ECET 4520

Industrial Distribution Systems, Illumination, and the NEC

Wire and Conductors

Wires and Conductors

<u>Wire</u> – a single, solid, cylindrical, flexible strand of metal that can be used to transmit electricity.

The term "wire" is also used to refer to a bundle of individual conductive strands that are wrapped together to form a single entity. (I.e. – "stranded wire")

<u>Conductor</u> – A wire that may be encased in one or more layers of insulation or other materials that provide electrical isolation, physical protection, and/or any other desired properties to the wire.

Wires and Conductors

Note that there is not a clear distinction between the terms "wire" and "conductor" and that they are often used interchangeably in conversation.

For this reason, they are often further characterized in order to convey their specific meaning:

- **solid wire**
- **bare wire**
- **insulated wire**
- **stranded wire**
- **bare conductor**
- **insulated conductor**

Cable

<u>Cable</u> – a grouping of two or more <u>insulated</u> conductors that are either wound together or contained within a common protective sheath.

Busbar

<u>Busbar</u> – typically a flat, rigid section of electrical conductor that is used to conduct large currents between two or more circuits in an electric distribution system.

Conductor Types

There are many different types of conductors used in electrical distribution systems.

Conductors are classified based on a variety of criteria:

- **Wire Size**
- **Solid or Stranded Construction**
- **Conductive Material (Copper or Aluminum)**
- **Insulation Type**
- **Voltage Rating**
- **Temperature Rating**

Wire Size

The sizes of wires used in electrical distribution systems are based on the <u>American Wire Gauge</u> (AWG).

The American Wire Gauge (AWG) is a standardized system used to define the size of <u>solid</u>, cylindrical wires based on their diameter.

Although defined for solid, cylindrical wires, the AWG standard can be extended to stranded or non-cylindrical conductors by maintaining a constant cross-sectional area.

American Wire Gauge (AWG)

The American Wire Gauge is based upon a standard set of 40 gauge sizes that relate to wires having diameters ranging exponentially from 0.005 inches to 0.46 inches.

The gauge sizes begin at #36 for a 0.005" wire and count up incrementally in size to #0 (zero), after which the sizes 00, 000 and 0000 are used.

(36, 35, 34, … 2, 1, 0, 00, 000, 0000)
(0.005" → 0.46")

Note that sizes 00, 000 and 0000 are often expressed as 2/0, 3/0 and 4/0 respectively.

American Wire Gauge (AWG)

Beginning with #36 (0.005”), there are a total of 39 incremental steps to reach size 0000 (0.46”).

The diameters of the intermediate sizes are defined by the exponential formula:

$$d_n = 0.005'' \times 92^{\frac{36-n}{39}}$$

where: ***n*** **is the AWG size** **(I.e. – For #12 AWG, *n* = 12)**

note: **For *m*/0 AWG, *n*=*1*-*m*** **(I.e. – For 3/0 AWG, *n* = 1-3 = -2)**

American Wire Gauge (AWG)

The following tables show the diameter of solid, cylindrical wires ranging in size from #36 AWG to 4/0 AWG.

AWG	Diameter	
	(inch)	(mm)
36	0.00500	0.127
35	0.00561	0.143
34	0.00630	0.160
33	0.00708	0.180
32	0.00795	0.202
31	0.00893	0.227
30	0.0100	0.255
29	0.0113	0.286
28	0.0126	0.321
27	0.0142	0.361
26	0.0159	0.405
25	0.0179	0.455
24	0.0201	0.511
23	0.0226	0.573
22	0.0253	0.644
21	0.0285	0.723
20	0.0320	0.812
19	0.0359	0.912
18	0.0403	1.024
17	0.0453	1.150

AWG	Diameter	
	(inch)	(mm)
16	0.0508	1.291
15	0.0571	1.450
14	0.0641	1.628
13	0.0720	1.828
12	0.0808	2.053
11	0.0907	2.305
10	0.1019	2.588
9	0.1144	2.906
8	0.1285	3.264
7	0.1443	3.665
6	0.1620	4.115
5	0.1819	4.621
4	0.2043	5.189
3	0.2294	5.827
2	0.2576	6.544
1	0.2893	7.348
0 (1/0)	0.3249	8.252
00 (2/0)	0.3648	9.266
000 (3/0)	0.4096	10.404
0000 (4/0)	0.4600	11.684

American Wire Gauge (AWG)

