File IN16969
Project 12CA25371

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Fact-Finding Report on Ambient Temperature Adjustment for Raceway and Cable Systems Exposed to Sunlight on Rooftops - - Part II – Additional Studies at Higher Elevations

Prepared for Travis Lindsay Consulting Services, Inc.
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NOTICE

EXECUTIVE SUMMARY

A UL Fact-Finding Investigation Report from 2011for Travis Lindsey Consulting Services involved a comprehensive temperature test study of several different types and sizes of conduits, wireways, and cable systems installed on laboratory test rooftops at elevations ranging from directly on the roof to 12 inches above the roof. Mr. Lindsey used that Report to substantiate a public proposal to revise Table 310.15(B)(3)(c) from the 2011 Edition of the NEC® to include a temperature adder of 60 °F for raceways and cables installed 0.5 inches or less from the roof, and 50 °F for raceways and cables installed greater than 0.5 inches off the roof. However, the NEC Code Panel chose to only accept part of Mr. Lindsey's proposal, and rejected any changes to the Table for distances greater than those tested (*e.g.*, wiring systems installed greater than 12 inches above the roof). The work described in this Report is an addendum to that original Fact-Finding Investigation of 2011, providing additional technical data for wiring systems mounted greater than 12 inches above the surface of the roof.

This additional work was conducted at the original Las Vegas, NV test site during the summer of 2012, and was conducted similarly to the work of 2011, but involved wiring systems at elevations of 36 inches and 60 inches off the roof. Additional testing with the wiring systems mounted at 12 inches off the roof was also conducted to make comparisons to that same elevation that was tested in 2011. Two rounds of tests were conducted, with some roof colors changed for the second round of tests to make comparisons between the effects of solar absorption from a black roof versus solar reflection from a white roof.

Using data analysis techniques similar to the previous work, this additional testing showed that for all wiring systems mounted 36 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 34.4 °F with a standard deviation of 6.0 °F. For this case, the maximum temperature rise above outdoor ambient for all wiring systems mounted 36 inches above the roof with a 95% confidence interval would be 46.2 °F. The testing also showed that for all wiring systems mounted 60 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 30.0 °F with a standard deviation of 5.4 °F. For this case, the maximum temperature rise above outdoor ambient for all wiring systems mounted 60 inches above the roof with a 95% confidence interval would be 40.6 °F.

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GENERAL

In 2011 UL conducted a Fact-Finding Investigation for Travis Lindsey Consulting Services, Inc., and issued a Report on Ambient Temperature Adjustment for Raceway and Cable Systems Exposed to Sunlight on Rooftops.[1] This work was conducted in conjunction with proposals by Mr. Lindsey for the 2008 and 2011 National Electrical Code® (NEC®), which recommended that for conduits and other wiring systems exposed to sunlight on rooftops, an adjustment temperature be added to the outdoor temperature when determining ambient temperature for the correction factors found in Section 310 of the NEC.

The 2011 UL Fact-Finding Investigation involved a comprehensive study of several different types and sizes of conduits, wireways, and cable systems installed on laboratory test rooftops at elevations ranging from directly on the roof to 12 inches above the roof. The results appeared to show that there was little difference between mean temperature rises over outdoor ambient for test samples of wiring systems mounted 0.5, 3.5, and 12.0 inches above the roof. Neglecting any heat convection or re-radiation from the surface of the roof, this was expected since the distance from the sun to the surface of the earth is large as compared to the distances between the three elevations tested. An analysis of variance (ANOVA) conducted with this data for the three elevations from the roof confirmed this observation.

In preparation for the 2014 NEC, Mr. Lindsey made a public proposal to revise Table 310.15(B)(3)(c) to include a temperature adder of 60 ^{o}F for raceways and cables 0.5 inches or less from the roof, and 50 ^{o}F for raceways and cables installed greater than 0.5 inches off the roof.[2] Mr. Lindsey's substantiation for this change included the results of the UL Fact-Finding Investigation. The NEC Code Panel chose to only accept part of Mr. Lindsey's proposal, and rejected any changes to the Table for distances greater than those tested (*e.g.*, wiring systems installed greater than 12 inches above the roof).

