ELECTRICAL WIRE AMPACITY

For HVAC Project Engineers

Fachgesprach – 8

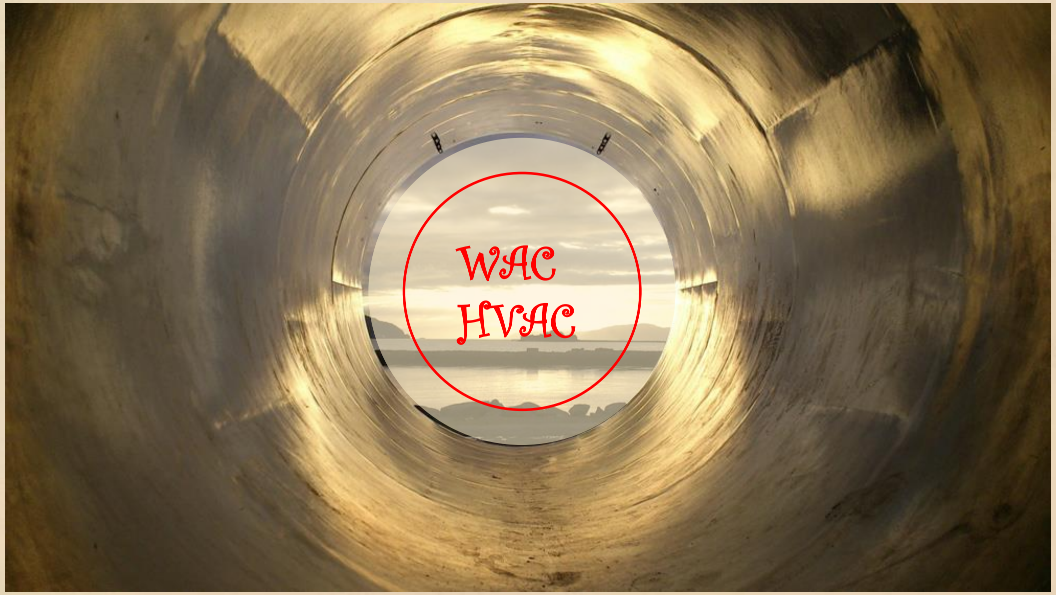
WTF Institute of Higher Learning

By Mat Ansari PE

1-24-2016

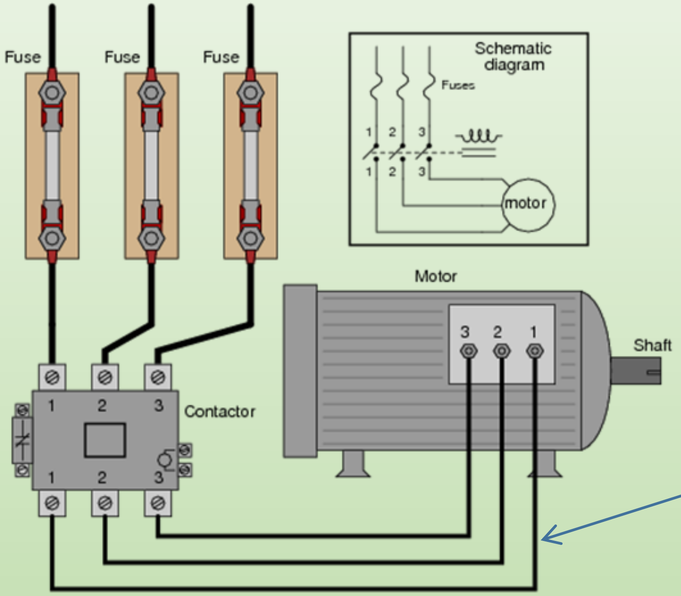
- For HVAC Project Engineer's Reference Use Only

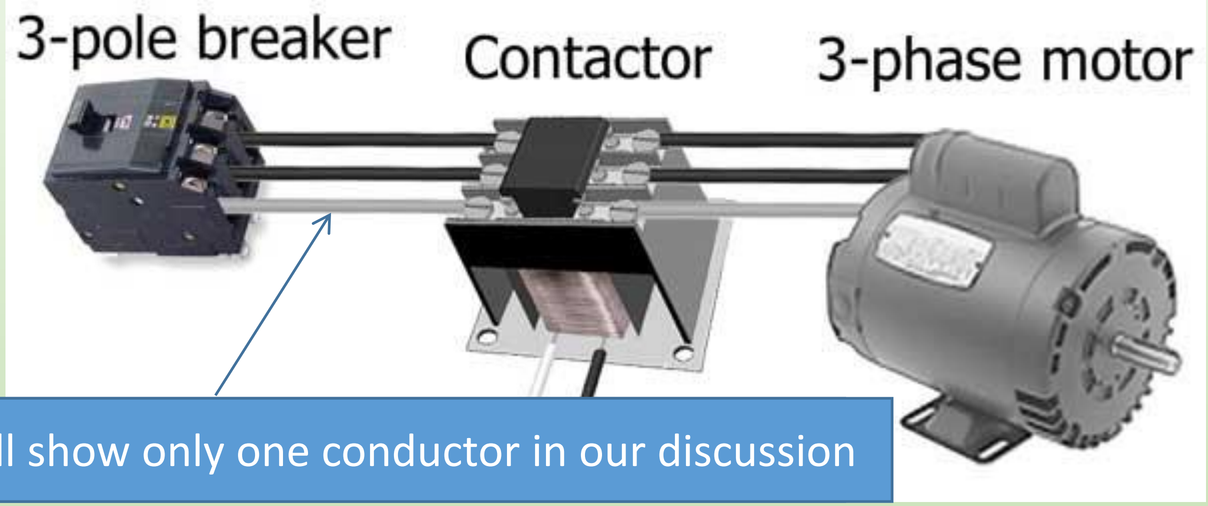
- Not for Electrical Design or Construction



A Tunnel Vision Look at NEC
No Code Articles Referenced

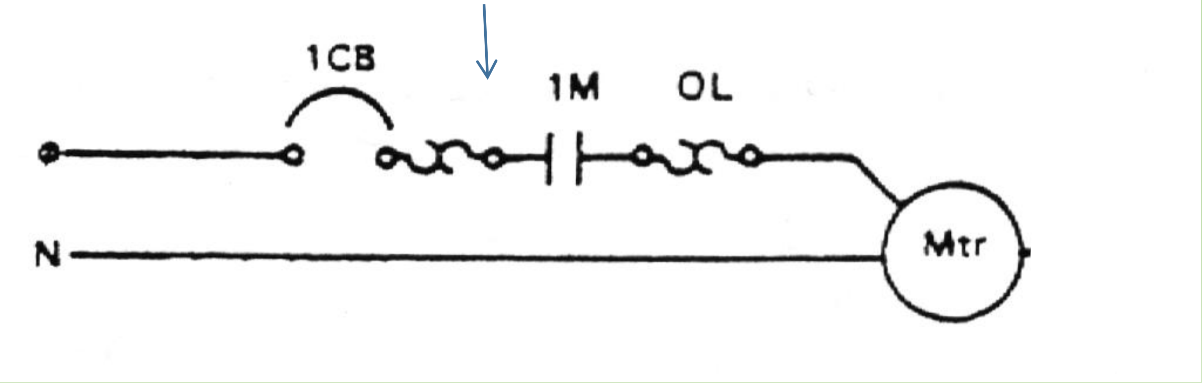
Motor Wiring Schematics





We will show only one conductor in our discussion

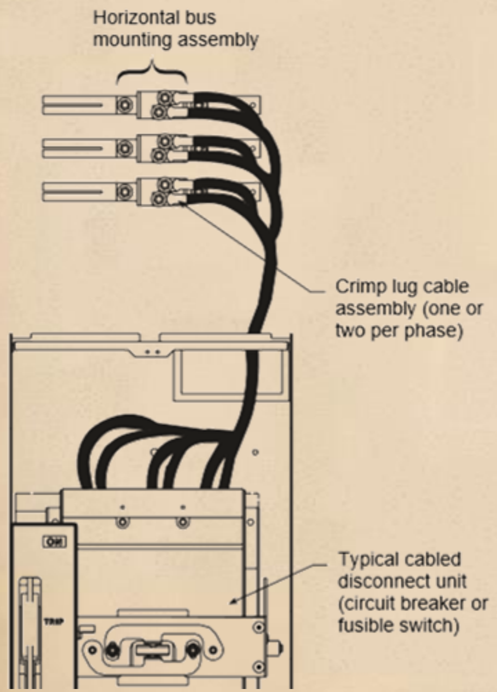
1-Phase 120 Volt (one Hot and one Neutral)

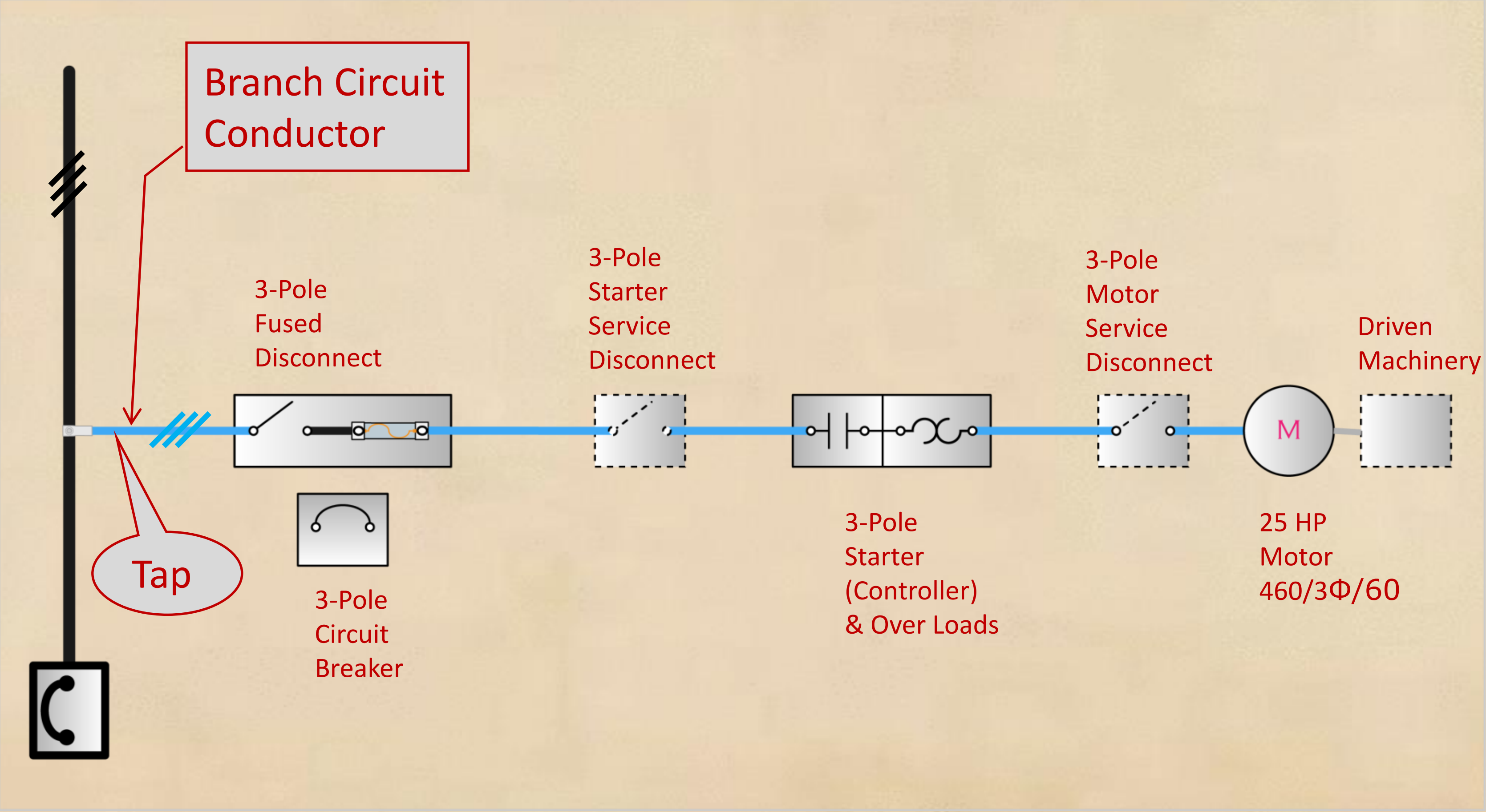


Motor Branch Circuits

Let us use a 480 Volt 3-Phase System for our example.