Although the AWG system is based on a set of gauges ranging from #36 to 4/0 AWG, the system can also be extended for smaller wires (>#36) by using the same formula:

$$d_n = 0.005'' \times 92^{\frac{36-n}{39}}$$

Example – For #40 AWG, $d_n = 0.005'' \times 92^{\frac{36-40}{39}} = 0.005'' \times 92^{\frac{-4}{39}} = 0.00314''$

AWG	Diameter (inch)	Diameter (mm)
↑	↑	↑
40	0.00314	0.0799
39	0.00353	0.0897
38	0.00397	0.101
37	0.00445	0.113
36	0.00500	0.127
↓	↓	↓

American Wire Gauge (AWG)

Although the AWG system is based on a set of gauges ranging from #36 to 4/0 AWG, the system can also be extended for smaller wires (>#36) by using the same formula:

$$d_n = 0.005'' \times 92^{\frac{36-n}{39}}$$

Wires larger in diameter than 4/0 AWG (0.46") are typically defined in terms of their cross-sectional area (expressed in thousands of circular mils) instead of by a gauge number.

Circular Mils

A circular mil (*cmil*) is a base unit of area equal to the area of a circle that has a $^{1}/_{1000}$ of an inch (i.e. – 1mil) diameter.

Since the area of a circle is defined by:

$$A_{circle} = \pi \cdot \left(\frac{d}{2}\right)^2$$

the area of one circular mil is equivalent to:

$$A_{cmil} = \pi \cdot \left(\frac{0.001 in}{2}\right)^2 = \underline{7.854x10^{-7}\ in^2} \quad or \quad 5.0671x10^{-4}\ mm^2$$

Circular Mils

Note – to convert the cross-sectional area of any wire expressed in standard units (*in²* or *mm²*) to area in circular mils, divide the wire's cross-sectional area by the area of one circular mil expressed in the same units.

Example: Given a solid #12 AWG wire (d = 0.0808"), express its cross-sectional area in units of *in²* and *cmil*.

$$A_{\#12AWG} = \pi \cdot \left(\frac{0.0808 in}{2}\right)^2 = \underline{0.0051276\ in^2}$$

$$= \frac{0.0051276\ in^2}{7.854x10^{-7}\ in^2 / cmil} = \underline{6529\ cmil}$$

Standard Wire Sizes

The following table shows some of the standard AWG sized wires along with some larger wires whose sizes are defined by their cross-sectional area expressed in thousands of circular mils (kcmil).

AWG

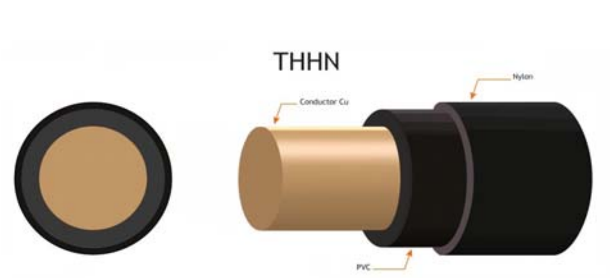
kcmil

Conductor (Wire) Size	Nominal Cross-Sectional Area (Bare Conductor)			Nominal Diameter (Bare Conductor)	
	cmil	in^2	mm^2	in	mm
AWG					
14	4110	0.00323	2.08	0.073	1.85
12	6530	0.00513	3.31	0.092	2.34
10	10 380	0.00815	5.26	0.116	2.95
8	16 510	0.01296	8.36	0.146	3.71
6	26 240	0.02060	13.29	0.184	4.67
4	41 740	0.03277	21.14	0.232	5.89
3	52 620	0.04131	26.65	0.260	6.60
2	66 360	0.05209	33.61	0.292	7.42
1	83 690	0.06570	42.38	0.332	8.43
0 or 1/0	105 600	0.08290	53.48	0.373	9.47
00 or 2/0	133 100	0.10448	67.41	0.419	10.64
000 or 3/0	167 800	0.13172	84.98	0.470	11.94
0000 or 4/0	211 600	0.16611	107.16	0.528	13.41
kcmil					
250	250 000	0.19625	126.61	0.575	14.61
300	300 000	0.23550	151.94	0.630	15.00
350	350 000	0.27475	177.26	0.681	17.30
400	400 000	0.31400	202.58	0.728	18.49
500	500 000	0.39250	253.23	0.813	20.65
600	600 000	0.47100	303.87	0.893	22.68
700	700 000	0.54950	354.52	0.964	24.49
750	750 000	0.58875	379.84	0.998	25.35
800	800 000	0.62800	405.16	1.030	26.16
900	900 000	0.70650	455.81	1.090	27.69
1000	1 000 000	0.78500	506.45	1.150	29.21
1500	1 500 000	1.17750	759.68	1.410	35.81
2000	2 000 000	1.57000	1012.90	1.630	41.40

Solid vs. Stranded Wire

The conductors utilized in electrical distribution systems can be constructed using either solid or stranded wire.

