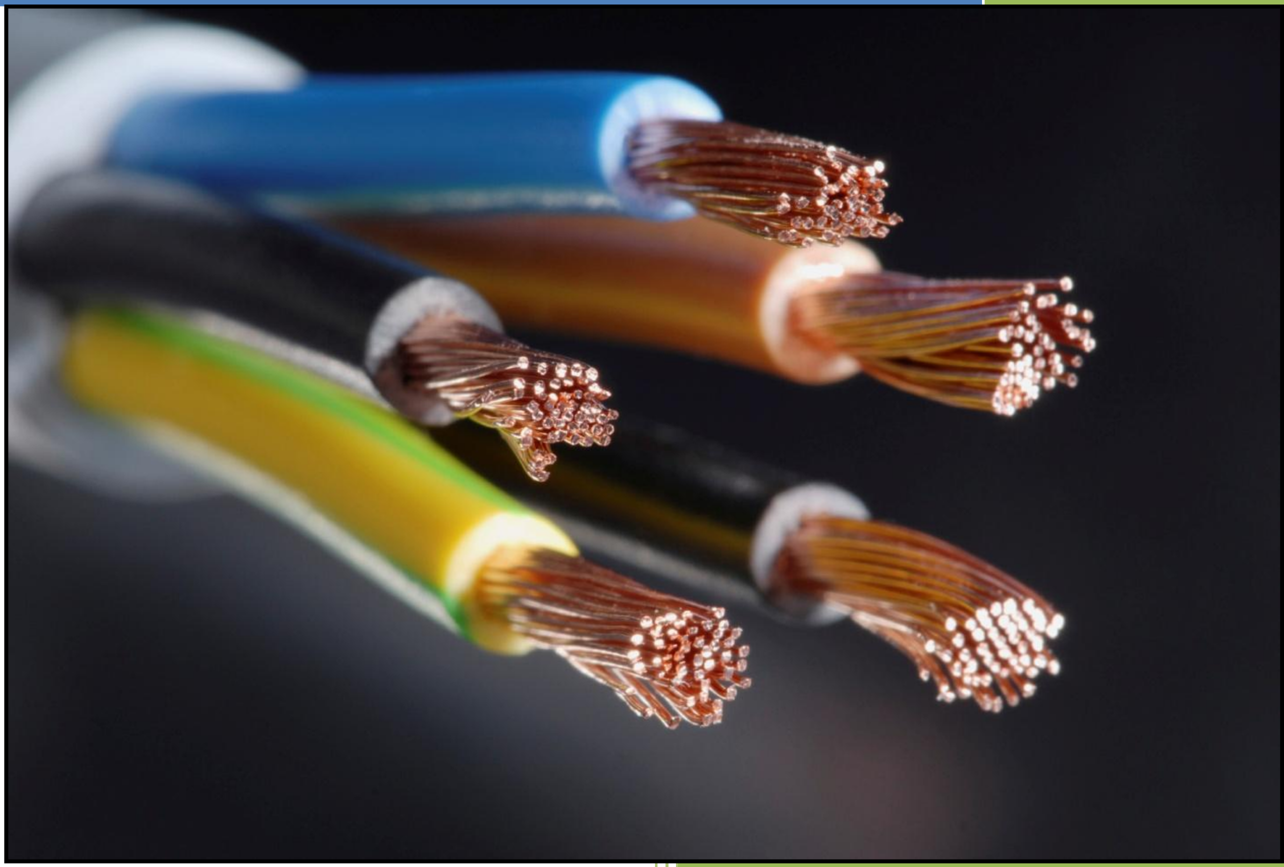
2013

Building Management System



Prepared by:
Amjad Marmash
Amjad Qutob
Abdalla Mousa

Submitted to:
Dr. Jamal Kharrosha

AN-Najah National University
Department of Electrical Engineering

Content

Chapter 3

Electrical Installation

3.5 Emergency lighting and loads.

3.5.1 Emergency lighting

When general artificial lighting fails after a power outage, the emergency lighting system takes over. Where there is a risk of accident after a power failure, safety lighting needs to be activated.

Emergency and safety lighting ensures that a minimum level of brightness is guaranteed after a failure of the general lighting. But it also helps in other emergencies. Where a building needs to be evacuated, for example, it plays a key role in helping people unfamiliar with the building to get their bearings and find their way to safe areas along escape routes.

3.5.1.1 Features of Emergency lighting

The standard DIN EN 1838 requires these good general illumination for escape routes.

- Luminaries for illuminating and identifying an escape route need to be mounted at least 2 meters above floor level. (see Fig. 3.28).
- All escape signs at emergency exits and at exits along escape routes are illuminated or back-lit.
- Where an emergency exit is not directly visible, one or more illuminated and back-lit escape signs need to be positioned along the escape route.

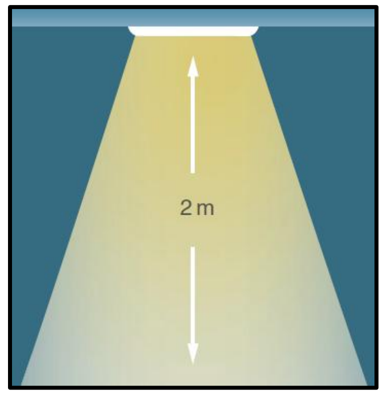


Fig. 3.5.1 Luminaire height.

3.5.1.2 Escape route safety lighting (DIN EN 1838)

Escape route safety lighting needs to ensure adequate conditions for visual orientation along escape routes and in adjoining areas of the building. Fire extinguishing and security equipment needs to be easy to locate and use.

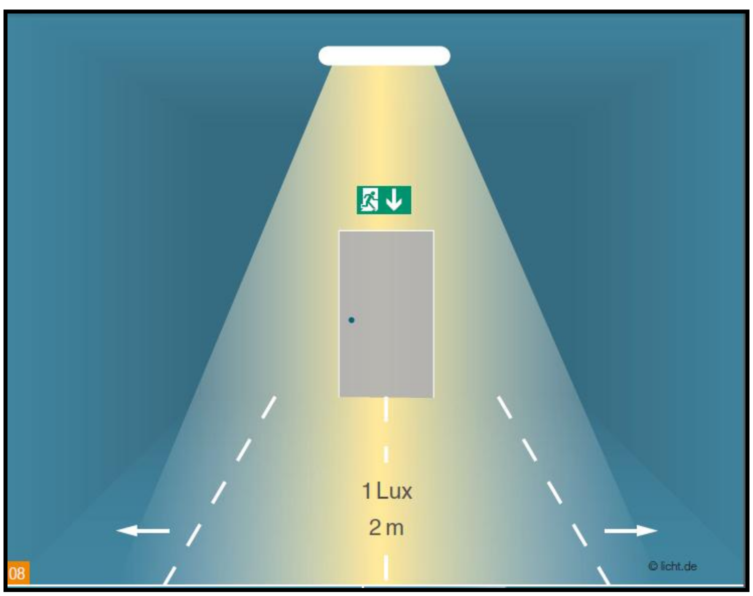


Fig. 3.5.2 Escape route safety lighting specification

Illuminance:	E_{min} = 1 lx E_{min} = minimum horizontal illuminance at floor level
Uniformity:	$E_{max} : E_{min} \leq 40 : 1$

Glare limitation:

h/m	< 2.5	$2.5 \leq h < 3$	$3 \leq h < 3.5$	$3.5 \leq h < 4$	$4 \leq h < 4.5$	≥ 4.5
I_{max}/cd	500	900	1,600	2,500	3,500	5,000

The values in this table must not be exceeded at any azimuth angle between 60° and 90° to the vertical.

Colour rendering:	$R_a \geq 40$
Rated operating time for escape routes:	1 hour
Power-on delay:	50 % of required illuminance within 5 seconds 100 % of required illuminance within 60 seconds

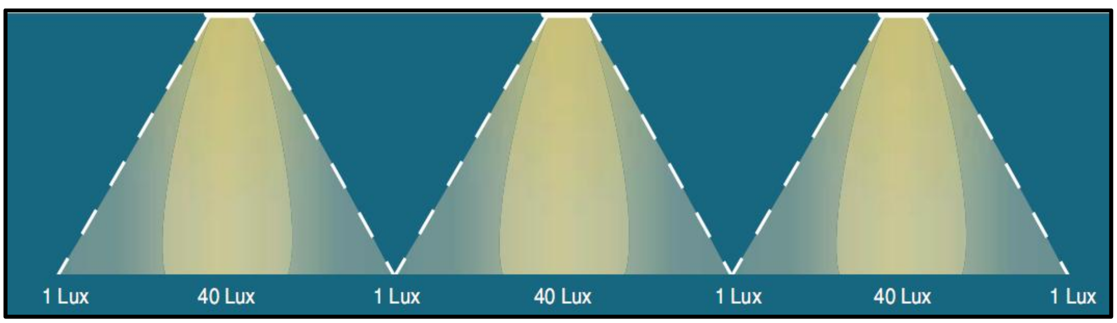


Fig. 3.5.3 The ratio of the highest to lowest illuminance along the central axis must not exceed 40:1.

3.5.1.3 Safety signs: quality is crucial

Safety signs for escape routes can be either illuminated escape signs, i.e. with an external light source, or back-lit escape signs with an internal light source. DIN EN 1838 and DIN 4844-1 present different requirements for illuminated and back-lit safety signs in terms of the lighting parameters to be met for the different operating conditions.

Escape sign luminaries are easier to recognize than ordinary photo luminescent signs. There are several reasons for this, one of which is that the green safety color is clearly identifiable even in emergency operation.

Comparison of lighting requirements

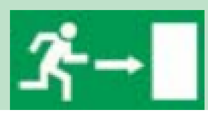
	DIN 4844-1	*DIN EN 1838*
Environment	bright and dark	dark
Mains/ emergency power	mains	emergency
Maintained operation	yes	–
Uniformity of green/white surfaces	$g \geq \frac{L_{min}}{L_{max}}$ 0.2	$g \geq \frac{L_{min}}{L_{max}}$ 0.1
Luminance contrast between green and white surfaces	$k = \frac{L_{white}}{L_{green}} = 5:1$ to $15:1$	
Average luminance of *white* contrast colour	≥ 500 cd/m²	–
Luminance of *green* safety colour	–	≥ 2 cd/m²
Calculated average luminance of *the sign as a whole*	≥ 200 cd/m²	≥ 5 cd/m²
Illuminance of the illuminated sign	≥ 50 lx (preferably ≥ 80 lx)	–
Graphic symbol		

Table 3.5.1 The different requirements for illuminated and back-lit safety signs.

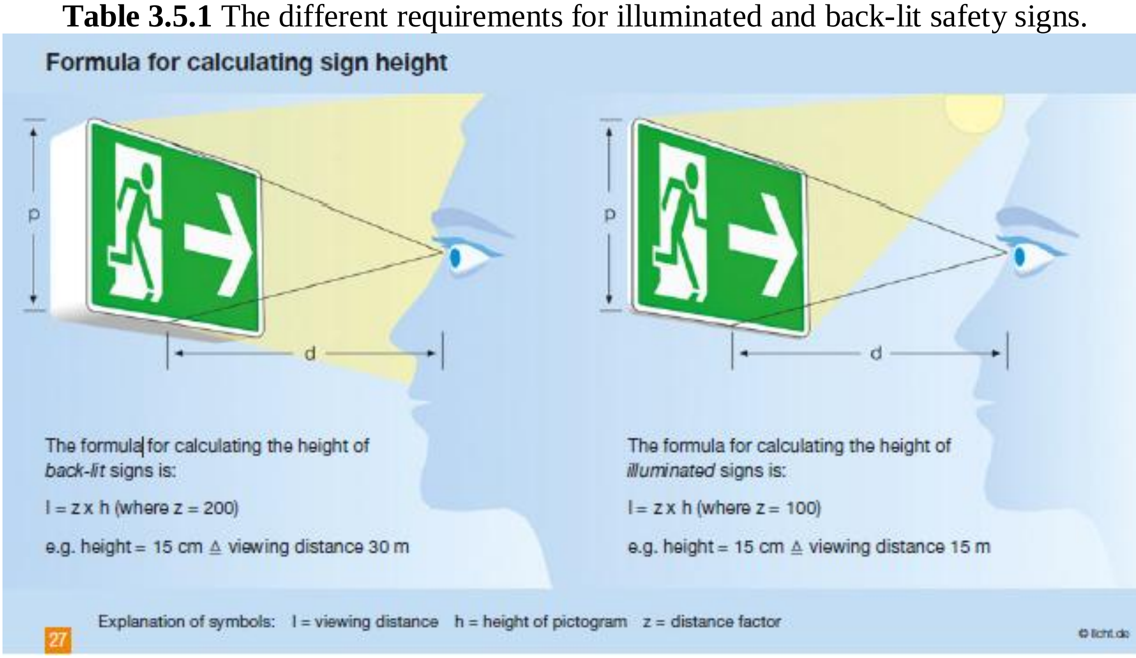


Fig. 3.5.4 Formula for calculating sign height.

3.5.1.4 Emergency lighting Power source

Wherever people are present in large numbers, safety lighting is a must. Its moment comes when mains voltage fails. In that event, safety lighting needs to be activated immediately by a back-up power source.

Standby energy is obtained from a "power source for safety services". Its purpose is to supply parts of an electrical safety system, including e.g. safety lighting. Suitable sources for standby energy are battery systems, generating sets or two separate and independent mains feeds. If only one power source for safety services is available, it must not be used for other purposes.

