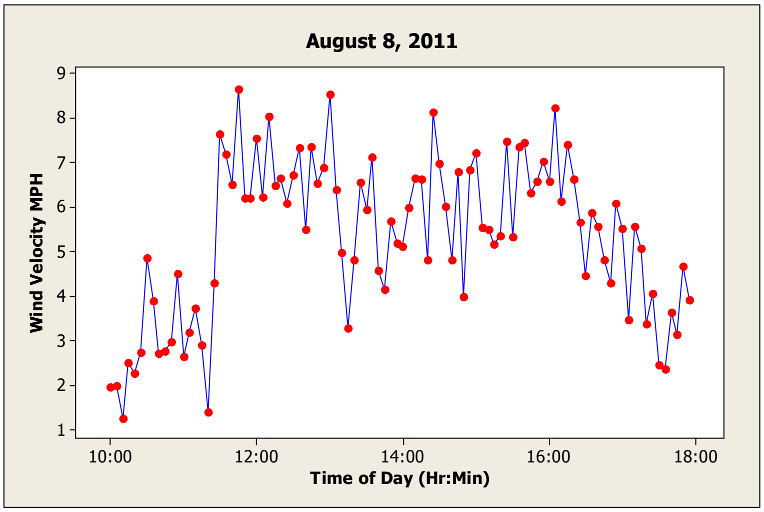
Time of Day (Hr:Min)

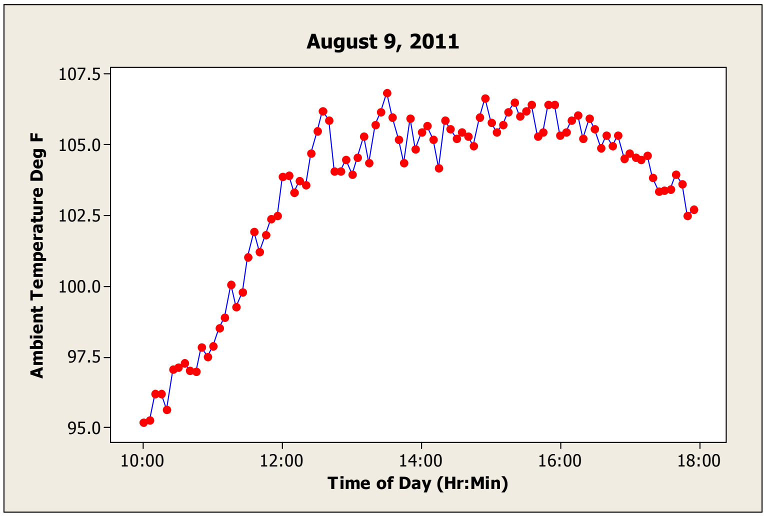

August 6, 2011
Solar Watts / square meter
1100
1000
900
800
700
600
500
400
300
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

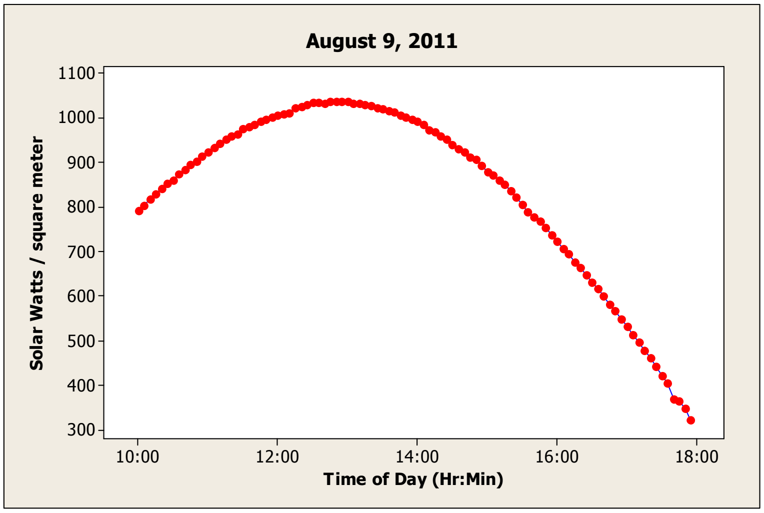

August 6, 2011
Wind Velocity MPH
8
7
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