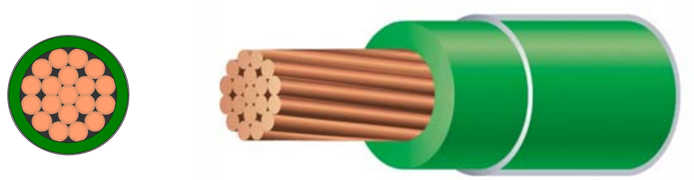
Solid – wire that is composed of a single, solid, cylindrical conductor.



Solid vs. Stranded Wire

The conductors utilized in electrical distribution systems can be constructed using either solid or <u>stranded</u> wire.

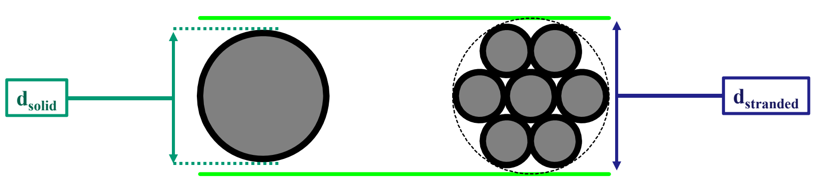
<u>Stranded</u> – wire that is composed of a set of small, conductive strands that are bundled together to form a single, larger conductor.



Solid vs. Stranded Wire

AWG wire sizes are extended from solid to stranded wire by keeping a <u>constant</u>, <u>cross-sectional</u>, (conductive) <u>area</u>.

Thus, a stranded wire will have a larger overall diameter than an equivalently-sized solid wire in order to compensate for the spacing between the individual strands.



Overall diameter of solid and stranded wires with the same conductive cross-sectional area.

Solid vs. Stranded Wire

Table 8 in the NEC shows the physical dimensions for both solid and stranded wire in a variety of sizes.

Solid →
Stranded →

Size (AWG or kcmil)	Area mm²	Area Circ. mils	Stranding Quantity	Stranding Diameter mm	Stranding Diameter in.	Overall Diameter mm	Overall Diameter in.	Overall Area mm²	Overall Area in.²
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087

Portion of "Table 8 – Conductor Properties" (NEC)

The column labeled "Diameter" under "Stranding" shows the diameter of the individual strands.

Solid vs. Stranded Wire

Note that only stranded wire information is provided for wire size #6 AWG and larger-diameter wires.

Size (AWG or kcmil)	Area mm²	Area Circ. mils	Stranding Quantity	Stranding Diameter mm	Stranding Diameter in.	Overall Diameter mm	Overall Diameter in.	Overall Area mm²	Overall Area in.²
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087

Stranded only

Although solid wire is typically chosen for the smaller conductor sizes, stranded wire is used almost exclusively when #6 AWG or larger-sized conductors are utilized in a distribution system.

Solid vs. Stranded Wire

Stranded wire construction is chosen for large-diameter conductors for a variety of reasons:

- **Despite its larger overall diameter, stranded wire is more flexible than solid wire and thus easier to install.**
- **Stranded wire tends to have a lower AC resistance than solid wire, especially as conductor size and/or frequency increases, due to the larger total surface area of the combined strands. (I.e. – Less skin-effect)**

Stranding Classes

Concentric-Lay Conductors

Class B – Power cables
Class C – Power cables where more flexible stranding than B is desired
Class D – Power cables where extra flexible stranding is desired

Rope-Lay & Bunch Stranded Conductors

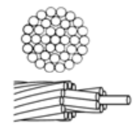
Class G – All cables for portable use
Class H – Cables that require extreme flexibility (ie – take-up reels)
Class I – Apparatus cable and motor leads

Class	Conductor Sizes		
	14-2 AWG	1-4/0 AWG	250-500 MCM
B	7	19	37
C	19	37	61
D	37	61	91
G	49	133	259
H	133	259	427
I	Combinations of 24 AWG Wires		

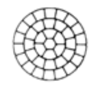
Types of Stranding

Bunched – Strands are gathered together with no particular design or arrangement, providing great flexibility.