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[1] Fact-Finding Report on Ambient Temperature Adjustment for Raceway and Cable Systems Exposed to Sunlight on Rooftops, dated October 10, 2011, File IN16969, Project 11CA25532. Prepared for Travis Lindsay Consulting Services, Inc., by Underwriters Laboratories Inc.

[2] Available for review at the National Fire Protection Association (NFPA) Headquarters, Quincy, Ma. Reference Report on Proposals A2013, Proposal 6-29, Log# 1654, NEC-P06.

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 greater than 12 inches above rooftops. In particular, this investigation involves tests with wiring systems mounted 36 inches and 60 inches above the surface of the roof.

The information in this report, which includes results of these tests, are intended to assist code making panel members in rendering a decision on Mr. Lindsey's public comments to his proposal 2-29 (Log #1654) for the 2014 NEC.[2]

PREVIOUS WORK

The previous work of the Fact-Finding Investigation Report of October 10, 2011 described tests on 17 different cable and raceway systems as shown in Table 3 of that Report[3]. The testing was conducted at an outdoor laboratory site located in Las Vegas, Nevada. 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 0.5, 3.5, and 12 inches above the roof. For wiring systems tested directly on the roof and at 0.5 inches 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 0.5 inches above the roof, the roof surface was asphalt painted white in color to account for additional heating from solar reflection from the roof.

With thermocouples installed on the wires in the conduit, wireway, or cable systems as appropriate, temperatures were measured at one-minute increments throughout the day, and the maximum of each of these one-minute increments within a five-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 surrounding 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.

For the purpose of analyzing the results, 10 days were chosen during the summer months of 2011 where the solar irradiance exceeded 1000 W/m^2 for several hours. For each of these 10 days, the temperature data were analyzed for the period of time where the solar irradiance was greater than or equal to 1000 W/m^2. 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 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.

The results showed that 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 of 6.8 ^{o}F. For this case,

[3] Table 3 from the Report of October 10, 2011 is duplicated in Appendix A of this Report for reference. Appendix A of the Report of October 10, 2011 also includes a more detailed description of each wiring system.

maximum temperature rise above outdoor ambient for all wiring systems mounted directly on the roof with a 95% confidence interval (C.I.) of 62.2 ^{o}F. Similarly, 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 of 6.6 ^{o}F. 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 be 51.4 ^{o}F.

ADDITIONAL WORK

Additional work was conducted at the Las Vegas, NV test site during the summer of 2012. This additional work was conducted similarly to the work of 2011, but involved wiring systems at elevations of 36 inches and 60 inches (3 feet and 5 feet) off the roof. An additional test with the wiring systems mounted at 12 inches off the roof was also included in order to make comparisons to a same elevation that was tested in 2011. Two rounds of tests were conducted, with some roof colors changed for the second round of tests to make comparisons between the effects of solar absorption from a black roof versus solar reflection from a white roof.

Fig. 1 – Wiring Systems Mounted 3 Feet off Roof

Fig. 2 – Wiring Systems Mounted 5 Feet off Roof

Round 1 Testing

For the first round of testing, with the wiring systems tested at distances of 12 inches and 60 inches above the roof, the roof surface was asphalt painted white in color to account for additional heating from solar reflection from the roof. For the wiring system tested at 36 inches above the roof, the roof was asphalt painted black in color to account for additional heating from solar absorption on the roof.

As with the previous testing, to analyze the differences between wiring systems at the different distances from the roof, a compilation of all of the wiring system 90th percentile temperature rises 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 made for each of the three elevations (12 inches, 36 inches, and 60 inches). Data were recorded during the month of June 2012. For the purpose of analyzing results, 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. 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 35 minutes as shown in Table 1. Table 1 also includes the average wind speed and maximum outdoor ambient temperature for that period of time.

