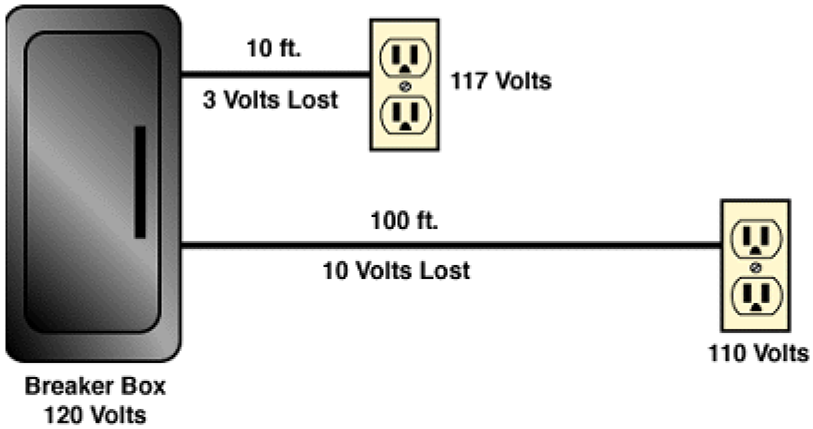
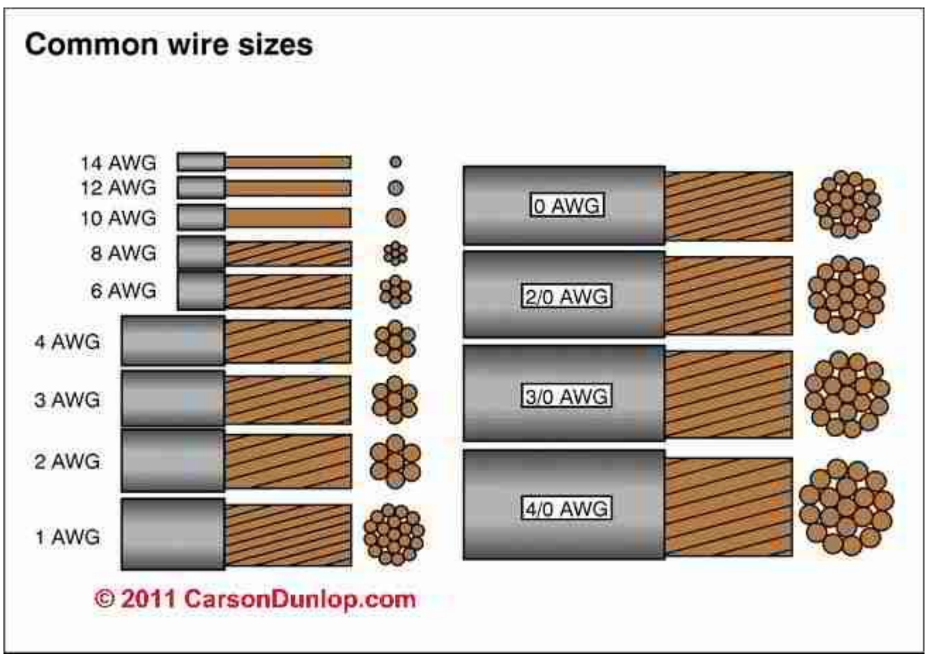
Voltage Drop

Answers



Most building electrical calculations solve for current or voltage drop.
- Current sets conductor size.
- Excess voltage drop may require an increase in conductor size.



THHN Wire stands for - Thermoplastic High Heat-resistant Nylon coated.
THHN is UL listed with a rated 90 degrees Celsius in dry locations or 75 degrees Celsius in wet applications with a THWN rating.