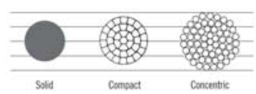
Concentric – Strands are arranged in a circular pattern, with each layer alternating direction in order to provide mechanical strength and crush resistance



Compact – Layers are rolled to a predetermined ideal shape to provide a smooth surface with practically no interstices (air spaces), resulting in a smaller diameter



Rope Lay – The most flexible type of stranding with strands that are arranged into cabled groups



Lookup Table Pitfalls

Warning – Be careful when looking up diameter in a table that provides only one set of values without clearly stating whether they refer to solid or stranded wires.

Conductor (Wire) Size	Nominal Cross-Sectional Area (Bare Conductor)			Nominal Diameter (Bare Conductor)	
	cmil	in²	mm²	in	mm
AWG					
14	4110	0.00323	2.08	0.073	1.85
12	6530	0.00513	3.31	0.092	2.34
10	10 380	0.00815	5.26	0.116	2.95
8	16 510	0.01296	8.36	0.146	3.71
6	26 240	0.02060	13.29	0.184	4.67
4	41 740	0.03277	21.14	0.232	5.89
3	52 620	0.04131	26.65	0.260	6.60
2	66 360	0.05209	33.61	0.292	7.42
1	83 690	0.06570	42.38	0.332	8.43

All of the diameters in the above table match the diameters shown in Table 8 of the NEC for stranded conductors.

AWG gauge	Conductor Diameter Inches	Conductor Diameter mm	Ohms per 1000 ft.	Ohms per km	Maximum amps for chassis wiring	Maximum amps for power transmission	Maximum frequency for 100% skin depth for solid Cu. conductor	Breaking force Soft Annealed Cu 37000 PSI
OOOO	0.46	11.684	0.049	0.16072	380	302	125 Hz	6120 lbs
OOO	0.4096	10.40384	0.0618	0.202704	328	239	160 Hz	4860 lbs
OO	0.3648	9.26592	0.0779	0.255512	283	190	200 Hz	3860 lbs
0	0.3249	8.25246	0.0983	0.322424	245	150	250 Hz	3060 lbs
1	0.2893	7.34822	0.1239	0.406392	211	119	325 Hz	2430 lbs
2	0.2576	6.54304	0.1563	0.512664	181	94	410 Hz	1930 lbs
3	0.2294	5.82676	0.197	0.64616	158	75	500 Hz	1530 lbs
4	0.2043	5.18922	0.2485	0.81508	135	60	650 Hz	1210 lbs
6	0.162	4.1148	0.3951	1.295928	101	37	1100 Hz	760 lbs
8	0.1285	3.2639	0.6282	2.060496	73	24	1650 Hz	480 lbs
10	0.1019	2.58826	0.9989	3.276392	55	15	2600 Hz	314 lbs
12	0.0808	2.05232	1.588	5.20864	41	9.3	4150 Hz	197 lbs
14	0.0641	1.62814	2.525	8.282	32	5.9	6700 Hz	119 lbs

All of the diameters in the above table match the diameters shown in Table 8 of the NEC for solid conductors

Lookup Table Pitfalls

Warning – Be careful when looking up diameter in a table that provides only one set of values without clearly stating whether they refer to solid or stranded wires.

Additionally, when looking up other characteristics such as resistance or ampacity, be sure that you understand the conditions for which the table values hold true.

For example – resistance is affected by the conductor's temperature, while ampacity is affected by both the conductor's temperature rating (max. allowable operating temperature) and the ambient temperature of the surrounding air.

Lookup Table Pitfalls

Other notes when looking up conductor information in tables:

- **The information shown in NEC Table 8 is for "Class B" stranding. There are other stranding configurations available (concentric, compressed, compact) that affect the conductor's diameter, flexibility, cost, and termination requirements.**

Stranded wires are sometimes specified with three numbers:

· The overall AWG size,
· The number of strands, and **(Ex. – A #8 AWG 7/16)**
· The AWG size of each strand.

Material Type

Although wires can be made from any conductive material, distribution system wires are typically constructed from:

- **Copper**
- **Aluminum**

Other materials, such as silver and gold, may actually be better conductors of electricity (i.e. – have less resistance), but copper and aluminum conductors are utilized due to their lower cost and/or other material properties.

