Temperatures of Bundled Electrical Cables
Installed in Bored Holes in Residential Wood Framing

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SUMMARY

As part of a larger study of elevated ambient temperatures in residential and non-residential structures in Las Vegas, NV, an experiment was carried out on the effect of bundling of six Type NM-B cables (twelve current-carrying conductors) in residential buildings. Such bundles are not uncommon in wall top-plates above load centers and at other points where electrical use is heavy. When cables pass through these top-plates, they must be fire- and draft-stopped, greatly increasing the possibility of built-up heat at these points.

With a combination of high outdoor temperatures and heavy electrical loads, bundle temperatures reached high values, constituting a clear safety hazard in the CDA experiment.

The most alarming aspect of the experiment was that, when loads near 80% were applied to all the conductors and the outdoor temperature was high, temperatures higher than 230 F were experienced in the bundle, grossly in excess of the 194 F (90 C) rated limit of Type NM-B cables.

Statistical evaluation of the data indicated that outdoor temperatures as low as 87 F, in combination with 73% loading of all the cables, could trigger bundle temperatures in excess of the cables' 194 F rating. This extends a level of concern to all areas of the USA, not just to hot locations such as Las Vegas.

It is recommended that the NEC institute de-rating for bundled NM-type cables in wood top-plates at much smaller lengths than 24 inches.

INTRODUCTION

Anecdotal information has suggested that, when electrically loaded cables are "bundled" together in a restricted area, there is a heating effect that could cause safety problems under real-world conditions. It has even been suggested that a "runaway" situation can occur in extreme cases, where I^2R heat from the loaded conductors, being unable to escape, further heats the conductors, thus raising the conductors' resistance, which causes more I^2R heating, increasing the temperature still further, and that this cycle can continue to failure.

The National Electrical Code addresses bundling in Section 310.15(B)(2)(a). Here the definition of a bundle is restricted to having a minimum length of 600 mm (24 in.), and no suggestion is made that a shorter bundle needs to be derated.

In the course of conducting an Elevated Ambient Temperature Study (EATS) in residential and non-residential structures, Copper Development Association Inc. included one bundle of NM-type cables in a residential-type structure, to determine if there were safety issues during heavy, but Code-acceptable, levels of loading. Since it is common for bundled cables to pass through top plates in walls above load centers and at other locations containing a concentration of electrical applications, a top plate was used for the bundle experiment.

EXPERIMENTAL PROCEDURE

Building. The experiment was conducted in a single-story 10-foot by 12-foot simulated residential building at CDA's research site in Las Vegas, NV during the summer months of 2002. The building is a free-standing wood-framed structure with a hip-type roof with a slope of 4:12 on all four sides **(Figure 1)**. The building is oriented so that one 12-foot wall (in which the experiment was conducted) faces south.

Figure 1. Test residential structure used in experiment (South-facing wall on right)

The exterior height of the roof at the peak is approximately 11 feet above floor level. The roof is sheathed with ½-inch plywood and covered with two layers of 15-pound roofing felt and one layer of GAF charcoal asphalt shingles.

The building has wall framing of 2 X 4 Douglas Fir #2 on 16-inch centers. Exterior sheathing is 5/8-inch T1-11 wood siding, while interior walls are 5/8-inch gypsum drywall. Wall insulation is R-13 Owens Corning fiberglass batts faced with kraft paper on the interior side.

The ceiling is also 5/8-inch gypsum drywall. Ceiling insulation consists of R-19 Owens Corning fiberglass batts faced with kraft paper on the interior side. The attic is ventilated at 1/150th of the attic area using circular eave vents in the small overhang in each joist space.

The living space in the building was air conditioned to approximately 78 F, though this temperature could rise temporarily when the door was opened on a hot day.

