ECET 4520

Industrial Distribution Systems, Illumination, and the NEC

Electrical System Design

Branch Circuits

Electric Distribution System Design

The National Electric Code (NEC) provides a set of guidelines relating to the design, installation, and operation of electric distribution systems.

But, the NEC does not specify the design process itself.

Thus, it is the goal of this presentation to cover some of the aspects that are common to the design process for a typical electric distribution system.

Electric Distribution System Design

Note that this presentation is not meant to be all-inclusive. Instead, it will limit its focus to the aspects of the design process that are covered by the specified course topics.

Furthermore, since each system can have its own set of unique requirements and challenges, there is no all-encompassing set of steps that can be followed in order to complete every system design. For this reason, the material covered within this presentation should only be considered as a starting-point to the design process.

Pre-Design Tasks

The following tasks should be completed before beginning the design of the electric distribution system for a facility:

- **Determine Availability & Type of Service**
- **Meet with the architect to discuss the space allocated for and the location of the service entrance equipment, power and lighting panels, transformers, and other required system components.**

Additionally, obtain a list of the facility's infrastructure equipment along with the device locations and ratings.

Pre-Design Tasks

The following tasks should be completed before beginning the design of the electric distribution system for a facility:

- **Obtain a list of the type and location of the appliances and other equipment that will require electricity from the owner and/or the architectural designer.**
- **Discuss any future plans for changing or expanding the facility with the owner.**
- **View/Consider Existing Installations**
  - **Existing installations can provide insight into the design for current project**

Beginning the System Design

The actual design typically begins with the specification of the branch circuits based on the loads that they will serve.

The type and rating of the various loads will greatly influence the initial design decisions for the system:

- **Load Type – Lighting, Motor, HVAC, Receptacle, etc…**
- **Voltage Rating – AC/DC, 3Φ/1Φ, 480/277/240/208/120V, etc…**
- **Current/Power Ratings – kVA, kW, Amps, Transient/Continuous**

Additionally, the load locations can drastically influence many of the design decisions including the Conductor Types and Lengths, the Raceways utilized, the Insulation Types, etc…

Branch Circuit Design

Branch circuit design typically involves the following steps:

1) Locate the known loads and determine their ratings.

- **Infrastructure Equipment**
  - **This can include any mechanical equipment such as HVAC compressors and blowers, pumps, etc…**
- **Appliances and other general Equipment**
- **Lighting Fixtures and Signage**

Branch Circuit Design

Branch circuit design typically involves the following steps:

2) Locate all of the convenience receptacles.

3) Determine which panel will serve each of the loads and then allocate the branch circuits required to serve the loads based on their type, their voltage & current ratings, their physical location, NEC guidelines, standard design practice, etc…

- **Confirm that the overall load served by each panel is equally distributed across the phases… make adjustments as necessary to balance the loads**

Branch Circuit Design

Branch circuit design typically involves the following steps:

4) Specify the path (length and raceway type) that will be utilized to run each of the circuits and note which (if any) circuits will share a common raceway.

5) Specify the branch circuit conductors (type and size) based on the load ratings requirements along with any environmental concerns (ambient temperature, etc…)

6) Specify the overcurrent protection device that will be utilized to protect each of the branch circuits.

Branch Circuit Design

Branch circuit design typically involves the following steps:

7) Perform the necessary voltage-drop calculations and make adjustments to any branch circuit whose voltage-drop exceeds the limitations noted in the NEC.

Note – Step 7 can be performed after the initial system design is complete.

NEC Design Requirements

Article 210
Branch Circuits

210.1 – Scope

This article covers branch circuits except for those that supply only motor loads, which are covered in Article 430. Provisions of this article and Article 430 apply to branch circuits with combination loads.

Branch Circuits

210.2 – Other Articles for Specific-Purpose Branch Circuits

Branch circuits shall comply with this article and also with the applicable provisions of other articles of this *Code*. The provisions for branch circuits supplying equipment listed in Table 210.2 amend or supplement the provisions in this article.

Table 210.2 Specific-Purpose Branch Circuits

Equipment	Article	Section
Air-conditioning and refrigerating equipment		440.6, 440.31, 440.32
Audio signal processing, amplification, and reproduction equipment		640.8
Busways		368.17
Circuits and equipment operating at less than 50 volts	720	
...		
Recreational vehicles and recreational vehicle parks	551	
Switchboards and panelboards		408.52
Theaters, audience areas of motion picture and television studios, and similar locations		520.41, 520.52, 520.62
X-ray equipment		660.2, 517.73

Branch Circuits

210.3 – Rating

Branch circuits recognized by this article shall be rated in accordance with the maximum permitted ampere rating or setting of the overcurrent device.

The ratings for "other than individual" branch circuits shall be 15, 20, 30, 40, and 50 amperes.

Where conductors of higher ampacity are used for any reason, the ampere rating or setting of the specified overcurrent device shall determine the circuit rating.

Branch Circuits

210.8 – Ground-Fault Circuit-Interrupter Protection…

Ground-fault circuit-interrupter protection for personnel shall be provided as required in 210.8(A) through (C). The ground-fault circuit-interrupter shall be installed in a readily accessible location.

(A) Dwelling Units. All 125-volt, single-phase, 15- and 20-ampere receptacles installed in the locations specified in 210.8(A)(1) through (10) shall have ground-fault circuit interrupter protection for personnel.

Branch Circuits

210.8 – Ground-Fault Circuit-Interrupter Protection…

Ground-fault circuit-interrupter protection for personnel shall be provided as required in 210.8(A) through (C). The ground-fault circuit-interrupter shall be installed in a readily accessible location.

(A) (1) Bathrooms
(2) Garages…
(3) Outdoors
(5) Unfinished Basements
(6) Kitchens…
(7) Sinks…
(9) Bathtubs…
(10) Laundry Areas

Branch Circuits

210.8 – Ground-Fault Circuit-Interrupter Protection…

Ground-fault circuit-interrupter protection for personnel shall be provided as required in 210.8(A) through (C). The ground-fault circuit-interrupter shall be installed in a readily accessible location.

(B) Other Than Dwelling Units. All 125-volt, single-phase, 15- and 20-ampere receptacles installed in the locations specified in 210.8(B)(1) through (8) shall have ground-fault circuit interrupter protection for personnel.

Branch Circuits

210.8 – Ground-Fault Circuit-Interrupter Protection…

Ground-fault circuit-interrupter protection for personnel shall be provided as required in 210.8(A) through (C). The ground-fault circuit-interrupter shall be installed in a readily accessible location.

(B) (1) Bathrooms
(2) Kitchens
(3) Rooftops
(4) Outdoors
(5) Sinks…
(6) Indoor Wet Locations
(7) Locker Rooms…
(8) Garages…

Branch Circuits

210.11 – Branch Circuits Required

Branch circuits for lighting and for appliances, including motor-operated appliances, shall be provided to supply the loads calculated in accordance with 220.10. In addition, branch circuits shall be provided for specific loads not covered by 220.10 where required elsewhere in this Code and for dwelling unit loads as specified in 210.11(C).

Branch Circuits

210.11 – Branch Circuits Required

(A) Number of Branch Circuits. The minimum number of branch circuits shall be determined from the total calculated load and the size or rating of the circuits used. In all installations, the number of circuits shall be sufficient to supply the load served. In no case shall the load on any circuit exceed the maximum specified by 220.18.