(1-Phase motors will have only one pole like below.   One hot and one Neutral/Grounded. You are not allowed to switch or fuse the Grounded conductor.)





The NEC

Conductor Sized Per NEC
Is A Minimum Size For Safety
Neither a "Recommended" Size
Nor "Good Design Practice"

Wire Sizing - The 2 Steps

How Much Current is the Conductor REQUIRED to Carry in the Branch Circuit?

<

How Much Current CAN the Conductor Carry (Safely) Per NEC

Step-1

Step-2

Let us call this the
Minimum **C**ircuit **A**mpacity required.
[MCA]

How much Current does the conductor need to carry?

1. HVAC Equipment (Packaged, Unitary, and Split etc.)

   The wire must safely carry the Manufacturer's MCA (Minimum Circuit Ampacity).

2. Stand Alone Motors (Fans and Pumps etc.)

   The wire must safely carry 125% of the motor FLC per NEC Table.

   Do NOT use Motor Nameplate FLA.

3. Multiple Motors Served by One Branch Circuit

   125% of the largest motor FLC Amps plus 100% of all others.

4. Non-Motor and Non-A/C loads (HVAC PE's viewpoint)

   Like Boilers, Heaters etc.

   125% of all continuous loads + 100% of all non-continuous loads

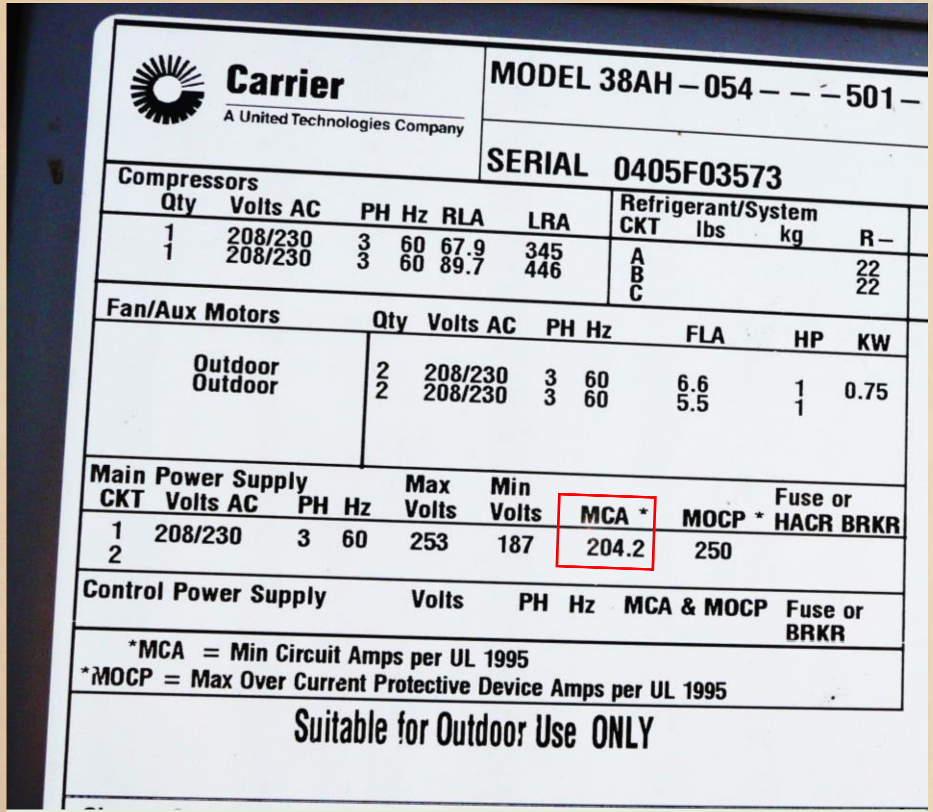
MCA - HVAC Equipment (Packaged, Unitary, and Split etc.)

- This group is easy. UL requires them to publish the Minimum Circuit Ampacity – MCA.
- Your Conductor selection must be able to safely carry the published MCA for the equipment.
- MCA is calculated by the Manufacturer as follows:

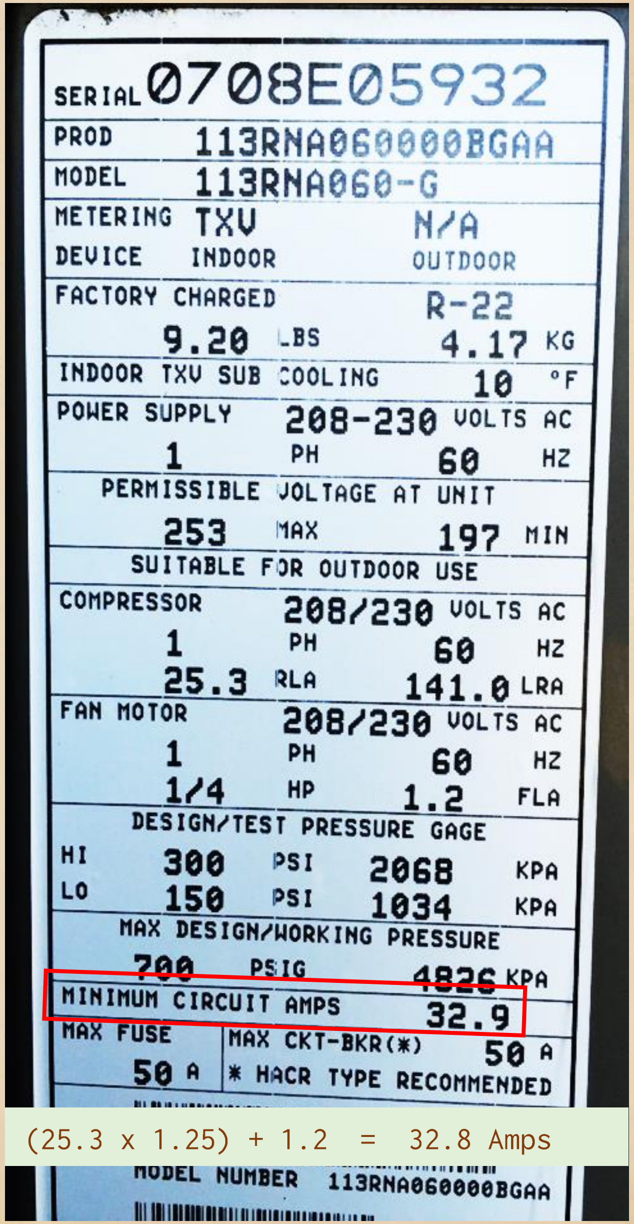
  125% Largest Motor RLA (Amps) + 100% Other Loads (Amps)

- RLA is Rated Load Amps, a "calculated" number, based on UL mandated bench testing procedures. It is not the same as Full Load Amps (FLA).
- RLA represents the actual expected compressor draw at given operating pressures and temperatures. The same compressor/motor when used for cold-storage and air-conditioning will have different RLAs.
- If there are 2 or more "largest" motors, then 125% of just one and 100% of the rest.
- Example: 80 Condensing Unit 460V/3-phase:
  - (2) 40 Ton Compressors RLA = 52 Amps each
  - (4) Condenser Fans RLA = 1.5 Amps each
  - MCA = (52 x 1.25) + 52 + 1.5 + 1.5 + 1.5 + 1.5 = 123 Amps

MCA - Minimum Circuit Ampacity



(89.7 x 1.25) + 67.9 + 2 x 6.6 + 2 x 5.5 = 204.2 Amps



(25.3 x 1.25) + 1.2 = 32.8 Amps

ACTUAL NAME PLATE EXAMPLES.

Note: Be careful if motors are not the same voltage. Then there must be a transformer. Take the VA of the transformer and divide by large motor voltage to get "other "amps.

BUT - Bottom Line: Forget all the formulas – just use MCA for wire sizing!

MCA – Stand Alone Motors [Fans, Pumps Etc.]

Table 430.250 Full-Load Current, Three-Phase Alternating-Current Motors

The following values of full-load currents are typical for motors running at speeds usual for belted motors and motors with normal torque characteristics.

	Induction-Type Squirrel Cage and Wound Rotor (					
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	5 Vo
½	4.4	2.5	2.4	2.2	1.1	
¾	6.4	3.7	3.5	3.2	1.6	
1	8.4	4.8	4.6	4.2	2.1	
1½	12.0	6.9	6.6	6.0	3.0	
2	13.6	7.8	7.5	6.8	3.4	
3	—	11.0	10.6	9.6	4.8	
5	—	17.5	16.7	15.2	7.6	
7½	—	25.3	24.2	22	11	
10	—	32.2	30.8	28	14	1
15	—	48.3	46.2	42	21	1
20	—	62.1	59.4	54	27	2
25	—	78.2	74.8	68	34	2
30	—	92	88			
40	—	120	114			
50	—	150	143	130	65	5
60	—	177	169	154	77	6
75	—	221	211	192	96	7
100	—	285	273	248	124	9
125	—	359	343	312	156	12
150	—	414	396	360	180	14
200	—	552	528	480	240	19

Premium Eff = 30 Amps

For a single MOTOR use NEC FLC tables.

Table 430-250 for 3-Phase. Table 430-248 for 1-Phase

FLC = "Full Load Current" as Defined by NEC

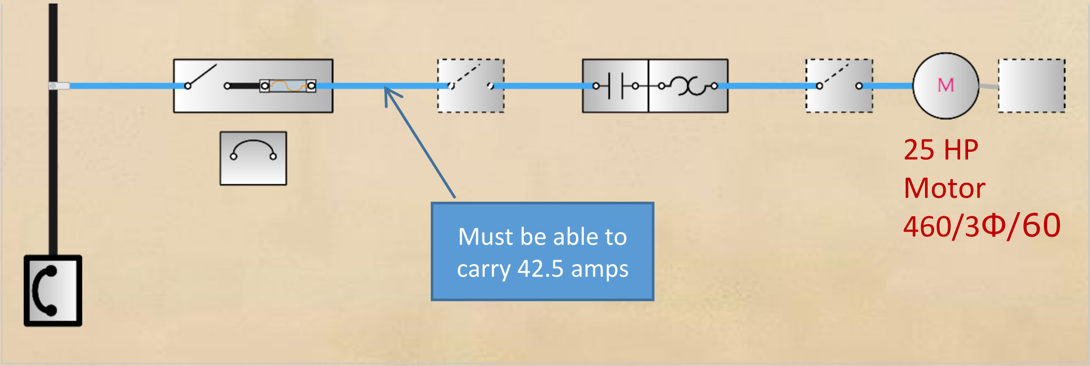
Again - DO NOT USE Motor Nameplate FLA.

