

**Electrical Power Plans for Building Construction –
A Description of Electrical Load Calculations**

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Electrical Power Plans for Building Construction – Basics for Electrical Load Calculations

I. INTRODUCTION

This paper is to provide information to contractors, engineers, and others in developing and/or understanding an electrical plan for buildings. While the electrical energy is the capacity or strength of an electrical system, such as the electrical circuit(s) or the electrical device(s), the “electrical power” is the input to this system. Representing power by an equation, then

$$P = (V) (I), \quad [1]$$

where P is electrical power expressed in watts (W), V is voltage expressed in volt (V), I is current expressed in ampere (A). An electrical ‘load’ is the required power for a closed circuit system to be functioning.

This paper shall not discuss in detail the source of electrical power and how the required load for a building is determined. It assumes that the source of electrical power is sufficient and the required circuits or the types of devices have been identified for the building. Therefore, It concentrates on the calculations of electrical loads for each individual circuit and for the entire electrical system. For simplicity, the electrical load for a building or facility can also be represented by the total current (I) or the total amount of amperes.

The objectives of this paper are:

- (1) To present information on the calculation of loads for the electrical system of a building so that one can read or prepare an electrical plan for the building.
- (2) As part of the construction plans, one is able to understand and take the electrical plan for building permit applications.
- (3) With a full understanding of the electrical plan, the contractor can better estimate the cost of a construction project.

II. TERMINOLOGY

Following terms are essential for understanding of load calculations or preparing an electrical plan for a building:

- (1) **Current (I)** is the flow of the electrical charge for a given time period. The electrical charge represents a number of electrons. The unit of current is Coulombs per second, or Ampere (A/ Amp). A current of an amp is 1 Coulomb of electrons passing through any point in one second.

(2) **Voltage (V)** is the work that causes the current to flow. It is the required work to move a charge from one point to another point of an electrical circuit. The unit of voltage is volt (V).

(3) **Resistance (R)** is an element to limit the current flow. $I = V/R$. Without a resistance, or $R = 0$, the current shall surge without limit and thus causes dangerous conditions. The unit of resistance, R, is in ohms.

(4) **Power (P)** is an input to the electrical circuit or a circuit system. It is the rate of electrical energy delivered to the circuit system. Mathematically, $P = VI$, or $P = IR^2$ (Reference 1, Cathey and Nasar). Power is expressed in the unit of watts.

(5) **Load (L)** is the power consumed in a closed circuit system. The “average load” is an average value of the power consumed in the circuit system during a specific time period. The “maximum load” is the maximum value of the consumed loads during the same time period under all conditions. The “demand load” is the required power to satisfy an adequate operation of a device or a circuit system. Load can be expressed in the same unit, i.e., watts.

(6) **NEC** is National Electrical Code (Reference 2, Rosenberg), which is a minimum safety standard for electrical installations. NEC is a common one of many codes and standards published by the National Fire Protection Association (NFPA). Load calculations discussed in this paper is in accordance with the standards of NEC.

(7) **Phase** is a wave of alternating current in a sinusoidal form. This type of sine wave moves in a series of 360° cycles (see Figure 1). **A single phase circuit** has only one sine-wave, alternating current flow; while **a three phase circuit** consists of three, sine-wave, alternating current flows. The three different waves are displaced in 120 degrees from each other (Figure 2). Most electric power sources in the United States are either three-phase or single phase, although there is two-phase source of power. The three phase power is more efficient and often used in commercial and industrial facilities. The single phase power is often referred to under many situations. It can also be derived from a three phase circuit. In general, single phase power (Figure 3) has a lower voltage and is often used for domestic purposes.

(8) **Power efficiency (E)** is a ratio of the power output from an electrical system to the power input into the system. There is a “system loss” from input to output. Guyer (J. P. Guyer, Reference 3) has estimated the system loss for a building, which is about 6 percent. Therefore “E” is always less than 1 or below 100 percent. In this connection, the connected load or the required power for the circuit system has to be more than the specified power input. In a mathematical form, $L = (VI)/E$, where E is power efficiency.