Branch Circuits

210.11(C) – Branch Circuits Required- Dwelling Units

(1) Small Appliance Branch Circuits. In addition to the number of branch circuits required by other parts of this section, two or more 20-ampere small-appliance branch circuits shall be provided for all receptacle outlets specified by 210.52(B).

(2) Laundry Branch Circuits. In addition to the number of branch circuits …, at least one additional 20-ampere branch circuit shall be provided to supply the laundry receptacle outlet(s) required by 210.52(F). This circuit shall have no other outlets.

Branch Circuits

210.11(C) – Branch Circuits Required- Dwelling Units

(3) Bathroom Branch Circuits. In addition to the number of branch circuits required by other parts of this section, at least one 120-volt, 20-ampere branch circuit shall be provided to supply a bathroom receptacle outlet(s). Such circuits shall have no other outlets.

Branch Circuits

210.19(A)(1) – Conductors – Min Ampacity & Size

Branch-circuit conductors shall have an ampacity not less than the maximum load to be served. Conductors shall be sized to carry not less than the larger of 210.19(A)(1)(a) or (b).

(a) Where a branch circuit supplies continuous loads or any combination of continuous and non-continuous loads, the minimum branch-circuit conductor size shall have an allowable ampacity not less than (100% of) the non-continuous load plus 125% of the continuous load.

Branch Circuits

210.19(A)(1) – Conductors – Min Ampacity & Size

Branch-circuit conductors shall have an ampacity not less than the maximum load to be served. Conductors shall be sized to carry not less than the larger of 210.19(A)(1)(a) or (b).

(b) The minimum branch-circuit conductor size shall have an allowable ampacity not less than the maximum load to be served after the application of any adjustment or correction factors.

Branch Circuits

210.19(A)(1) – Conductors – Min Ampacity & Size

Branch-circuit conductors shall have an ampacity not less than the maximum load to be served. Conductors shall be sized to carry **not less than the larger of 210.19(A)(1)(a) or (b)**.

(a) … ampacity not less than (100% of) the non-continuous load plus 125% of the continuous load.

(b) … ampacity not less than the maximum load to be served after the application of any adjustment/correction factors.

Note – do not need to apply both the 125% continuous factor and the ampacity adjustment/correction factors

Branch Circuits

210.20 – Overcurrent Protection

Branch-circuit conductors and equipment shall be protected by overcurrent protective devices that have a rating or setting that complies with 210.20(A) through (D).

Branch Circuits

210.20(A) – Continuous & Non-continuous Loads

Where a branch circuit supplies continuous loads or any combination of both continuous and non-continuous loads, the rating of the overcurrent device shall not be less than 100% of the non-continuous load plus 125% of the continuous load.

Exception: Where the assembly, including the overcurrent devices protecting the branch circuit, is listed for operation at 100 percent of its rating, the amp rating of the overcurrent device shall be permitted to be not less than the sum of the continuous and non-continuous loads.

Branch Circuits

210.20(C) – Equipment

The rating or setting of the overcurrent protective device shall not exceed that specified in the articles referenced in Table 240.3 for equipment.

Table 240.3 Other Articles

Equipment	Article
Air-conditioning and refrigerating equipment	440
Appliances	422
Assembly occupancies	518
Audio signal processing, amplification, and reproduction equipment	640
Branch circuits	210
...	
Receptacles	406
Services	230
Solar photovoltaic systems	690
Switchboards and panelboards	408
Theaters, audience areas of motion picture and television studios, and similar locations	520
Transformers and transformer vaults	450
X-ray equipment	660

Branch Circuits

210.23 – Permissible Loads

In no case shall the load exceed the branch-circuit ampere rating.

A branch circuit supplying two or more outlets or receptacles shall supply only the loads specified according to its size as specified in 210.23(A) through (D) and as summarized in 210.24 and Table 210.24.

Branch Circuits

210.23(A) – 15A & 20A Branch Circuits

A 15 or 20 ampere branch circuit shall be permitted to supply lighting units or other utilization equipment, or a combination of both, and shall comply with 210.23(A)(1) and (A)(2).

Exception: The small appliance, laundry, and bathroom branch circuits required in a dwelling unit by 210.11(C)(1), (C)(2), and (C)(3) shall supply only the receptacle outlets specified in that section.

Branch Circuits

210.23(A)(1) – Cord-and-Plug Equipment Not Fastened…

The rating of any one cord-and-plug-connected utilization equipment not fastened in place shall not exceed 80% of the branch-circuit ampere rating.

210.23(A)(2) – Utilization Equipment Fastened in Place

The total rating of utilization equipment fastened in place, other than luminaires (lighting fixtures), shall not exceed 50% of the branch-circuit ampere rating where lighting units, cord-and-plug-connected utilization equipment not fastened in place, or both, are also supplied.

Branch Circuits

210.23(B) – 30A Branch Circuits

A 30-ampere branch circuit shall be permitted to supply fixed lighting units with heavy-duty lamp-holders in other than a dwelling unit or utilization equipment in any occupancy.

A rating of any one cord-and-plug-connected utilization equipment shall not exceed 80% of the branch-circuit ampere rating.

Branch Circuits

210.23(C) – 40A & 50A Branch Circuits

A 40 or 50 ampere branch circuit shall be permitted to supply fastened-in-place cooking appliances in any occupancy.

In other than dwelling units, such circuits shall be permitted to supply fixed lighting units with heavy-duty lamp-holders, infrared heating units, or other utilization equipment.

210.23(D) – Branch Circuits Larger than 50A

Branch circuits larger than 50 amperes shall supply only non-lighting outlet loads.

Summary of Branch Circuit Requirements

210.24 – Branch-Circuit Requirements – Summary

Table 210.24 Summary of Branch-Circuit Requirements

Circuit Rating	15 A	20 A	30 A	40 A	50 A
Conductors (min. size):					
Circuit wires[1]	14	12	10	8	6
Taps	14	14	14	12	12
Fixture wires and cords — see 240.5					
Overcurrent Protection	**15 A**	**20 A**	**30 A**	**40 A**	**50 A**
Outlet devices:					
Lampholders permitted	Any type	Any type	Heavy duty	Heavy duty	Heavy duty
Receptacle rating[2]	15 max. A	15 or 20 A	30 A	40 or 50 A	50 A
Maximum Load	**15 A**	**20 A**	**30 A**	**40 A**	**50 A**
Permissible load	See 210.23(A)	See 210.23(A)	See 210.23(B)	See 210.23(C)	See 210.23(C)

[1]These gauges are for copper conductors.
[2]For receptacle rating of cord-connected electric-discharge luminaires (lighting fixtures), see 410.30(C).

Branch Circuits

210.50 – (Required Outlets) General

Receptacle outlets shall be installed as specified in 210.52 through 210.64.

(C) Appliance Receptacle Outlets. Appliance receptacle outlets installed in a dwelling unit for specific appliances, such as laundry equipment, shall be installed within 6 ft. of the intended location of the appliance

Branch Circuits

210.52(A) – Dwelling Unit Receptacle Outlets - General

In every kitchen, family room, dining room, living room, parlor, library, den, sunroom, bedroom, recreation room, or similar room or area of dwelling units, receptacle outlets shall be installed in accordance with the general provisions specified in 210.52(A)(1) through (A)(4).