Cable bundle. The bundle consisted of a total of six NM-B cables, two each of 14/2 w/G, 12/2 w/G, and 10/2 w/G. The bundle is located in the top plate at about the middle of the south wall of the building. The cables were of the color-coded types with jackets colored white for AWG 14, yellow for AWG 12 and orange for AWG 10. The bundle was located in a top plate which consisted of two-2X4s and one-1X4, for a total bundle length within the 1-1/2" hole bored vertically through the top plate of approximately 3-1/2 inches. The six cables were actually three cables passing up through the hole, then looped above the top plate (with care taken to separate the cables to minimize any bundling effects outside the bored hole) and passing back down through the hole. The cables were spread apart below the hole as well to minimize the length of the bundle effect. **Figure 2** is a photograph of the bundle before fire-stopping and installation of the insulation and interior drywall.

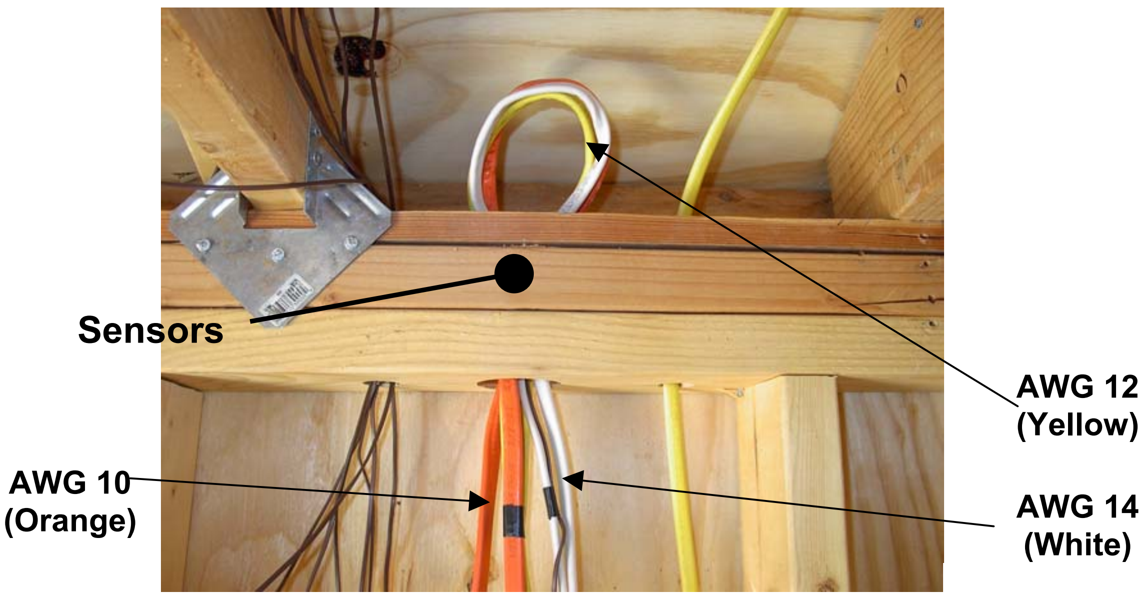

Figure 2. Bundle of 6 NM-B cables installed in top plate

Fire- and draft-stopping was accomplished, in accordance with accepted practice, using foam insulating material, with some fiberglass added from the top side to complete the seal.

Electrical loading. There were 12 loaded conductors in the 1-1/2" diameter bundle – six phase conductors and six grounded (neutral) conductors. This consisted of 4-AWG 14, 4-AWG 12 and 4-AWG 10 copper conductors. The six bare grounding conductors, which carried no current, were not considered. Currents were generated using resistance loads – mineral insulated heating cables, supplemented by incandescent lamps to "fine-tune" the currents. The load elements were remote from the test building so that their heating would have no effect on the experiment.

At various times the cables were subjected to loads varying from 60% of rated loads to the limit (for continuous loads) of 80%. The reason for this is that it took considerable time to "fine-tune" the experiment by adjusting resistance loads. (The bundle experiment was only a small part of an overall experimental program.) In the earlier days of the experiment (early June 2002), the loading was at about 60%, and the loads were applied only from 10 AM to 4 PM. To be consistent only that same six-hour period of the day was analyzed for the 73% loading in July and the 80% loading in August, even though the experiment was turned on for more hours.