Luminaries for safety lighting can be operated in three modes:

- Non-maintained operation – The safety luminaries are activated only in the event of a power failure. This mode may be used for escape route lighting in all types of building.
- Maintained operation – The safety luminaries are permanently activated. With few exceptions, maintained operation is the only option allowed for escape sign luminaries.
- Switched maintained operation – The safety luminaries are activated and deactivated with the general lighting luminaries.

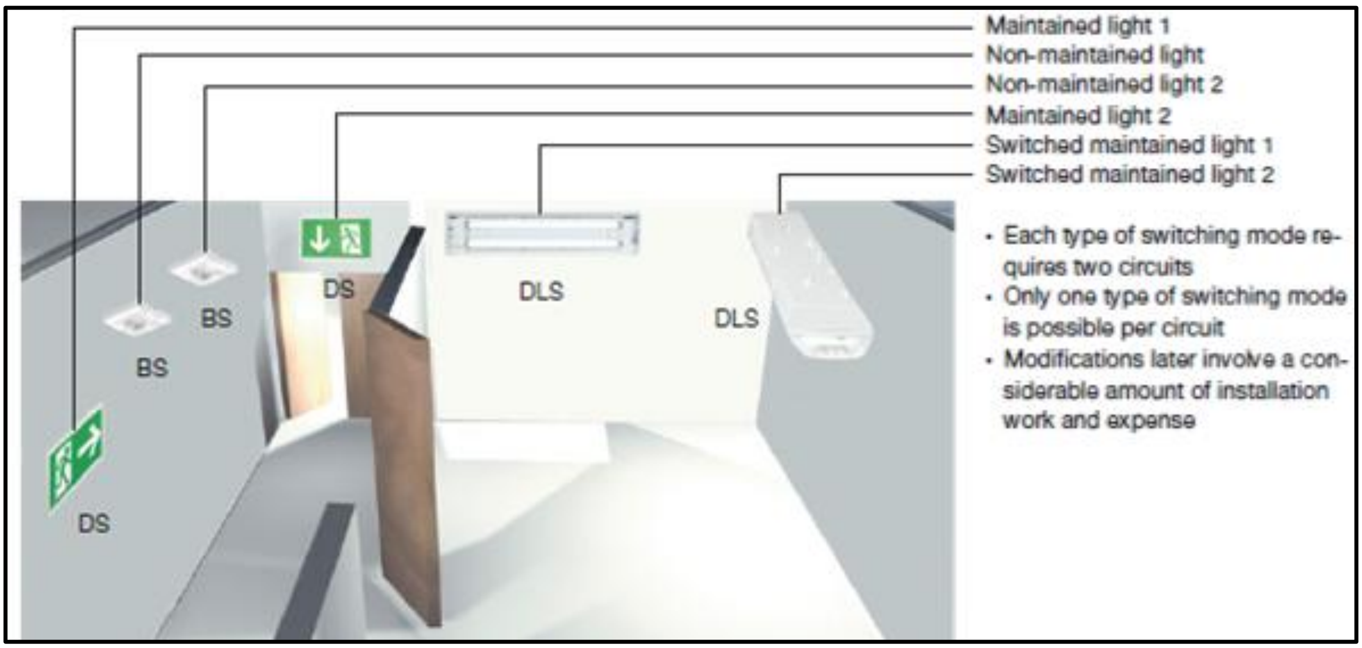


Fig. 3.5.5 safety lighting modes.

3.5.1.5 Design and Result

An emergency (panic, signs) lighting system shall be provided in the project to prevent panic in the crowded area during main power supply and emergency power supply transfers. Also, this system will maintain an adequate illumination level at exits, stairs and escape routes, in case of emergency. Exit luminaires will be provided for all exits, stairs and escape routes. Exit luminaires will be illuminated type equipped with (1 x 8 W) lamp. The exit luminaires will be of the ceiling or wall mounted type with indication arrow and existing both in Arabic and English.

Our design for Safety lights luminaires depend on DIN EN 1838 criteria which specify the horizontal illuminance on the floor level no less than 1 lux and ratio of highest to lowest illuminance does not exceed 40:1, color rendering index Ra of lamps at least 40 to ensure clear identification of safety colors and nominal operating time for escape routes at least one hour (50 % of required illuminance within five seconds, 100 % within 60 seconds).

We are used dedicated Safety luminaire that have a rated power (16 W), activated only in the event of a power failure (non-maintained mode), they are connected with central power supply consist of standby UPS with limited output (LPS) has an operating time for about 1 hour.

Luminaires spaced maximum 13.8m to ensure minimum illuminance no less than 1 lux. (See Fig. 3.33).

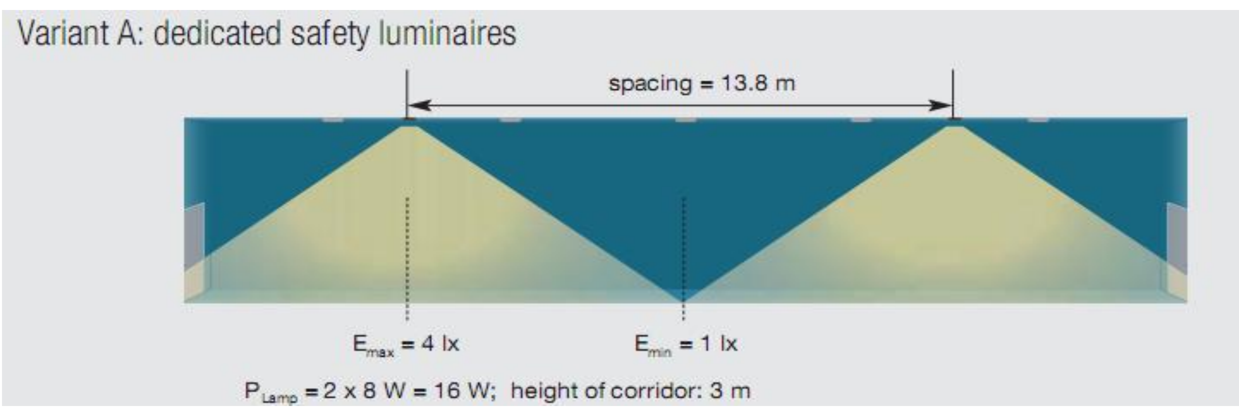


Fig. 3.5.6 Luminaries for safety lighting modes.

Type	quantity	Luminaire Power (W)	Total Power (KW)
SAFTY LIGHT LUMINAIRS	42	16	672
ESCAPE SIGNS	36	8	288
Total Emergency light load (KW)			0.96

Table 3.5.2 Luminaries quantities.

3.5.2 Emergency load power sources

the electrical loads in any building can be divided into normal and emergency loads, the main difference between them is that in emergency loads the power shouldn't be cut off. The emergency loads are connected to emergency distribution boards are fed from the several sources such as standby generators or/and UPS system in the cases of the power cut off.

The switching of the power source (between main & standby supply) can be done either manually (Manual Transfer switching) or automatically ATS (automatic transfer switch).

Usually the emergency loads are 10-20% in the buildings (lighting scape routes, fire exits, alarm systems, telephones, elevators, etc…). In hospitals, the emergency load can be up to 50% of the loads.

3.5.2.1 ATS (Automatic Transfer Switch)

ATS is a device that can transfer the supply of any emergency distribution board automatically in the case of the power outage from the main source (usually the electrical distribution company) to the back-up power source such as generator or UPS system as shown below.

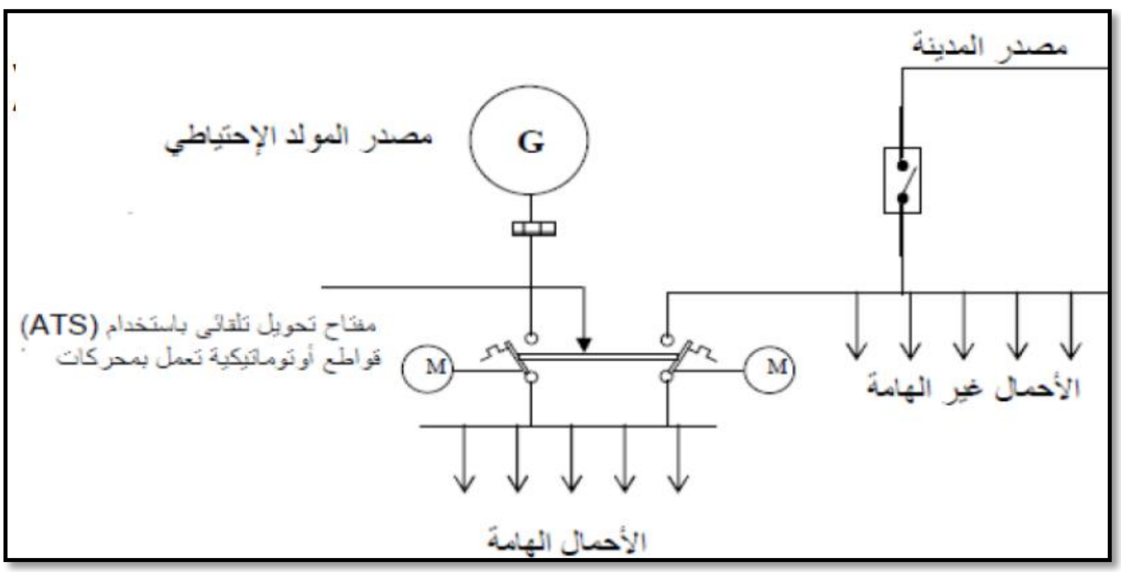


Fig. 3.5.7 Emergency distribution board.

3.5.2.2 UPS (Un interrupted power supply)

The most important loads in the building such as the emergency light or computers/ servers in banks, which needs to be activated immediately by a back-up power source without any significant delay, should be supplied through UPS system to assure that there is no supply interrupt at all.

3.5.2.3 Design and results

As we mentioned before, the emergency loads represent 10-20% of the buildings loads. So, Two separate and independent mains feeds, one for emergency light, consist of UPS & battery systems, and another source composed of standby generator to supply another emergency loads such as fire alarm systems, telephones, security, elevators, etc…

Standby UPS design

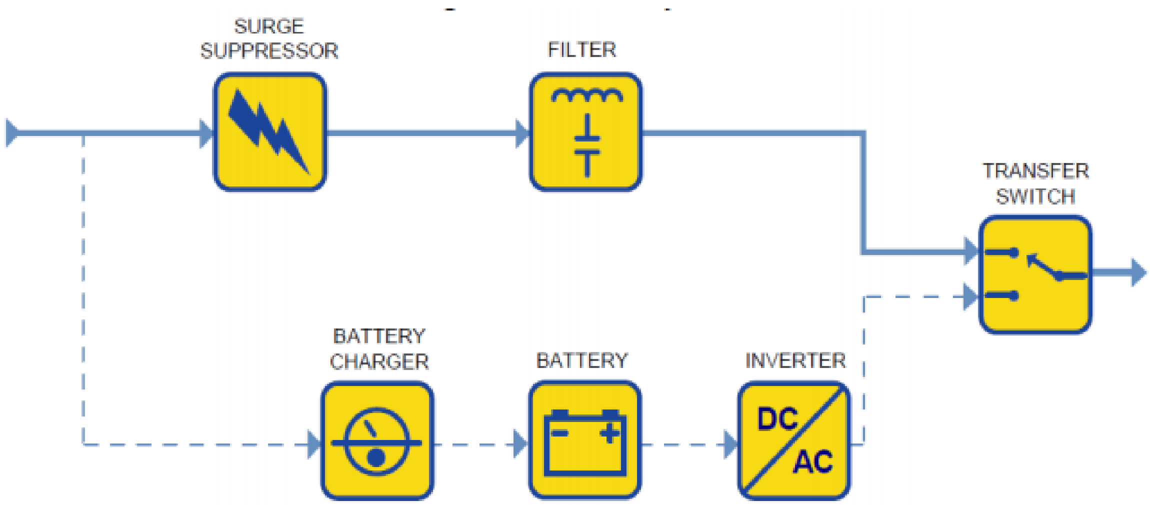


Fig. 3.5.8 Standby UPS.

As you can see in the figure above in this design the transfer switch is set to choose the filtered AC input as the primary power source (solid line path) at normal condition, and switches to the battery / inverter as the backup source when the primary source fail (dashed path).

The inverter only starts when the power fails, hence the name "Standby”. This type characteristics: high efficiency, small size and low cost are the main benefits of this design.

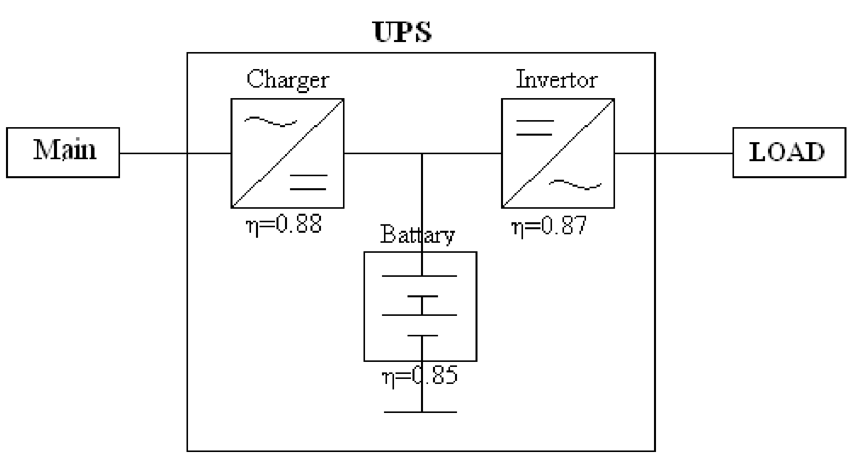


Fig. 3.5.9 UPS parameter.