(1) Spacing. Receptacles shall be installed such that no point measured horizontally along the floor line of any wall space is more than 6 ft. from a receptacle outlet.

Branch Circuits

210.52(A) – Dwelling Unit Receptacle Outlets - General

(2) Wall Space. As used in this section, a wall space shall include the following:

- **Any space 2 ft. or more in width (including space measured around corners) and unbroken along the floor line by doorways and similar openings, fireplaces, and fixed cabinets.**
- **The space afforded by fixed room dividers, such as freestanding bar-type counters or railings.**

Branch Circuits

210.52(B) – Dwelling Unit Receptacles - Small Appliances

(1) Receptacle Outlets Served. In the kitchen, … dining room or similar area of a dwelling unit, the two or more 20-amp small-appliance branch circuits required by 210.11(C)(1) shall serve all wall and floor receptacle outlets covered by 210.52(A), all countertop outlets covered by 210.52(C), and receptacle outlets for refrigeration equipment.

Exception No.2: The receptacle outlet for refrigeration equipment shall be permitted to be supplied from an individual branch circuit rated 15 amperes or greater.

Branch Circuits

210.52(B) – Dwelling Unit Receptacles - Small Appliances

(2) No Other Outlets. The two or more small-appliance branch circuits specified in 210.S2(B)(1) shall have no other outlets.

(3) Kitchen Receptacle Requirements. Receptacles installed in a kitchen to serve countertop surfaces shall be supplied by not fewer than two small-appliance branch circuits, either or both of which shall also be permitted to supply receptacle outlets in the same kitchen and in other rooms specified in 210.52(B)(1). … No small appliance branch circuit shall serve more than one kitchen.

Branch Circuits

210.52(C) – Dwelling Unit Receptacles - Countertops

In kitchens, pantries, breakfast rooms, dining rooms, and similar areas of dwelling units, receptacle outlets for countertop spaces shall be installed in accordance with 210.52(C)(1) through (C)(5).

(1) Wall Countertop Spaces. A receptacle outlet shall be installed at each wall countertop space that is 12 in. or wider. Receptacle outlets shall be installed so that no point along the wall line is more than 24 in. measured horizontally from a receptacle outlet in that space.

Branch Circuits

210.52(C) – Dwelling Unit Receptacles - Countertops

(4) Separate Spaces. Countertop spaces separated by rangetops, refrigerators, or sinks shall be considered as separate countertop spaces in applying the requirements of 210.S2(C)(1). … Each separate countertop space shall comply with the applicable requirements in 210.52(C).

(5) Receptacle Outlet Location. Receptacle outlets shall be located on or above, but not more than 20 in. above, the countertop.

Branch Circuits

210.52(D) – Dwelling Unit Receptacles - Bathrooms

In dwelling units, at least one receptacle outlet shall be installed in bathrooms within 3 ft. of the outside edge of each basin. The receptacle outlet shall be located on a wall or partition that is adjacent to the basin or basin countertop, located on the countertop, or installed on the side or face of the basin cabinet…

Branch Circuits

210.52(E) – Dwelling Unit Receptacles - Outdoors

Outdoor receptacle outlets shall be installed in accordance with 210.52(E)(1) through (E)(3).

(1) One- and Two-Family Dwellings. For a one family dwelling and each unit of a two-family dwelling that is at grade level, at least one receptacle outlet readily accessible from grade and not more than 6½ ft. above grade level shall be installed at the front and back of the dwelling.

Branch Circuits

210.52(E) – Dwelling Unit Receptacles - Outdoors

Outdoor receptacle outlets shall be installed in accordance with 210.52(E)(1) through (E)(3).

(3) Balconies, Decks, and Porches. Balconies, decks, and porches that are attached to the dwelling unit and are accessible from inside the dwelling unit shall have at least one receptacle outlet accessible from the balcony, deck, or porch. The receptacle outlet shall not be located more than 6½ ft. above the balcony, deck, or porch walking surface.

Branch Circuits

210.52(F) – Dwelling Unit Receptacles - Laundry Areas

In dwelling units, at least one receptacle outlet shall be installed in areas designated for the installation of laundry equipment.

Branch Circuits

210.52(G) – Dwelling Unit Receptacles - Basements/Garages/…

For a one-family dwelling, at least one receptacle outlet shall be installed in the areas specified in 210.52(G)(1) thru (3). These receptacles shall be in addition to receptacles required for specific equipment.

(1) Garages. In each attached garage… The branch circuit supplying this receptacle(s) shall not supply outlets outside of the garage…

(3) Basements. In each separate unfinished portion of a basement.

Branch Circuits

210.52(H) – Dwelling Unit Receptacles - Hallways

In dwelling units, hallways of 10 ft. or more in length shall have at least one receptacle outlet. As used in this subsection, the hallway length shall be considered the length along the centerline of the hallway without passing through a doorway.

210.52(I) – Dwelling Unit Receptacles - Foyers

Foyers that are not part of a hallway in accordance with 210.52(H) and that have an area that is greater than 60 ft^2 shall have a receptacle(s) located in each wall space 3 ft. or more in width.

Branch Circuits

210.70 – Lighting Outlets Required

Lighting outlets shall be installed where specified in (A)…(C).

(A)(1) Dwelling Units – Habitable Rooms. At least one wall switch-controlled lighting outlet shall be installed in every habitable room and bathroom.

(A)(2) Dwelling Units – Additional Locations

(A)(3) Dwelling Units – Storage or Equipment Spaces

Design Example

Electrical System for a Single-Family Dwelling

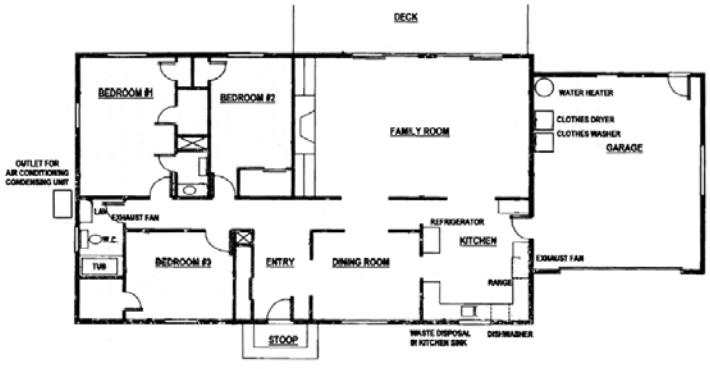


FIGURE 19.12 Layout of locations of convenience receptacles and other outlets for design example.

Common Design Guidelines

Convenience Outlets

- **Convenience outlets in habitable spaces should be placed such that no point along the floor-line of any useable wall space is no more than 6 feet from an outlet in that wall. (I.e. – receptacles should be placed ≤ 12 feet apart)**
- **Any wall 2 feet or more in length must have a convenience receptacle.**

Common Design Guidelines

Switches

- **Wall switches should be located at the latch-side of doors, within the room where the lighting outlets are located.**
- **Wall switches should be located at each entry to a habitable space.**

Common Design Guidelines

Building Exterior

- One or more lighting outlets should be located at or near each building entrance.
- Weatherproof convenience receptacles should be provided on exterior walls (or other predetermined locations) for outside work. GFCI protection is required.
- One or more outlets may be required for exterior equipment. (HVAC, etc.)