(They are worried about your replacing a hi-efficiency motor with a cheap low-efficiency motor later on.)

MCA = (FLC x 1.25) Amps

In our example for a 25hp motor: FLC = 34 Amps

MCA = 34 x 1.25 = 42.5 Amps



FLC Table For Single Phase Motors

Table 430.248 Full-Load Currents in Amperes, Single-Phase Alternating-Current Motors

The following values of full-load currents are for motors running at usual speeds and motors with normal torque characteristics. The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120 and 220 to 240 volts.

Horsepower	115 Volts	200 Volts	208 Volts	230 Volts
1/6	4.4	2.5	2.4	2.2
1/4	5.8	3.3	3.2	2.9
1/3	7.2	4.1	4.0	3.6
1/2	9.8	5.6	5.4	4.9
3/4	13.8	7.9	7.6	6.9
1	16	9.2	8.8	8.0
1 1/2	20	11.5	11.0	10
2	24	13.8	13.2	12
3	34	19.6	18.7	17
5	56	32.2	30.8	28
7 1/2	80	46.0	44.0	40
10	100	57.5	55.0	50

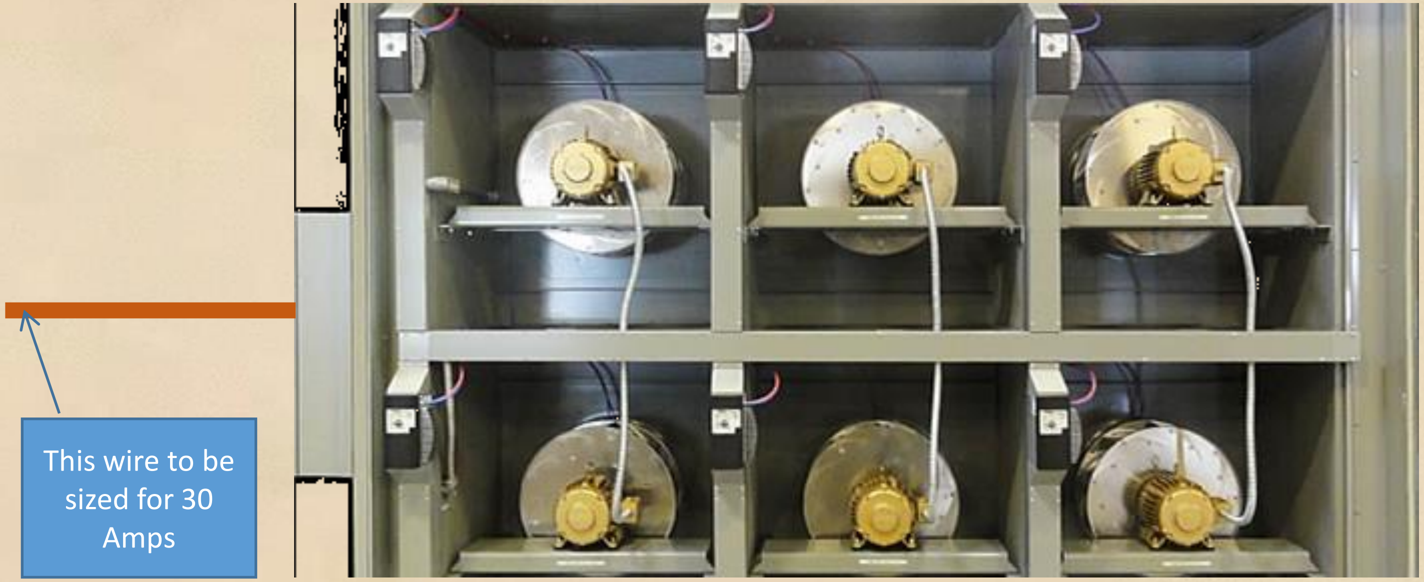
MCA - Multiple Motors Served by One Branch Circuit

- Say a Branch Circuit feeding a Fan-Wall with 6 fans, 3 hp, 460 Volts 3-phase.

1. Look up NEC Table 430.250 (previous slide).
   FLC = 4.8 Amps

2. The rule is:
125% of the largest motor + 100% of all others.

1. MCA = (4.8 x 1.25) + 5 x 4.8 = 30 Amps



Non-Motor and Non-A/C loads (HVAC PE's Viewpoint)

1. This may be a boiler control circuit plus some lights or water heater controls etc. etc.

2. Add all the loads

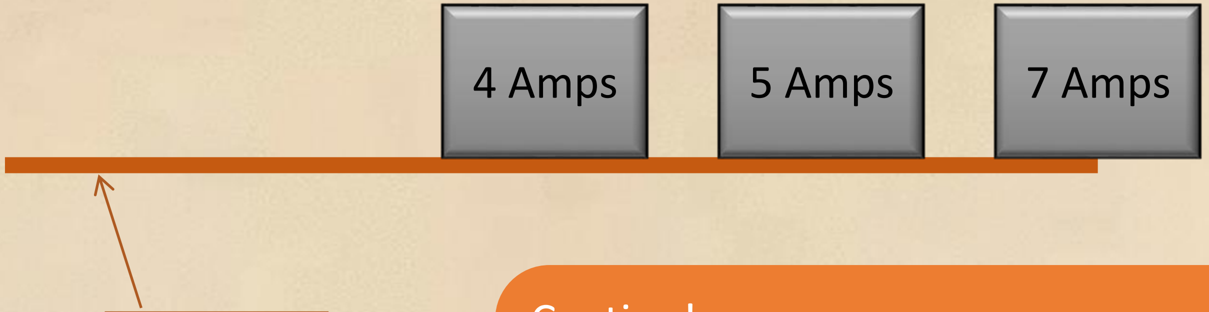
3. Do not try to figure out Continuous/Non-Continuous per NEC

4. Times the total by 1.25 (Note the difference compared to motors.)

5. That is the Conductor Ampacity you need

6. MCA = 1.25(4 + 5 + 7) = 20 Amps

Note: Per NEC
125% of Continuous Loads + 100% of Non-Continuous.
Where Continuous is 3 hours or more operation.



This wire to be sized for 20 Amps

Note:
Allow for future loads

Caution!

This is not PIPE. Don't even think of saving money by reducing line size downstream. ☺

We will discuss OCP in our next session.

Non-Motor and Non-A/C loads (HVAC PE's Viewpoint)

1. How many VAV box controllers on one circuit?

2. 12 gage 20 amp circuit is the most common 120 Volt 1-phase circuit. (We will see later why it is called a 20 amp circuit.)

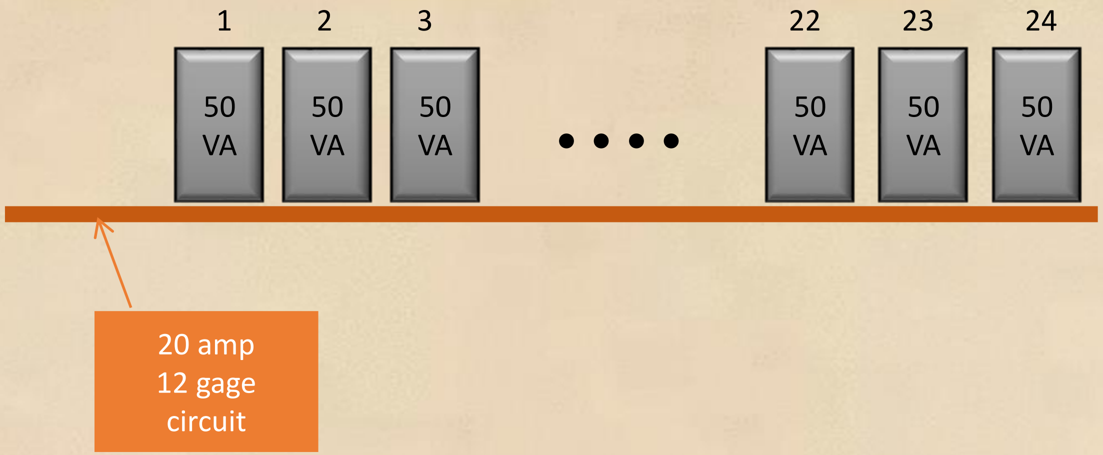
3. We can have 20 ÷ 1.25 = 16 amps max. continuous amps

4. But that will load the circuit 100%. So let us choose a safe lower number with room for future loads. Say 10 amps.

5. 10 amps at 120 Volts is 1200 VA

6. VAV control transformer usually around ≈ 50 VA

7. 1200 VA ÷ 50 VA per box = 24 VAV boxes. (Just roughly.)



Wire Sizing - The 2 Questions

How Much Current is the Conductor REQUIRED to Carry in the Branch Circuit?

$<$

How Much Current CAN the Conductor Carry (Safely) Per NEC

So we have a pretty good handle on what is the required ampacity of the branch circuit.

Note: Do not adjust this side for de-rating factors.

Let us now talk about finding out what size conductor will carry the required ampacity safely.

Table 310.15(B)(16) (formerly Table 310.16)
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).]		
Size AWG or kcmil	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, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
18	—	[7] —	14
16	—	[10] —	18
14**	15	[15]** 20	25
12**	20	[20]** 25	30
10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

Wire Size

Max Amps

Table 310.15(B)(16)
(formerly Table 310.16)
(Table Chopped up. AL and larger wire sizes not show.)

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, or Earth (Directly Buried),

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*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.

Sidebar-Slide
How Hot Does The Insulation Get?

WATER TEMPERATURE Deg. F	Deg. C	TIME FOR A MILD First Degree Burn	TIME FOR PERMANENT Second Degree Burns
110	43	Normal Hot Shower	
116	47	Pain Threshold Approx	
116	47	35 Minutes	45 Minutes
120	49	3 Minutes	9 Minutes
122	50	1 Minute	5 Minutes
126	52	30 Seconds	90 Seconds
131	55	5 Seconds	25 Seconds
140	60	2 Seconds	5 Seconds
149	65	1 Second	2 Seconds
154	68	Instantaneous	1 Second

SOURCE: Moritz and Henriques, "Study of Thermal Injury: II"
American Journal of Pathology 1947; 23: 695-720
Technical Bulletin 34, US Government Memorandum, C.P.S.C.