Copper vs. Aluminum Wire

Copper (Cu)
- **lower resistance (higher current limits)**
- **higher weight**
- **higher cost**
- **easier to splice**

Aluminum (Al)
- **higher resistance (lower current limits)**
- **lower weight**
- **lower cost**
- **requires extra care when splicing/terminating**

Copper vs. Aluminum Wire

Aluminum is typically reserved for #6 AWG and larger wires since the cost and weight advantages of aluminum for large diameter wires can outweigh its lower current-carrying ability and splicing disadvantages.

THHN or THWN-2 Copper Conductor

Size (AWG or kcmil)	Number of Strands	Nominal Outside Diameter (mils)		Approx. Net Weight per 1000 ft (lb)	
		Solid	Stranded	Solid	Stranded
14	1, 19	102	109	15	16
12	1, 19	119	128	23	24
10	1, 19	150	161	37	38
8	19	—	213	—	62
6	19	—	249	—	95
4	19	—	318	—	152

THHN or THWN-2 Aluminum Conductor

Size (AWG or kcmil)	Number of Strands	Nominal Outside Diameter (mils)		Approx. Net Weight per 1000 ft (lb)	
		Solid	Stranded	Solid	Stranded
6	7	—	239	—	38
4	7	—	305	—	62

Coated vs. Uncoated Wire

Due to the corrosive chemicals contained in the insulating materials that were used in the past, a <u>tin coating</u> was added to copper wires to protect them from corrosion.

Although the "tinned" wires were less subject to corrosion, they had a slightly higher resistance due to the slightly smaller-than-normal copper wires that were utilized in order to maintain the correct standardized wire diameter.

Size (AWG or kcmil)	Area		Conductors: Stranding			Conductors: Overall				Direct-Current Resistance at 75°C (167°F): Copper				Aluminum	
				Diameter		Diameter		Area		Uncoated		Coated			
	mm^2	Circular mils	Quantity	mm	in.	mm	in.	mm^2	$in.^2$	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25

Coated vs. Uncoated Wire

Note – there is a common misunderstanding within the electrical community:

Many people mistakenly associate coated wire with insulated wire, and uncoated wire with bare wire.

Almost all currently manufactured wire (bare or insulated) is <u>uncoated</u> wire due to advances in the insulating materials.

			Conductors							Direct-Current Resistance at 75°C (167°F)					
			Stranding			Overall				Copper					
Size (AWG or kcmil)	Area			Diameter		Diameter		Area		Uncoated		Coated		Aluminum	
	mm^2	Circular mils	Quantity	mm	in.	mm	in.	mm^2	$in.^2$	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25

Insulated Conductors

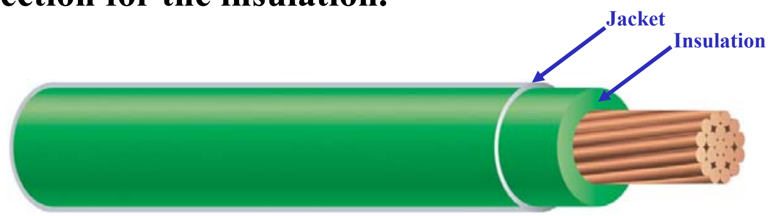
<u>Insulated</u> wires or conductors are almost exclusively utilized in (non-aerial) electric distribution systems.

Insulated conductors consist of wires that are surrounded by one or more layers of (non-conductive) materials in order to electrically isolate the conductors from other conductors or grounded objects.

Note – the insulation also minimizes the risk of electrocution to people coming into contact with an energized conductor.

Insulated Conductors

In addition to the insulation layer, insulated conductors are often surrounded by an outer jacket that provides physical protection for the insulation.



Additional material layers may also be included to provide further physical qualities to the conductor such as water resistance, flame retardancy, and axial pull strength.

Insulated Conductors

The type of insulation and other materials depends on the location in which the conductor will be used.
(I.e. – dry, damp, wet, sunlight-exposed, underground, etc.)

The overall diameter of an insulated conductor is determined by both the overall diameter of the wire and the thickness of the insulation (along with any other protective layers).

The thickness of the insulation is primarily affected by:

- The type of insulating material, and
- The voltage rating of the conductor

Conductor Voltage Rating

The voltage rating of a conductor specifies the maximum voltage for which the conductor is designed to operate, and is based on the amount of electrical isolation provided by the conductor's insulation.