Now, to determine the correct UPS size we should consider these parameter:

- The total emergency light load for which the UPS should supply power: **960 Watt.**
- The time for which it should provide back up: **about one hour.**
- The input voltage required by the invertor: **24 V (because 1to 5 KVA UPS work on 24v battery).**
- The efficiency of the charger, battery and invertor: **0.88, 0.85 & 0.87 respectively.**

The relation between these parameter is given by the following formulas:

- The total emergency light load = $960 \times 1.2 = \mathbf{1152}$ **Watt.** (Consider a safety factor of 1.2).
- The total power at the input of the UPS = $\frac{Pout}{\eta i \times \eta bc} = \frac{1152}{0.87 \times 0.88} = \mathbf{1504.7}$ **Watt**. Where, ηi: invertor efficiency and ηbc: battery charger efficiency.
- So, the rated power of UPS: **1500 Watts.**
- The total energy load = $Pout \times backup\ time\ in\ hours = 1152 \times 1 = \mathbf{1152}$ **Wh.**
- The total energy at the input of the inverter (output of the battery) = $\frac{1152}{0.87} = \mathbf{1324.13}$ **Wh.**
- The battery capacity required in ampere hour = $\frac{Eb}{\eta b \times Vb} = \frac{1324.13}{0.85 \times 24} = 64.9 \approx \mathbf{65}$ **AH.**

Therefore we will select two battery cell with **12V/65AH** connected in series as follows:

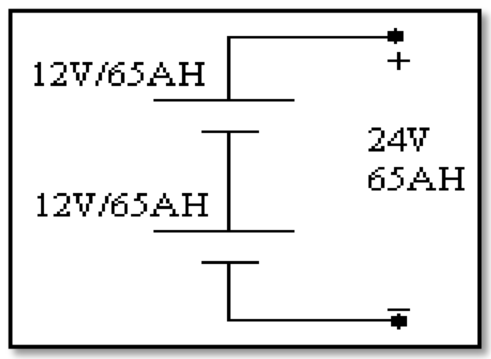


Fig. 3.5.10 Battery configuration.

The desired UPS has the following specifications:

VA	Watts	Back up time	Batteries voltage	Batteries capacity	Input volts	Input Amps
2300	1500	1 hour	2x12 volts	65 AH	220 volts (AC)	11 Amps

Table 3.5.3 UPS specifications.

Standby generator design

In our building we will select a diesel generator supplies 10% of the building loads, so that the total power of the whole building = 130KW and the required capacity of the diesel generator should be as follows:

The installed capacity of the diesel generator = $P \times 10\% \times Ks = 130 \times 0.1 \times 1.2 = 15.6 \approx \mathbf{15}$ **KW.**
Where: Ks is a safety factor.

3.6 Control Panels Circuits

Electrical control systems are used on everything from simple pump controls to car washes, to complex chemical processing plants. Automation of machine tools, material handling/conveyor systems, mixing processes, assembly machines, metal processing, textile processing and more has increased productivity and reliability in all areas of manufacturing, utilities and material processing.

Control panels consist of **Power and Control circuits**, the first one is a type of circuit that carries power to electrical loads. Power circuits often carry high current and consist of incoming main power, main contacts of contactors, protection devices (C.Bs, Fuses, heated coil for overload) and the loads terminals. Another one uses control devices (timer, sensor, pushbutton, relay, ..etc.) to determine when loads are energized or de-energized by controlling current flow in power circuit. Control circuits usually carry lower current than power circuits.

3.6.1 Contactors

A contactor is a special type of relay designed to handle heavy power loads that are beyond
the capability of control relays and consist of main contacts capable to carry power loads in addition to auxiliary contacts (N.O, N.C) used in control circuits.

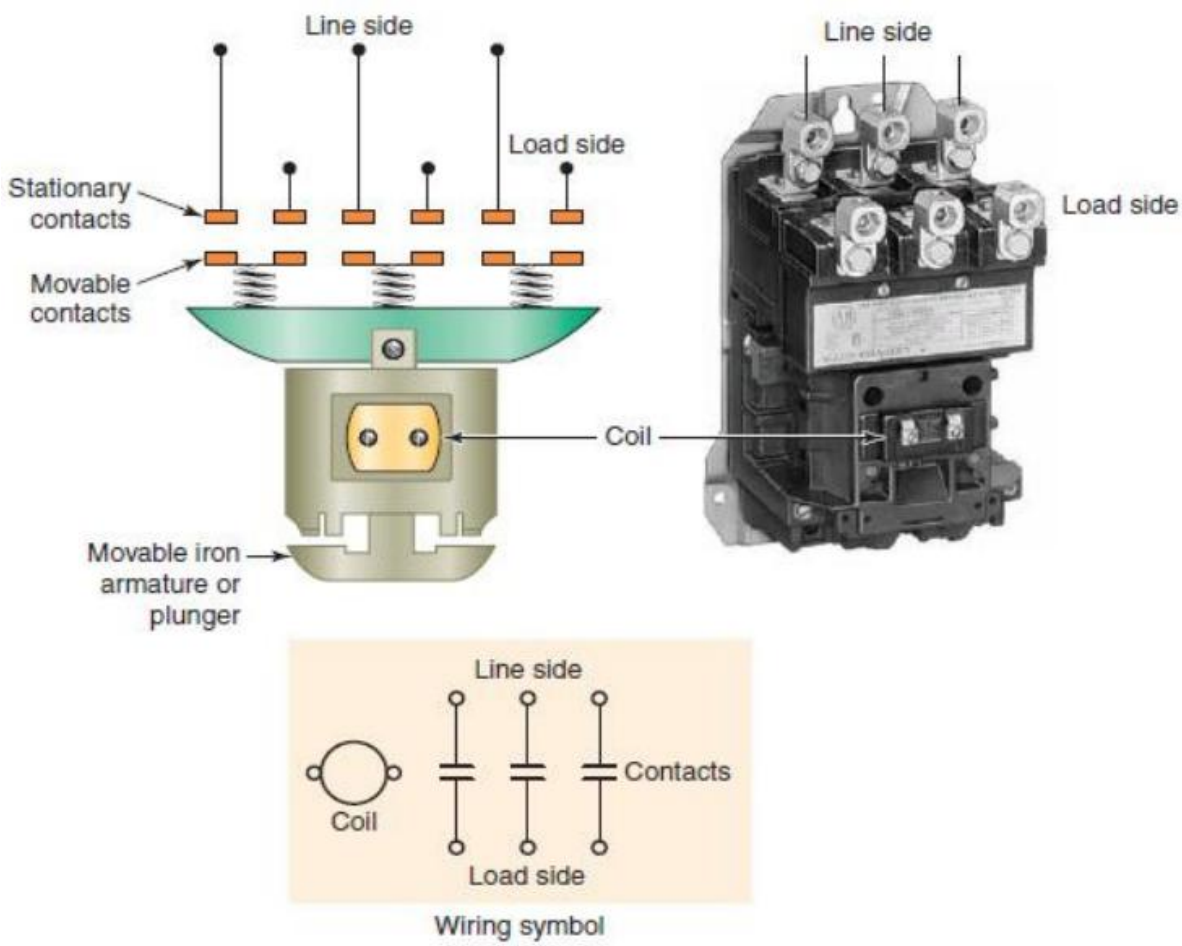


Fig. 3.6.1 Three-pole magnetic contactor

3.6.2 Timers (on-delay timer)

The time can be assigned in the timer in order the system to work or shut down after a certain time. When a voltage (220v) applied to point A1 & A2, the time count in the timer will start, if our plant connected throw points 15 & 16, then it will run for a certain time then stop, but if our plant is connected throw points 15 & 18, it will run after a certain time and continue to run.

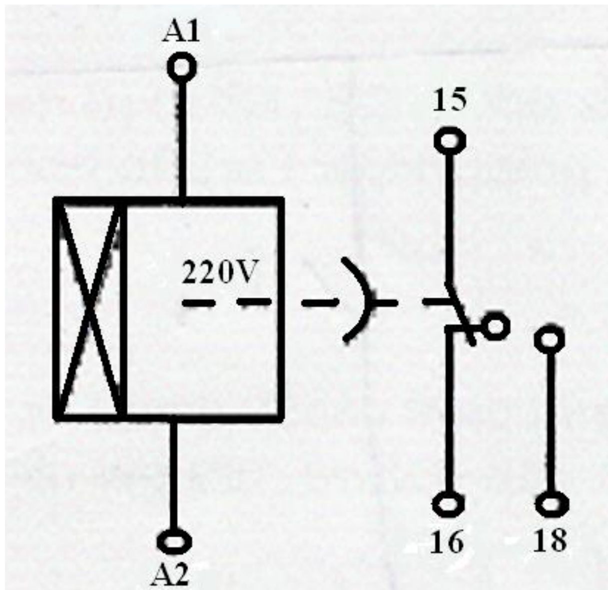


Fig. 3.6.2 Timer symbol

3.6.3 Design and results

In this project we aims to design some control panels go into control the lighting systems for football stadium, swimming pool, indoor and outdoor courts. Such that luminaires operation performed in sequential mode with time delay, in order to reduce the starting current drawing by luminaires and automating these operation.

3.6.3.1 Football Stadium Panel

- **Functional description**

The proposed control circuit for the lighting system of football stadium designed with three state of operation, one for televised event, another for leagues or club event and the third one for training event. The principle of operation for lighting system will be implemented in sequential manner, so that each set of luminaires will be lit separately with time delay for about 5sec between them to avoid drawing over current at the beginning if all luminaire running at the same time.

- **Switching conditions**

1) The control circuit is to be designed with push buttons, timers and contactor latching.
2) Pushbutton operation with self-holding contactor for each mode (TV, Club & Train).
3) Each mode of operation will be indicated by a lamp located at the outside surface of the panel.
4) Using pushbutton to turn off all luminaires at the same time.

5) Transition from mode to another without needing to shut down all luminaires previously.

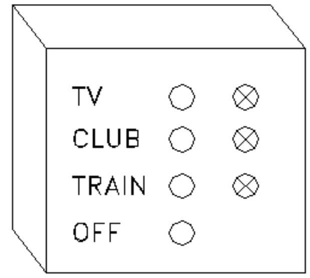


Fig. 3.6.3 Outside appearance of control panel

- **Luminaires distribution**

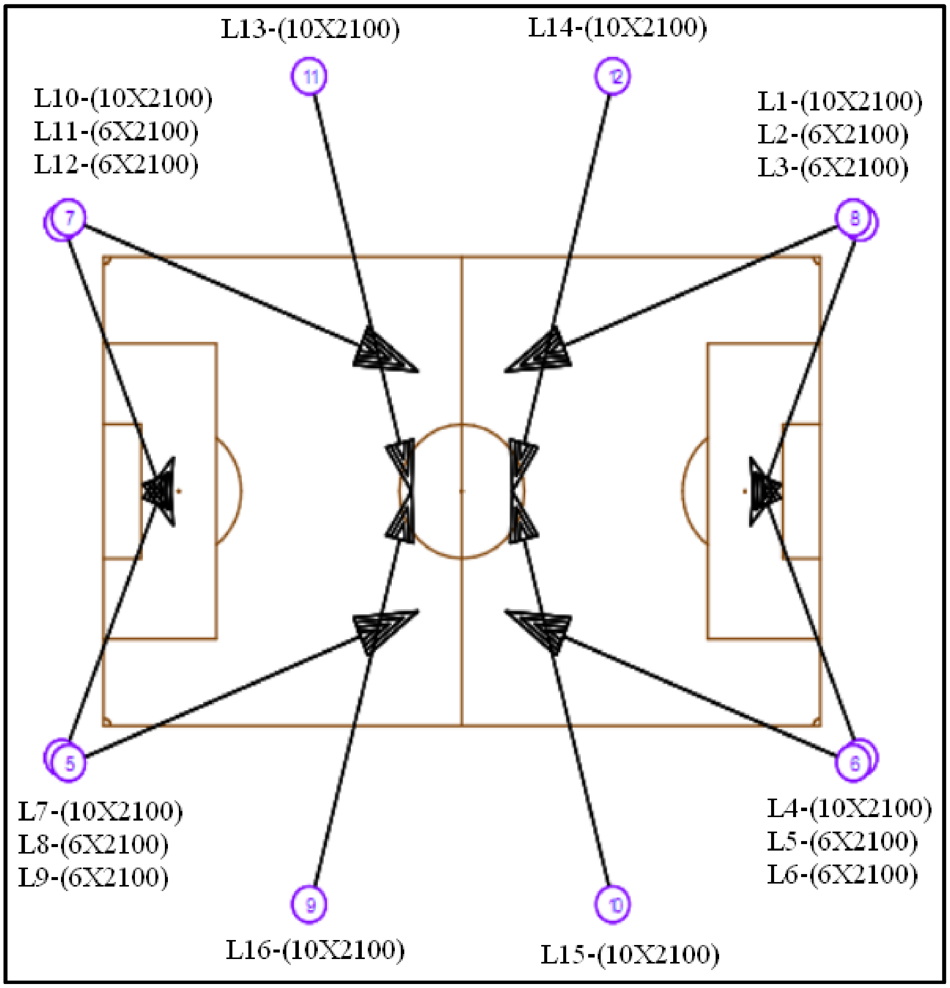


Fig. 3.6.4 Luminaires distribution.