Common Design Guidelines

Other Guidelines (Dwellings)

- At least two 20A, small-appliance circuits must be provided for countertop areas in the kitchen, with at least one receptacle for each two linear-feet of workspace. This is in addition to any circuits required for ranges, refrigerators, etc.
- At least one GFCI-protected receptacle must be provided within 3 feet of each lavatory basin in all bathrooms.

Design Example

Electrical System for a Single-Family Dwelling

Part I – Branch Circuit Design

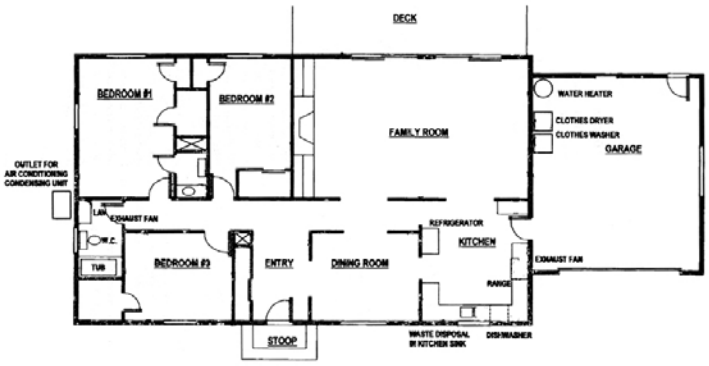


FIGURE 19.12 Layout of locations of convenience receptacles and other outlets for design example.

Design Example – Branch Circuits

STEP 1 – Locate the convenience receptacles on the floor plan using the appropriate symbols.

Notes: Convenience receptacles are intended for general-purpose use. Receptacles used to supply specific appliances will be placed during the next step.

Switch placement, conductor sizing, and circuit layout are not part of this step.

Design Example – Branch Circuits

STEP 1 – Locate the convenience receptacles on the floor plan using the appropriate symbols.

Initial Placement Rules

- **6ft-Rule for receptacle placement… no more than 12ft separation distance between adjacent receptacles**
- **Receptacles are preferably located near wall-ends instead of centers**
- **Walls ≥ 2ft in length must have receptacle**

Design Example – Branch Circuits

STEP 1 – Locate the convenience receptacles on the floor plan using the appropriate symbols.

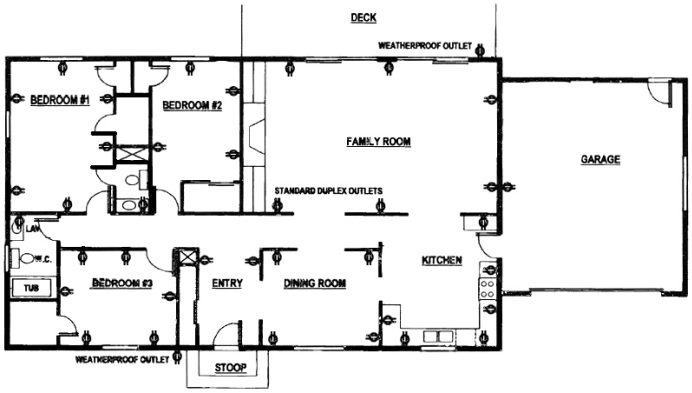
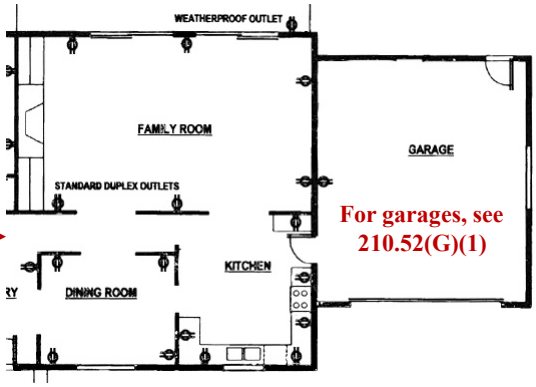


FIGURE 19.12 Layout of locations of convenience receptacles and other outlets for design example.

Design Example – Branch Circuits

Note – Some areas, such as garages, are not considered habitable spaces. These areas may be addressed elsewhere in the code, but if not, logic should be used when placing receptacles in these locations.

For hallway areas see 210.52(H)



For garages, see 210.52(G)(1)

Design Example – Branch Circuits

STEP 2 – Locate all of the appliance and equipment outlets on the floor plan.

- **Create a list of all (known) appliances and equipment that will require electricity.**
- **Include their load requirements and/or any other important design constraints**

  (i.e. – do the items require an individual circuit, etc.)

Design Example – Branch Circuits

STEP 2 – Locate all of the appliance and equipment outlets on the floor plan.

• Water Heater	FI	3,800VA	(Manufacturer's Data)
• Clothes Dryer	FI	4,400VA	(Manufacturer's Data)
• Dishwasher	FI	1,000VA	(Manufacturer's Data)
• Range	FI	11,700VA	(Manufacturer's Data)
• Waste Disposal	FI	1000VA	(Manufacturer's Data)
• Air Conditioner	FI	6300VA	(Manufacturer's Data)
• Garage Door Opener	FI	1000VA	(Manufacturer's Data)
• Clothes Washer	I	1,200VA	(Table 19.12)
• Refrigerator		600VA	(Table 19.12)
• Exhaust Fan/Ventilator		500VA	(Tables 19.12 & 19.16)

(F – Fixed Load, I – Individual Circuit)

Design Example – Branch Circuits

STEP 2 – Locate all of the appliance and equipment outlets on the floor plan.

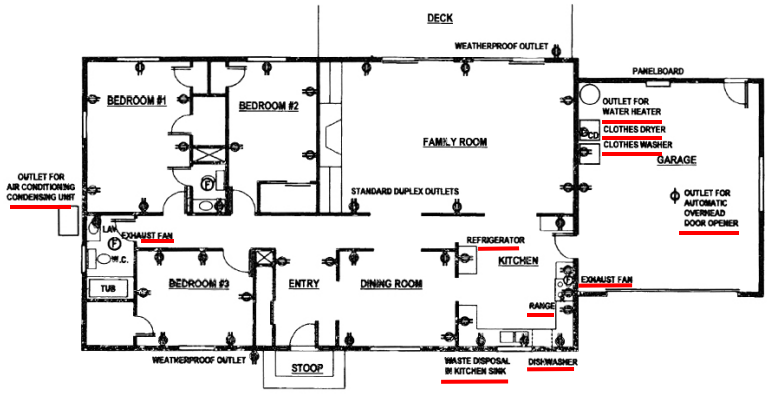


FIGURE 19.12 Layout of locations of convenience receptacles and other outlets for design example.

Design Example – Branch Circuits

STEP 3 – Locate all of the lighting fixtures on the floor plan.

(using appropriate symbols)

Included with this step:

- **Make a list of types of luminaires (lights) and their load requirements.**
- **Include the list as a Luminaire Schedule in the design specifications or on the electrical drawings.**

Design Example – Branch Circuits

STEP 3 – Locate all of the lighting fixtures on the floor plan.