Table 1 – 10 Days of Analyzed Data for Round 1

Day (2012)	Period of Solar Radiation ≥ 1000 W/m^2 (Hours:Minutes) Beginning	End	Elapsed Time	Avg Wind Speed (MPH)	Outdoor Ambient Deg F
June 15	11:15	14:10	2 hr 55 min	4.1	99
June 15	11:20	14:20	3 hr 00 min	5.1	96
June 16	11:30	14:05	2 hr 35 min	3.9	99
June 17	11:15	14:15	3 hr 00 min	5.7	104
June 18	11:05	14:25	3 hr 20 min	6.7	103
June 19	11:20	14:10	2 hr 50 min	3.7	100
June 20	11:15	14:20	3 hr 05 min	2.4	100
June 21	11:20	14:10	2 hr 50 min	4.0	103
June 23	11:10	14:25	3 hr 15 min	7.2	95
June 24	11:20	14:20	3 hr 00 min	6.9	100

Round 2 Testing

For the second round of testing, the wiring systems were tested at distances of 12 inches and 36 inches above the roof, and the roof surface was asphalt painted white in color to account for additional heating from solar reflection from the roof. For the previous Round 1 testing, the wiring system mounted 36 inches above the roof was tested with the roof surface painted black in color. However, this resulted in lesser temperatures than the wiring system tested at 60 inches above the roof with the roof surface painted white in color. This indicated that as wiring systems are mounted further from the roof, solar reflection off the roof becomes more of an influencing factor than the solar absorption by the roof.

Round 2 testing was conducted in August and early September of 2012. As with the previous testing, a compilation of all of the 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 for each of the elevations. However, because of the variable weather conditions during that time period in the Las Vegas area, only three days were found where the solar irradiance was greater than or equal to 1000 W/m^2 for an extended period of time, and even on those three days, the time period those days where that solar irradiance exceeded 1000 W/m^2 was only for about one hour. These three days are shown in Table 2.

Table 2 – 3 Days of Analyzed Data for Round 2

	Period of Solar Radiation ≥ 1000 W/m^2 (Hours:Minutes)				Outdoor Ambient
Day (2012)	Beginning	End	Elapsed Time	Avg Wind Speed (MPH)	Deg F
August 18	12:40	13.50	1 hr 10 min	2.6	103
August 21	13:10	14:00	0 hr 50 min	8.4	102
September 3	13:05	14:15	1 hr 10 min	3.2	103

Test Results

Table 3 shows the mean 90th percentile temperatures that were calculated for each test sample at each elevation for the period of time each day when the solar radiation was greater than or equal to 1000 W/m^2. The Table also includes the temperature adder that was accepted by the Code Making Panel during the proposal stage in preparation for the 2014 NEC for Table 310.15(B)(3)(c) for the distance above the roof as shown.[4] For comparison purposes, the results of the testing with wiring systems at a distance of 12 inches (1 foot) above the roof for Round 1 and Round 2, as well as the testing at 12 inches above the roof in the previous work of 2011 are also shown in Table 3.

[4] Available for review at the National Fire Protection Association (NFPA) Headquarters, Quincy, Ma. Reference Report on Proposals A2013, Proposal 6-29, Log# 1654, NEC-P06.

Table 3 – Test Results (90th Percentile Temperature Rise Above Outdoor Ambient)