On a given day both electrical loading and ambient heat built up during the daylight hours caused the conductors to heat up, thus increasing their resistance (R). As the resistance increased, the current passing through each of the circuits gradually decreased, since the applied voltage (E) from the utility was essentially constant (I=E/R). No corrections were made for these decreases in current as a typical day progressed (such as by further increasing the load elements). The three ranges shown in the final tabulation are a nominal 60% range for the June 6-9, 2002 period, a nominal 73% for the July 25-31, 2002 period and a nominal 80% for the August 11-15, 2002 period. It should be noted again that these ranges were not pre-selected, but the pattern of loading resulted from evolution of the larger experimental program.

Comparison Temperatures. Outdoor temperatures were measured, using a standard six-plate solar radiation shield containing a thermocouple installed in a housing. For comparison purposes temperatures were also measured within other bays of the south wall on the jackets of unloaded NM-B cables of the same type and AWG sizes as the cables in the bundle. Either of these can be considered the "base" temperature to which bundle temperatures can be compared.

Temperature measurement. Temperatures were measured using copper-constantan thermocouples attached with electrical tape to the outer jackets of each of the three cables before they were bundled together. The cables were then inserted in the bored hole so that the thermocouples were positioned approximately midway in the 3-1/2" length of the hole (Figure 2), and the aforementioned fire-stop materials were then applied. The thermocouple wires were run to a high-capacity data logger in an adjacent building, which recorded and stored the temperatures at one-minute intervals. All tabulations were done with data at 15-minute intervals. (Note: The overall CDA experiment involved a total of about 160 temperature measurement points; hence the need for the high-capacity data logger.) The same measurement method was used for the unloaded NM cables in other bays of the south wall of the building, which were used for comparison.

Further details of the experimental procedures and equipment used are available on request.

RESULTS

A typical pattern for the temperature of the unloaded cable in the south wall, the temperature of the cable in the bundle and the outdoor temperature is shown in **Figure 3** for June 6, 2002. By 10 AM the current is just being turned on and the bundle temperature is 12 F higher than that of the unloaded cable, and about the same as the outdoor temperature. As the effect of the 60% current (12 amps for the AWG 12 wire shown here) becomes apparent the cable in the bundle heats up considerably higher than the unloaded wires, the latter staying about the same as the outdoor temperature. The difference between the loaded and unloaded wires reaches a peak of about 58 F at 3:30 PM.