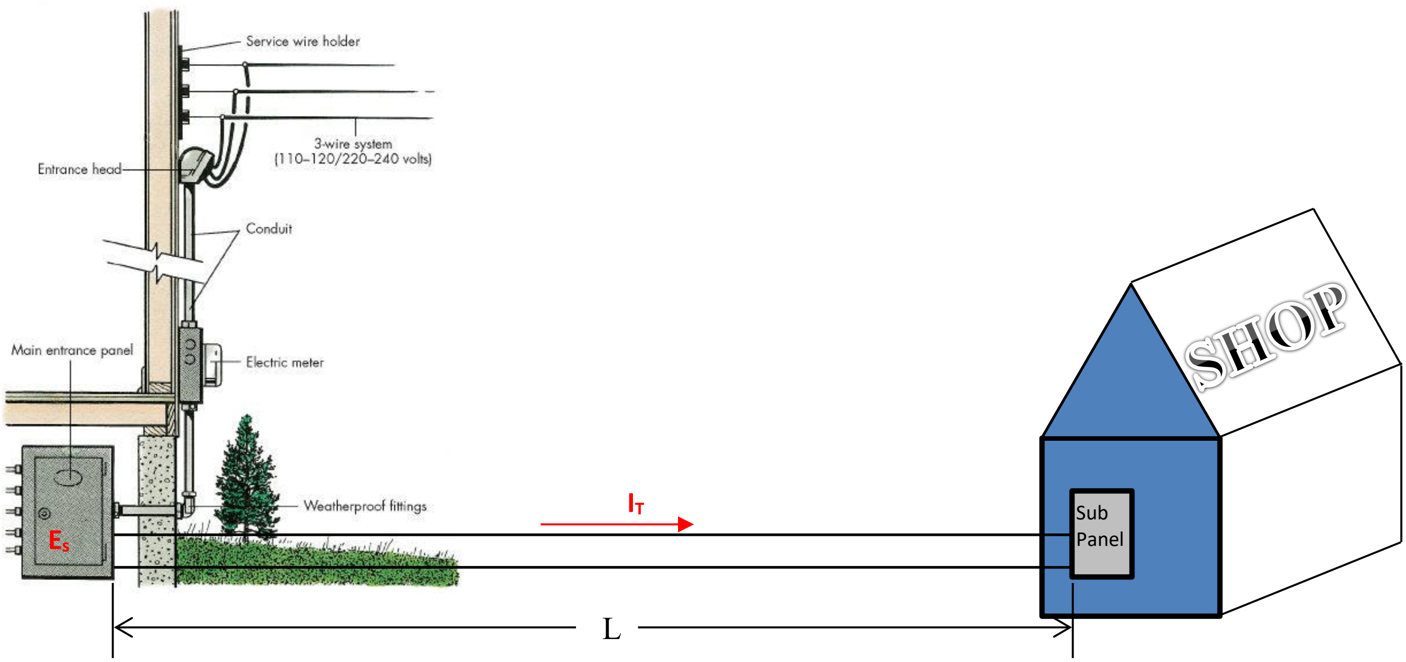
Excessive voltage drop in a circuit can cause:
- Lights to flicker or burn dimly
- Heaters to heat poorly
- Motors to run hotter than normal and burn out

This condition causes the load to work harder with less voltage pushing the current.

The National Electrical Code (NEC) recommends limiting the voltage drop from the breaker box to the farthest outlet for power, heating, or lighting to 3 percent of the circuit voltage. [Article 210.19 (A)]
This is done by selecting the right size of wire.

Two Primary Electrical Design Concerns

1. Current Required
2. Voltage Drop



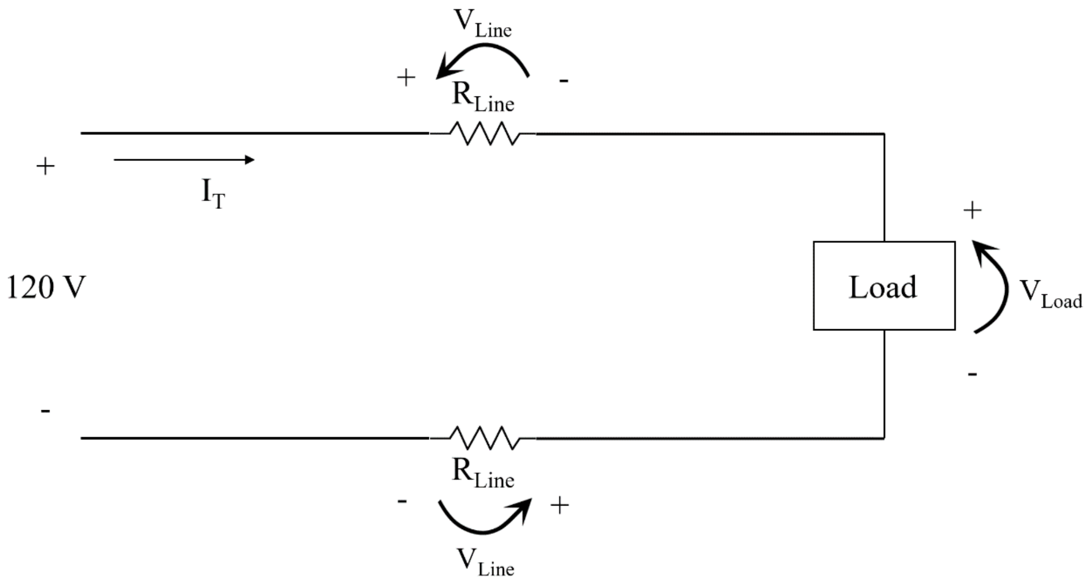
Total connected load for all the lights and equipment in the shop is 15 kW.