	2012 Data					2011 Data
	90th Percentile Temperature Rise Above Ambient (°F) Distance Above Roof					
	5 feet[a]	3 Feet[b]	1 Foot[a]	3 Feet[c]	1 Foot[c]	1 Foot
3/4" EMT	26.8	28.3	37.9	38.2	40.1	36.3
1/2" RMC	18.3	24.2	30.0	30.9	31.7	29.2
1-1/2" EMT	24.3	26.6	34.5	33.0	37.0	29.4
1-1/2" RMC	26.6	20.6	38.8	27.9	41.2	40.0
4" EMT	29.9	30.2	39.0	38.3	42.9	29.7
4" RMC	34.2	31.8	43.9	40.3	45.9	38.7
3/4" PVC	33.6	27.2	39.6	28.6	37.4	37.0
1-1/2" PVC	29.8	29.3	41.6	31.7	39.6	37.4
4" PVC	30.9	29.7	40.7	28.9	35.4	38.5
4" DUCT	32.3	30.6	43.4	42.0	47.4	43.5
8" DUCT	31.4	31.0	39.5	42.1	44.4	39.7
#12 MC	29.4	28.3	39.7	33.8	41.8	40.3
#1/0 MC	32.2	31.8	45.1	38.9	46.6	46.3
#1/0 SE	26.8	27.5	38.3	30.1	38.0	34.9
Tray 1/0 SE	25.0	15.8	35.4	20.3	35.1	31.5
Tray 1/0 TC	44.6	35.8	49.8	40.6	51.0	51.0
#500 MC	33.8	32.7	46.6	39.2	47.3	47.6
NEC Adder[d]	25	25	50	25	50	50

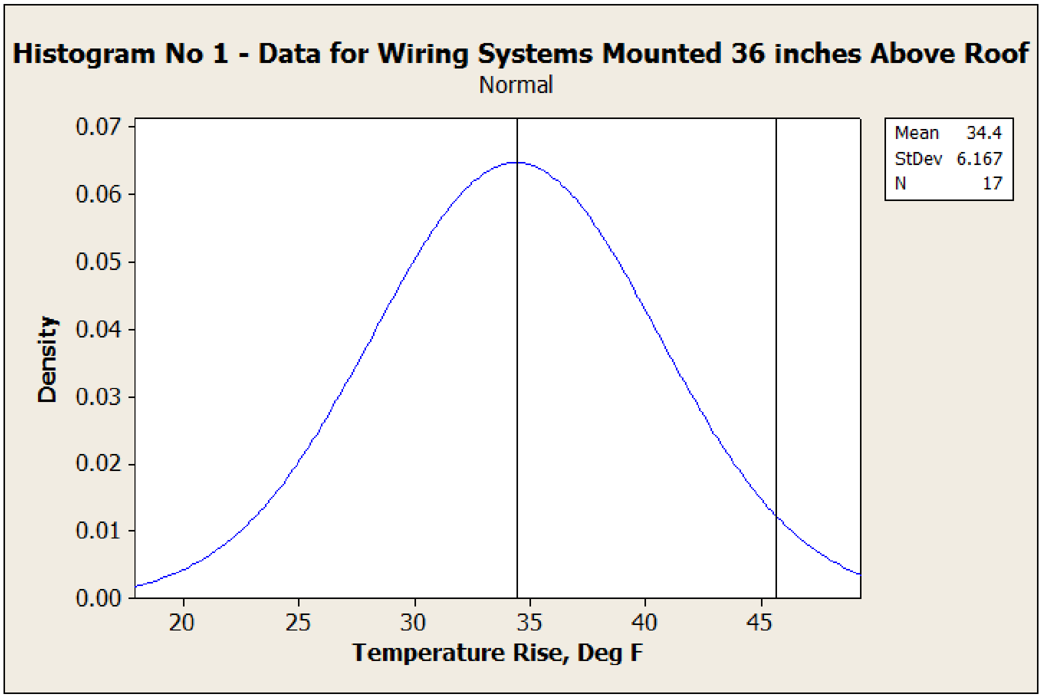
a - roof surface painted white (Round 1)
b - roof surface painted black (Round 1)
c - roof surface painted white (Round 2)
d - proposed for the 2014 NEC