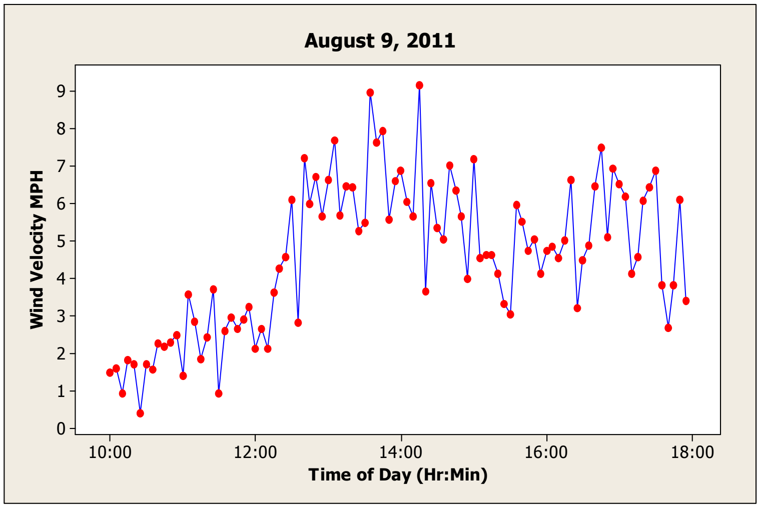

August 8, 2011
Ambient Temperature Deg F
107.5
105.0
102.5
100.0
97.5
95.0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 8, 2011
Solar Watts / square meter
1100
1000
900
800
700
600
500
400
300
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 8, 2011
Wind Velocity MPH
9
8
7
6
5
4
3
2
1
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

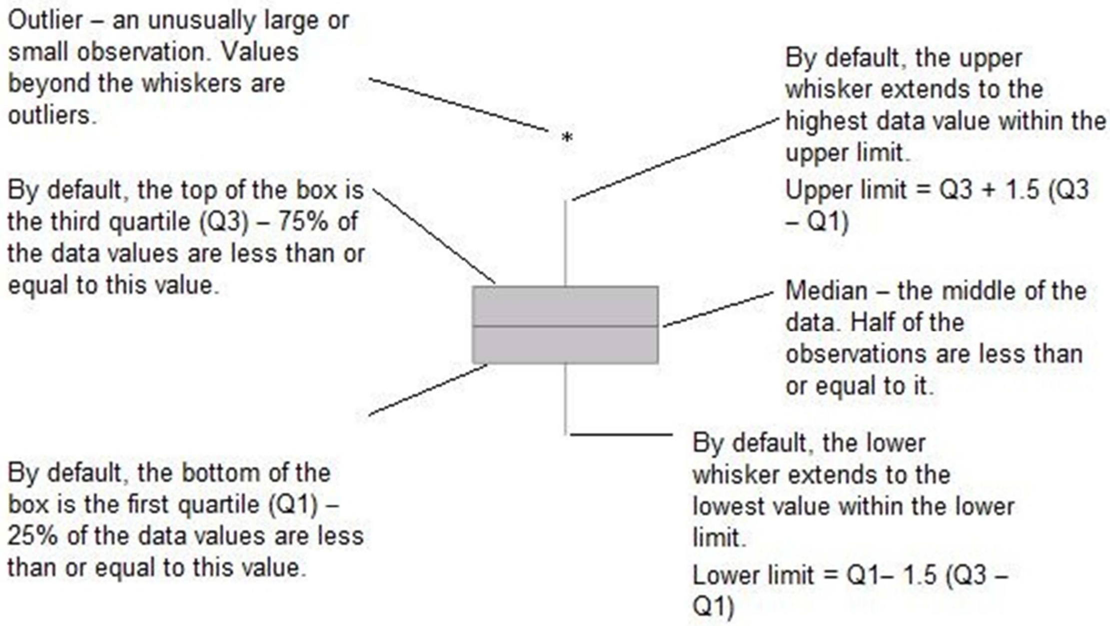

August 9, 2011
Ambient Temperature Deg F
107.5
105.0
102.5
100.0
97.5
95.0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 9, 2011
Solar Watts / square meter
1100
1000
900
800
700
600
500
400
300
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)


August 9, 2011
Wind Velocity MPH
9
8
7
6
5
4
3
2
1
0
10:00
12:00
14:00
16:00
18:00
Time of Day (Hr:Min)

APPENDIX D

Description of Boxplot Diagrams for Data Analysis



Note – A crosshairs within a box also represents the mean (average) of the data.