Standard Wire For Commercial HVAC

THHN/THWN-2 COPPER 90°C

Item (sold by the foot unless noted otherwise)	O.D. (inches)	Ampacity @ 90°C
14 AWG THHN, 500ft or 2500ft Spool »	0.109	15
12 AWG THHN, 500ft, 1000ft or 2500ft Spool »	0.128	20
12 AWG THHN 100ft or 200ft Coil »	0.128	20
10 AWG THHN, 500ft, 1000ft or 2500ft Spool »	0.161	30
10 AWG THHN, 100ft or 200ft Coil »	0.161	30
8 AWG THHN »	0.213	55
6 AWG THHN »	0.249	75
4 AWG THHN »	0.318	95
3 AWG THHN »	0.346	110
2 AWG THHN »	0.378	130
1 AWG THHN »	0.435	150
1/0 THHN »	0.474	170
2/0 THHN »	0.518	195
3/0 THHN »	0.568	225
4/0 THHN »	0.624	260

Wire Type THHN/THWN-2

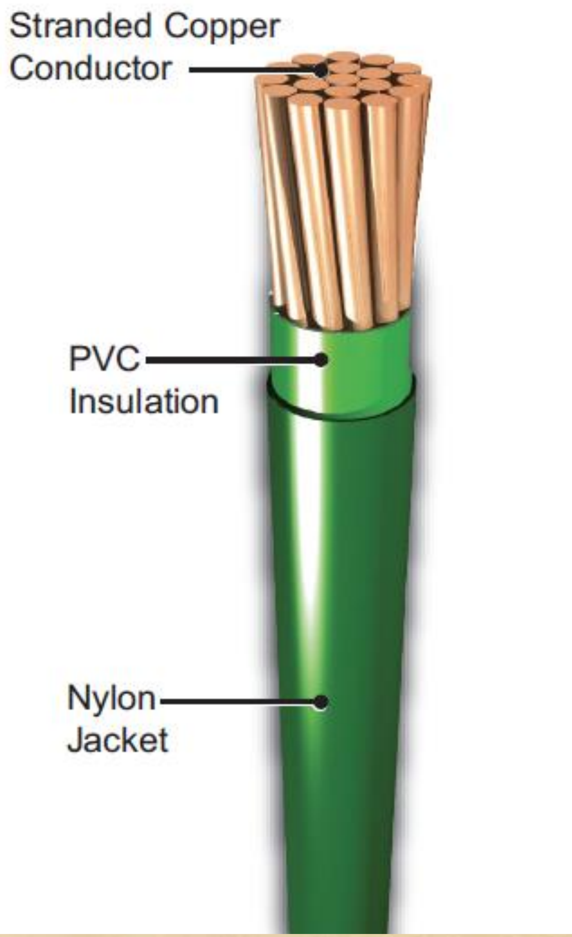

Table 310.15(B)(16) (formerly Table 310.16)
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Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]		
	60°C (140°F)	75°C (167°F)	90°C (194°F)
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
18	—	[7] —	14
16	—	[10] —	18
14**	15	[15]** 20	25
12**	20	[20]** 25	30
10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

WEIRD RULES – Table 310.15(B)16 Usage
(Why it is misused so often.)

RULE #1

You can never use an ampacity higher than that in the 75°C Column.
If you have a 90°C conductor (like we usually do), you can use the 90°C rating before applying the "corrections" and "adjustments" but the final number cannot be any higher than the 75°C value.

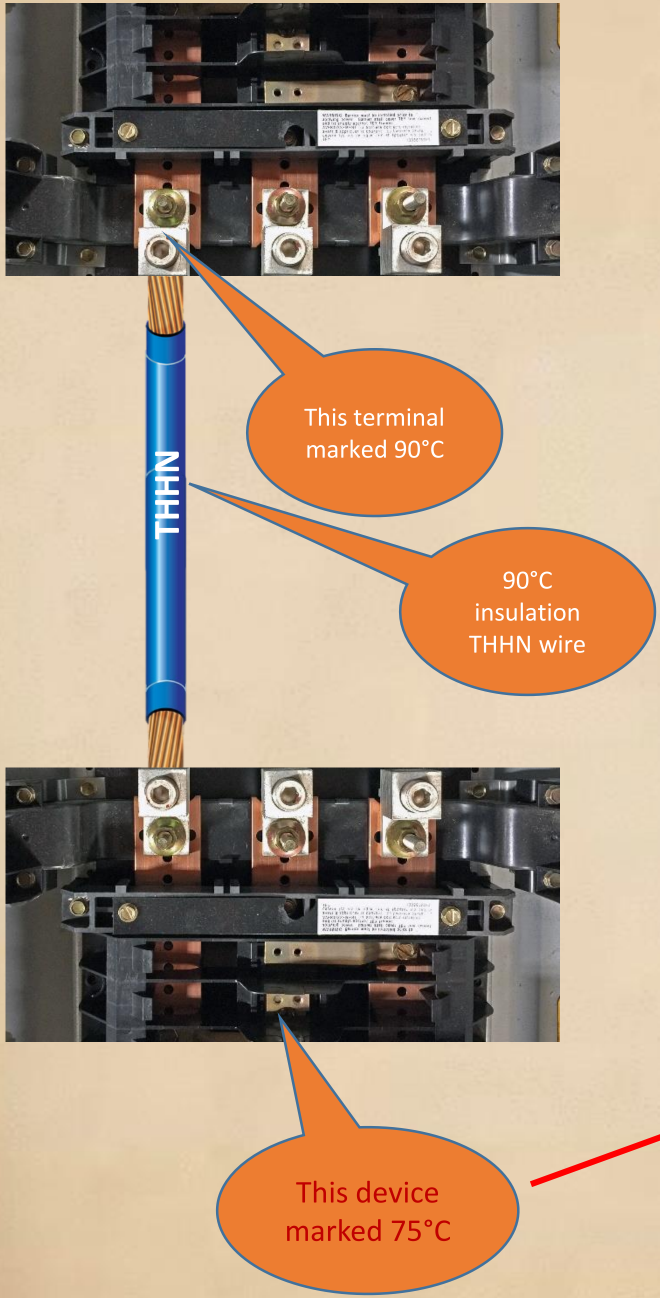
RULE #2

Loads < 100 Amps --- Use 60°C
Loads > 100 Amps --- Use 75°C
(Ignoring terminal markings.)

RULE #3

Non-Motor Loads --- Note small gage wire limits on Circuit Protection [xx]**

Terminal/Equipment Ratings



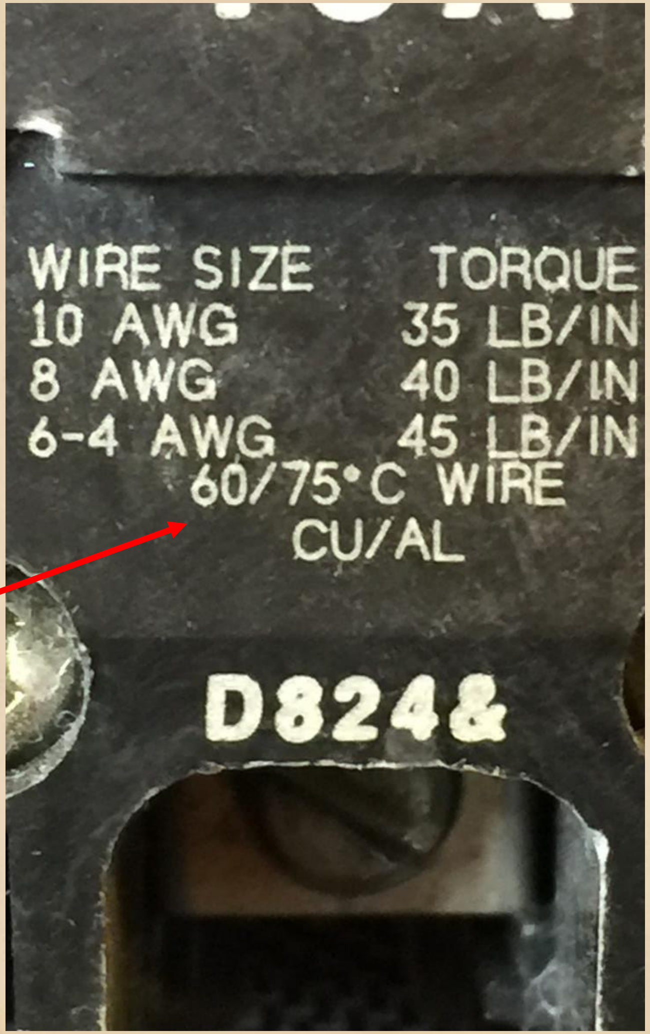
All electrical devices and terminals have temperature ratings under which they have been tested for continuous operation.

Most of the time (for larger equipment) the terminal rating is stamped on the device and is 75°C. There is no 90°C listed device under 600 Volts. (Disconnects, Circuit Breakers and Starters etc.).

Per NEC you cannot use wire ampacity from a column higher than the lowest wire/terminal/device rating (WEAKEST LINK CONCEPT).
So in this case we have to use 75°C Ampacity column even though the wire THHN is rated for 90°C. Remember you can start derating from 90°C THHN ampacity – but can never exceed the 75°C capacity.

Note that there is also a "heat rejection" factor. The testing and certification of a device might have used lower temp., larger dia. wire (more mass) to qualify.

If no rating is marked on the equipment, (or unknown at time of design) then it is assumed to be rated at 60°C. (For < 100 amps. 75°C always OK for > 100 amps). Motor Branch circuits are an exception and 75°C can always be used.



Ampacity Corrections and Adjustments

1. Adjust Ampacity for more than 3 current-carrying conductors in a conduit. Green (or bare) equipment grounding conductors are not current carrying and therefore do not count. Count all spares, if any.

2A. Correct Ampacity for higher than 86°F ambient. (Ignore lower temp. credit.)

2B. Correct Ampacity for running on rooftop.

3. Check voltage drop. Branch circuit voltage drop should not be more than 3%. (Not Code but just good practice.)

The ampacity of the conductor after corrections should not be less than the MCA required.

EXAMPLE: NO ADJUSTMENTS

Outdoor Condensing Unit 480V/3-Phase

MCA 204.2Amps

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	Temperature Rating of Conductor [See Table 310.104(A).]		
	60°C (140°F)	75°C (167°F)	90°C (194°F)
Size AWG or kcmil	Types TW, UF	...THW, TH..., XHHW, USE ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
18	—	[7] —	14
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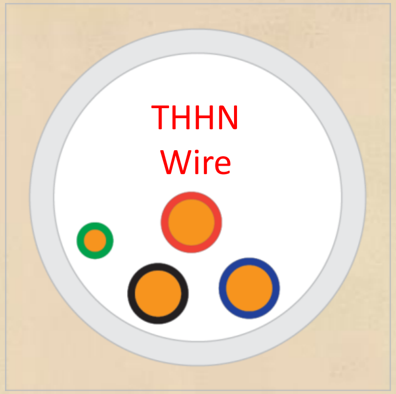
14**	15	[15]** 20	25
12**	20	[20]** 25	30
10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

Start Here. Find the first row that exceeds the MCA Reqd.

Ambient Temp. < 86°F



3 Current Carrying conductors. Green Equipment Grounding Conductor does not count.

We cannot go to the 90°C column and select 3/0 AWG wire. The NEC terminations rule disallows that. We have to stay in the 75°C column. Therefore the proper selection is 4/0 AWG. Ampacity 230.

EXAMPLE:

> 3 Conductors Adjustment

(2) Outdoor Condensing Units 480V/3-Phase

MCA 204.2Amps THHN Wire

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Not More Than Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly Buried)
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Temperature Rating of Conductor [See Table 310.104(A).]

Size AWG or kcmil	60°C (140°F) Types TW, UF	75°C (167°F) Types THW, THHW, XHHW, USE, ZW	90°C (194°F) Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
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10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

Start Here.
Find the first row that exceeds the MCA Reqd.

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

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

(1) Number of conductors is the total number of conductors in the raceway or cable adjusted in accordance with 310.15(B)(5) and (6).

Ambient Temp. < 86°F

6 Current Carrying conductors.
Green Equipment Grounding Conductors do not count.

Adjustment Factor = 80%

This is where the 90°C insulation pays off.
If we had a 75°C Wire then 230 x 0.8 = 184 Ampacity
We would not be able to use 4/0 wire.
But THHN is 90°C and the Code allows 90°C Column to use as basis for derating. 260 x 0.8 = 208 Ampacity

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10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

EXAMPLE: Ambient > 86 °F

Outdoor Condensing Unit 230V/1-Phase

MCA 32.9Amps

Assume that the conduit runs (for a major part of its run) through a hot attic. Ambient 110°F.