(using appropriate symbols)

Fixture Designation	Fixture Type	Description	Lamp Type	Mounting
A 75W R30	A	Recessed downlight or similar Halo's H7UICT, with No. 310W White Collex Baffle cone and white trim ring.	75W R30	Ceiling
A1 75W R30	A1	Recessed downlight or similar Halo's H7UICT, with No. 310 Black Collex Baffle cone and white trim ring.	75 W R30	Ceiling
B 75W R30	B	Recessed downlight or similar Halo's H7T, with No. 310W White Collex Baffle cone and white trim ring.	75W R30	Ceiling
	C	Owner furnished hung chandelier/ceiling mounted light fixture.		Ceiling
D 90W PAR38	D	Recessed downlight designed for sloped ceilings, or similar Halo's H47ICT, with No. 14199 Collex Baffle and white trim ring.	90W PAR38	Sloped ceiling
E1 75W	E1	Recessed combination light fixture/exhaust fan unit similar to Nutone's "QuieTTest" Model QT140L. Fan to be capable of delivering a minimum of 150 cfm and must have a sound rating of 2.0 sones or better. Provide new exhaust ductwork to exterior in accordance with manufacturer's specifications.	75W	Ceiling
E2 75W	E2	Recessed exhaust fan unit similar to Nutone's "QuieTTest" Model QT200. Fan to be capable of delivering a minimum of 150 cfm and must have a sound rating of 2.0 sones or better. Provide new exhaust ductwork to exterior in accordance with manufacturer's specifications.	75W	Ceiling
F 40RS	F	Surface mounted fluorescent fixture with prismatic lens, 48" long, sim. to KLP's Model MWB140A.	40RS	Ceiling
	G	Owner furnished exterior wall mounted fixture.		Wall

Figure 19.14 (partial) – An example of a light fixture (luminaire) schedule.

Design Example – Branch Circuits

STEP 3 – Locate all of the lighting fixtures on the floor plan.

(See NECA100 – Symbols for Electrical Construction Drawings)

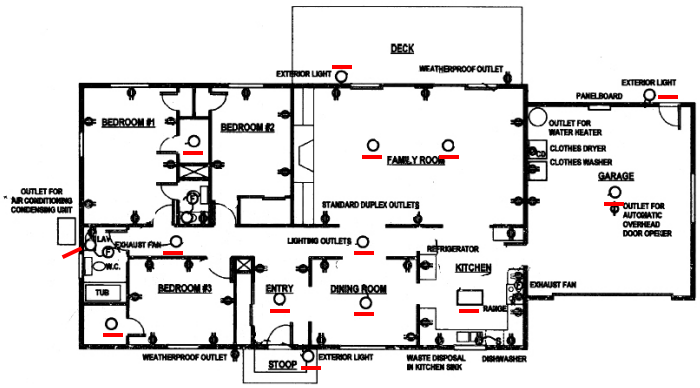


FIGURE 19.13 Layout of lighting outlets and related switches for lights and outlets for design example.

Design Example – Branch Circuits

Consider the placement and type of luminaires that will be used in the following locations:

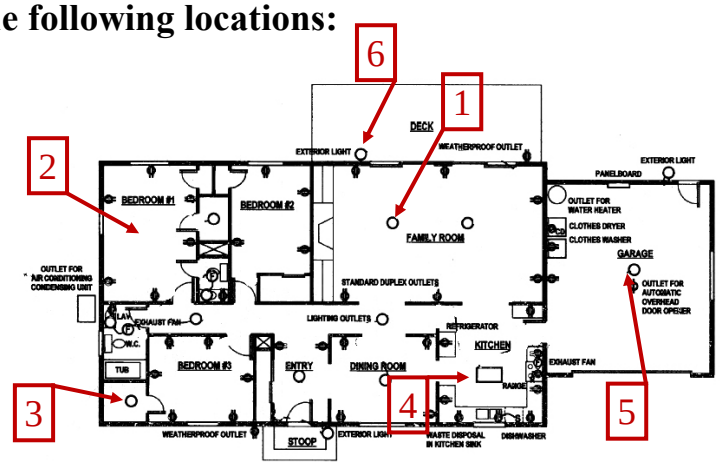


FIGURE 19.13 Layout of lighting outlets and related switches for lights and outlets for design example.

Design Example – Branch Circuits

STEP 4 – Layout the switches that control the lights, etc...

- **Rooms w/ more than one entrance should be equipped w/ multiple-switch controls**
- **Wall switches should be placed in room where the lighting outlets are located**
- **Wall switches should be placed at latch-side of doors**

Design Example – Branch Circuits

STEP 4 – Layout the switches that control the lights, etc...

Draw the connection from each switch to all of the lighting outlets that are controlled by that switch.

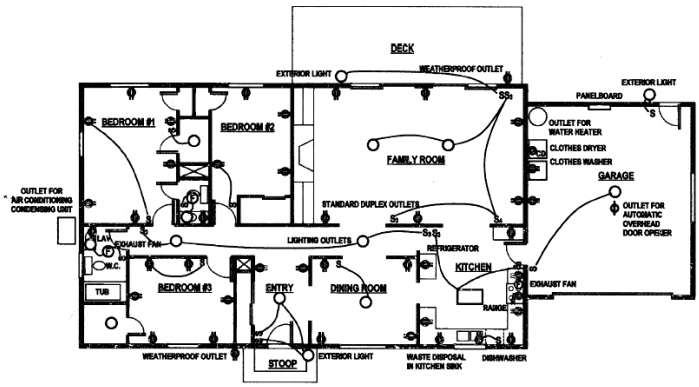


FIGURE 19.13 Layout of lighting outlets and related switches for lights and outlets for design example.

Design Example – Branch Circuits

STEP 5 – Locate the panelboard(s) in a convenient location.

Note – The location(s) may be predetermined by the architectural design of the building.

The location of the panelboard for this example is in the garage, as shown in the previous figures.

Design Example – Branch Circuits

STEP 6 – Layout individual branch circuits serving the large appliances and equipment.

Note – A single, fixed-in-place load that is supplied by a general-purpose branch circuit is limited to no more than 50% of the circuit's rating.

Design Example – Branch Circuits

STEP 6 – Layout individual branch circuits serving the large appliances and equipment.

Individual branch circuits are generally required for:

- Kitchen Ranges
- Ovens
- Built-in Microwaves
- Waste Disposals
- Dishwashers
- Clothes Washers
- Clothes Dryers
- Electric Water Heaters
- Furnaces
- Boiler Pump Motors
- HVAC Air-Handlers
- Large Machinery (elevators, table saws, etc.)
- Large Equipment (copy machines, compressors, etc.)

Design Example – Branch Circuits

STEP 6 – Layout individual branch circuits serving the large appliances and equipment.

Show the "home-run" to the panelboard from each outlet on the drawing.

Note – Although the circuit numbers do not need to be determined during this step, it may be helpful to begin assigning them at this point instead of waiting until step 8.

Design Example – Branch Circuits

STEP 6 – Layout individual branch circuits serving the large appliances and equipment.