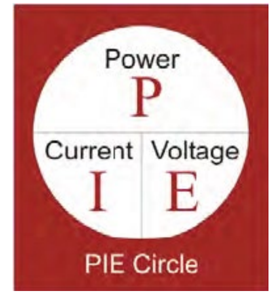
1 kW = 1,000 Watts

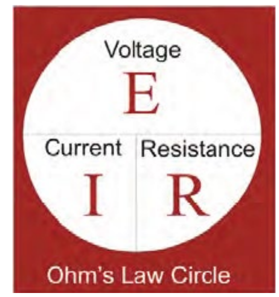
Find the current required for the shop's electrical service at:

Service Voltage = 120 V, 1ϕ	Service Voltage = 240 V, 1ϕ
$I = \frac{P}{E} = \frac{15{,}000\ W}{120\ V} = 125\ A$	$I = \frac{P}{E} = \frac{15{,}000\ W}{240\ V} = 62.5\ A$
NEC 310.15(B)(16) (75°)	NEC 310.15(B)(16) (75°)
Minimum Size Conductor **#1 AWG**	Minimum Size Conductor **#6 AWG**
Conductor Resistance **0.154** (Ω/1000 ft)	Conductor Resistance **0.491** (Ω/1000 ft)

Kirchhoff's Voltage Law







$\Sigma V_{Loop} = 0$

$120V - V_{Line} - V_{Load} - V_{Line} = 0$

$V_{Load} = 120V - \underbrace{V_{Line} - V_{Line}}_{VD_{Line}}$

R_{Line} = (2 x Ohms per 1000 ft x L) [Note: this is the TOTAL resistance of the line, i.e. $R_{Line} + R_{Line}$]

$VD_{Line} = I_T \times R_{Line}$

$V_{Load} = 120V - VD_{Line}$

$\%VD = (V_{Load} / 120V) \times 100$

Example 1. Find the percentage voltage drop for the length (L) shown in the table.

Case 1: 120 V, 125 A, #1 CU – Load Power 15kW

Supply Voltage = 120 V, Load Power = 15 kW

Supply Current = 125 A

Minimum Conductor Size = #1

R_{Line} = (2 x 0.154 Ω x L) / 1000

Complete the table:

Length of Conductor (L)	R_{Line} (Ω)	VD_{Line} (V)	V_{Load} (V)	% VD
90 ft	0.02772	3.465	117	2.89
120 ft	0.03696	4.62	115	3.85
150 ft	0.0462	5.775	114	4.81
230 ft	0.07084	8.855	111	7.38

Case 2: 120 V, 125 A, #1/0 CU – Load Power 15kW

Supply Voltage = 120V, Load Power = 15 kW

Supply Current = 125 A

Minimum Conductor Size = **#1/0 (increased wire size from #1)**

R_{Line} = (2 x 0.122 Ω x L) / 1000

Complete the table:

Length of Conductor (L)	R_{Line} (Ω)	VD_{Line} (V)	V_{Load} (V)	% VD
90 ft	0.02196	2.745	117	2.29
120 ft	0.02928	3.66	116	3.05
150 ft	0.0366	4.575	115	3.81
230 ft	0.05612	7.015	113	5.85

Case 3: 240 V, 62.5 A, #6 CU – Load Power 15kW

Supply Voltage = 240 V, Load Power = 15 kW **(Increased supply voltage)**

Supply Current = 62.5 A

Minimum Conductor Size = #6

R_{Line} = (2 x 0.491 Ω x L) / 1000

Complete the table:

Length of Conductor (L)	R_{Line} (Ω)	VD_{Line} (V)	V_{Load} (V)	% VD
90 ft	0.08838	5.52375	234	2.30
120 ft	0.11784	7.365	233	3.07
150 ft	0.1473	9.20625	231	3.84
230 ft	0.22586	14.11625	226	5.88

Example #2

A residential electric water heater is rated at 4.5 kW and operates at 208V (single phase wiring).

1. Determine the recommended Over Current Protection (Circuit Breaker amperage rating)

   See Rheem Use & Care Manual

   or

   P = I x E

   I = P / E = 4500 W / 208 V = 21.63 A

   NEC 240.4

   240.4 Protection of Conductors. Conductors, other than flexible cords, flexible cables, and fixture wires, shall be protected against overcurrent in accordance with their ampacities specified in 310.15, unless otherwise permitted or required in 240.4(A) through (G).