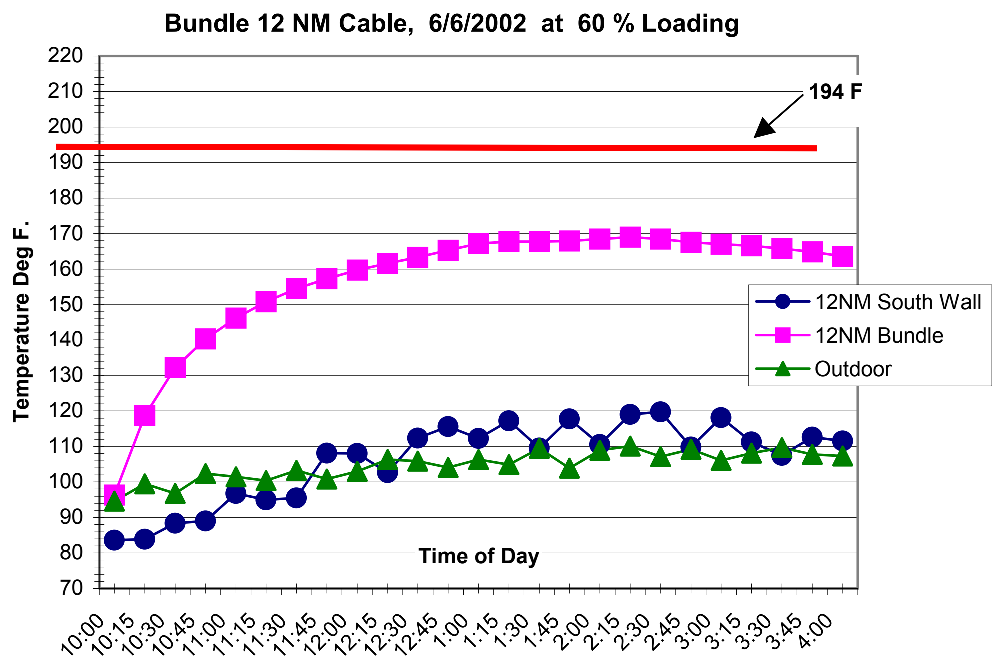

Figure 3. Relationship of outdoor temperature and the temperatures of unloaded cable and bundled cables (60% loading) on June 6, 2002

Figure 4 shows the same data for August 14, when the cable was loaded at 80% (16 amps). This day actually had about the same outdoor temperature as June 6, with most of the day in the 100 – 110 F range. Here the loaded cable is above the 194 F limit over the entire 10 AM - 4 PM period, and runs as much as 109 F hotter than the unloaded cable. Of special note is that the cable temperature reaches a peak temperature of 233 F at 2:45 PM. *This latter temperature is nearly 40 F higher than the allowable limit for 90 C (194 F) cable.*

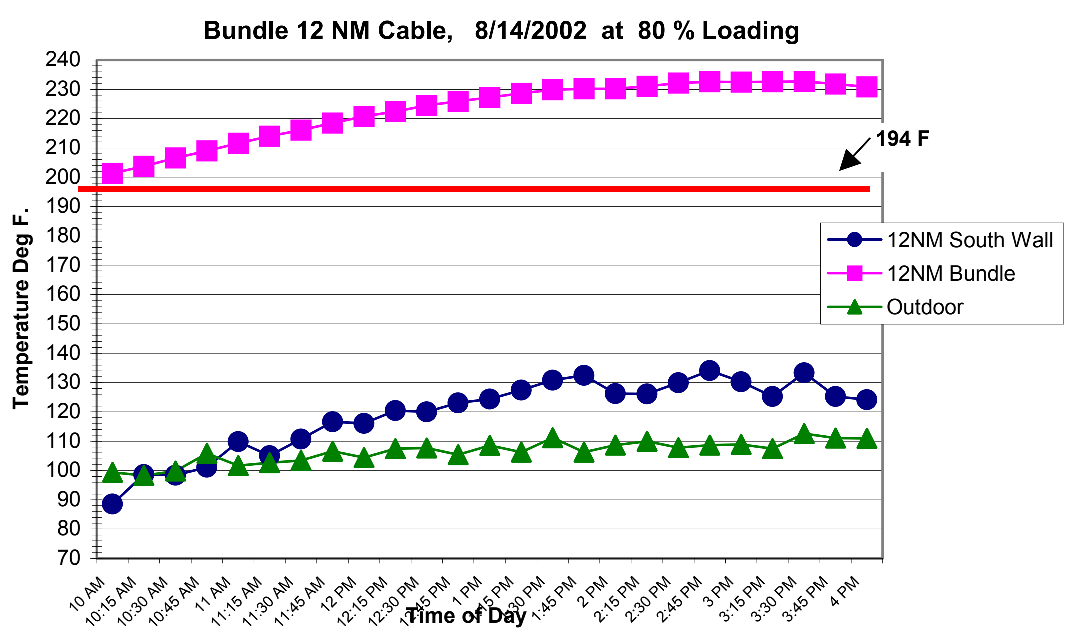

Figure 4. Relationship of outdoor temperature and the temperatures of unloaded cable and bundled cables (80% loading) on August 14, 2002