As you can see above, there is 128 luminaries divided into 16 light circuits (feeders) in order to operate each set of feeder alone according to following three classes.

classes	Luminaires Quantity	Operated Feeders	Power (KW)
Training event	40	L1,L4,L7,L10	84
Leagues and clubs event	64	L1,L2,L4,L5,L7,L8,L10,L11	134.4
Televised event	128	All feeders	268.8

Table 3.6.1 Luminaires Part list.

■ **Power Circuit**

Power circuit consist of six contactors, some of protection devices (17XC.B & 6XRCD) and 3-phase bus bars. There is six stages to operate all the lamps in the stadium.

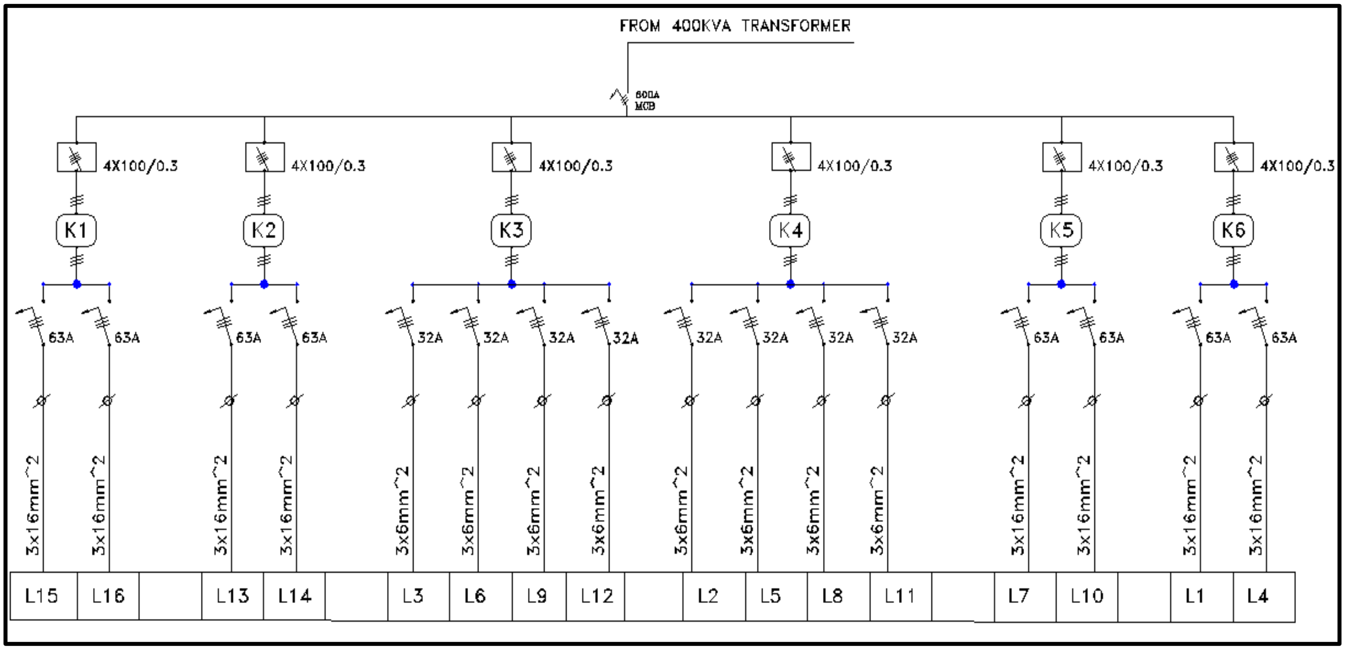


Fig. 3.6.5 Schematic of power circuit.

Control Circuit

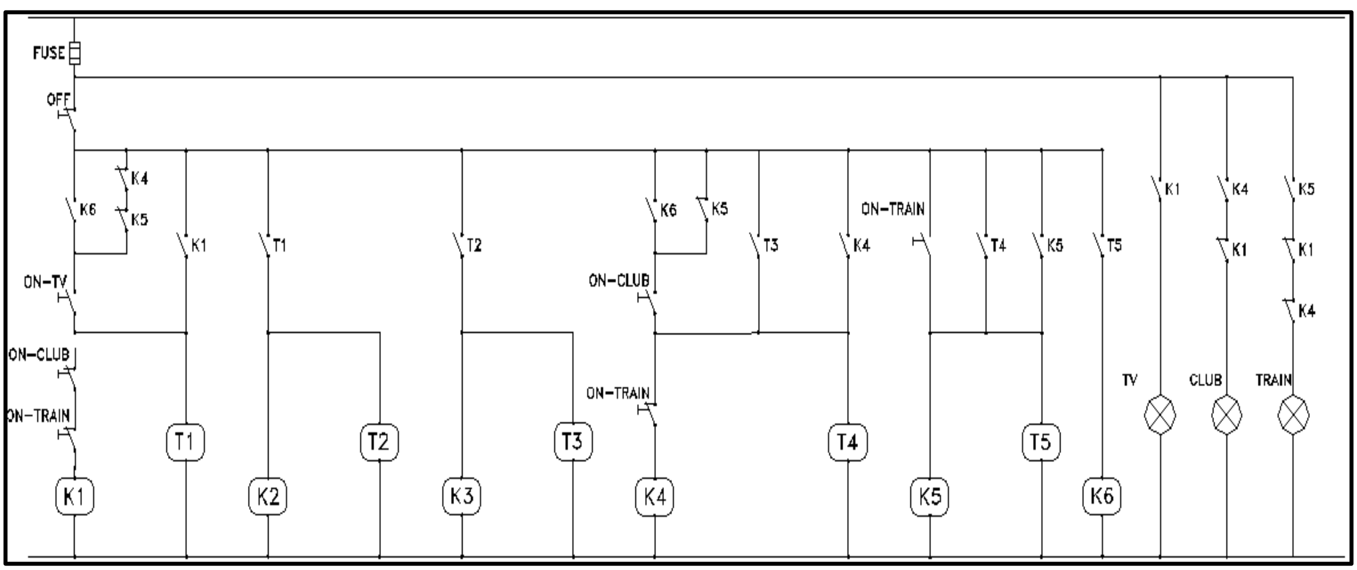


Fig. 3.6.6 Schematic of control circuit.

Set all timers time to 5sec which is sufficient for the current to return to its steady state value and jumps control to next stage of operation.

3.6.3.2 Swimming Pool & Indoor Handball Court Panels

- **Functional description**

The construction of control circuit which build for lighting system of swimming pool and indoor handball court football is the same. the design consisted of two state of operation, one for high level of lighting event and the second one for medium level event. As we mentioned before, the operation for lighting system will be in sequential manner.

- **Switching conditions**

1) The control circuit is to be designed with push buttons, timers and contactor latching.
2) Pushbutton operation with self-holding contactor for each mode (High and Med.).
3) Each mode of operation will be indicated by a lamp located at the outside surface of the panel.
4) Using pushbutton to turn off all luminaires at the same time.
5) Transition from mode to another without needing to shut down all luminaires previously.

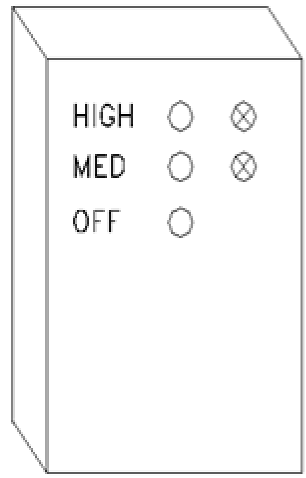


Fig. 3.6.7 Outside appearance of control panel

- **Luminaires distribution**

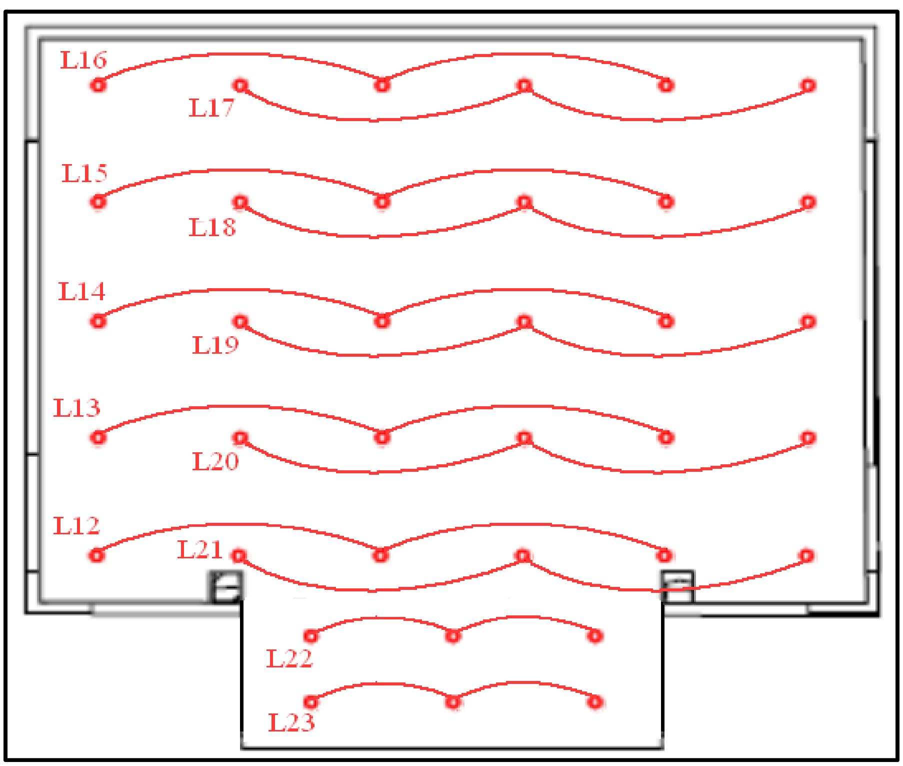


Fig. 3.6.8 Luminaires distribution.

From above, there is 36 luminaries divided into 12 light circuits (feeders) in order to operate each set of feeder alone according to following two modes.

Modes	Luminaires Quantity	Operated Feeders	Power (KW)
High	24	L12,L14,L15,L17 L19,L20,L22,L23	8.7
Medium	36	All feeders	13.5

Table 3.6.2 Luminaires Part list.

- **Power Circuit**

Power circuit consist of three contactors, 12-circuit breakers (C.B) and 3-phase bus bars. There is three stages to operate all the lamps.

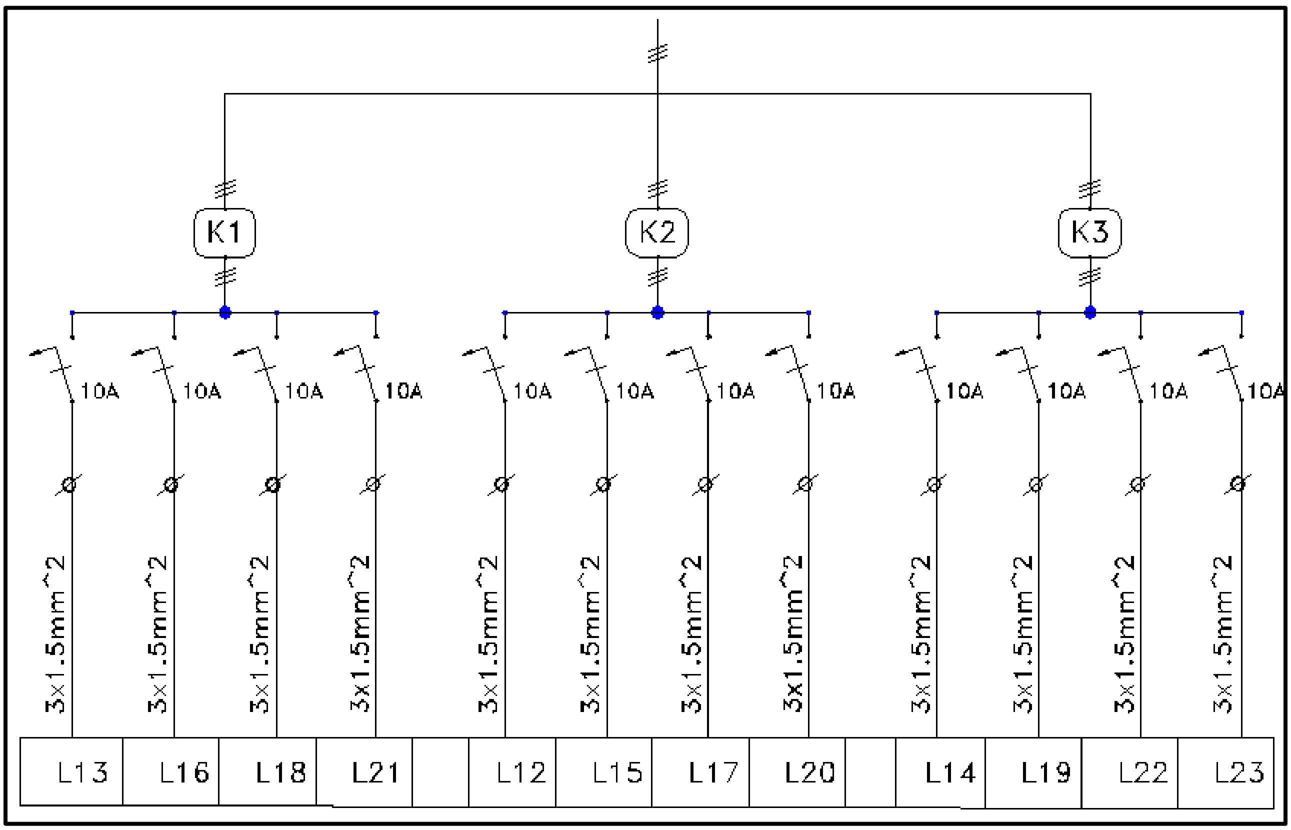


Fig. 3.6.9 Schematic of power circuit.