   (B) Overcurrent Devices Rated 800 Amperes or Less. The next higher standard overcurrent device rating (above the ampacity of the conductors being protected) shall be permitted to be used, provided all of the following conditions are met:

   (1) The conductors being protected are not part of a branch circuit supplying more than one receptacle for cord-and-plug-connected portable loads.

   (2) The ampacity of the conductors does not correspond with the standard ampere rating of a fuse or a circuit breaker without overload trip adjustments above its rating (but that shall be permitted to have other trip or rating adjustments).

   (3) The next higher standard rating selected does not exceed 800 amperes.

   Use a 30A circuit Breaker

2. Determine the copper wire size AWG based on NEC.

   See Rheem Use & Care Manual

   Or

   Article 310

   Table 310.15(B)(16)

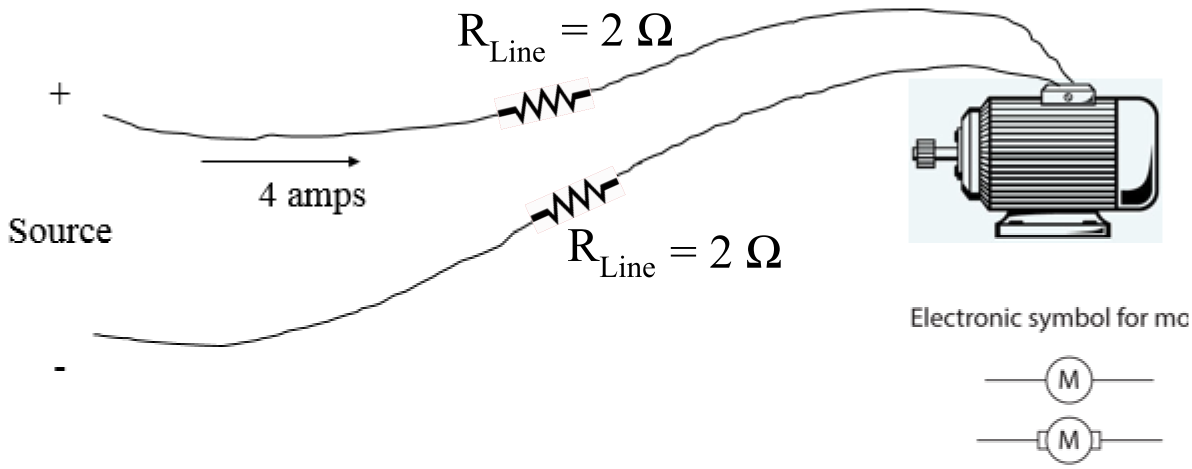
   90°C CU THHN - #10 AWG

   Or

   Article 240.4

Example #3

A current of 4 amps is flowing in a conductor that has a resistance of 2Ω per 1,000 feet. Find the voltage drop if the distance from the source to the load is 1,000 feet.



Supply Current = 4 A

$R_{Line} = 4\ \Omega$

$VD_{Line} = 4\ A \times 4\ \Omega = 16\ V$

Example #4

An extension power cord made of CU #12 THWN is powering a lamp 300 feet from the source. The lamp resistance is 72 Ω and the source voltage is 120 V. Find the voltage drop across the light bulb.

From Chapter 9, Table 8 Conductor Properties

12 AWG CU

Solid	1.93 ohm/kFT	
Stranded	1.98 ohm/kFT	Extension cords use stranded wire

R_{Line} = 2 x 1.98 ohm/kFT x 300 FT = 1.188 Ω

Total Circuit Current (including resistance of the conductors)

$I_T = E_T / R_T$ = 120 V / (1.188 Ω + 72 Ω) = 1.64 A

$E_{Lamp} = I_T \times R_{Lamp}$ = 1.64 A x 72 Ω = 118 V

Check using VD_{Line} equation

I_T = 120 V / 72 Ω = 1.67 A

VD_{Line} = 1.67 A x [2 x 1.98 ohm/kFT x 300 Ft] = 1.98 V = 2 V

E_{Lamp} = 120 V – 2 V = 118 V

Example #5 - Temporary Job Site Light, Tripod, Corded (AC), Lumens 8000, Number of Lamp Heads 1