Here again you see that running a 90°C wire makes the Code minimum.

10 AWG THHN 90°C
40 x 0.87 = 34.8 Ampacity
OK

10 AWG any 75°C insulation
35 x 0.82 = 28.7 Ampacity
Not enough

Note: NEC has exception for very small part of length through warm area.

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 (°F)	Temperature Rating of Conductor		
	60°C	75°C	90°C
50 or less	1.29	1.2	1.15
51–59	1.22	1.15	1.12
60–68	1.15	1.11	1.08
69–77	1.08	1.05	1.04
78–86	1	1	1
87–95	0.91	0.94	0.96
96–104	0.82	0.88	0.91
105–113	0.71	0.82	0.87
114–122	0.58	0.75	0.82
123–131	0.41	0.67	0.76
132–140	—	0.58	0.71

More Than One Adjustment:

MULTIPLY CORRECTION FACTORS

15(B)(16) (formerly Table 310.16)
Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts
ugh 90°C (140°F Through 194°F)
han Three Current-Carrying Conductors in Raceway, Cable, Earth (Directly
mbient 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)
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
18	—	[7] —	14
16	—	[10] —	18
14**	15	[15]** 20	25
12**	20	[20]** 25	30
10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

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 (°F)	Temperature Rating of Conductor		
	60°C	75°C	90°C
50 or less	1.29	1.2	1.15
51–59	1.22	1.15	1.12
60–68	1.15	1.11	1.08
69–77	1.08	1.05	1.04
78–86	1	1	1
87–95	0.91	0.94	0.96
96–104	0.82	0.88	0.91
105–113	0.71	0.82	0.87
114–122	0.58	0.75	0.82
123–131	0.41	0.67	0.76
132–140	—	0.58	0.71

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

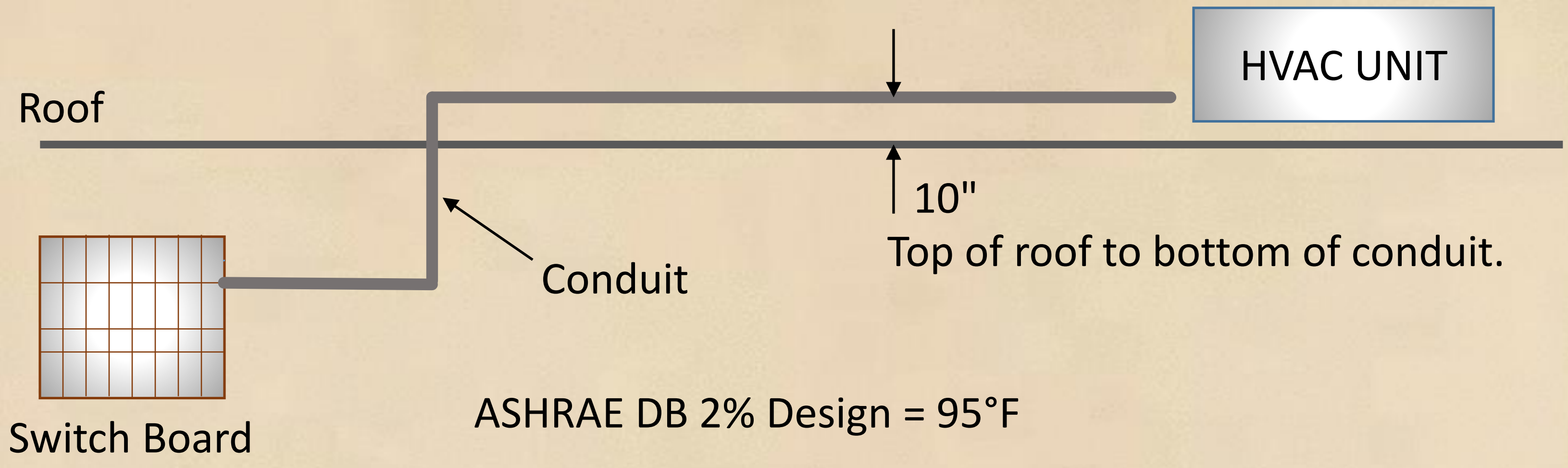
Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary %
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

(1) Number of conductors is the total number of conductors in the raceway or cable adjusted in accordance with 310.15(B)(5) and (6).

Ampacity of 10 AWG 90°C Conductor:
= 40 x 0.87 x 0.8 = 27.8 Amps

Ampacity Adjustment For Conduit On Roof

Table 310.15(B)(3)(c) Ambient Temperature Adjustment for Circular Raceways Exposed to Sunlight on or Above Rooftops	
Distance Above Roof to Bottom of Conduit	Temperature Add To ASHRAE 2% Design
	°F
0 - 0.5 inches	60
Above 0.5 to 3.5 inches	40
Above 3.5 to 12 inches	30
Above 12 to 36 inches	25



ASHRAE DB 2% Design = 95°F

ADDER from Table 310.15(B)(3)(c) = 30°F

Ambient to use for correction = 95 + 30 = 125°F

EXAMPLE: Conduit on Roof
Outdoor Condensing Unit 230V/1-Phase
MCA 32.9Amps

Table 310.15(B)(16) (formerly Table 310.16)
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)
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
18	—	[7] —	14
16	—	[10] —	18
14**	15	[15]** 20	25
12**	20	[20]** 25	30
10**	30	[30]** 35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

* Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

** Refer to 240.4(D) for conductor overcurrent protection limitations.

Rooftop conduit correction can be very significant.

(Newer add to Code -2008?)

Let us check if our previous selection of 10 AWG will work:

40 x 0.76 = 30.4 Amps
Less than MCA required.
No good.

For 8 AWG
55 x 0.76 = 41.8 Ampacity
OK

Note: NEC has exception for very small part of length through warm area.

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 (°F)	Temperature Rating of Conductor		
	60°C	75°C	90°C
50 or less	1.29	1.2	1.15
51–59	1.22	1.15	1.12
60–68	1.15	1.11	1.08
69–77	1.08	1.05	1.04
78–86	1	1	1
87–95	0.91	0.94	0.96
96–104	0.82	0.88	0.91
105–113	0.71	0.82	0.87
114–122	0.58	0.75	0.82
123–131	0.41	0.67	0.76
132–140	—	0.58	0.71

Voltage Drop

- Good Practice to limit branch circuit Voltage drop to 3%
- Formulae available on the web
- Use free Voltage Drop calculators on web
- Need special care with "small" wire (18, 14, 12, 10 gage) @ 120 Volts
- For above small wire check Voltage drop if one-way length greater than 100 feet.

- Example Using 12 AWG running at full (Max) allowable 16 Amps:
  - 100 feet distance. (One-way)
  - Staring Voltage 120 Volts
  - Ending Voltage 114.9 Volts - (per my iPhone app)
  - 5.1 Volts or 4.2% (Over NEC "recommended".)

Equipment Grounding Conductor

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350

(The Green or Bare Wire)

Use NEC Table 250.122.

Check rule about increasing size if the current carrying conductors are increased in size due to voltage drop calculations.

Never larger than the current carrying conductors. Quite possible with motors.

Non-Motor Circuits Small Conductors

If the circuit is not serving a motor (and some other special equipment) then NEC limits:

14 AWG	=	15 Amps Circuit	= 15 Amp Circuit Breaker
12 AWG	=	20 Amps Circuit	= 20 Amp Circuit Breaker
10 AWG	=	30 Amps Circuit	= 30 Amp Circuit Breaker

We use 12 AWG 20 Amp circuit for all small 120 Volt 1-Phase loads e.g. boiler control panel, DDC control panel, and power to VAV controller etc.

The End

I know who slept through this shit!

Model	CVHE	Compressor size	500
Impeller size	230	Orifice size	500
Motor size	287		
Motor frequency	60 Hz	Motor voltage	460
Incoming line frequency	60 Hz	Incoming line voltage	460
Evap shell size	050S	Cond shell size	050S
Evap bundle size	390	Cond bundle size	450
Evap tube type	TECU	Cond tube type	TECU
Evap tube thickness	0.025"	Cond tube thickness	0.028"
Evap passes	Two pass evap water box	Cond passes	Two pass cond water box

A

BHP 385
400 HP Motor ??
FLA 477

Design Information

Cooling capacity	400.0 tons	HCFC-123 refrigerant charge	600 lb
Primary power	245.7 kW	Shipping weight	17822 lb
Primary efficiency	0.614 kW/ton	Operating weight	19593 lb
NPLV	0.388 kW/ton	Free cooling option	No
Low voltage AFD type	Unit mounted low voltage AFD	Green Seal certification	No
Unit heat rejected to ambient	4.19 MBh	Application type	Standard cooling
AFD heat rejected to ambient	8.62 MBh		

BHP 329

B

T-24?

Evaporator Information

Evap leaving temp	42.00 F	Evap pressure drop	14.58 ft H2O
Evap flow rate	682.6 gpm	Evap fluid type	water
Evap entering temp	56.00 F	Evap fluid concentration	N/A
Evap flow/capacity	1.71 gpm/ton	Evap water box type	non-marine
Evap fouling factor	0.00010 hr-sq ft-deg F/Btu	Evap water box pressure	150 psig

Condenser Information

Cond entering temp	85.00 F	Cond pressure drop	20.20 ft H2O
Cond flow rate	1080.0 gpm	Cond fluid type	water
Cond leaving temp	95.53 F	Cond fluid concentration	N/A
Cond flow/capacity	2.70 gpm/ton	Cond water box type	non-marine
Cond fouling factor	0.00025 hr-sq ft-deg F/Btu	Cond water box pressure	150 psig

Electrical Information

LRA = Locked Rotor Amps

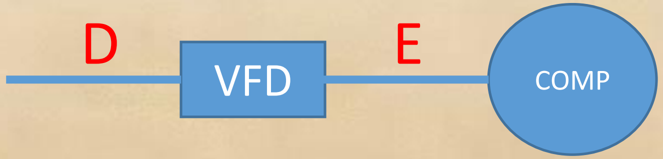
Motor LRA	2234 A	Compressor motor RLA	346.30 A
Primary RLA (Incoming line)	321.7 A	Min circuit ampacity	411 A
Un-corrected power factor	0.89	Max overcurrent protection	700 A

C D E F G

RLA = Rated Load Amps

CHILLER SUBMITTAL Discussion Points:

1. Let us start at TAG B. This is the kW draw at the full load Temperature and Pressure Conditions.
   1. Divide by 0.746 to get 329 BHP.
   2. Divide by 400 Tons to get kW/Ton (T-24 Legal?)
2. TAG A: This is the max. kW power OUTPUT of the motor actually used.
   1. Divide by 0.746 to get 385 BHP (or Shaft HP)
   2. Obviously this is a 400 HP Motor.
   3. Now there is a Full Load Amps (and NEC FLC) value associated with this 400 HP motor and it is ≈ 477 Amps. WE DON'T USE THIS VALUE. We use the MCA value which in turn is based on the RLA given below.
   4. This clearly shows the difference between FLA and RLA.
   5. The safeties are all set to trip in relation to the RLA and way before the FLA is ever reached.
3. TAG D: RLA is Rated Load Amps. (Not "Running" ☺)
   1. Dictated by UL bench testing at design Temp/Press.
   2. All safeties are keyed to this number.
   3. Wire sizing MCA is based on this number.
4. TAG C: LRA is Locked Rotor Amps. Used in conjunction with Starter Type in determining MOCP. Gen Set Sizing.
5. TAG G: MOCP Important for (Electrical) Cost and VE opportunity. Often over-sized on electrical drawings.
6. TAG F: MCA = 125% of Largest RLA + 100% of other
   1. $MCA = RLA \times 1.25 + VA_{Xformer}/Motor_{Volts}$
   2. MCA = 321.7 x 1.25 + 4000/460 = 411 Amps
7. TAG E: What is going on? Why is it different?
   1. VFD has a different (better) PF than the Compressor Motor. If you just forward the submittal to the Elec Sub, he will always use the higher number and cost you money.