(9) **Ratios of single phase loads** refer to two different set of loads derived from a three phase circuit. For a symmetrical, three phase, four wire wye system (see Figure 4), the voltage between any two phases (V_{LL}) is greater than the voltage between any phase and the neutral wire (V_{LN}). The multiplier of V_{LL} to V_{LN} is $3^{0.5}$, i.e., $(V_{LL})/(V_{LN}) = 3^{0.5} = 1.733$.

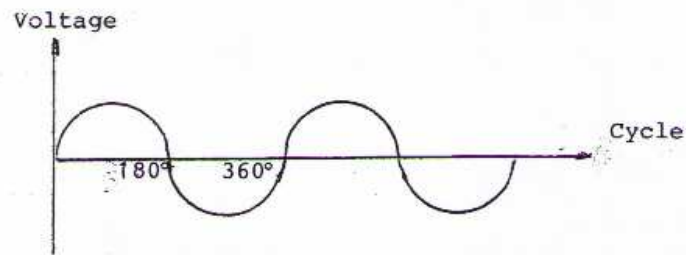


Figure 1. A single-phase power system

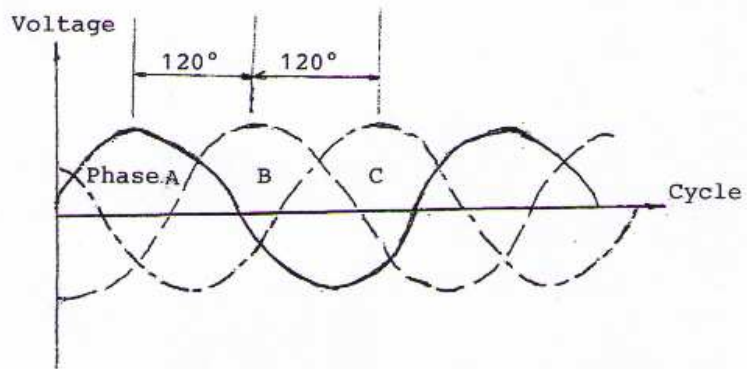
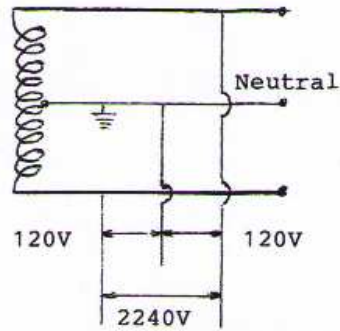
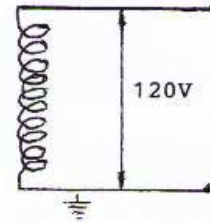


Figure 2. A three-phase power system

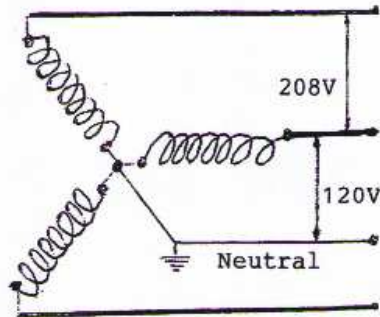


(a) A single phase 3-wire circuit

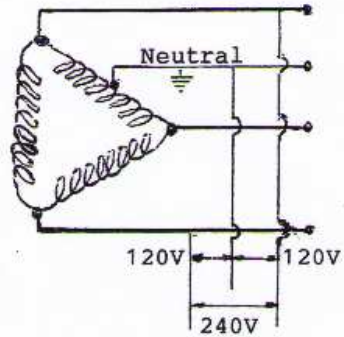


(b) A simple 2-wire circuit

Figure 3. Single phase circuits (3(a) is popular)



(a) A 3 phase 4-wire Wye circuit



(b) A 3 phase 4-wire Delta circuit

Figure 4. Three phase multi-wire circuits

For the same token, this ratio for a balanced, three phase, four wire delta system is 2.0, i.e., $(V_{LL})/(V_{LN}) = 2.0$. Figures 4(a) and 4(b) presents the above-described wye and delta system. This paper shall not discuss the details of these two different systems.