Complete the Table below for the Temporary Job Site Light

Technical Specs

Item	**Temporary Job Site Light**	Lamp Watts	**500**
Type - Job Site Lighting	**Tripod**	Color	**Copper**
Power Source - Job Site Lighting	**Corded (AC)**	Item - Job Site Lighting	**Temporary Job Site Light**
Lumens	**8000**	Lamp Included	**Yes**
Number of Lamp Heads	**1**	Rated Life	**2000 hr.**
Cord Length - Job Site Lighting	**5 ft.**	NEC Cord Designation	**SJTW**
Max. Extension Height	**63"**	Gauge/Conductor	**18/3**
Lighting Technology	**Halogen**	NEMA Plug Configuration	**5-15P**
Light Distribution - Job Site Lighting	**Flood**	Guard Type	**Metal**
IP Rating	**IP54**	Replacement Lamp	**500W 4-5/8" T3**
Safety Rated	**Not Safety Rated**	Features	**Weatherproof ON/OFF Switch, Telescopes From 40" to 67" With "Easy Grip" Locking Nuts**
Voltage	**120VAC**	Standards	**UL, cUL**

$$VD_{Line} = 120V - 115V = 5V \quad (\text{MAXIMUM})$$

$$I_T = \frac{P_T}{E_T} = \frac{500W}{120V} = 4.17\ A$$

$$R_{Line} = 2 \times \frac{ohm}{K\ ft} \times L$$

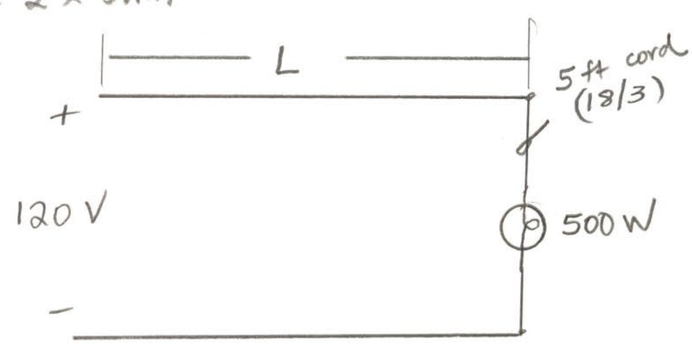
$$VD_{Line} = I_T \times R_{Line} = I_T \times \left(2 \times \frac{ohm}{K\ ft} \times L\right)$$

$$L = \frac{VD_{Line} \times 1000\ ft}{I_T \times 2 \times ohm}$$

$$= \frac{5V \times 1000\ ft}{4.17A \times 2 \times ohm}$$

Chpt 9. Table 8

Gauge/Conductor	Ohms/kFT	Length (L) ft
18/3	7.95	75
16/3	4.99	120
14/3	3.14	191
12/3	1.98	303



$$VD_{cord} = 4.17A \times 2 \times \frac{7.95\Omega}{1000\ ft} \times 5\ ft$$

$$= 0.33V$$

Example #6

A single-phase, 240-volt air-conditioner is being installed for a small commercial building. The nameplate reads: "Minimum Circuit Ampacity 40 Amperes." The circuit originates at the main panel located 125 ft from the air-conditioner unit.

1. Determine the maximum voltage drop of the line recommended by the NEC?
2. What is the minimum size THWN CU conductors required and where in the NEC do you find this?
3. Determine the voltage drop due to the conductors. Does it meet the code requirement? If not, what should be done to meet the code?

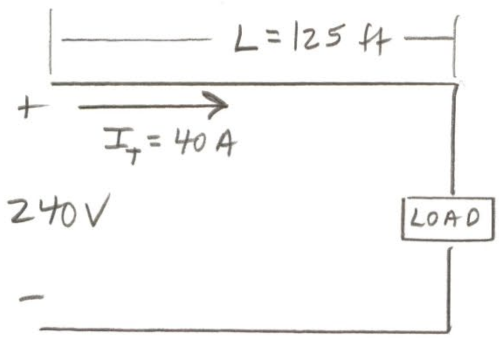
1. NEC recommends no more than 3%

$$VD_{Line} = 240\text{ V} \times 0.03 = 7.2\text{ V} \quad \text{MAX}$$

2. Table 310.15(B)(16) [Article 310 310.60]

THWN 75°C #8 AWG CU (50 A)

3.



Chapter 9, Table 8

Stranded 8 AWG $\frac{0.778 \text{ ohm}}{\text{K ft}}$

$$VD_{Line} = I_T \times R_{Line}$$

$$= 40\text{ A} \times \left(2 \times \frac{0.778\text{ ohm}}{1000\text{ ft}} \times 125\text{ ft}\right)$$

$$= 7.78\text{ V}$$

7.78 V > 7.2 V (Exceeds 3% recommendation)

Increase wire size to #6 $\frac{0.491\text{ ohm}}{\text{K ft}}$

$$VD_{Line} = 40\text{A} \times 2 \times \frac{0.491\text{ ohm}}{\text{K ft}} \times 125\text{ ft} = 4.91\text{ V} \checkmark$$