The relationship of bundle temperature and degree of electrical loading is shown in **Figure 5**, again for AWG 12 cable, with very similar results for AWG 14 and 10 cables. In this figure all the 15-minute data points for the three time periods were plotted. The results show up as three fairly tight clusters of data points. The lower left cluster is for the June 6-9 period at about 60% loading, the middle cluster was for the July 25-31 period at 73% loading and the upper right cluster is for 80% loading in the August 11-15 period. This figure shows dramatically that 60% is a "safe" level, at least in terms of the bundle temperature remaining below the critical 194 F rating of the cable. 73% loading, on the other hand, resulted in many points being above the critical temperature, and at the Code limit of 80% loading every single data point was above 194 F during this hot week in August. The line drawn above the three clusters crosses the 194 F line at about 13 amps, or 65% loading, indicating potential problems if higher loading is done.

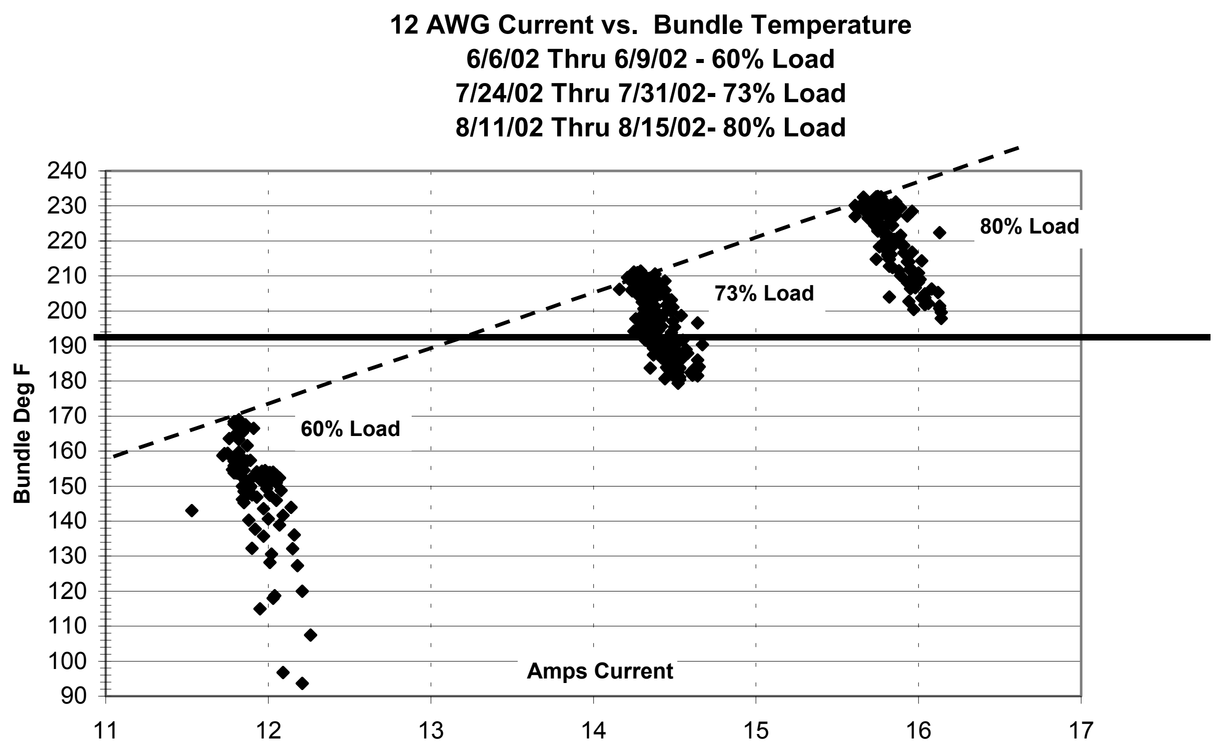

Figure 5. Relationship of the temperatures of bundled cables and the degree of electrical loading

To factor in the outdoor temperatures, **Figures 6 through 8** show the bundle temperature vs. outdoor temperature for first the 60% loading, then 73% loading, and finally 80% loading of the AWG 12 cables. In all cases it is seen that there is a trend for the bundle temperature to rise as the outdoor temperature rises (to as high as 113 F in the hot days of a Las Vegas summer).