(10) **Transformer** is a machinery to transform electrical power from one circuit to another. For an economic or consumptive reason, the electrical voltage of a circuit can be changed from low to high, or vice versa, through a transformer. The current of the new circuit is increased or decreased at the same time. There are different types of transformer. In particular, an “auto transformer” is one where the ratio between the high voltage and the transformed low voltage is less than two (2). This transformation is cost effective.

(11) **Conductors and American Wire Gauge (AWG)**: Conductors are metal wires, mostly copper, which carries flow or current for an electrical system. A current-carry conductor is insulated from possible outside contacts. For commercial or industrial uses, conductors are installed in metal conduits or raceways. AWG is a standardized wire gauge system used in North America for measurement of diameters of conductors. Larger conductors have smaller AWG numbers.

(12) **Raceway and Auxiliary Gutter**: Raceway is an enclosed channel, in metal or nonmetallic form, used for holding electrical wires or conductors. Auxiliary gutter is a sheet metal, or nonmetallic trough with a removable cover, to be used in non-raceway location. It encloses conductors and distributes them to places such as meter centers, distribution boxes, and/or similar points of wiring systems.

(13) **Factors for load calculations and analysis** refer to some equations or ratios (Reference 3). “Demand Factor” is the ratio of the maximum demand load to the total load connected. When the power input is connected to a circuit system, whether the switch is closed or open, the maximum demand load should always be equal or smaller than the connected load because of a system loss and various other reasons. “Coincidence Factor” is the maximum system demand divided by the sum of individual maximum demand, while “Diversity Factor” is its reciprocal, i.e., the sum of individual maximum demands (nominator) divided by the maximum system demand (denominator). The power plan is generally more effective for a greater “Diversity Factor” because the value of nominator is fixed but the value of denominator or the maximum system demand changes with different designs of the power plans. “Load Factor” is the ratio of the average load to the maximum load. The maximum load should occur under the “Worst Case Load Event” as defined by White (R. M. White, Reference 4). In this connection, the average load should always be less than the maximum load. It would likely be more economical in developing a power plan if these two values are closer. This shall depend on the qualities of the devices and equipment in the building.

III. CIRCUITS FOR ELECTRICAL POWER

The common types of electrical power consist of single-phase and three-phase circuits. As defined earlier, these powers are alternating currents, moving in wave form as shown in Figures 1 - 2. For the single-phase power, a popular circuit is shown in Figure 3a (Reference 2).

The voltage between the two power lines (V_{LL}) is twice of the voltage between the neutral line and each of the power lines (V_{LN}). The neutral line is grounded. Figure 3b is a simple form of single-phase power, which has only one power line and a grounded neutral line.

For the three-phase power, there are two types of phase connections, the wye type and the delta connection as shown in Figures 4(a) and 4(d). For the Wye system, the voltage between any two power lines (V_{LL}) is 1.733 times of the voltage between any power line and the neutral line (V_{LN}). In a Delta system, the voltage between any two power lines (V_{LL}) is twice (2 times) of the voltage between any power line and the neutral line (V_{LN}). For each of the two connection types, the neutral line is grounded.

IV. POWER PLAN AND LOAD CALCULATIONS FOR A BUILDING

The electrical load calculations for buildings consist of several components. These components constitute an electrical power plan, which becomes part of the construction plans for a building. This paper assumes a building of about 4,800 square-foot (SF) and is equipped as an office (1,600 SF) and a warehouse (2,800 SF). A small portion of the building is designated for a snack/food service room (400 SF). All of the areas are air-conditioning covered. There are various types of equipment or devices being placed in the building, which receive electrical power for functioning. The following paragraphs provide a description of the power plan and the corresponding electrical load calculations.