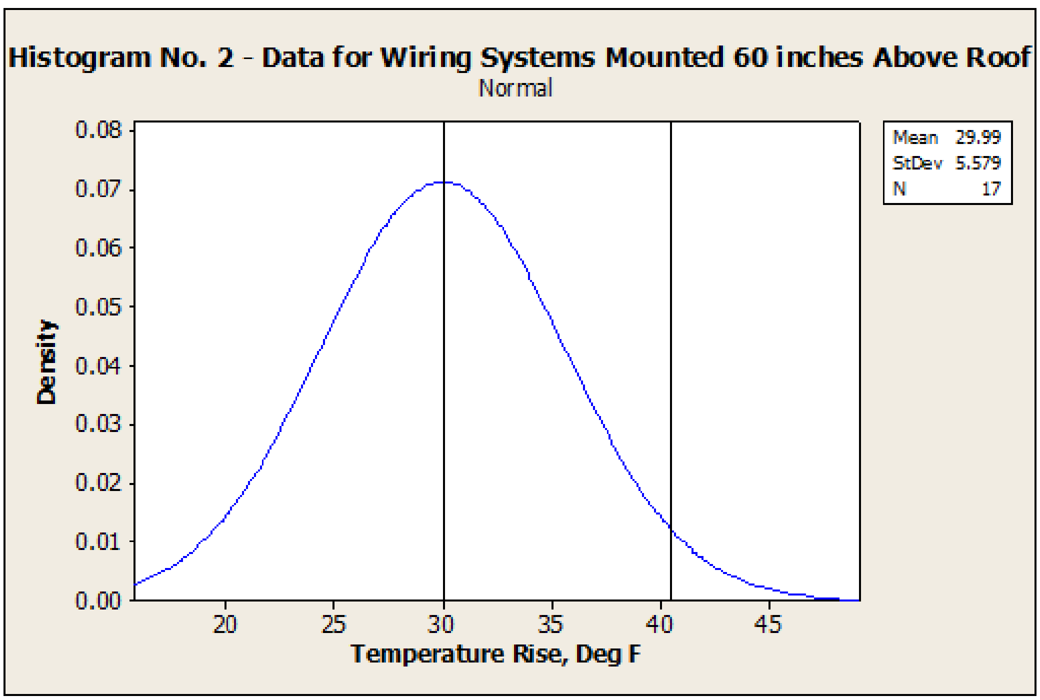
An analysis of the test results showed that for all of the 17 test samples of wiring systems mounted 36 inches above the roof, the mean (average) temperature rise above outdoor ambient was 34.4 ^{o}F with a standard deviation of 6.0 ^{o}F. Confidence intervals (C.I.) are often used as a statistical estimate to bracket data parameters with a known degree of certainty. As with the previous work, 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 36 inches above the roof with a 95% C.I. would be 46.2 ^{o}F. The test results also showed that for all of the 17 test samples of wiring systems mounted 60 inches above the roof, the mean (average) temperature rise was 30.0 ^{o}F with a standard deviation of 5.4 ^{o}F. For this case, maximum temperature rise for all wiring systems mounted 5 feet above the roof with a 95% C.I. would be 40.6 ^{o}F. The results of this analysis are shown in Table 4, and Histograms 1 and 2.

Table 4 – Analysis of Test Results at 60 Inches (5 Feet) and 36 Inches (3 Feet)

	90th Percentile Temperature Rise Above Ambient (°F)	
	Distance Above Roof	
	5 feet[a]	3 Feet[b]
3/4" EMT	26.8	38.2
1/2" RMC	18.3	30.9
1-1/2" EMT	24.3	33.0
1-1/2" RMC	26.6	27.9
4" EMT	29.9	38.3
4" RMC	34.2	40.3
3/4" PVC	33.6	28.6
1-1/2" PVC	29.8	31.7
4" PVC	30.9	28.9
4" DUCT	32.3	42.0
8" DUCT	31.4	42.1
#12 MC	29.4	33.8
#1/0 MC	32.2	38.9
#1/0 SE	26.8	30.1
Tray 1/0 SE	25.0	20.3
Tray 1/0 TC	44.6	40.6
#500 MC	33.8	39.2
Mean	30.0	34.4
SD	5.4	6.0
95% C.I.	40.6	46.2
NEC Adder[c]	25	25

a - roof surface painted white (Round 1)
b - roof surface painted white (Round 2)
c - proposed for the 2014 NEC