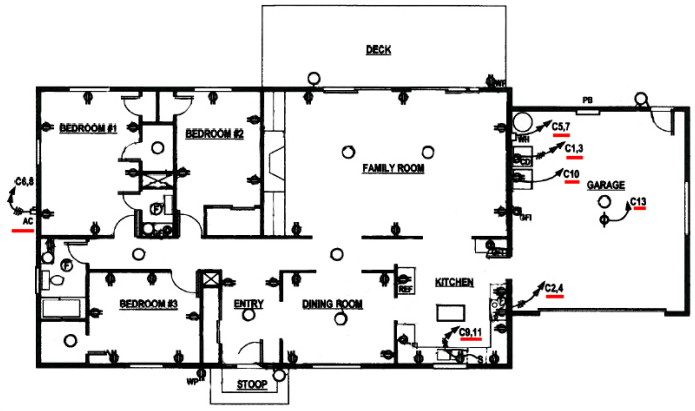


FIGURE 19.15 Circuit layout and numbering for design example.

Design Example – Branch Circuits

STEP 7 – Layout circuiting for the lighting and convenience receptacles on general-purpose branch circuits.

- **15A & 20A circuits for are used for small appliances, convenience receptacles, and luminaires**
- **Be sure to comply with "code" requirements**
- **It is good practice to be conservative:**
  - **Limit each 15A circuit to 1000-1200VA**
  - **Limit each 20A circuit to 1300-1600VA**
  - **Limit convenience receptacles to 6-8 per circuit**

Design Example – Branch Circuits

STEP 7 – Layout circuiting for the lighting and convenience receptacles on general-purpose branch circuits.

- **Draw a connection between all of the outlets served by a specific branch circuit and show the "home-run" to panelboard at a logical location for that circuit.**
- **Organize circuits in a logical manner based on the layout of the building.**

Design Example – Branch Circuits

STEP 7 – Layout circuiting for the lighting and convenience receptacles on general-purpose branch circuits.

- **Show a connection from each switch to one of the outlets or luminaires controlled by that switch.**
- **Show a connection between all of the switches for a multiple-switch controlled outlet.**

Design Example – Branch Circuits

STEP 7 – Layout circuiting for the lighting and convenience receptacles on general-purpose branch circuits.

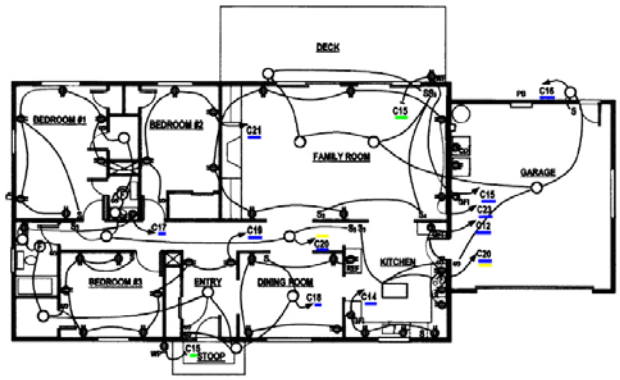


FIGURE 19.15 Circuit layout and numbering for design example.

Design Example – Branch Circuits

STEP 7 – *The following figure shows one of the general-purpose branch circuits (C23) highlighted in orange.*

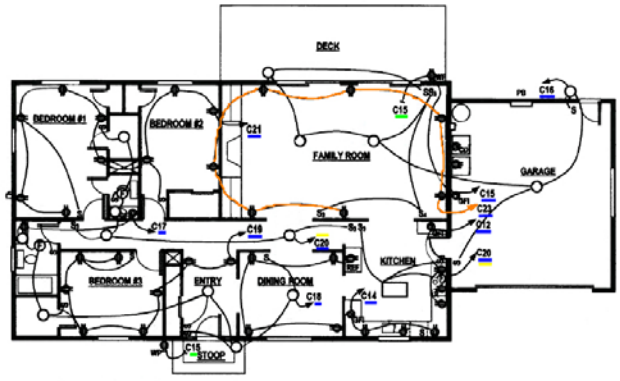


FIGURE 19.15 Circuit layout and numbering for design example.

Design Example – Branch Circuits

STEPS 6 & 7 – ***The following figure shows all of the branch circuits on the same diagram.***

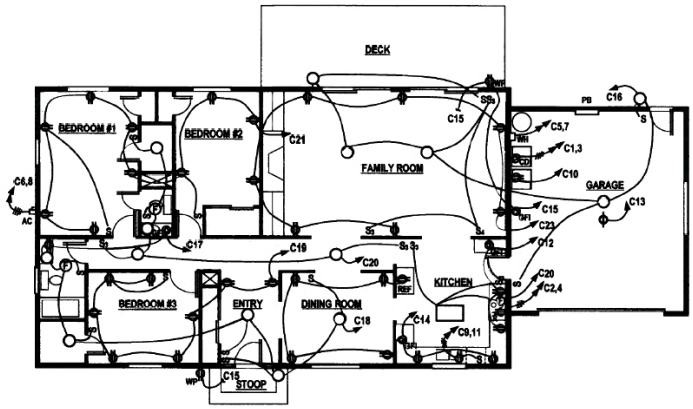


FIGURE 19.15 Circuit layout and numbering for design example.

Design Example – Branch Circuits

STEP 8 – Layout the panel circuits.

- **Choose a panel configuration based on the type and number of circuits that the panel will supply.**
- **The panel rating will be determined after the load calculations are complete.**
- **Be sure to allow for future expansion.**

Design Example – Branch Circuits

STEP 8 – Layout the panel circuits.

TABLE 18.4 COMMON PANELBOARD AND LOAD CENTER RATINGS AND CAPACITIES.

Single-Phase, Three-Wire Panelboards and Load Centers

Frame Size	Disconnect Rating	Capacity
Amperes	Amperes	Maximum Number of Circuit Breakers
50	50	8, 10, 12
100	100	6, 8, 10, 12, 14, 16, 18, 20
125	125	6, 8, 10, 12, 14, 16, 18, 20, 24
150	150	20, 24, 28, 30
200	200	20, 24, 28, 30, 36, 40

Three-Phase, Four-Wire Panelboards

Frame Size	Disconnect Rating	Capacity
Amperes	Amperes	Maximum Number of Poles
100	100	16, 18, 20, 22, 24, 26, 28, 30
125	125	20, 22, 24
225	225	22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42
400	400	30, 42

Design Example – Branch Circuits

STEP 8 – Layout the panel circuits.

- **Create a Panelboard Layout diagram that shows the circuit #'s, circuit descriptions, expected loads, and the ratings of the circuit breakers.**
- **Create a Wiring Layout diagram showing circuit #'s, circuit descriptions, and the wire sizes required for each circuit.**

Design Example – Branch Circuits

STEP 8 – Layout the panel circuits.