1. Electrical Riser Diagram: A diagram as shown in Figure 5 is an important element of the electrical power plan. It usually depicts the power source and its distribution on the outside wall of the building. In Figure 5, the three phase electric power of “277/480V” comes in either from a power post or from the underground. This power goes through a utility meter for measurement. A transformer is also needed so the voltage can fit to the power requirement of the equipment in the building. The transformer lowers the power to “120/208V” from the incoming electricity. Conductors from the transformer pass through an auxiliary gutter and create two lower voltage boxes. Each box can carry up to 200 Amps input. Based on load calculations, Box 1 and Box 2 are equipped with 150 and 100 Amp fuses, respectively. From there the electricity is distributed to equipment in the building through two breaker panels.

2. Electrical Loads for Devices: Devices in a building usually consist of three categories, the lighting groups, the receptacles, and the power equipment. Lighting groups consist of paneled fluorescent lights, and recessed ceiling lights. Receptacles are generally designated for tools, and consumer devices such as refrigerators, microwave ovens, coffee machines, etc. Power equipment usually refers to machinery devices such as air conditioning equipment, heating furnaces, walk-in cooler and freezer, etc. When the devices are placed for functioning, the electrical powers in the closed circuits are the connected loads. These loads can generally be determined from the following information.

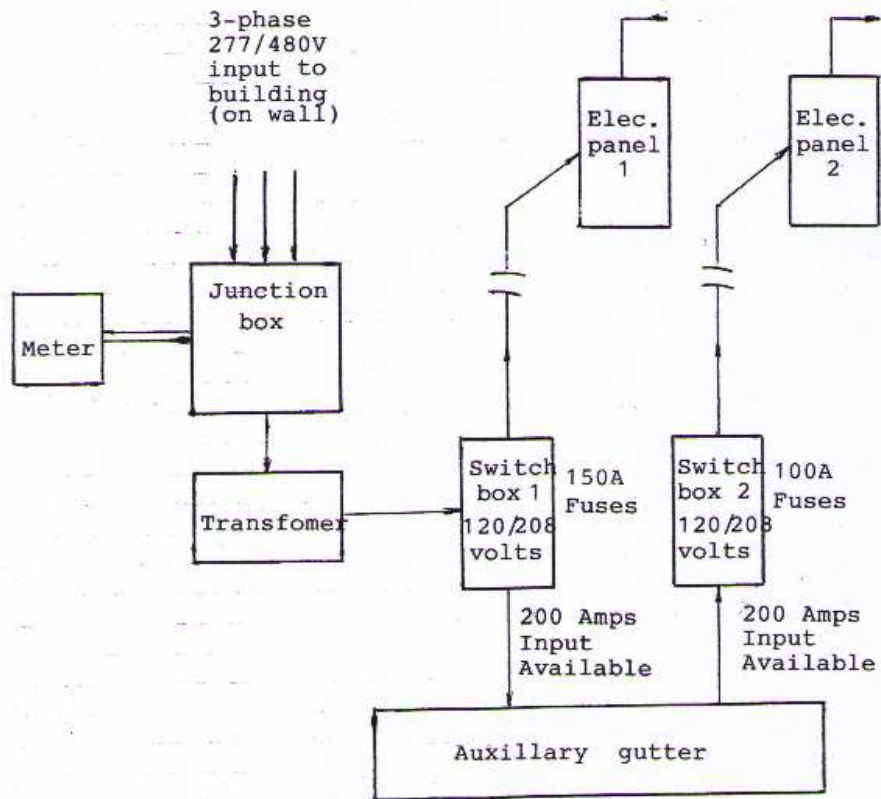


Figure 5. Electrical power riser diagram for a building

(1) The manufacturing company of a device provides information on electrical load by specifying voltage and current quantities for functioning. For example, an 18-cubic feet refrigerator may require a voltage of 120 volts and a current of 6 amperes for operation. The maximum demand load is therefore 720 watts. For the same token, a group of 40-watt, fluorescent lights of 20 pairs (20 x 2) is to draw an electrical load of 1,600 watts. Also, a 5-ton air conditioning condenser may generate energy of about 60,000 B.T.U., which is equivalent to a power capacity of up to 17, 580 watts. Its circuit load is likely smaller, may be about 8,000 watts, or even less, depending on the efficiency of the condenser.