In general, the higher the voltage rating of the conductor, the larger the overall diameter of the conductor due to the thickness of the insulation layer required to provide the necessary electrical isolation.

Conductor Temperature Rating

Conductors are assigned a base temperature rating by their manufacturer.

The base temperature rating of a conductor is a maximum temperature (at any location along its length) that the conductor can withstand for a prolonged period of time without serious degradation its insulating materials.

The most common temperature ratings for conventional building conductors and cable are 60°C, 75°C and 90°C.

Conductor Temperature Rating

The base temperature rating of a conductor is determined by the type of insulation that is used for the conductor.

Example – Thermoplastic, extra heat resistant, nylon-jacketed (THHN) type conductor has a base temperature rating of 90°C (194°F)

The base temperature rating of a conductor must be greater than or equal to the operational temperature rating of the system (or portion thereof) in which it is used.

Conductor Temperature Rating

External factors, such as the rating of connected devices, may require that a lower operational temperature rating be applied to a conductor when used in a distribution system.

For example –As per the NEC, when using THHN conductors…

"Termination provisions of equipment for circuits rated ≤ 100 amps … shall be used only for one of the following:

(2) Conductors with higher temperature ratings, provided the ampacity of such conductors is determined based on the 60°C (140°F) ampacity of the conductor size used."

→ Although THHN conductors have a max temperature rating of 90°C, they must be rated at 60°C in circuits rated ≤ 100 amps.

Conductor Heating

The temperature rating of a conductor has a direct effect on the amount of current that can be allowed to flow continuously through the conductor.

During normal operation, heat is generated within an electrical conductor at a rate that is equal to:

$$P_{heat} = |I|^2 \cdot R_{conductor}$$

If heat is generated at a rate that is greater than the conductor's ability to dissipate that heat, then the temperature of the conductor will increase. Over time, this may cause the conductor to exceed its temperature rating.

Conductor Heating

Although the rate at which heat is produced by a conductor is a simple function of the conductor's resistance and the conductor current, many factors affect a conductor's ability to dissipate heat, such as:

- The type of insulation used,
- The thickness of the insulation,
- The conductor's actual temperature,
- The ambient (surrounding) temperature,
- The location of the conductor,
- The proximity of other heat sources (including other current-carrying conductors)

Conductor Ampacity

Conductor Ampacity – the maximum current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

In addition to the factors that affect a conductor's temperature rating (insulation type, connected equipment, etc…), ampacity is greatly affected by the size and material type of the wire used within conductor.

Conductor Ampacity

Since ampacity is defined as the maximum continuous current that a conductor can carry…

The conductor will be able to maintain a temperature below its rated value as long as the continuous current flowing in the conductor does not exceed its ampacity value.

Note that a conductor can withstand transient currents that exceed its ampacity rating provided that their duration is limited based on their overall magnitude.

Conductor Ampacity

Once a conductor's temperature rating has been assigned, an initial ampacity value can be determined using a look-up table based on conductor size and material type.

Note that, when using an ampacity table, it is important to know the external conditions for which the table is valid since adjustments to the ampacity values may have to be made if the external conditions are not met.

TABLE 10.11 PROPERTIES OF COPPER AND ALUMINUM CONDUCTORS WITH THHN AND THWN-2 INSULATION THAT ARE USED IN CONDUIT AND CABLE TRAYS FOR SERVICES, FEEDERS, AND BRANCH CIRCUITS IN COMMERCIAL OR INDUSTRIAL APPLICATIONS. COMPILED FROM INDUSTRY SOURCES.

THHN or THWN-2 Copper Conductor

Size (AWG or kcmil)	Number of Strands	Nominal Outside Diameter (mils) Solid	Nominal Outside Diameter (mils) Stranded	Approx. Net Weight per 1000 ft (lb) Solid	Approx. Net Weight per 1000 ft (lb) Stranded	Ampacity 60°C 140°F	Ampacity 75°C 167°F	Ampacity 90°C 194°F
14	1, 19	102	109	15	16	15	15	15
12	1, 19	119	128	23	24	20	20	20
10	1, 19	150	161	37	38	30	30	30
8	19	—	213	—	62	40	50	55
6	19	—	249	—	96	55	65	75
4	19	—	318	—	152	70	85	95
3	19	—	346	—	188	85	100	110
2	19	—	378	—	234	95	115	130
1	19	—	436	—	299	110	130	150
1/0	19	—	474	—	371	125	150	170
2/0	19	—	518	—	461	145	175	195
3/0	19	—	568	—	574	165	200	225
4/0	19	—	624	—	717	195	230	260
250	37	—	694	—	850	215	255	290
300	37	—	747	—	1011	240	285	320
350	37	—	797	—	1173	260	310	350
400	37	—	842	—	1333	280	335	380
500	37	—	926	—	1653	320	380	430
600	61	—	1024	—	1985	355	420	475
750	61	—	1126	—	2462	400	475	535
1000	61	—	1275	—	3254	455	545	615