150A, 24 POLE PANELBOARD LAYOUT
120/240V, 1Φ, 3-WIRE

CIRCUIT NO.	CIRCUIT DESCRIPTION	CONNECTED LOAD VA	BREAKER A	HOT LEGS A	HOT LEGS B	BREAKER A	CONNECTED LOAD VA	CIRCUIT DESCRIPTION	CIRCUIT NO.
1	CLOTHES DRYER	2200	30			50	5850	RANGE	2
3	CLOTHES DRYER	2200	30			50	5850	RANGE	4
5	WATER HEATER	1900	30			40	3150	AIR CONDITIONER	6
7	WATER HEATER	1900	30			40	3150	AIR CONDITIONER	8
9	DISHWASHER	1000	20			20	1000	LAUNDRY	10
11	WASTE DISPOSAL	1000	20			20	1500	SMALL APPLIANCE	12
13	GARAGE DOOR OPENER	1000	20			20	1500	SMALL APPLIANCE	14
15	GFCI RECEPTACLES	1500	20			20	800	LIGHTS	16
17	GFCI RECEPTACLES	1500	20			20	800	LIGHTS	18
19	RECEPTACLES	1600	20			20	800	LIGHTS	20
21	RECEPTACLES	1600	20					SPARE	22
23	RECEPTACLES	1600	20					SPARE	24

FIGURE 19.16 Panelboard and wiring layout and numbering for design example.

Panelboard Layout Diagram

Design Example – Branch Circuits

STEP 8 – Layout the panel circuits.

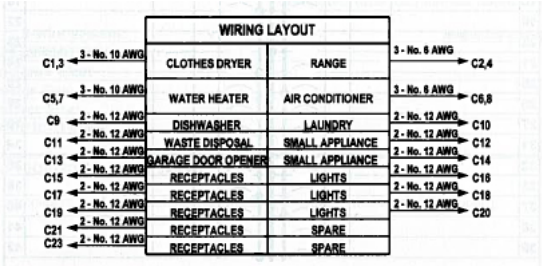


FIGURE 19.16 Panelboard and wiring layout and numbering for design example.

Wiring Layout Diagram

System Design – Load Calculation

Article 220 of the NEC covers branch-circuit, feeder, and service load calculations:

- **Part I – General Requirements**
- **Part II – Branch-Circuit Loads**
- **Part III – Feeder and Service Loads**
- **Part IV – Optional Feeder & Service Loads**
- **Part V – Farm Loads**

Note – This presentation will focus on "Non-Dwelling Unit" types of facilities.

System Design – Load Calculation

Table 220.3 lists articles that provide additional requirements to, or modifications of, those stated within article 220.

Table 220.3 Additional Load Calculation References

Calculation	Article	Section (or Part)
Air-Conditioning and Refrigerating Equipment, Branch-Circuit Conductor Sizing	440	Part IV
Cranes and Hoists, Rating and Size of Conductors	610	610.14
Electric Welders, ampacity calculations	630	630.11, 630.31
Electrically Driven or Controlled Irrigation Machines	675	675.7(A), 675.22(A)
Electrolytic Cell Lines	668	668.3(C)
Electroplating, Branch-Circuit Conductor Sizing	669	669.5
Elevator Feeder Demand Factors	620	620.14
Fire Pumps, Voltage Drop (mandatory calculation)	695	695.7
Fixed Electric Heating Equipment for Pipelines and Vessels, Branch-Circuit Sizing	427	427.4
Fixed Electric Space Heating Equipment, Branch-Circuit Sizing	424	424.3
Fixed Outdoor Electric Deicing and Snow-Melting Equipment, Branch-Circuit Sizing	426	426.4
Industrial Machinery, Supply Conductor Sizing	670	670.4(A)
Marinas and Boatyards, Feeder and Service Load Calculations	555	555.12
Mobile Homes, Manufactured Homes, and Mobile Home Parks, Total Load for Determining Power Supply	550	550.18(B)
Mobile Homes, Manufactured Homes, and Mobile Home Parks, Allowable Demand Factors for Park Electrical Wiring Systems	550	550.31
Motion Picture and Television Studios and Similar Locations — Sizing of Feeder Conductors for Television Studio Sets	530	530.19
Motors, Feeder Demand Factor	430	430.26
Motors, Multimotor and Combination-Load Equipment	430	430.25
Motors, Several Motors or a Motor(s) and Other Load(s)	430	430.24
Over 600 Volt Branch Circuit Calculations	210	210.19(B)
Over 600 Volt Feeder Calculations	215	215.2(B)
Phase Converters, Conductors	455	455.6
Recreational Vehicle Parks, Basis of Calculations	551	551.73(A)
Sensitive Electrical Equipment, Voltage Drop (mandatory calculation)	647	647.4(D)
Solar Photovoltaic Systems, Circuit Sizing and Current	690	690.8
Storage-Type Water Heaters	422	422.11(E)
Theaters, Stage Switchboard Feeders	520	520.27

System Design – Load Calculation

220 Part II – Branch Circuit Loads

Branch-circuit loads shall be calculated as shown in articles 220.12, 220.14, and 220.16.

- **220.12 – Lighting Loads**
- **220.14 – Other Loads**
- **220.16 – Additions to Existing Installations**

System Design – Load Calculation

220.12 – Lighting Loads

A unit load of not less than that specified in Table 220.12 for occupancies specified therein shall constitute the minimum lighting load.

Table 220.12 General Lighting Loads by Occupancy

Type of Occupancy	Unit Load	
	Volt-Amperes per Square Meter	Volt-Amperes per Square Foot
Armories and auditoriums	11	1
Banks	39[b]	3½[b]
Barber shops and beauty parlors	33	3
Churches	11	1
Clubs	22	2
Court rooms	22	2
Dwelling units[a]	33	3
Garages — commercial (storage)	6	½
Hospitals	22	2
Hotels and motels, including apartment houses without provision for cooking by tenants[a]	22	2
Industrial commercial (loft) buildings	22	2
Lodge rooms	17	1½
Office buildings	39[b]	3½[b]
Restaurants	22	2
Schools	33	3
Stores	33	3
Warehouses (storage)	3	¼
In any of the preceding occupancies except one-family dwellings and individual dwelling units of two-family and multifamily dwellings:		
Assembly halls and auditoriums	11	1
Halls, corridors, closets, stairways	6	½
Storage spaces	3	¼

System Design – Load Calculation

220.12 – Lighting Loads

The floor area for each floor shall be calculated from the outside dimensions of the building, dwelling unit, or other area involved.

For dwelling units, the calculated floor area shall not include open porches, garages, or unused or unfinished spaces not adaptable for future use.

Table 220.12 General Lighting Loads by Occupancy

Type of Occupancy	Unit Load	
	Volt-Amperes per Square Meter	Volt-Amperes per Square Foot
Armories and auditoriums	11	1
Banks	39[b]	3½[b]
Barber shops and beauty parlors	33	3
Churches	11	1
Clubs	22	2
Court rooms	22	2
Dwelling units[a]	33	3
Garages — commercial (storage)	6	½
Hospitals	22	2
Hotels and motels, including apartment houses without provision for cooking by tenants[a]	22	2
Industrial commercial (loft) buildings	22	2
Lodge rooms	17	1½
Office buildings	39[b]	3½[b]
Restaurants	22	2
Schools	33	3
Stores	33	3
Warehouses (storage)	3	¼
In any of the preceding occupancies except one-family dwellings and individual dwelling units of two-family and multifamily dwellings:		
Assembly halls and auditoriums	11	1
Halls, corridors, closets, stairways	6	½
Storage spaces	3	¼

System Design – Load Calculation

220.12 – Lighting Loads

The value achieved by applying Table 220.12 is the minimum allowable calculated lighting load for the facility.