(2) The above-described load, as specified by the manufacturer, should be adjusted for a system loss when the circuit is closed. Additional load should be added in considering the system loss (Reference 3). In other word, the connected load is equal to the specified load divided by the “power efficiency” as pointed out in Section II, Item (8). This efficiency is considered to be about 94 percent (Reference 3).

3. List of Devices/Equipment and Their Electrical Loads: This paper provides an example of building and its devices as specified in Section IV. Each device or a group of devices is connected to a specific circuit. These devices or equipment have a demand load as described in Section IV-2-(1). Table 1 presents a list of equipment and the grouped devices in the building, and their corresponding characteristics. Based on Table 1, this paper calculated loads for various electrical circuits. It further develops electrical power/lighting plans for the building.

4. Electrical Power Plans for a Building: This component presents two electrical power plans as listed in Tables 2 and 3. Table 2 is a power plan of load calculations for mostly power equipment. Table 3 is a power plan of load calculations for light groups in the building. Each of the two plans presents a total load and a current capacity. In mathematical form, the total connected load is:

$$L_T = \text{Sum of } [(V_i)(I_i)(DF_i)], \quad i = 1, 2, 3, \dots, n \quad [2]$$

where L_T is total load in watts, V_i is voltage for each circuit of a device or a device group in volts, and I_i is the current for each circuit of a device or a device group in amperes. The Demand Factor, DF, is a ratio as defined in Section II, item 13. The values of DF are between zero and one. The final calculation is to find the total current capacity for each electrical power plan. This capacity equals the total load divided by the product of a voltage and a conversion factor. In equation, it is:

$$I_T = L_T / [(1.733)(V_p)], \quad [3]$$

where I_T is the total current capacity for the power plan or electrical system, in amperes, and V_p is voltage for a three-phase power, in volts. In this paper, the voltage for each 3-phase power plan is 208 volts. The value of 1.733 is a “conversion factor” as defined in Section II, Item (9), i.e., $208V/120V = 1.733$.

Table 1. List of Electrical Equipment and Circuits in the Described Building

Equipment ID	Equipment Description	Power/Phase	Number of Circuits	Power Voltage for Each Circuit	Breaker Ampacity for Each Circuit	Equipment Location
C1	AC cooling unit, 5 tons (CU)	3	3	120V	40	Roof
C2	AC cooling unit, 5 tons (CU)	3	3	120V	40	Roof
C3	AC cooling unit, 5 tons (CU)	3	3	120V	40	Roof
H1	Heating, furnace unit (HU)	3	3	120V	30	Ceiling
H2	Heating, furnace unit (HU)	3	3	120V	30	Ceiling
H3	Heating, furnace unit (HU)	3	3	120V	30	Ceiling
WCC	Walk-in cooler condenser (WC)	3	2	208V	20	Roof
WCF	Walk-in cooler fan (WC)	3	2	208V	20	Cooler
WFC	Walk-in freezer condenser (WF)	3	2	208V	20	Roof
WFF	Walk-in freezer fan (WF)	3	2	208V	20	Freezer
R1~R2	Two 208V receptacles (REC)	3	2	208V	20	Warehouse
P1~P3	24 general purpose plugs (GP)	3	2	120V	20	Warehouse
P4~P6	24 general purpose plugs (GP)	3	3	120V	20	Office & snack room
L1~L3	30 fluorescent downlight (4-bulb, 25W each)	3	3	120V	20	Warehouse
L4~L6	32 recessed, 80W fluorescent downlight	3	3	120V	20	Office & snack room
F1~F12	12 ceiling fans with lights	3	3	120V	20	Warehouse
F13~F20	8 ceiling fans with lights	3	2	120V	20	Office
F21~F24	4 ceiling fans with lights	3	2	120V	20	Snack room