Quick Sizing Electrical Service: Chiller (Or Any Large HVAC Equipment)

- Example – 400 Ton Water Cooled Centrifugal Chiller
- To "Ball Park" water cooled centrifugal chiller electrical service:
- Title-24 mandates certain minimum efficiency levels. 0.6kw/ton is a good budget number. (T-24 See Handout)
- 400 tons x 0.6 kW/ton = 240 kW
- 3 phase kW = (V x Amps x 1.73 x PF) ÷ 1000
- Amps = (kW x 1000) ÷ (V x 1.73 x PF) = kW x 1.42 for 480v and 0.85PF
- Amps = 240 kW x 1.42 = 340 Amps RLA
- MCA = 340 x 1.25 = 425 MCA
- (Compare to previous slide (411 Amps). Difference due to kW/ton, PF and ignoring CT amps.)
- Need to get kW per ton from COP and EER. See next slide.

EER • COP • kW/Ton

kW/Ton x EER = 12

Kw/Ton x COP = 3.517

Model	CVHE	Compressor size	500
Impeller size	230	Orifice size	500
Motor size	287		
Motor frequency	60 Hz	Motor voltage	460
Incoming line frequency	60 Hz	Incoming line voltage	460
Evap shell size	050S	Cond shell size	050S
Evap bundle size	390	Cond bundle size	450
Evap tube type	TECU	Cond tube type	TECU
Evap tube thickness	0.025"	Cond tube thickness	0.028"
Evap passes	Two pass evap water box	Cond passes	Two pass cond water box

Verify "tube pull" Clearance

Verify connection side

Verify connection side

Design Information

1.5 - 2 lbs/ton ? R134a similar

Cooling capacity	400.0 tons	HCFC-123 refrigerant charge	600 lb
Primary power	245.7 kW	Shipping weight	17822 lb
Primary efficiency	0.614 kW/ton	Operating weight	19593 lb
NPLV	0.388 kW/ton	Free cooling option	No
Low voltage AFD type	Unit mounted low voltage AFD	Green Seal certification	No
Unit heat rejected to ambient	4.19 MBh	Application type	Standard cooling
AFD heat rejected to ambient	8.62 MBh		

Rigging Wt.
Operating Wt.

Chiller room load

Evaporator Information

Evap leaving temp	42.00 F	Evap pressure drop	14.58 ft H2O
Evap flow rate	682.6 gpm	Evap fluid type	water
Evap entering temp	56.00 F	Evap fluid concentration	N/A
Evap flow/capacity	1.71 gpm/ton	Evap water box type	non-marine
Evap fouling factor	0.00010 hr-sq ft-deg F/Btu	Evap water box pressure	150 psig

Min. Flow ?

14°F ΔT Coil?

CHW PP Sizing

Hi-Rise Static Check

Condenser Information

Cond entering temp	85.00 F	Cond pressure drop	20.20 ft H2O
Cond flow rate	1080.0 gpm	Cond fluid type	water
Cond leaving temp	95.53 F	Cond fluid concentration	N/A
Cond flow/capacity	2.70 gpm/ton	Cond water box type	non-marine
Cond fouling factor	0.00025 hr-sq ft-deg F/Btu	Cond water box pressure	150 psig

Tower Performance Spec.

Compare

Note this is 10.5°F ΔT but much lower than 3 gpm per ton on dwgs.

CDW PP Sizing

Hi-Rise Static Check

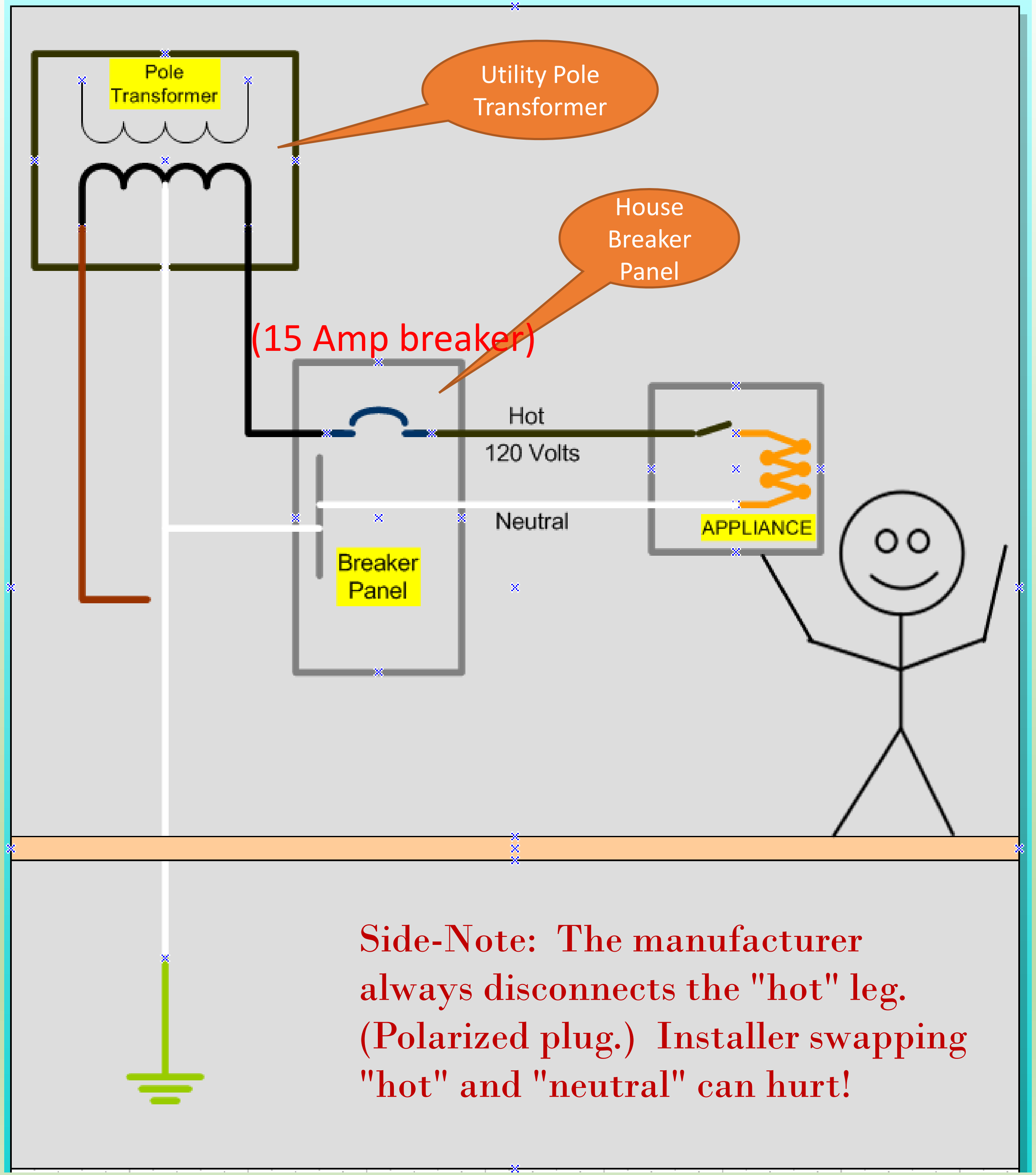
Electrical Information

Motor LRA	2234 A	Compressor motor RLA	346.30 A
Primary RLA (Incoming line)	321.7 A	Min circuit ampacity	411 A
Un-corrected power factor	0.89	Max overcurrent protection	700 A

Mechanical Discussion Points:

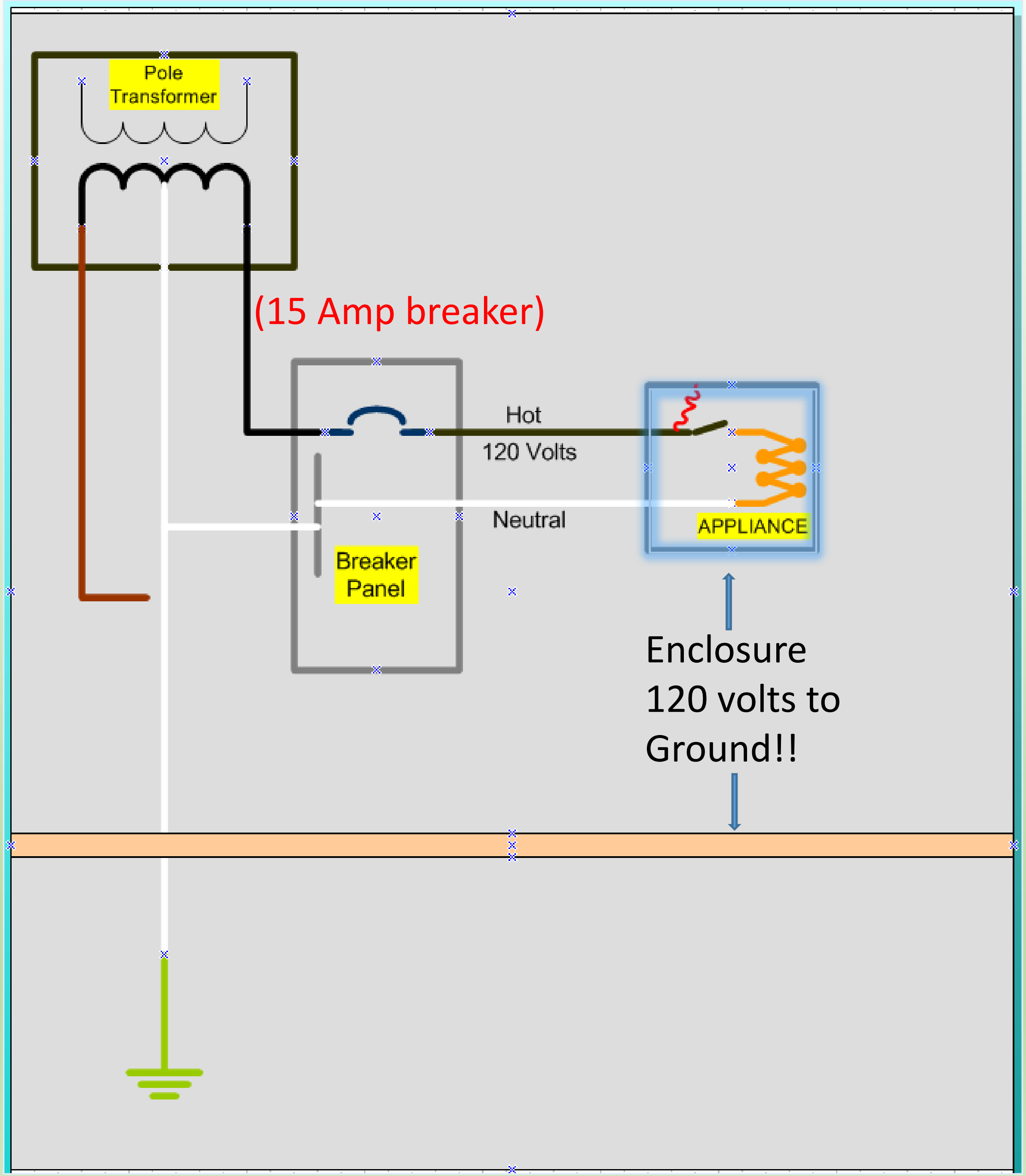
1. Connecting Water boxes can be switched in the field but better to order them correctly. Example "facing the control panel" RHS or LHS connections
2. Number of Passes – Even on the same end. Odd opposite ends.
3. Verify "tube pull" clearance
4. Chiller Room ventilation load
5. Refrigerant Charge – You may need to buy separate.
6. Rigging Weight / Operating Weight. Make sure the rigger gets the right one and the Structural Engineer gets the right one.
7. Evaporator Flow Ask about min. Flow or Velocity
8. Chilled water ΔT. Check against Coil ΔT. Allow 1°F(?) temperature rise between chiller and air-handler.
9. Evaporator Water Pressure Drop – Pump Sizing. Flow follows square curve.
10. Evaporator Working Pressure – Hi-Rise design
11. Condenser Flows
12. Condenser Water Pressure Drop – Pump Sizing
13. Condenser Working Pressure – Hi-Rise design
14. Condenser fouling factor way to optimistic – careful when comparing 2 chiller performances.