- **Control Circuit:**

Set all timers time to 5sec, which is sufficient for the current to return to its steady state value and jumps control to next stage of operation.

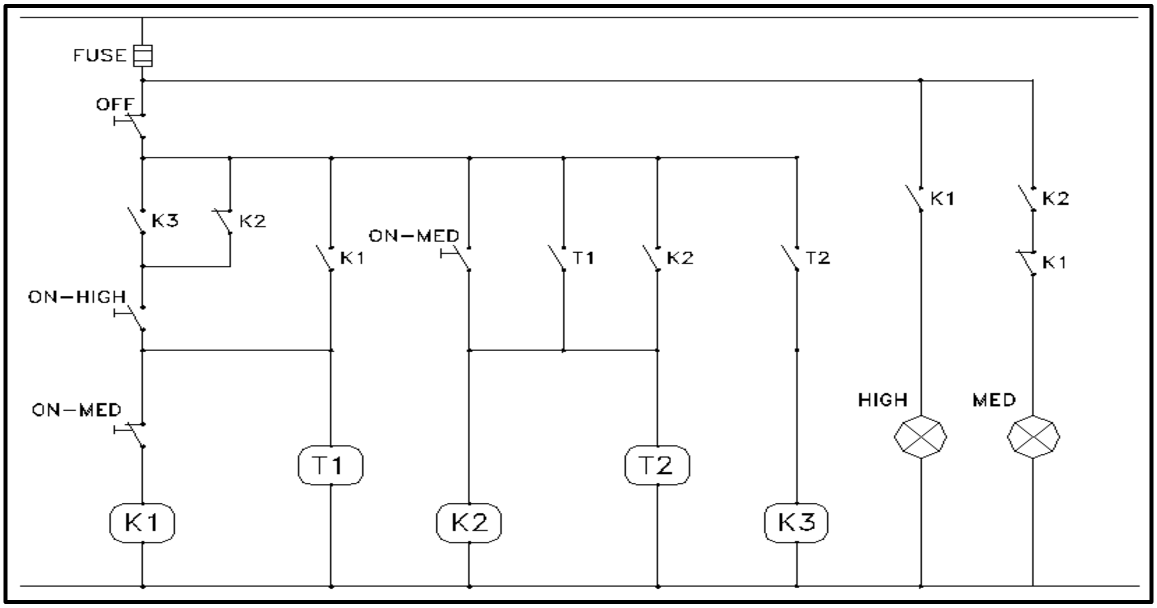


Fig. 3.6.10 Schematic of control circuit.

3.6.3.3 Outdoor Court Panel

- **Functional description**

The suggested control of lighting system for outdoor court also the same as above but with minor differences. the design consisted of two state of operation, one for high level of lighting event and the second one for medium level event.

- **Switching conditions**
  1) The control circuit is to be designed with push buttons, timers and contactor latching.
  2) Pushbutton operation with latching for each mode (High and Med.).
  3) Each mode of operation will be indicated by a lamp located at the outside surface of the panel.
  4) Using pushbutton to turn off all luminaires at the same time.
  5) Transition from mode to another without needing to shut down all luminaires previously.

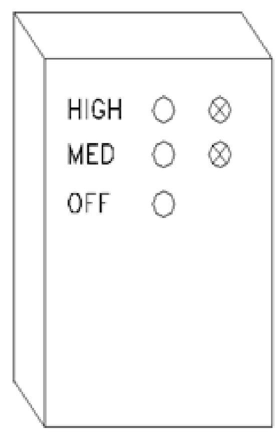


Fig. 3.6.11 Outside appearance of control panel

- **Luminaires distribution**

As you can see above, there is 22 luminaries divided into 11 light circuits (feeders) in order to operate each set of feeder alone according to following two modes.

Modes	Luminaires Quantity	Operated Feeders	Power (KW)
High	24	L19,L21,L23,L25 L26,L27,L28	8.54
Medium	36	All feeders	15.58

Table 3.6.3 Luminaires Part list.

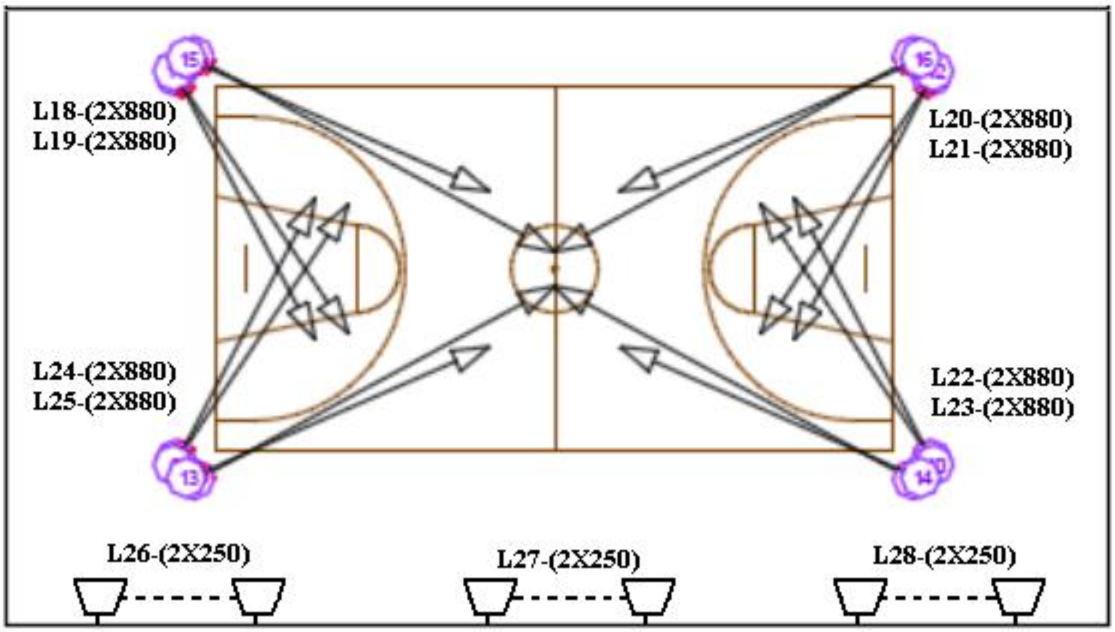


Fig. 3.6.12 Luminaires distribution.

- **Power Circuit**

Power circuit consist of three contactors, 11-circuit breakers (C.B) and 3-phase bus bars. There is three stages to operate all the lamps.

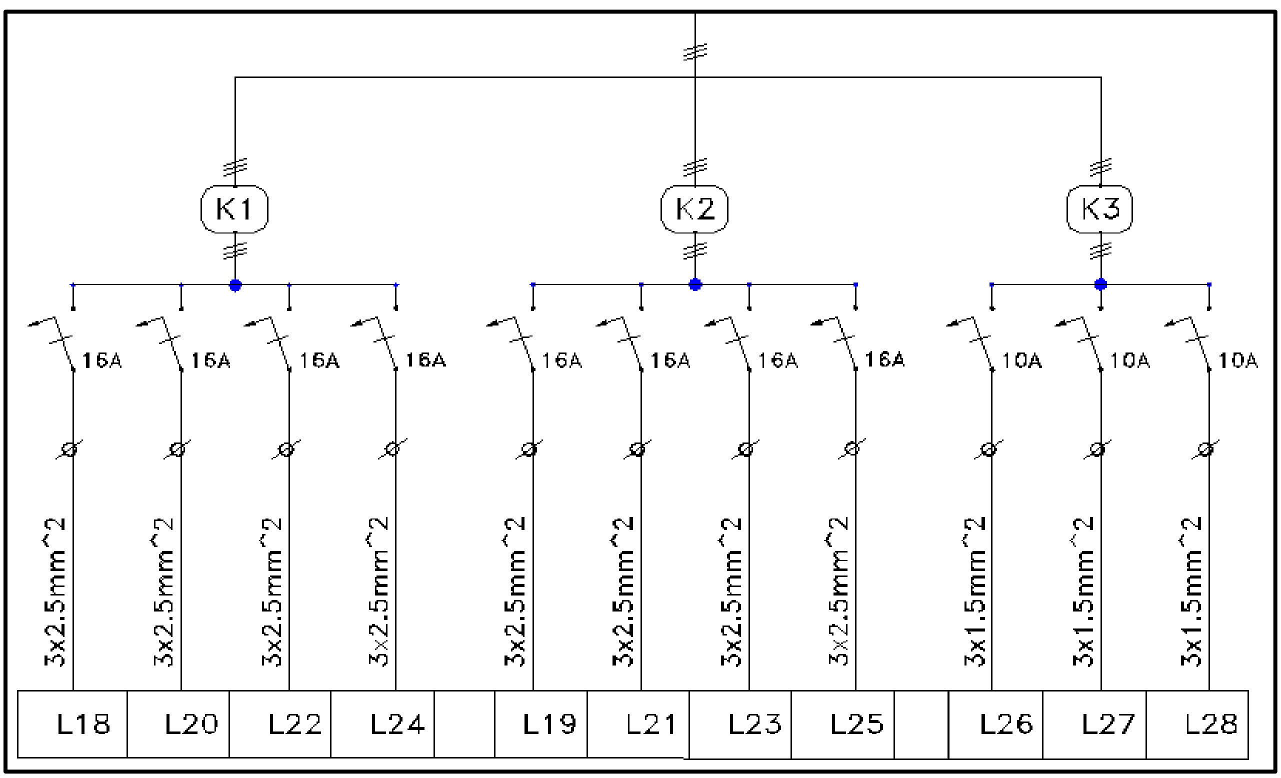


Fig. 3.6.13 Schematic of power circuit.

- **Control Circuit**

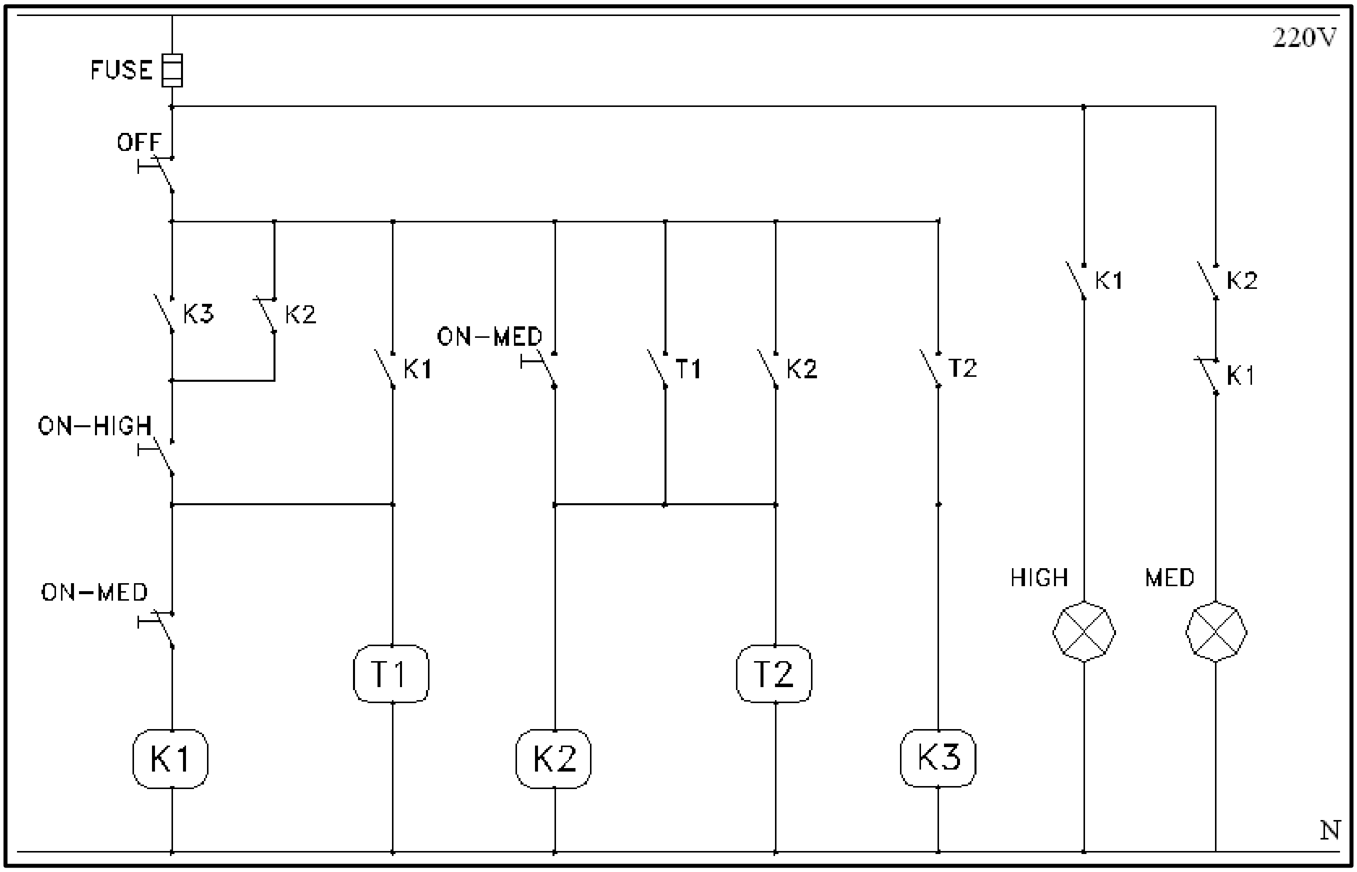


Fig. 3.6.14 Schematic of control circuit.