**Table 2. Power Plan - Electric Load Calculations for the Described Building
(Switch Box 1 / Panel 1 - 150 Amp Fuses)**

Circuit No. (1)	Description According to Table 1 (2)	Power Phase (3)	Breaker Ampacity for Ea. Circuit (4)	Estimated. Max. Demand Load*, Watts (5)	Demand Factor, 0.00 ~ 1.00 (6)	Connected Load, Watts (7) = (5) x (6)
1	CU-C1	A	40	2,700	1.00	2,700
2	CU-C1	B	40	2,700	1.00	2,700
3	CU-C1	C	40	2,700	1.00	2,700
4	HU-H1	A	30	2,100	0.00	0
5	HU-H1	B	30	2,100	0.00	0
6	HU-H1	C	30	2,100	0.00	0
7	CU-C2	A	40	2,700	1.00	2,700
8	CU-C2	B	40	2,700	1.00	2,700
9	CU-C2	C	40	2,700	1.00	2,700
10	HU-H2	A	30	2,100	0.00	0
11	HU-H2	B	30	2,100	0.00	0
12	HU-H2	C	30	2,100	0.00	0
13	CU-C3	A	40	2,700	1.00	2,700
14	CU-C3	B	40	2,700	1.00	2,700
15	CU-C3	C	40	2,700	1.00	2,700
16	HU-H3	A	30	2,100	0.00	0
17	HU-H3	B	30	2,100	0.00	0
18	HU-H3	C	30	2,100	0.00	0
19	WC-WCC	A	20	2,000	1.00	2,000
20	WC-WCC	B	20	2,000	1.00	2,000
21	WC-WCF	A	20	1,400	1.00	1,400
22	WC-WCF	B	20	1,400	1.00	1,400
23	WF-WFC	A	20	2,000	1.00	2,000
24	WF-WFC	C	20	2,000	1.00	2,000
25	WF-WFF	A	20	1,400	1.00	1,400
26	WF-WFF	C	20	1,400	1.00	1,400
27	REC - R1~R2	B	20	2,600	0.50	1,300
28	REC - R1~R2	C	20	2,600	0.50	1,300
Totals				60,400		40,500
Total estimated load: L = 40,500 Watts for the 3-phase, 120/208V power plan (for switch/panel box 1).						
Ampacity $I = L / [(V) (\text{Conv. Factor})] = 40,500 / [(208) (1.733)] = \mathbf{112.36 \text{ Amps}}$ (Eq. [3], specified before).						
* Maximum demand load can be estimated using data specified by the equipment company.						

**Table 3. Lighting Plan - Electric Load Calculations for the Described Building
(Switch Box 2/Panel 2 - 100 Amp Fuses)**

Circuit No. (1)	Description According to Table 1 (2)	Power Phase (3)	Braker Ampacity for Ea. Circuit (4)	Estimated Max. Demand Load*, Watts (5)	Demand Factor, 0.00 ~ 1.00 (6)	Connected Load, Watts (7) = (5) x (6) (6)
1	Office lighting, L4	A	20	1,200	1.00	1200
2	Office lighting, L5	B	20	1,200	0.50	600
3	Snack room lighting, L6	C	20	800	0.50	400
4	Warehouse lighting, L1	A	20	1,250	1.00	1250
5	Warehouse lighting, L2	B	20	1,250	1.00	1250
6	Warehouse lighting (WH), L3	C	20	1,250	0.50	625
7	WH gen. purp. plugs, P1	A	20	1,440	0.50	720
8	WH gen. purp. plugs, P2	B	20	1,440	0.50	720
9	WH general purpose plugs (GP), P3	C	20	1,440	0.50	720
10	Office GP plugs, P4	A	20	1,440	1.00	1440
11	Office GP plugs, P5	B	20	1,440	0.50	720
12	Snack room GP plugs, P6	C	20	1,440	1.00	1440
13	WH Exh. Fans, F1~F12	A	20	5,040	0.75	3780
14	Office Exh. Fans, F13~F20	B	20	3,360	0.75	2520
15	Snack Room. Exh. Fans, F21~F24	C	20	1,680	1.00	1680
	Totals			25,670		19,065
Total estimated Load: L = 19,065 watts for the 3-phase, 120/208V lighting plan (for switch/panel box 2).						
Ampacity $I = L / [(V) (Conv. Factor)] = 19,065 / [(208) (1.733)] = \mathbf{52.90 Amps}$ (Eq. [3], specified before)						
* Maximum demand load can be estimated using data specified by the equipment company.						