Conductor Ampacity

The following NEC ampacity table is for insulated conductors rated up to 2000V, based on a 30°C ambient temperature and a limit of up to three current-carrying conductors within the same raceway.

Table 310.15(B)(16) (Condensed) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	
	COPPER			ALUMINUM			
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500

Conductor Ampacity

A footnote at the bottom of the table refers the reader to an additional table that provides <u>correction factors</u> that can be applied to the ampacities for <u>ambient temperatures</u> that are <u>other than 30°C</u>.

Table 310.15(B)(16) (Condensed) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	
	COPPER			ALUMINUM			
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500

Table 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C (86°F)

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor			Ambient Temperature (°F)
	60°C	75°C	90°C	
10 or less	1.29	1.20	1.15	50 or less
11–15	1.22	1.15	1.12	51–59
16–20	1.15	1.11	1.08	60–68
21–25	1.08	1.05	1.04	69–77
26–30	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	132–140

Conductor Ampacity

A separate table provides additional <u>correction factors</u> for cases where <u>more than three current-carrying conductors</u> are located <u>within the same raceway</u>.

Table 310.15(B)(16) (Condensed) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	
	COPPER			ALUMINUM			
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500

Table 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors

Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

Conductor Ampacity

Example – Two sets of 3Φ, THHN, 2/0, copper conductors are located within the same raceway.

Determine the ampacity of the conductors if an operational temperature rating of 75°C is applied to the conductors, assuming that the ambient temperature of the air surrounding the conductors (raceway) is 45°C.

Conductor Ampacity

Given – 2 sets of 3Φ, THHN, 2/0, Cu. conductors in raceway…

Note – Although THHN conductors have a 90°C base rating, a 75°C temperature rating is specified for this problem.

Table 310.15(B)(16) (Condensed) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW USE, ZW	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	
	COPPER			ALUMINUM			Size AWG or kcmil
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500

Conductor Ampacity

Given – 2 sets of 3Φ, THHN, 2/0, Cu. conductors in raceway…

The ampacity provided by the table for 2/0 copper conductors with a 75°C temperature rating is <u>175 amps</u>.

Table 310.15(B)(16) (Condensed) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW USE, ZW	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, RHH, RHW-2, THHN, THHW, USE-2, XHH, XHHW-2, ZW-2	
		COPPER			ALUMINUM		Size AWG or kcmil
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	[illegible]	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	[illegible]	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500

Conductor Ampacity

Given – 2 sets of 3Φ, THHN, 2/0, Cu. conductors in raceway…

But, an ambient temperature of 45°C requires a correction factor of <u>0.82</u> to be applied to the stated ampacity value.

Table 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C (86°F)

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor			Ambient Temperature (°F)
	60°C	75°C	90°C	
10 or less	1.29	1.20	1.15	50 or less
11–15	1.22	1.15	1.12	51–59
16–20	1.15	1.11	1.08	60–68
21–25	1.08	1.05	1.04	69–77
26–30	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	114–122

Conductor Ampacity

Given – 2 sets of 3Φ, THHN, 2/0, Cu. conductors in raceway…

Furthermore, since there are 6 current-carrying conductors in the same raceway, an additional correction (adjustment) factor of <u>80%</u> must also be applied to the stated ampacity.

Table 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors

Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

Conductor Ampacity

Given – 2 sets of 3Φ, THHN, 2/0, Cu. conductors in raceway…

Thus, the overall ampacity for the conductors is:

$$\begin{aligned} Ampacity_{corrected} &= Ampacity_{Base} \cdot (correction\ \ factors) \\ &= (175A)_{Base} \cdot (0.82)_{Amb.Temp} \cdot (0.80)_{6inRaceway} \\ &= 114.8A_{corrected} \\ &\approx \underline{115A_{corrected}} \end{aligned}$$