Set all timers time to 5sec, which is sufficient for the current to return to its steady state value and jumps control to next stage of operation.

3.7 Earthing and Lightning Systems:

3.7.1 Earthing Systems:

The earthing system will be in full compliance with the IEEE regulations. The TN-S system arrangement will be applicable. This means that separate neutral and protective conductors throughout the electrical distribution will be implemented on the LV distribution system.

3.7.1.1 What is a good ground value

Ideally the ground resistance of a system is zero ohms. But in reality, the goal is to achieve the lowest ground resistance possible that makes sense economically and physically.

NFPA & IEEE: Recommends a ground resistance value of 5.0 ohms or less.
Telecommunications Industry: Often uses 5.0 ohms or less as their value for grounding or bonding
NEC: Make sure the system to ground is 25.0 ohms or less. In facilities with sensitive equipment, it should be 5.0 ohms or less. (source – NEC 250.56)

3.7.1.2 The Earthing resistance depends on:

The NEC code requires a minimum ground electrode length of 2.5 meters (8.0 feet) to be in contact with the soil. But, there are five variables that affect the ground resistance of a ground system:

- Length / Depth of the ground electrode – double the length, reduce ground resistance by up to 40%
- Diameter of the ground electrode – double the diameter, lower ground resistance by only 10%
- Number of ground electrodes – for increased effectiveness, space additional electrodes at least equal to the depth of the ground electrodes
- The resistance of the soil where the electrode is buried - the humidity of the soil
- Ground system design – single ground rod, multiple ground electrodes, ground mesh & ground plate.

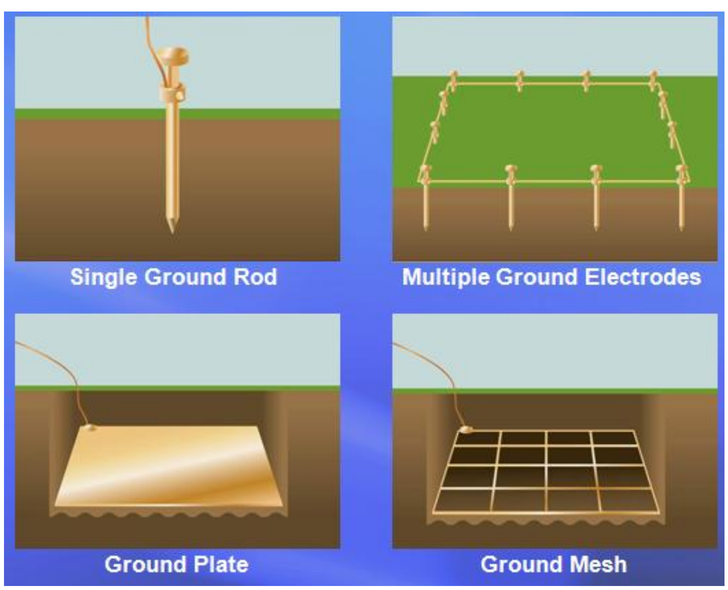


Fig. 3.7.1 Types of Ground Systems

3.7.1.3 Soil Resistivity

The purpose of soil resistivity measurements is to quantify the effectiveness of the earth where a grounding system will be installed.

So, soil resistivity testing is most necessary when determining the design of the grounding system for new installations. Ideally, you would find a location with the lowest possible resistance.

The soil composition, moisture content and temperature of the soil all impact the soil resistivity.

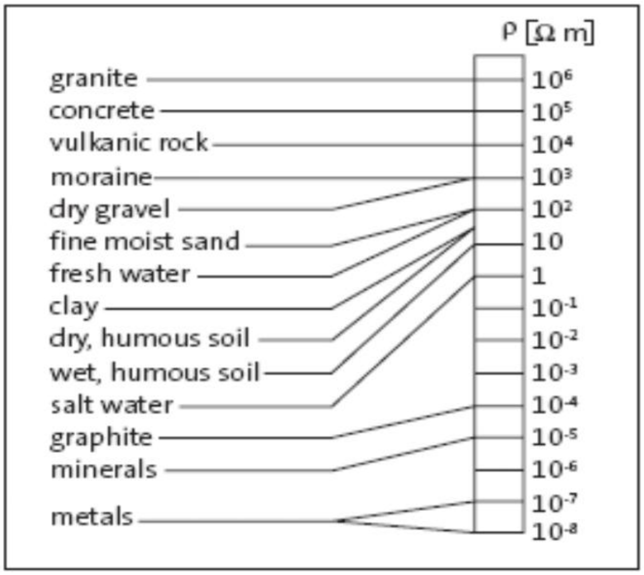


Fig. 3.7.2 Resistivity in various type of soil.

<u>There is two ways to reduce the resistivity of the soil</u>

1. by using electrodes buried deeply in the ground
2. processing the soil by adding one of the following salts :

- magnesium sulphate
- copper sulphate
- carbon or coal
- Iron filling

Usually it needs about 30-40 kg from salt for processing the soil around the vertical electrode and this will reduce the resistivity of the soil by 2 to 6 times.

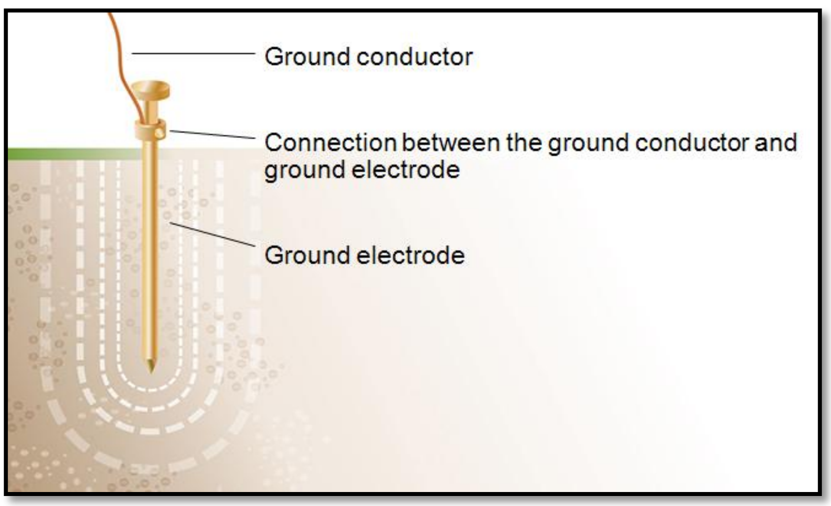


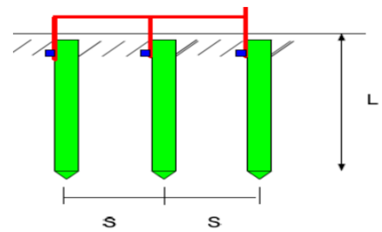
Fig. 3.7.3 Components of a ground electrode

3.7.1.4 Calculation Methodology

Approximated method to calculate earthing resistance:

- single vertical electrode ($R_V = \frac{\rho}{L}$)
- Single horizontal electrode ($R_H = \frac{2\rho}{L}$)
- In the case of having N vertical electrodes connected in parallel ($R_{V-T} = \frac{R_V}{N\eta}$)

Where η_V: (screening coefficient less than 1) depends on two factors :



- The first one is S/L where s is the distance between electrodes (>3m) And L is the length of the electrode.
- The second factor is the number of electrodes N.

η	N	S/L	η	N	S/N	η	N	S/L
0.95 – 0.97	2	3	0.93 – 0.95	2	2	0.8 – 0.87	2	1
0.91 – 0.95	3		0.9 – 0.92	3		0.76 – 0.8	3	
0.89 – 0.92	5		0.85 – 0.88	5		0.67 – 0.72	5	
0.82 – 0.88	10		0.79 – 0.83	10		0.56 – 0.62	10	
0.79 – 0.81	20		0.74 – 0.79	20		0.5 – 0.47	20	

Table 3.7.1 Screening coefficient table.

- Total earth resistance will be ($R_{eq} = \frac{R_V \times R_H}{R_V + R_H}$)

3.7.1.5 Design Calculations and Results

The proposed earthing system consist of multiple horizontal strip conductors interconnected between the building foundations in addition to several vertical electrodes buried deeply in the ground.

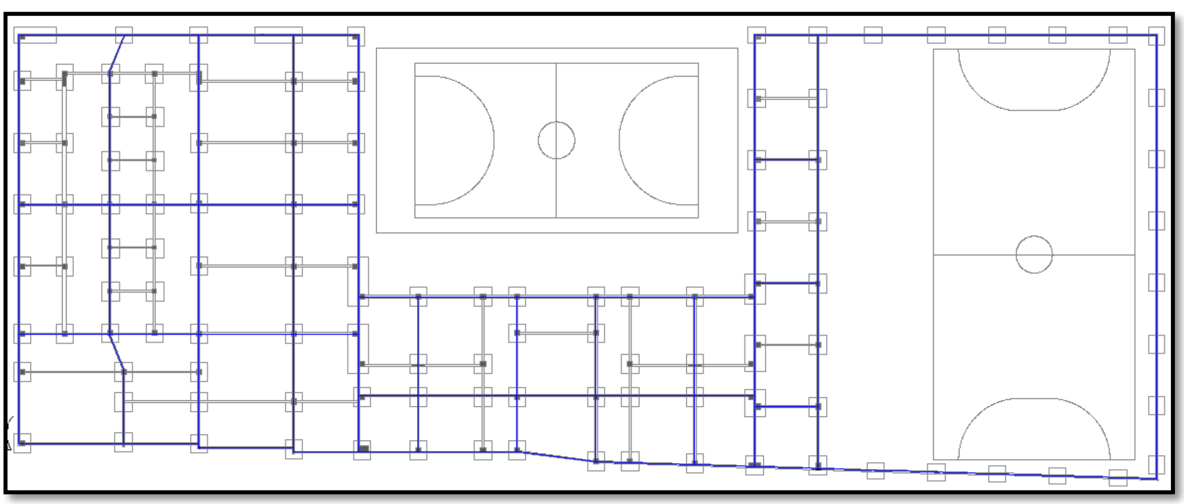


Fig. 3.7.4 Proposed earthing grid

The previous design of earthing grid (see the figure above) have the following parameters:

- Galvanized steel strip 30x3mm.
- The total length of the horizontal strip conductor equal approx. 750m.
- The soil resistivity around the site foundations to be approximately 400Ω.m.
- Four earthing manhole (30x30cm), 5m spaced and each electrode 2.5m long.
- The soil resistivity inside earthing manhole after soil processing about 100Ω.m.

Using the previous simplified equations, the resistance of the earthing grid is:

- ✓ $\text{Rv} = \frac{\rho}{\text{L}} = \frac{100}{2.5} = 40\Omega$
- ✓ $\frac{\text{S}}{\text{L}} = \frac{5}{2.5} = 2$, N=4 rods, η = 0.89
- ✓ $\text{Rv-T} = \frac{\text{Rv}}{N\eta} = \frac{40}{4\times0.89} = 11.23\Omega.$
- ✓ $\text{RH-T} = \frac{2\rho}{L\eta} = \frac{2\times400}{750\times0.7} = 1.52\Omega.$
- ✓ $\text{Req} = \frac{\text{Rv x RH}}{\text{Rv+RH}} = \frac{11.23 \text{ x } 1.52}{11.23+1.52} = 1.338\Omega.$

So, the total ground resistance value is 1.338Ω and still below the recommended value (5Ω).

To determine the requested cross sectional area of the ground conductor, the first step is to find the maximum short circuit current in the building as follows:

- The building power supplied with 150KVA transformer have 0.05 impedance.
- The short circuit apparent power of the transformer S s.c = $\frac{\text{S base}}{\text{X}} = \frac{150\text{KVA}}{0.05} = 3$ MVA.
- So, the short circuit current $Is.c = \frac{S\ s.c}{\sqrt{3}\times0.38} = \frac{3}{\sqrt{3}\times0.38} = 4.558\ KA$
- Then, the appropriate cross sectional area $A = 9 \times \sqrt{t} \times I\ s.c = 9\times \sqrt{0.5} \times 4.558 = 29mm2$
- And the nearest standard X-section area is 35mm2

Now the required protective conductor cross sectional area depends on the following table:

Lowest area of the protective earth in mm^2	Area of the phase conductor(s)
s	S<= 16
16	16<S<=35
s/2	S>35

Table 3.7.2 Protective conductor X-sectional area table.

The total current in the building approximately 160A - 35mm2, consequently the X-section area of the protective conductor is 16mm^2.