The two power plans have the total current capacities of 112.36 and 52.90 Amps, respectively. To accommodate these current capacities, the two switch boxes should be equipped with fuses of 150 and 100 Amps, accordingly.

5. Load Analysis: The analysis for the load calculations described above refers to the effectiveness of the power plan or electrical system for a building. The effectiveness can be identified by some “factors” as specified in Section II, Item (13). For example, the “Diversity Factor” is defined to be the sum of individual maximum demands divided by the maximum system demand. The greater the Diversity Factor, the power plan is more effective. In other word, the requirement of the sum of demand loads, or the total current capacity, can be reduced by decreasing the maximum system demand via a better-designed power plan.

Essentially, load analysis is to present values of all identified factors. Common values of some other factors such as “demand factor” and “load factor” for buildings are presented in a publication referenced previously (Reference 3). It is useful to read these data for load calculations or in developing an electrical plan.

6. Diagrams, Notes, and Legends for An Electrical Plan: The details of this section are beyond the scope of this paper. Nevertheless, the designer must present all diagrams, notes, and legends for an electrical plan.

Diagrams generally include a riser diagram (Figure 5), a drawing which shows the relative locations of receptacles and electrical power equipment, and the lighting plans which usually consist of a ceiling plan and a floor plan to show the relative locations and connections of the lighting groups.

Notes are writings placed in the designed power plan. They may include general notes, key notes, and work specifications. General notes often refer to coordination matters such as wordings to require electrical contractor to communicate with owner or architects about exact locations of some lights and receptacles. Also, the notes may require installation of additional switches for some power equipment. Key notes are writings to require special attentions. For example, they may require an independent circuit for a small group of electrical devices. They may warn about using special types of equipment or wires installation for some part of the power plan. Work specifications usually refer to job scope, NEC codes, permit and inspections, special wiring instructions, and schedules of lights and equipment (schedules are generally prepared as separate tables).

Legends are symbols and marks placed on the drawing of electrical power plans. They generally include lighting symbols, marks and lines of electrical connections, and receptacles and power equipment drawings.

V. CONCLUSIONS

The circuit of an electrical device system receives power for function from the source of electricity. The required power for a closed or functioning circuit is the electrical load. This paper discusses the basics of electricity and the contents of an electrical plan for a building. Conclusions for this paper are specified below:

- (1) An electrical plan is an important portion of plans for construction of a building or facility. It provides information for cost estimates and permitting needs.
- (2) The plan consists of several components. Essentially, it describes the source of power, list of devices or equipment and their corresponding electrical loads, and the load calculations.
- (3) This paper presents method or procedure in load calculations. The calculations are to divide electrical devices in a building into different groups and to calculate loads based on power source, the quality or characteristics of devices, and an estimated "Demand Factor."
- (4) Tables 1 to 3 provide an example of load calculations and how the electrical power plan for a building is developed.
- (5) The criterion for developing an electrical plan is to minimize the electrical power required for devices operation, subject to the conditions of power source, selection of devices or device groups, and the quality and usage of the devices.

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