

THERMAL MODELING  
OF  
ELECTRICAL CONDUCTORS WITH EMPHASIS ON  
SOLAR HEATING

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The temperature of an insulated conductor is affected internally by self-generated  $I^2R$  heating and externally by ambient temperature. In the case of a wire in conduit, as current flows through the conductor metal, heat flows from the copper conductor, through the insulation, through the air within the conduit, through the conduit, and thence to the surrounding atmosphere. In each step of heat flow, the difference in temperature, delta-T, is the force causing heat to flow from one element to the next. When the temperature of two elements is approximately the same, delta-T approaches zero, no heat flows from the conductor, and the conductor system simply increases in temperature due to its continuous  $I^2R$  heating.

Each type of conductor with its insulation system is rated for a maximum temperature, defined in NEC<sup>®</sup> Table 310.104(A) (Table 310.13(A) in the 2008 NEC). Above this maximum temperature, excessive insulation aging and damage can occur. The NEC, engineers, and scientists have attempted to prevent this damage by defining current magnitude and ambient temperature in Table 310.15(B)(16) (Table 310.16 in the 2008 NEC), and have further attempted to consider additional items that modify thermal flow. Two of the things that decrease delta-T are mutual heating from surrounding conductors [accommodated by bringing to bear Table 310.15(B)(3)(a) (Table 310.15(B)(2)(a) in the 2008 NEC) and solar heating of above-grade conduits [accommodated by bringing to bear Table 310.15(B)(3)(c) (Table 310.15(B)(2)(c) in the 2008 NEC). Both of these tables intend to accommodate the physical reality that in circumstances of reduced heat flow, reduced line current for the reduction in  $I^2R$  conductor heating is required to offset the reduced heat flow from the conductors to the surrounding atmosphere to keep the conductor insulation temperature below the temperature at which it would be damaged.

When an object is increased in temperature, it emits long-wave heat energy. When sunlight falls on an object, the object gains heat energy and increases in temperature until its emission of heat equals the amount of energy it is absorbing from the sunlight. Although the emissivity of the object is an important variable in this energy absorption/emission balance, calculations and measurements reveal that typical non-shiny metals, such as galvanized steel conduit, can be expected to reach 167°F (75°C) in the US latitudes in the summertime due to exposure to sunlight, even if the surrounding air temperature is only in the 100°F (40°C) range. At least one international major oil company has a strict standard that equipment subjected to sunlight must be designed to

*begin* operation at this 75°C value. Obviously, conductors rated at a maximum operating temperature of 167°F (75°C) cannot carry any current at all without exceeding their maximum temperature rating. The 167°F (75°C) allowable ampacities become the maximum operating conductor ampacity to prevent overheating the terminations in compliance with NEC 110.14(C).

From an engineering perspective, wherein NEC 310.15(C) is followed, the TA variable (ambient temperature in degrees Celsius) must consider solar heating. Similarly, from an electrician's or designer's perspective, the factors in Table 310.15(B)(2)(c) are necessary to consider to account for that solar heat. One can immediately witness the effect of solar heating by merely leaving a wrench or conduit in the afternoon sun for a few minutes and then lifting it with bare hands, observing that it is literally almost too hot to touch.

The circumventing of Table 310.15(B)(3)(c) (Table 310.15(B)(2)(c) in the 2008 NEC) would simply ignore the related physics and would ultimately result in the operation of conductors at temperatures above their ratings.

Operating conductors at temperatures above their rating would result in premature aging and failure. (It is possible that more capable insulation types are, or may become, available than are provided for in NEC Tables 310.15(B)(16) through 310.15(B)(19) (Tables 310.16 through 310.19 in the 2008 NEC). For use with standard conductor insulation systems, **we recommend Table 310.15(B)(3)(c) (Table 310.15(B)(2)(c) in the 2008 NEC)** as part of a method with which electricians and designers can approximate the 310.15(C) physics calculations of engineers. Solar heating must be considered as a major factor in any electrical installation if we are to maintain validity of design and uphold the stated purpose of the NEC to protect persons and property from hazards arising from the use of electricity.