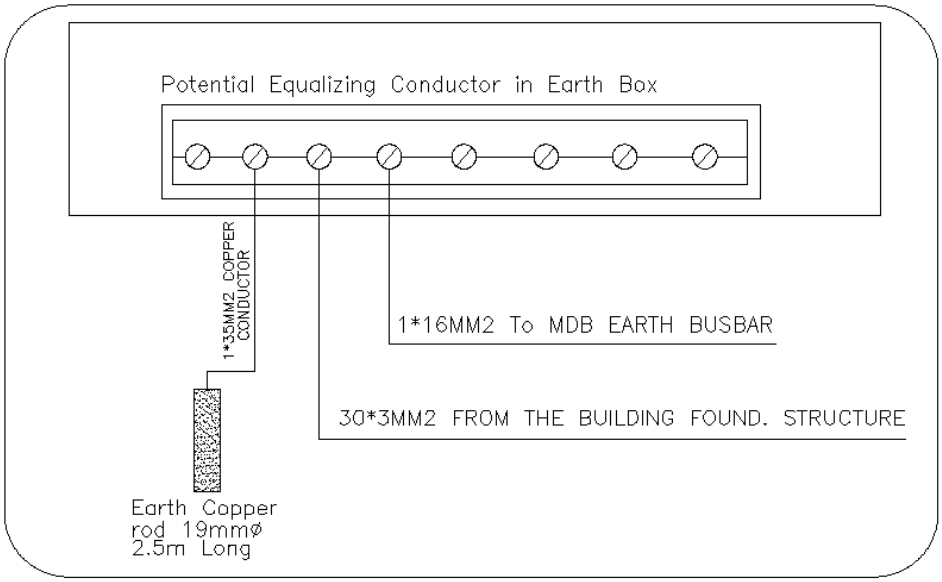


Fig. 3.7.5 Main Earthing Busbar (MET).

3.7.2 Lightning Protective System

3.7.2.1 Plant Building and Structures

The need for the protection of plant buildings such as substation, control room, office buildings, work shop, warehouse etc., and cooling towers shall be assessed taking into consideration the exposure risk and the following factors:

- Use to which structure is put.
- Nature of its construction.
- Value of its contents or consequential effects.
- The location of the structure and
- The height and the effective collection area of the structure.

The overall risk factor shall be established as per the guidelines of IS:2309 to decide the need for protection. Structures of exceptional vulnerability by reason of explosive or highly flammable contents need special consideration and every possible protection need to be provided even against the rare occurrence of a lightning discharge.

3.7.2.2 General Design Requirements

A lightning protection system (Conventional Air Terminal System) consists of the following three basic components:

- Air terminal
- Down conductor
- Earth connection

Air Termination System

- ❖ The air terminal shall be capable of drawing the lightning discharge to it in preference to vulnerable parts of the protected structure. The air terminations can be of vertical or horizontal type. Conductors shall be interconnected to form a closed loop.

- ❖ Vertical air terminations shall be used for very high structures with small base areas e.g. non-conducting chimneys etc. Minimum 2 nos. vertical terminations shall be provided for chimneys.

- ❖ Vertical air terminations shall project at least 300 mm above the protected structure.

- ❖ All the vertical air terminations provided on the same structure shall be interconnected.

- ❖ All non-current carrying metal parts such as metal piping, railing etc. on roof and building façade curtain walling shall be bonded to the lightning protection network.

- ❖ Where a structure has two elevations; out of which lower is projecting outside and the higher elevation does not protect the lower elevation, separate network shall be provided for lower elevation. Both networks shall be interconnected by connecting the higher elevation down conductor to the lower network.

Down Conductors

The recommended spacing of down conductors is every 20 M of Perimeter for structures up to 20 M in height and every 10 M of perimeter for structured above 20 M height.

Earth Connections

- ❖ Each down conductor shall be provided with an earth electrode and all earth electrodes shall be interconnected through underground strip.

- ❖ The use of rod/pipe/strip electrodes is permissible. Their choice will depend upon site conditions, soil resistivity and economic considerations.

- ❖ The material of earth electrodes shall be galvanized iron.

- ❖ The whole of lightning protective system including any earth ring shall have a combined resistance to earth not exceeding 10 ohm.

3.7.2.3 Size and Material of Conductors

The material of air termination network, down conductor and earth termination shall be galvanized iron.

Lightning currents have very short duration, therefore thermal factors are of little consequence in deciding the cross-section of the conductor. The minimum size and spacing between the various components of lightning protection system shall be as follows:

- Vertical Air Termination: 25mm dia.,1000mm long GI-Pipe.

- Air termination 20" apart max. (6m).
- Horizontal air termination: 25x3mm GI-Strip (or) 40x5mm GI-Strip.
- Down conductors: Same as horizontal air termination.
- 20m spacing between down conductors.
- Earth terminations: 65mm dia., 3m long GI pipe in Test pit.

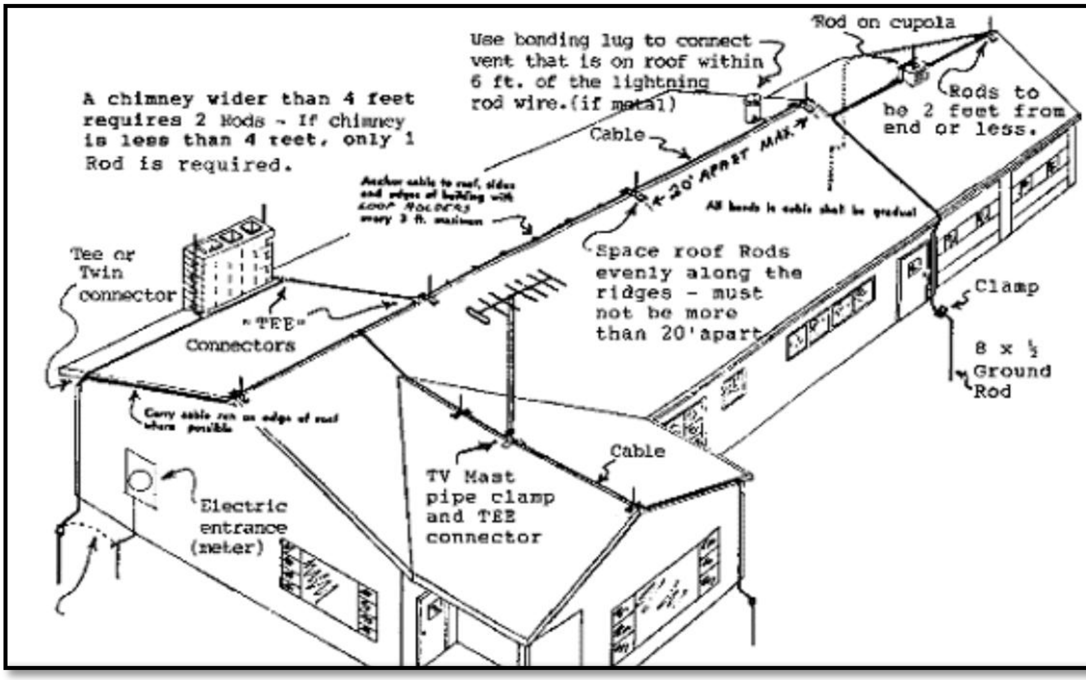


Fig. 3.7.6 Lightening protective system.

3.7.2.4 Design Calculation and Results

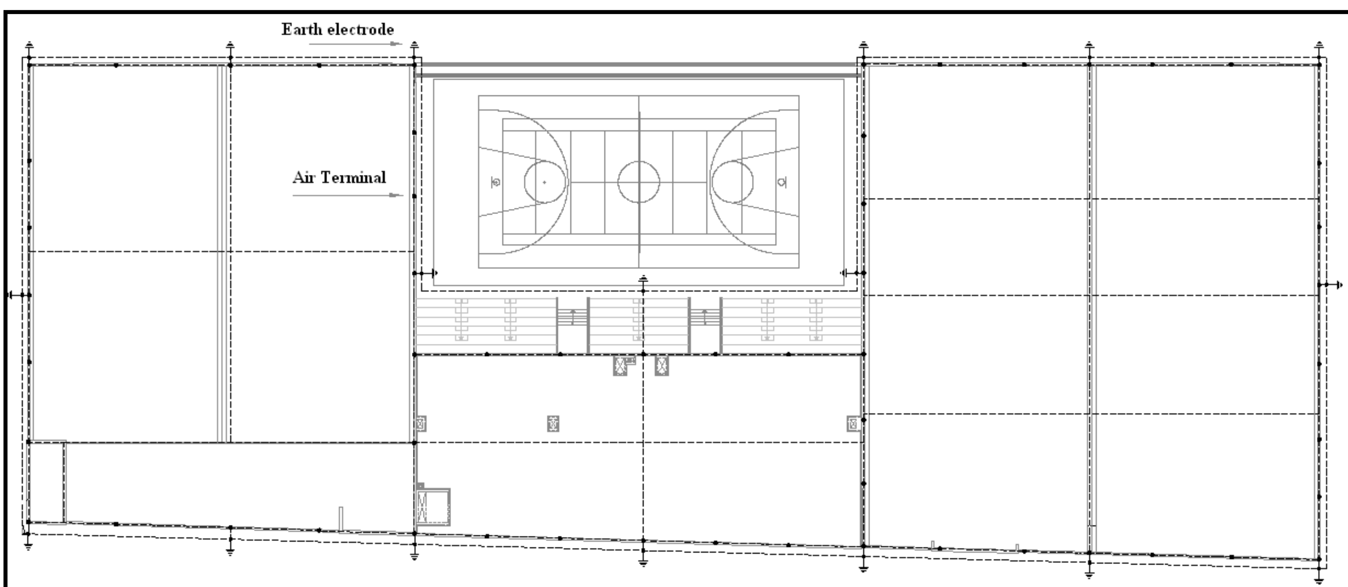


Fig. 3.7.7 The proposed lightening protective system design.

By doing some calculations using the previous approximated equations, the resistance of lightening protective system design is:

- ✓ $Rv = \frac{\rho}{L} = \frac{400}{3} = 133.33\Omega$
- ✓ $\frac{S}{L} = \frac{20}{3} = 6.667$, N=18 rods, η = 0.9
- ✓ Rv-T $= \frac{Rv}{N\eta} = \frac{133.33}{18\times0.9} = 8.23\Omega.$
- ✓ RH-T $= \frac{2\rho}{L\eta} = \frac{2\times400}{308\times0.7} = 3.71\Omega.$
- ✓ Req $= \frac{Rv \text{ x } RH}{Rv+RH} = \frac{8.23 \text{ x } 3.71}{8.23+3.71} = 2.55\Omega.$

So, the total lightning resistance value is 2.55Ω and still below the recommended value (10 Ω).

3.8 Low Voltage Installation

3.8.1 Introduction

Low voltage installation does not stand for traditionally 230-volt installations, instead, plans here stands for many equipment operating under this rated voltage.

For example, 5 volts circuits are used in lighting control panels when utilize PIR, other when using GLT fire sensor 12 volt is recommended.

Here we have various types of electrical plans for the sport complex:

- ✓ Fire Alarm system.
- ✓ TV-installations.
- ✓ Telephone installations.
- ✓ CCTV installations.
- ✓ Emergency installations.

3.8.2 Fire Alarm System

This Part provides recommendations for the planning, design, and servicing of fire detection and alarm systems in and around buildings.

This Part does not cover systems whose primary function to extinguish or control the fire, such as sprinkler or automatic extinguishing systems, even though they might have a secondary alarm function; it does cover the use of a signal from an automatic extinguishing element of a fire alarm system.

3.8.2.1 Types of Detectors.

- ✓ **Optical Smoke Detector,** Optical smoke detectors incorporate a pulsing LED located in a chamber within the housing of the detector. The chamber is designed to exclude light from any external source. At an angle to the LED is a photo-diode which normally does not register the column of light emitted by the LED. In the event of smoke from a fire entering the chamber, the light pulse from the LED will be scattered and hence registered by the photo-diode.

- ✓ **Ionization Smoke Detector,** The sensing part of the detector consists of two chambers - an open, outer chamber and a semi-sealed reference chamber within. Mounted in the reference chamber is a low activity radioactive foil of Americium 241 which enables current to flow between the inner and outer chambers when the detector is powered up. As smoke enters the detector, it causes a reduction of the current flow in the outer chamber and hence an increase in voltage measured at the junction between the two chambers.

- ✓ **FLAME DETECTOR,** A Flame detector is designed to detect either ultraviolet (UV) or infrared (IR) radiation emitted by a fire. The flame detector is sensitive to low-frequency, flickering radiation. This means that the detector can operate even if the lens is contaminated by a layer of oil, dust, water vapor or ice.

- ✓ **Heat Detector - Activated by Heat,** The A1R, BR and CR (rate-of-rise) heat detectors operate by using a matched pair of thermostats to sense heat. One thermostat is exposed to the ambient temperature, the other is sealed.

✓ **Rate-of-Rise Detectors,** Are designed to detect a fire as the temperature increases, but they also have a fixed upper limit at which the detector will go into alarm if the rate of temperature increase has been too slow to trigger the detector earlier.

✓ **Beam Detector,** A beam detector is designed to protect large, open spaces. When a fire develops, smoke particles obstruct the beam of light and, once a pre-set threshold has been exceeded, the detector will go into alarm .it is made up of three main parts:

1. The transmitter, which projects a beam of infra-red light.
2. The receiver registers the transmitted light and produces an electrical signal.
3. The interface, which processes the signal and generates alarm or fault signals.