- **If the installed load (based on luminaire ratings) is <u>less</u> than the minimum calculated load, the minimum calculated load still applies.**
- **If the installed load (based on luminaire ratings) is <u>greater</u> than the minimum calculated load, then the installed load should be applied.**

System Design – Load Calculation

220.12 – Lighting Loads

Note – the minimum calculated lighting load from Table 220.12 includes any general-use receptacles or outlets used for general lighting purposes.

System Design – Load Calculation

220.14 – Other Loads – All Occupancies

In all occupancies, the minimum load for each outlet for general-use receptacles and outlets not used for general illumination shall not be less than that calculated in 220.14(A) through (L), the loads shown being based on nominal branch-circuit voltages.

System Design – Load Calculation

220.14 – Other Loads – All Occupancies

The minimum load for each outlet for general-use receptacles and outlets not used for general illumination shall not be less than that calculated in 220.14(A) through (L).

- **(A) – Specific Appliances or Loads**
- **(C) – Motor Loads**
- **(D) – Luminaires**
- **(E) – Heavy-Duty Lamp Holders**
- **(H) – Fixed Multi-Outlet Assemblies**
- **(I) – Receptacle Outlets**
- **(J) – Dwelling Occupancies**
- **(L) – Other Outlets**

System Design – Load Calculation

220.14(A) – Specific Appliances or Loads

An outlet for a specific appliance or other load not covered in 220.14(B) through (L) shall be calculated based on the ampere rating of the appliance or load served.

220.14(C) – Motor Loads

Outlets for motor loads shall be calculated in accordance with the requirements in 430.22, 430.24, and 440.6.

- **430.22 – Single Motor.**
- **430.24 – Several Motors or Motors and Other Loads.**
- **440.6 – AC/Refrigeration Equipment - Ampacity and Rating.**

System Design – Load Calculation

430.22(A) – Single Motor – General

Conductors that supply a single motor used in a continuous duty application shall have an ampacity of not less than 125 percent of the motor's full-load current rating as determined by 430.6(A)(1).

System Design – Load Calculation

430.24 – Several Motors or Motors & Other Loads

Conductors supplying several motors, or a motor(s) and other load(s), shall have an ampacity not less than 125 percent of the full-load current rating of the highest rated motor plus the sum of the full-load current ratings of all the other motors in the group, as determined by 430.6(A), plus the ampacity required for the other loads.

System Design – Load Calculation

440.6 – (AC/Refrig. Equip.) Ampacity and Rating

The size of conductors for equipment covered by this article shall be selected from Table 310.16 through Table 310.19 or calculated in accordance with 310.15 as applicable. The required ampacity of conductors and rating of equipment shall be determined according to 440.6(A) and 440.6(B).

System Design – Load Calculation

220.14(D) – Luminaires

An outlet supplying luminaires shall be calculated based on the maximum volt-ampere rating of the equipment and lamps for which the luminaires are rated.

220.14(E) – Heavy-Duty Lamp Holders

Outlets for heavy-duty lamp holders shall be calculated at a minimum of 600 volt·amperes.

System Design – Load Calculation

220.14(H) – Fixed Multi-Outlet Assemblies

Fixed multi-outlet assemblies used in other than dwelling units or the guest rooms or guest suites of hotels or motels shall be calculated in accordance with (H)(1) or (H)(2)…

Multi-Outlet Assembly

System Design – Load Calculation

220.14(H) – Fixed Multi-Outlet Assemblies

(1) Where appliances are unlikely to be used simultaneously, each 1.5 m (5 ft) or fraction thereof of … shall be considered as one outlet of not less than 180 volt-amperes.

(2) Where appliances are likely to be used simultaneously, each 30 cm (1 ft) or fraction thereof shall be considered as an outlet of not less than 180 volt-amperes.

System Design – Load Calculation

220.14(I) – Receptacle Outlets

Except as covered in 220.14(J) and (K) [Dwellings, Banks and Offices], receptacle outlets shall be calculated at not less than 180 volt-amperes for each single or for each multiple receptacle on one yoke.

A single piece of equipment consisting of a multiple receptacle comprised of four or more receptacles shall be calculated at not less than 90 volt-amperes per receptacle.

System Design – Load Calculation

220.14(I) – Receptacle Outlets

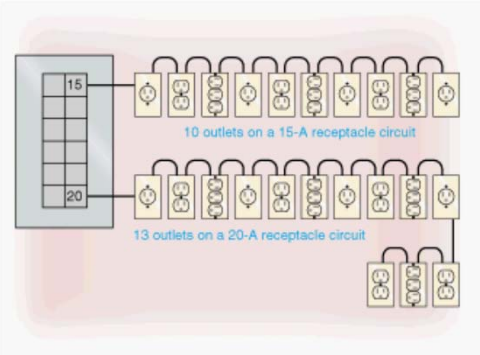
This provision shall not apply to the receptacle outlets specified in 210.11(C)(1) and (C)(2).

I.e. – it does not cover the two 20A small-appliance branch circuits required in the kitchen area or the 20A branch circuit required in the laundry area of a dwelling unit .

System Design – Load Calculation

220.14(I) – Receptacle Outlets

Note – Based on 220.14(I), the maximum number of outlets permitted on 15A and 20A branch circuits is:



System Design – Load Calculation

220.14(J) – Dwelling Occupancies

In one-family, …, and multifamily dwellings and in guest rooms … of hotels and motels, the outlets specified in (J)(1), (J)(2), and (J)(3) are included in the general lighting load calculations of 220.12. No additional load calculations shall be required for such outlets.

(1) All general-use receptacle outlets of 20-ampere rating or less, including receptacles connected to the circuits in 210.11(C)(3)

210.11(C)(3) – *Bathroom Branch Circuits*

System Design – Load Calculation

220.14(J) – Dwelling Occupancies

In one-family, …, and multifamily dwellings and in guest rooms … of hotels and motels, the outlets specified in (J)(1), (J)(2), and (J)(3) are included in the general lighting load calculations of 220.12. No additional load calculations shall be required for such outlets.

(2) The receptacle outlets specified in 210.52(E) & (G)

210.52(E)&(G) – *Outdoor Outlets / Basements & Garages*

(3) The lighting outlets specified in 210.70(A) & (B)

210.70(A)&(B) – *Switched Lighting Receptacles*

System Design – Load Calculation

220.14(K) – Banks or Office Buildings

In banks or office buildings, the receptacle loads shall be calculated to be the larger of (1) or (2):

(1) The computed load from 220.14

(2) 11 volt-amps/m^2 or 1 volt-amp/ft^2

220.14(L) – Other Outlets

Other outlets not covered in 220.14(A) through (K) shall be calculated based on 180 volt-amperes per outlet.

System Design – Load Calculation

220.18 – Maximum Loads

The total load shall not exceed the rating of the branch circuit, and it shall not exceed the maximum loads specified in 220.18(A) through (C) under the conditions specified therein.

System Design – Load Calculation

220.18(A) – Motor-Operated and Combo. Loads

Where a circuit supplies only motor-operated loads, Article 430 shall apply.

Where a circuit supplies only air-conditioning and/or refrigerating equipment, Article 440 shall apply.

For circuits supplying motor-operated utilization equip. that is fastened in place and has a motor larger than 1/8 hp along with other loads, the calc. load shall be 125% of the largest motor load plus the sum of the other loads.