EGC - 1



Side-Note: The manufacturer always disconnects the "hot" leg. (Polarized plug.) Installer swapping "hot" and "neutral" can hurt!

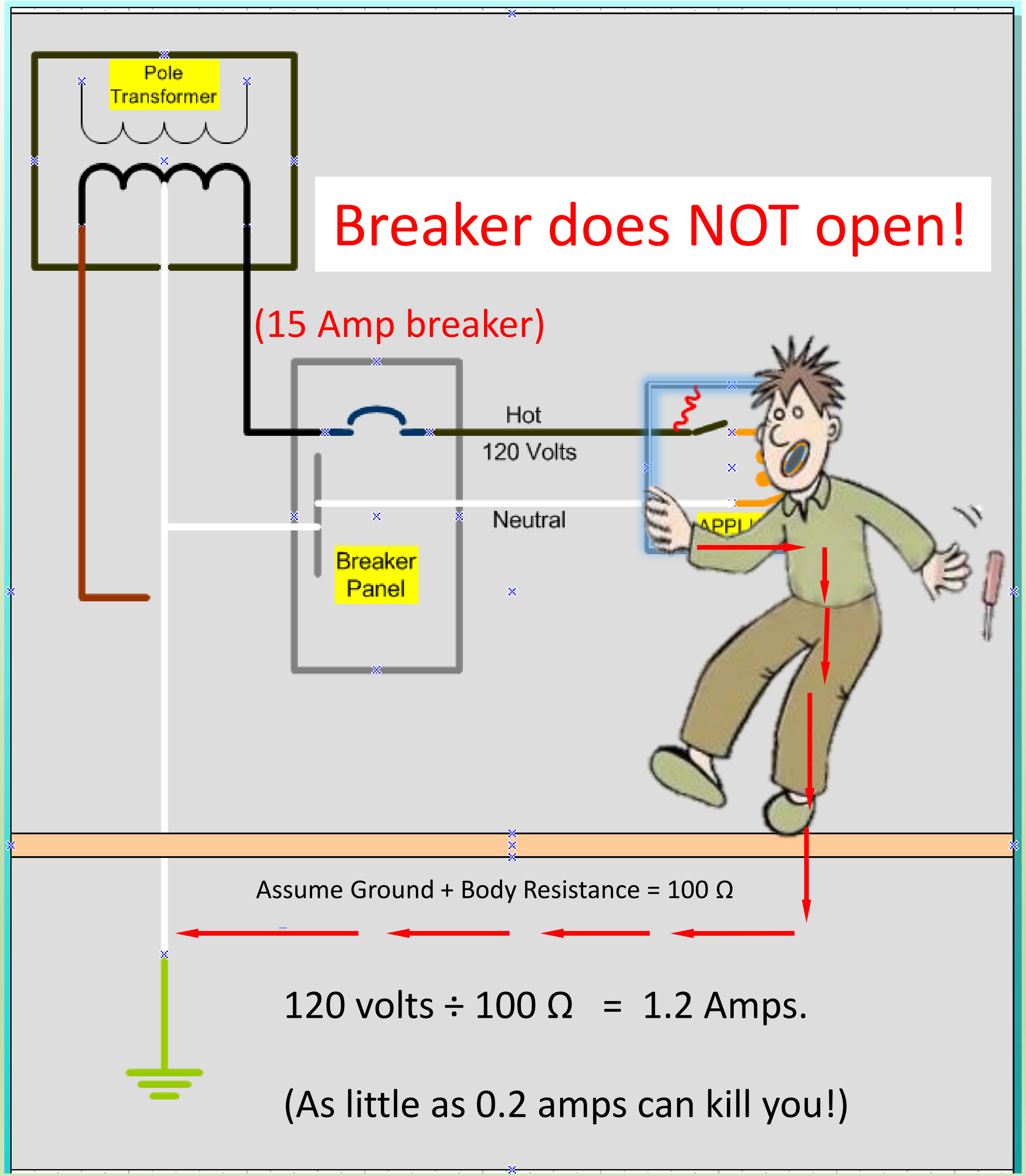
EGC - 2


Pole
Transformer
(15 Amp breaker)
Hot
120 Volts
Neutral
Breaker
Panel
APPLIANCE
Enclosure
120 volts to
Ground!!

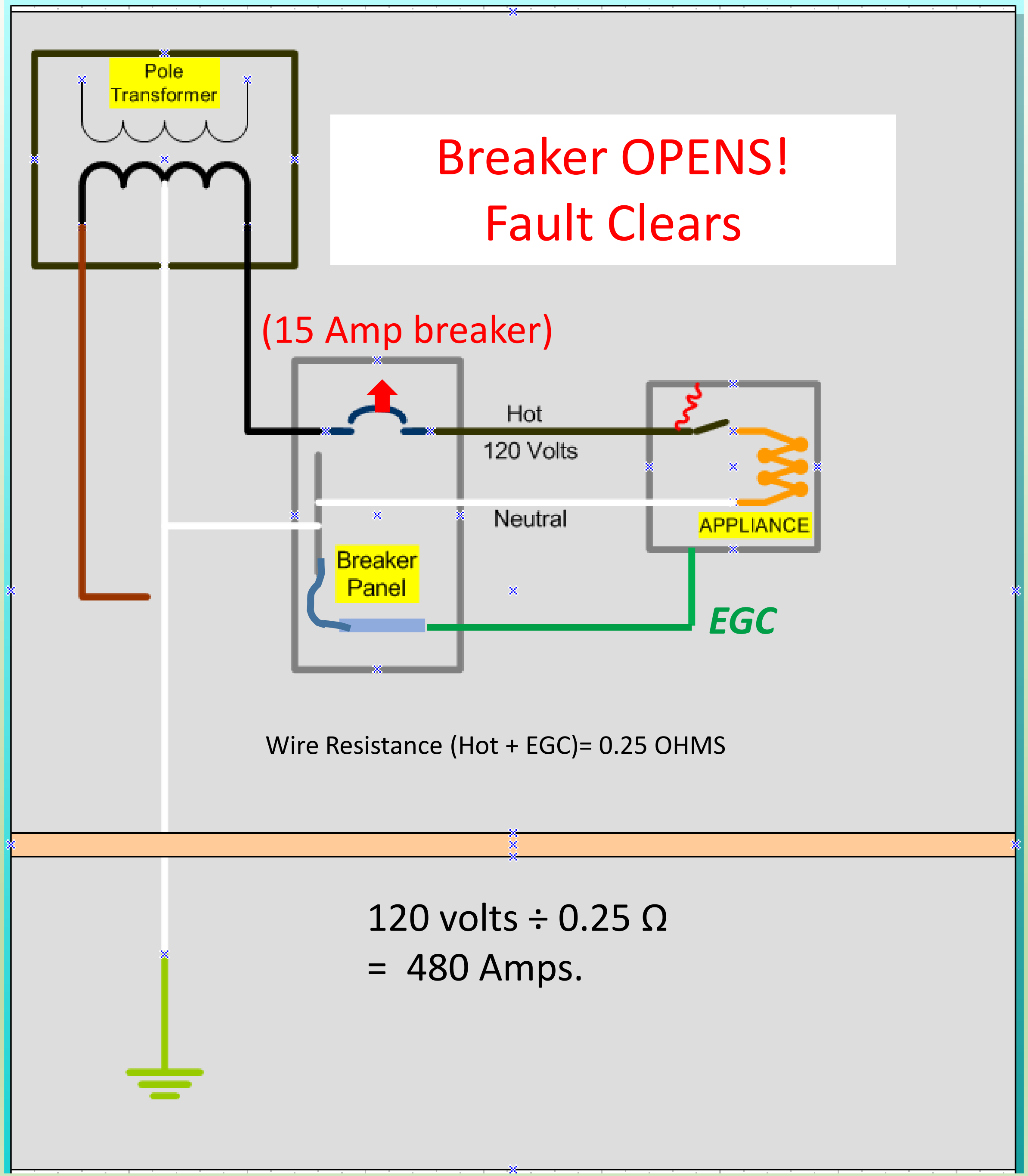
EGC - 3

OHM's Law

$$\text{Amps} = \frac{\text{Volts}}{\text{Resistance}}$$



EGC - 4


Pole Transformer
Breaker OPENS!
Fault Clears
(15 Amp breaker)
Hot
120 Volts
Neutral
APPLIANCE
Breaker Panel
EGC
Wire Resistance (Hot + EGC)= 0.25 OHMS
120 volts ÷ 0.25 Ω
= 480 Amps.

Conduit Sizing

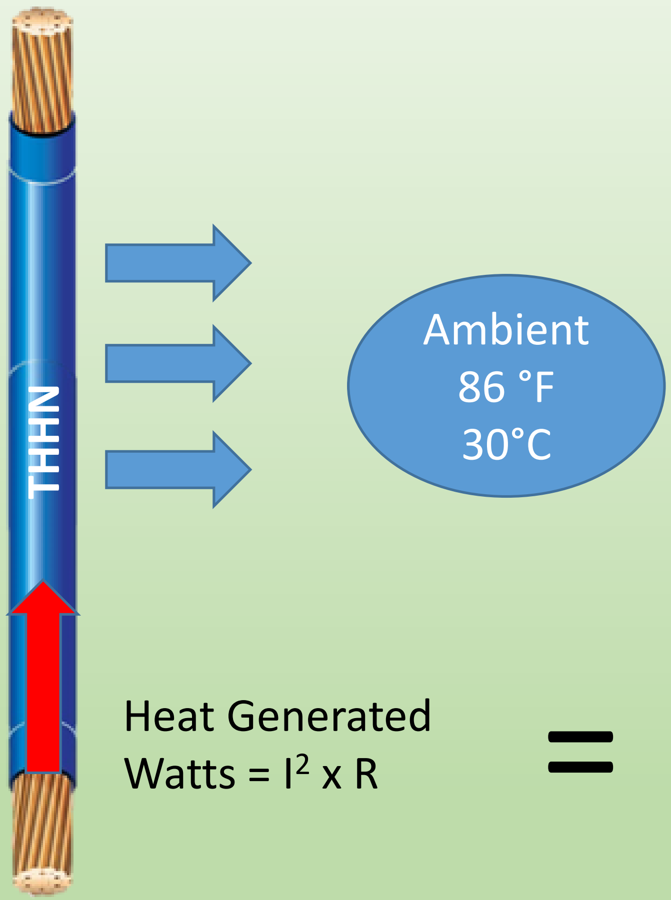
Don’t Guess. Don’t Calculate.
(Actually there is a lot of calculation in conduit sizing. ☺)
Use Tables freely available from Wire Suppliers.