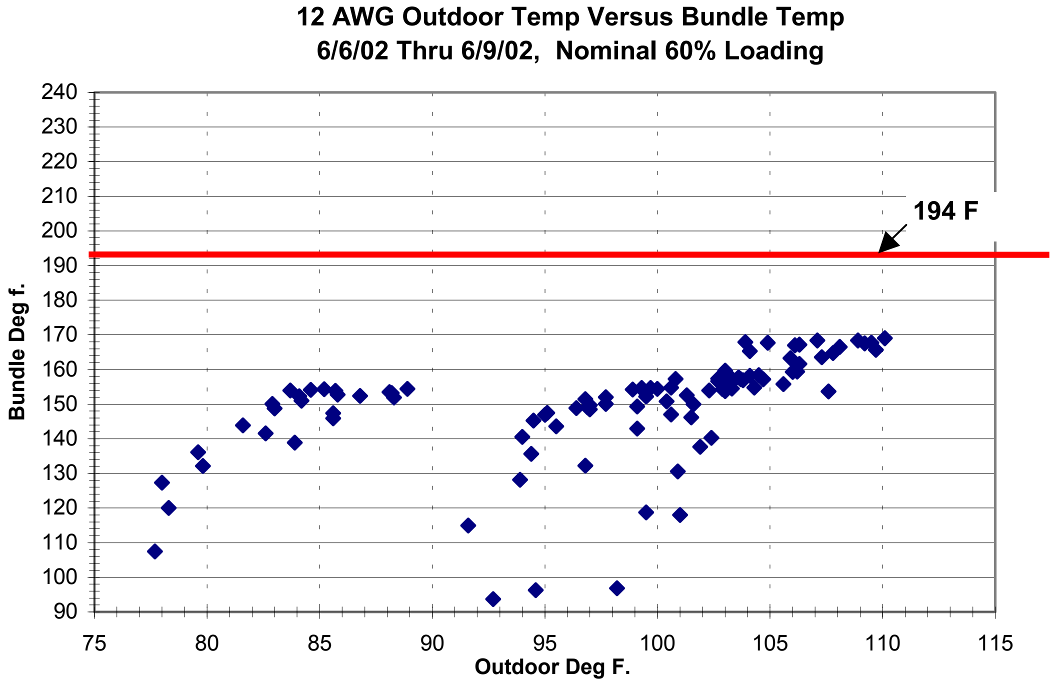

Figure 6. 60% loading

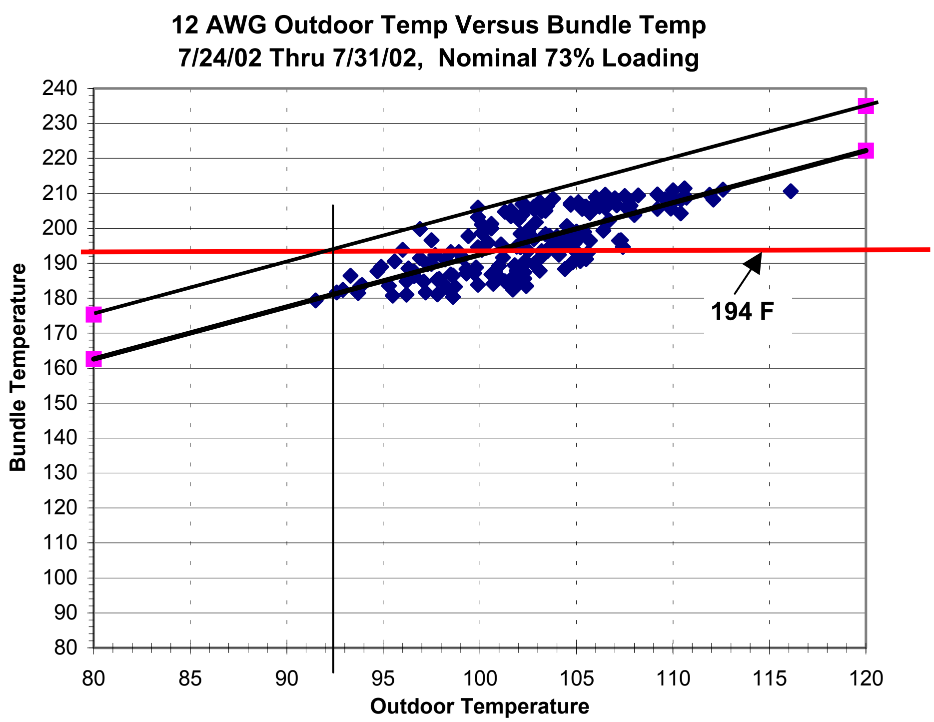

Figure 7. 73% loading

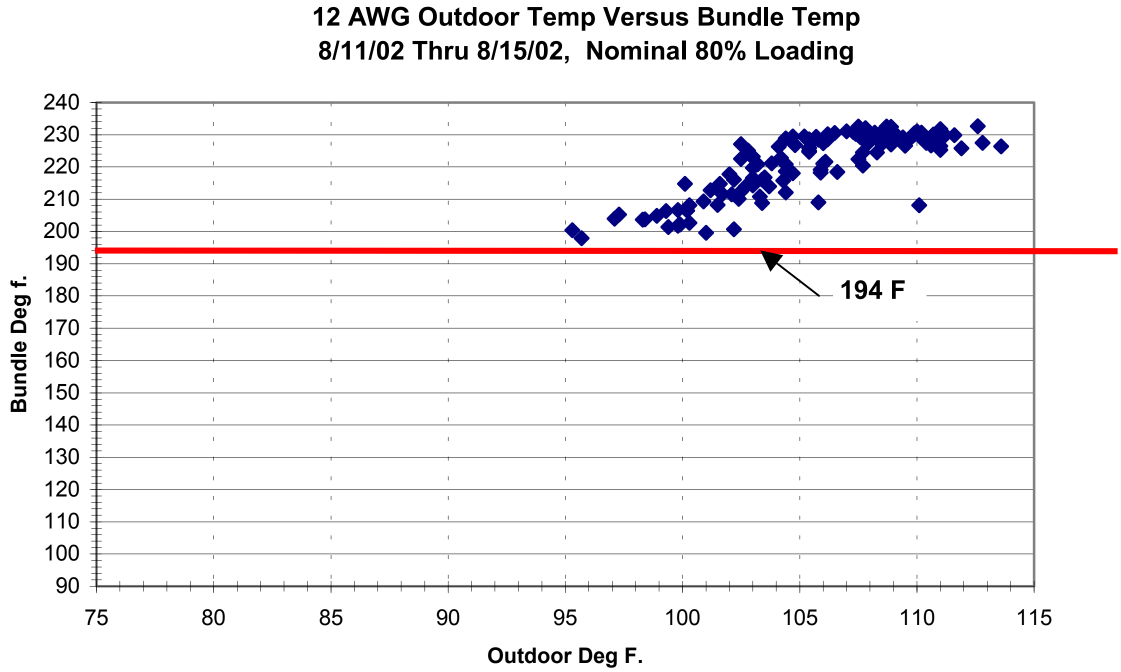

Figure 8. 80% loading

Since the data in Figure 7 straddle the critical 194 F limit for NM-B cable, a linear regression analysis was made of these data. The result was the line sloping upward to the right, which passes through the center of the data. Another line was drawn parallel to the trend line until the last data point was touched, so that more than 99% of the data points fell below the line. When this line was extended to the left it crossed the 194 F line at an outdoor temperature of about 93 F. This should be a good estimate of the maximum outdoor temperature at which the specific level of loading (73% in this case) would be acceptable in a top-plate location such as was used in the experiment.