Histogram No 1 - Data for Wiring Systems Mounted 36 inches Above Roof
Normal
Density
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
20
25
30
35
40
45
Temperature Rise, Deg F
Mean 34.4
StDev 6.167
N 17


Histogram No. 2 - Data for Wiring Systems Mounted 60 inches Above Roof
Normal
Density
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
20
25
30
35
40
45
Temperature Rise, Deg F
Mean 29.99
StDev 5.579
N 17

An analysis of the test results for wiring systems mounted 12 inches above the roof for Round 1, Round 2, and the testing from 2011 is shown in Table 5. The 95% C.I. for these tests were 49.2 ^{o}F, 51.3 ^{o}F, and 50.4 ^{o}F respectively. The temperature adder proposed for the 2014 NEC for wiring systems mounted 12 inches above the roof is 50 ^{o}F. The results of this analysis are shown in Table 5.

Table 5 – Analysis of Test Results at 12 Inches (1 Foot) with Three Different Tests

	90th Percentile Temperature Rise Above Ambient (^{o}F) Distance Above Roof		
	1 Foot[a]	1 Foot[b]	1 Foot[c]
3/4" EMT	37.9	40.1	36.3
1/2" RMC	30.0	31.7	29.2
1-1/2" EMT	34.5	37.0	29.4
1-1/2" RMC	38.8	41.2	40.0
4" EMT	39.0	42.9	29.7
4" RMC	43.9	45.9	38.7
3/4" PVC	39.6	37.4	37.0
1-1/2" PVC	41.6	39.6	37.4
4" PVC	40.7	35.4	38.5
4" DUCT	43.4	47.4	43.5
8" DUCT	39.5	44.4	39.7
#12 MC	39.7	41.8	40.3
#1/0 MC	45.1	46.6	46.3
#1/0 SE	38.3	38.0	34.9
Tray 1/0 SE	35.4	35.1	31.5
Tray 1/0 TC	49.8	51.0	51.0
#500 MC	46.6	47.3	47.6
Mean	40.2	41.3	38.3
SD	4.6	5.1	6.2
95% C.I.	49.2	51.3	50.4
NEC Adder[d]	50	50	50

a - roof surface painted white (Round 1)
b - roof surface painted white (Round 2)
c - roof surface painted white (2011 testing)
d - proposed for the 2014 NEC

SUMMARY

1. A previous UL Fact-Finding Investigation of 2011 showed that 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 of 6.8 ^{o}F. For this case, the 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. Similarly, 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 of 6.6 ^{o}F. For this case, maximum temperature rise above outdoor ambient for all wiring systems mounted off on the roof with a 95% C.I. would be 51.4 ^{o}F.

2. In preparation for the 2014 NEC, the NEC Code Panel accepted during the proposal stage revisions to Table 310.15(B)(3)(c) to include a temperature adder of 60 ^{o}F for raceways and cables 0.5 inches or less from the roof, and 50 ^{o}F for raceways and cables installed greater than 0.5 and up to 12 inches above the roof. The Code Panel needed more data to accept any new temperature adders for wiring systems mounted greater than 12 inches above the roof.

3. Additional testing has shown that for all wiring systems mounted 36 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 34.4 ^{o}F with a standard deviation of 6.0 ^{o}F. For this case, maximum temperature rise above outdoor ambient for all wiring systems mounted 36 inches above the roof with a 95% C.I. would be 46.2 ^{o}F.

4. Additional testing has shown that for all wiring systems mounted 60 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 30.0 ^{o}F with a standard deviation of 5.4 ^{o}F. For this case, maximum temperature rise above outdoor ambient for all wiring systems mounted 60 inches above the roof with a 95% C.I. would be 40.6 ^{o}F.

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APPENDIX A

Table 3 from Report of October 10, 2011

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.