You have to count the Green/Bare equipment grounding conductor.
Don’t forget "more than 3 conductor adjustment".

Trade Size in Inches		Wire Size (THWN, THHN) Cond											
		14	12	10	8	6	4	3	2	1	1/0	2/0	3/0
1/2	EMT	12	9	5	3	2	1	1	1	1	1	--	--
	IMC	14	10	6	3	2	1	1	1	1	1	1	--
	GALV	13	9	6	3	2	1	1	1	1	1	--	--
3/4	EMT	22	16	10	6	4	2	1	1	1	1	1	1
	IMC	24	17	11	6	4	3	2	1	1	1	1	1
	GALV	22	16	10	6	4	2	1	1	1	1	1	1
1	EMT	35	26	16	9	7	4	3	3	1	1	1	1
	IMC	39	29	18	10	7	4	4	3	2	1	1	1
	GALV	36	26	17	9	7	4	3	3	1	1	1	1
1 1/4	EMT	61	45	28	16	12	7	6	5	4	3	2	1
	IMC	68	49	31	18	13	8	6	5	4	3	3	2
	GALV	63	46	29	16	12	7	6	5	4	3	2	1
1 1/2	EMT	84	61	38	22	16	10	8	7	5	4	3	2
	IMC	91	67	42	24	17	10	9	7	5	4	4	3
	GALV	85	62	39	22	16	10	8	7	5	4	3	3

Trade Size in Inches		Wire Size (THWN, THHN) Conductor Size AWG/kc															
		14	12	10	8	6	4	3	2	1	1/0	2/0	3/0	4/0	250	300	350
2	EMT	138	101	63	36	26	16	13	11	8	7	6	5	4	3	2	1
	IMC	149	109	68	39	38	17	15	12	9	8	6	5	4	3	3	2
	GALV	140	102	64	37	27	16	14	11	8	7	6	5	4	3	3	2
2 1/2	EMT	241	176	111	64	46	28	24	20	15	12	10	8	7	6	5	4
	IMC	211	154	97	56	40	25	21	17	13	11	9	7	6	5	4	4
	GALV	200	146	92	53	38	23	20	17	12	10	8	7	6	5	4	3
3	EMT	364	226	167	96	69	43	36	30	22	19	16	13	11	9	7	6
	IMC	362	238	150	86	62	38	32	27	20	17	14	12	9	8	7	6
	GALV	309	225	142	82	59	36	31	26	19	16	13	11	9	7	6	5
3 1/2	EMT	476	347	219	126	91	56	47	40	29	25	20	17	14	11	10	9
	IMC	436	318	200	115	83	51	43	36	27	23	19	16	13	10	9	8
	GALV	412	301	189	109	79	48	41	34	25	21	18	15	12	10	8	7
4	EMT	608	443	279	161	116	71	60	51	37	32	26	22	18	15	13	11
	IMC	562	410	258	149	107	66	56	47	35	29	24	20	17	13	12	10
	GALV	531	387	244	140	101	62	53	44	33	27	23	19	16	13	11	10

Side Bar Note: Heat Balance in a Conductor



Heat Generated
Watts = $I^2 \times R$

=

Conductor Heat Loss is
Proportional to
ΔT = Wire Temp – Ambient Temp

Suppose we start with the circuit off

Then when you turn on the current, the temperature of the conductor will keep rising till delta T increases to a point where the Heat Generated is equal to Heat Loss.

Under adverse conditions it is possible that this will never happen till the insulation melts.

Model	CVHE	Compressor size	500
Impeller size	230	Orifice size	500
Motor size	287		
Motor frequency	60 Hz	Motor voltage	460
Incoming line frequency	60 Hz	Incoming line voltage	460
Evap shell size	050S	Cond shell size	050S
Evap bundle size	390	Cond bundle size	450
Evap tube type	TECU	Cond tube type	TECU
Evap tube thickness	0.025"	Cond tube thickness	0.028"
Evap passes	Two pass evap water box	Cond passes	Two pass cond water box

Verify "tube pull" Clearance

Verify connection side

Verify connection side

Design Information

1.5 - 2 lbs/ton ? R134a similar

Cooling capacity	400.0 tons	HCFC-123 refrigerant charge	600 lb
Primary power	245.7 kW	Shipping weight	17822 lb
Primary efficiency	0.614 kW/ton	Operating weight	19593 lb
NPLV	0.388 kW/ton	Free cooling option	No
Low voltage AFD type	Unit mounted low voltage AFD	Green Seal certification	No
Unit heat rejected to ambient	4.19 MBh	Application type	Standard cooling
AFD heat rejected to ambient	8.62 MBh		

Rigging Wt.
Operating Wt.

Chiller room load

Evaporator Information

Evap leaving temp	42.00 F	Evap pressure drop	14.58 ft H2O
Evap flow rate	682.6 gpm	Evap fluid type	water
Evap entering temp	56.00 F	Evap fluid concentration	N/A
Evap flow/capacity	1.71 gpm/ton	Evap water box type	non-marine
Evap fouling factor	0.00010 hr-sq ft-deg F/Btu	Evap water box pressure	150 psig

Min. Flow ?

14°F ΔT Coil?

CHW PP Sizing

Hi-Rise Static Check

Condenser Information

Cond entering temp	85.00 F	Cond pressure drop	20.20 ft H2O
Cond flow rate	1080.0 gpm	Cond fluid type	water
Cond leaving temp	95.53 F	Cond fluid concentration	N/A
Cond flow/capacity	2.70 gpm/ton	Cond water box type	non-marine
Cond fouling factor	0.00025 hr-sq ft-deg F/Btu	Cond water box pressure	150 psig

Tower Performance Spec.

Compare

Note this is 10.5°F ΔT but much lower than 3 gpm per ton on dwgs.

CDW PP Sizing

Hi-Rise Static Check

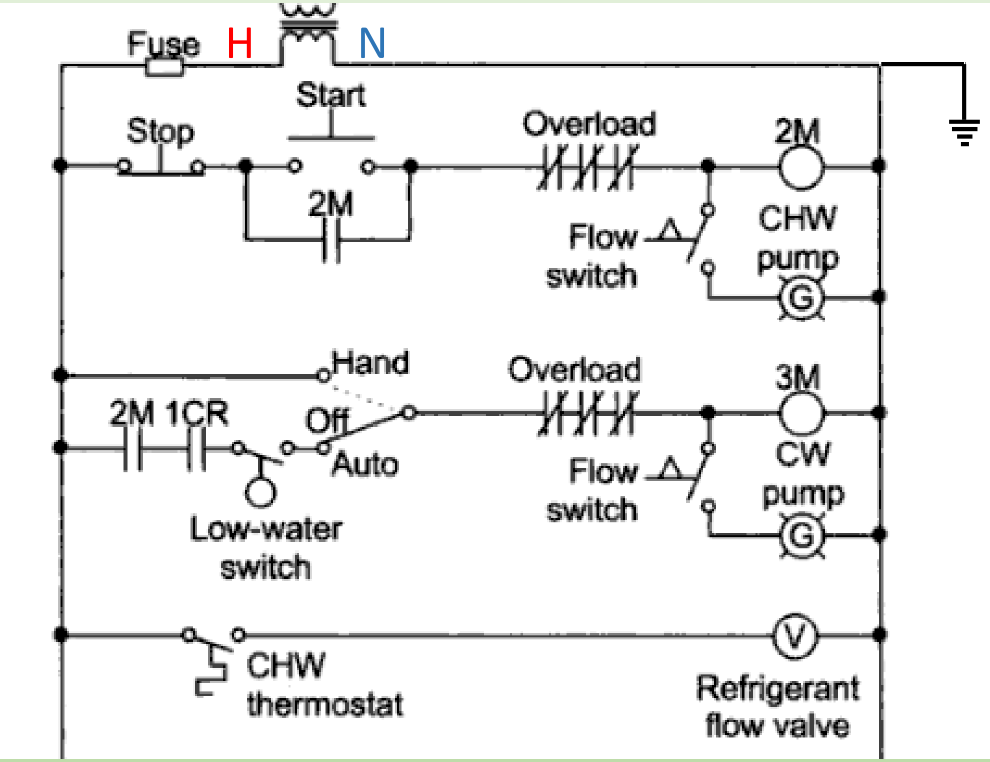
Electrical Information

Motor LRA	2234 A	Compressor motor RLA	346.30 A
Primary RLA (Incoming line)	321.7 A	Min circuit ampacity	411 A
Un-corrected power factor	0.89	Max overcurrent protection	700 A

Mechanical Discussion Points:

1. Water boxes can be switched in the field but better to order them correctly. Example "facing the control panel" RHS or LHS connections
2. Number of Passes – Even on the same end. Odd opposite ends.
3. Verify "tube pull" clearance
4. Chiller Room ventilation load
5. Refrigerant Charge – You may need to buy separate.
6. Rigging Weight / Operating Weight. Make sure the rigger gets the right one and the Structural Engineer gets the right one.
7. Evaporator Flow Ask about min. Flow or Velocity
8. Chilled water ΔT. Check against Coil ΔT. Allow 1°F(?) temperature rise between chiller and air-handler.
9. Evaporator Water Pressure Drop – Pump Sizing. Flow follows square curve.
10. Evaporator Working Pressure – Hi-Rise design
11. Condenser Flows
12. Condenser Water Pressure Drop – Pump Sizing
13. Condenser Working Pressure – Hi-Rise design
14. Condenser fouling factor way to optimistic – careful when comparing 2 chiller performances.

Sidebar-Slide
Never Switch The Grounded Wire



Note: the HOT leg is switched not the grounded leg

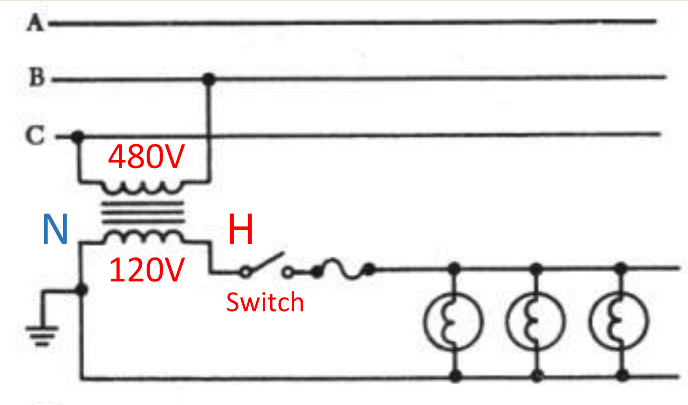


FIGURE 8–205. Step-down transformer using two-wire system.

Note: the HOT leg is switched not the grounded leg