Similar analyses were not made for the 60% load level in Figure 6, since all the data points fall below the 194 F level, nor for 80% loading in Figure 8, since all the points are above the failure point for NM-B cable.

It should be noted that a similar analysis of 73% loading of the AWG 14 data crossed the critical line at 87 F and the AWG 10 cable crossed at 92 F. For whatever reason both those sizes ran consistently hotter than the AWG 12 conductors shown here.

No fires or short circuits resulted from the experiment, but undoubtedly dangerous conditions were present in the top-plate bundle.

Finally, **Figure 9** shows the bundle after exposure to the conditions described, after the drywall was removed and before the top plate containing the bundle was taken out for further examination (not yet completed at this writing). Discoloration of the wire jackets was seen and the fire-stop material showed signs of overheating.

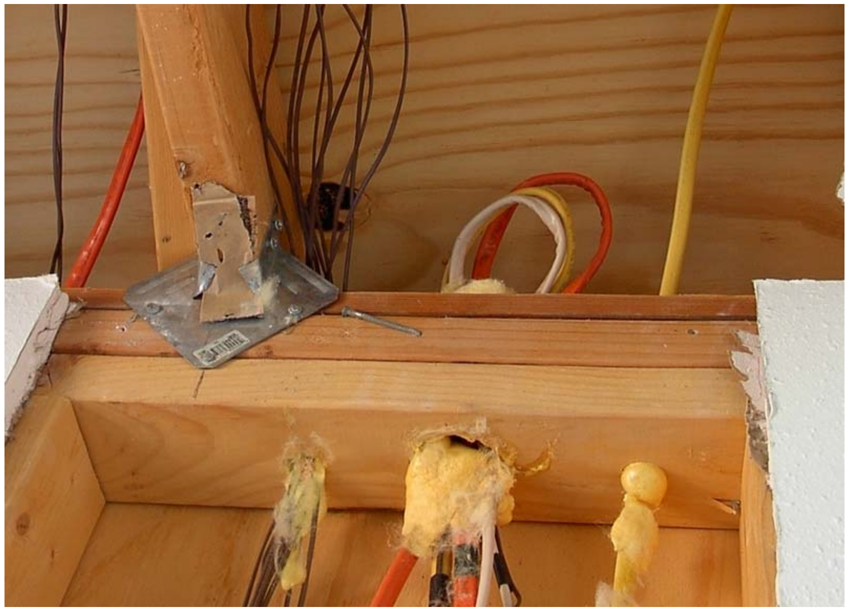

Figure 9. Wire bundle after completion of loading experiment

CONCLUSIONS

The bundling experiments show the possibility of dangerous conditions when loaded circuits are brought into close proximity with each other inside a fire- or draft-stop, where the ability to dissipate heat is extremely limited. The definition of a bundle in NEC 310-15, which includes a requirement for at least 24-inch length, is particularly suspect, and there appears to be little doubt that bundles of much shorter length should be subject to de-rating.

It may be argued that principles of load diversity should be applied to cable bundles, particularly in residential applications, and that 80% loading of all the cables in a bundle will seldom occur. On the other hand, it can be equally argued that the 80% limit will be exceeded in numerous situations, at least in one cable in a bundle. Also, in other cases where diversity principles are used, overcurrent devices provide protection against overloading. In this case the amperages are well below levels that would trip the overcurrent devices.

Although no fires or short circuits resulted from the experiment, the excessive heating of the cable and the surrounding wood structure is an obvious hazard.

Although experimental work is continuing, preliminary results indicate that immediate adjustments should be made to the NEC to apply at least to the specific case represented by the CDA experiment. Such a proposal is being made, with this report offered as technical support.