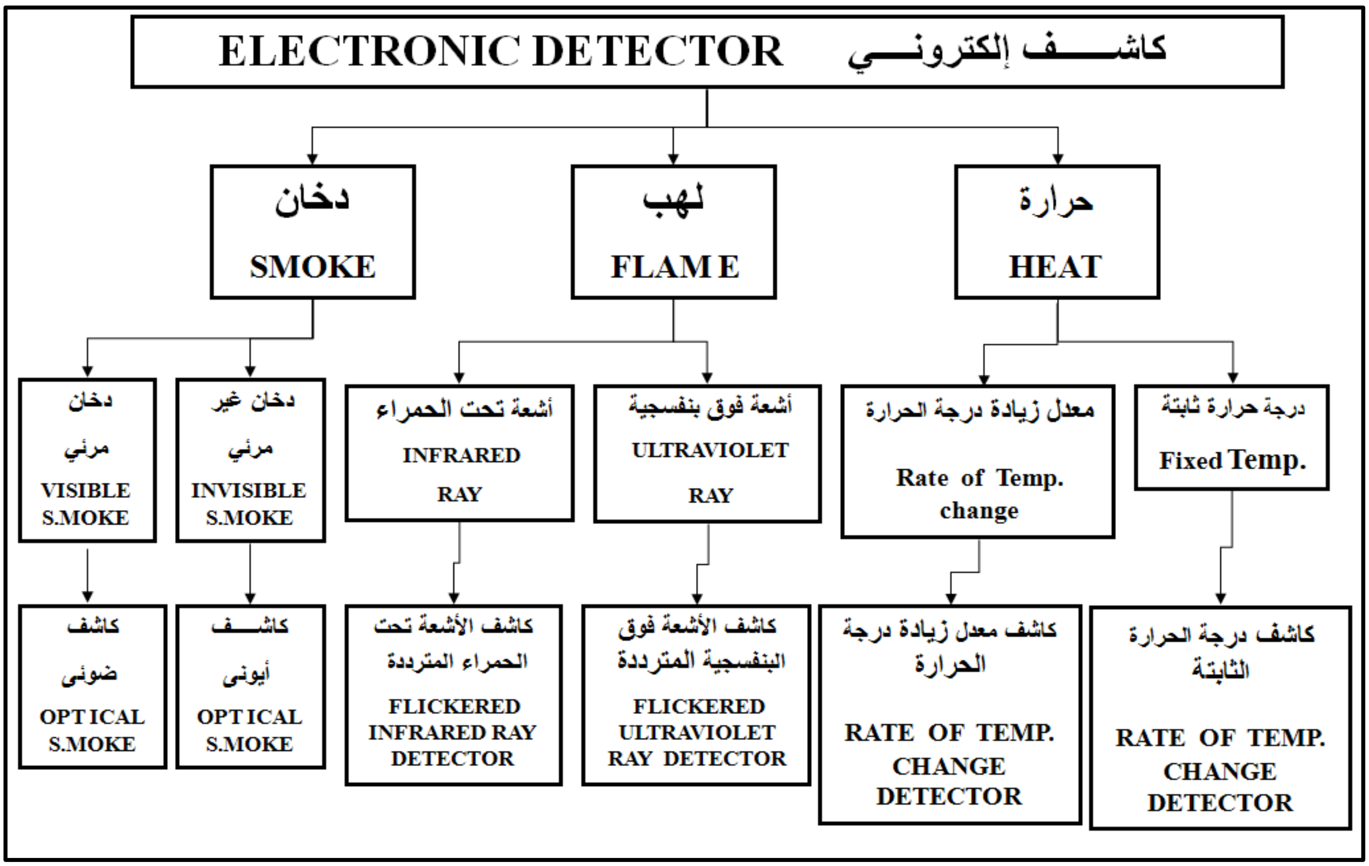


Fig. 3.8.1 Electronic detectors.

3.8.2.2 Methods of notification.

- Light (visible signals):
  - ✓ 15 cd to 1000 cd candela output.
  - ✓ 1 to 2 flashes per second.
- Sound (audible signals):
  - ✓ Usually around 3200 Hz due to component constraints.
  - ✓ 45dB to 120dB A weighted for human hearing.

3.8.2.3 Addressable system.

A system in which signals from each detector and/or call point are individually identified at the control panel. Hybrid systems are possible in which groups of devices on a circuit can be separately identified, but not individual devices within the group.

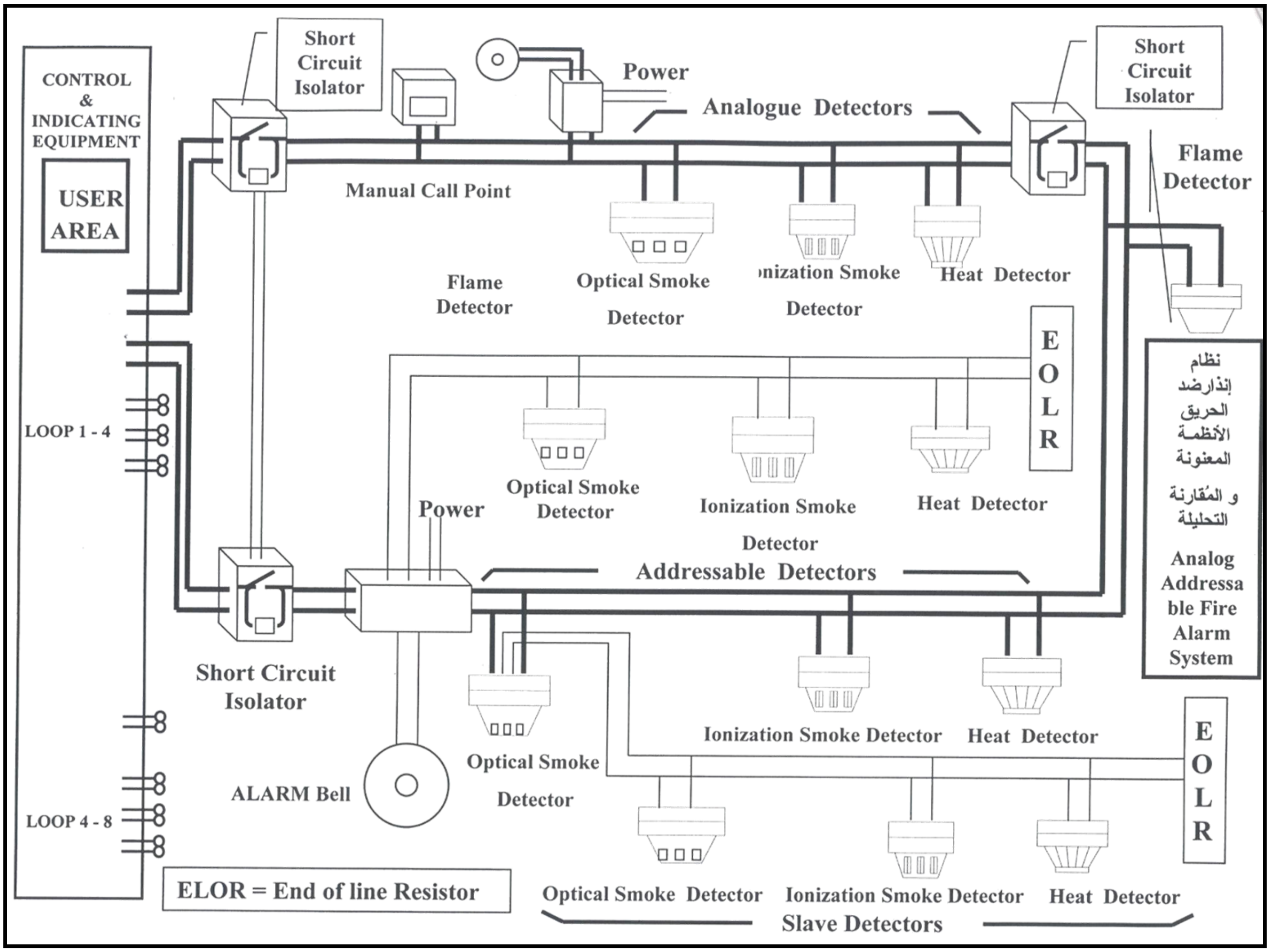


Fig. 3.8.2 Addressable system.

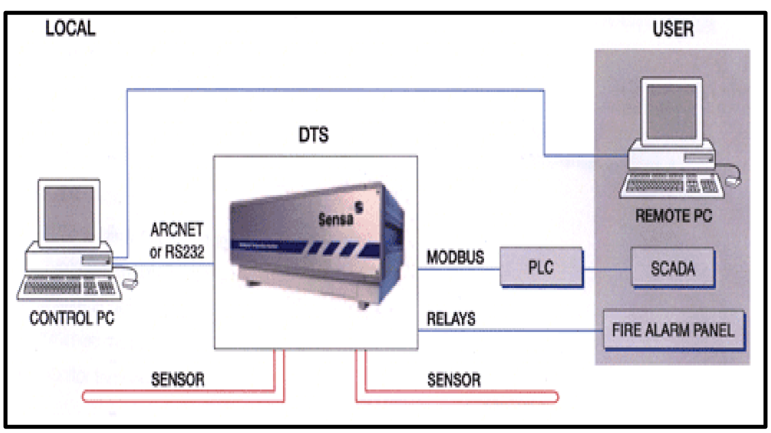


Fig. 3.8.3 Control system.

3.8.2.4 Fire Alarm Systems Design Concepts.

Choosing a suitable detector system:

Which detectors need to be specified, where, depends on the:

- Monitoring category or the general monitoring objectives of the fire detection system.
- Room height.
- Environmental conditions, including deceptive phenomena.

Choosing a detector for normal applications:

Normally a smoke detector can be chosen based on the following table, provided that disturbance variables are minor and occur only rarely. The principle criteria for choosing a detector and parameter set or sensitivity are the monitoring objective and the assessment of the fire risk exposure.

Monitoring Category	Projection / Monitoring Objective	Detectors		
		Opto	Poly	Thermo
I	- Flaming incipient fire	◗	●	●
II	- Flaming incipient fire - Smoldering incipient fire (desired)	●	●	○
III	- Flaming incipient fire - Smoldering incipient fire	●	◗	—

● Optimally suited ◗ Suited
○ Conditionally suited — Un suited

Table 3.8.1 Smoke detector selection table.

Influence of the room height:

With increasing of room height the influence of fire phenomena weakens which means that more sensitive detectors must be installed.

Room Height	Suitable detector type	Suitability	
		Flaming Fire	Smoldering
≤ 6 m	Heat detector (Cl.2)	●	-
≤ 7.5 m	Heat detector (Cl.1)	●	-
≤ 12 m	Smoke detector	●	●
12-20 m	Smoke detector / or Linear Smoke detector	● ●	◗ ●
≤ 20 m	Flame detector	●	-

● Optimally suited ◗ Suited
- Un suited

Table 3.8.2 Smoke detector selection table depend on room hight.

3.8.2.5 European and American standards:

Number	Title
EN54-1	Components of automatic fire detection systems: Introduction.
EN54-2	Control and indicating equipment.
EN54-3	Audible fire alarm devices.
EN54-4	Power supplies.
EN54-5	Heat sensitive detectors – point detectors containing a static element.
EN54-6	Heat sensitive detectors – rate of rise point detectors without static element.
EN54-7	Smoke detectors - point detectors using scattered light, transmitted light, or ionization.
EN54-8	High Temperature heat detectors.
EN54-9	Fire Tests for smoke detectors.
EN54-10	Flame detectors.
EN54-11	Manual call points
EN54-12	Optical beam detectors.
EN54-13	System requirements.
EN54-14	Guidelines for planning design, installation, commissioning, use and maintenance.
EN54-15	Point type multi-sensor fire detectors incorporating a smoke sensor in combination with a heat sensor.

Standards for fire detection systems

UL521	Heat detectors for fire protection signaling systems.
UL268	Smoke detectors for fire protection signaling systems.
UL268A	Smoke detectors for duct application.
UL38	Manual call point.
UL864	Control units for fire protection signaling systems
UL827	Central station for watchman, fire alarm and supervisory systems.
UL217	Single and multiple-station smoke detectors.
UL985	Household fire warning system unit

Table 3.8.3 European and American standards.

3.8.3 Magnetic Door Holders.

Magnetic door holders are installed to hold cabinet doors or light screen doors closed. The magnetic part of the holder is screwed into the inside trim of a cabinet or door jam of a light screen door. Screw the metal plate to the door where it will meet the magnet when closed.

Electromagnetic Door Holders have a holding force of approximately 15 to 25 lbf (66 to 111N). The device holds a door open while energized. When de-energized by a relay controlled by the fire alarm system or other switch, the door is released to a closed position, reducing the spread of smoke and flames. Electromagnetic door holders should be used and installed in accordance with local Building Codes and Standards.

3.8.3.1 Types of holders.

- **"Fail safe"** magnetic lock requires power to remain locked and is therefore not suitable for high security applications, because it is possible to bypass the lock by disrupting the power supply. However, "fail safe" maglocks are well suited for use on emergency exit doors, because they are less likely to fail to unlock.

- **"Fail secure"** maglocks use a permanent magnet to keep the door shut and use current passing through an electromagnet to cancel out the permanent magnet and release the door. These "fail secure" locks are therefore better suited to high security installations. Because power is required to release the "fail secure" locks, much more care is needed when deciding to use them for safety reasons. For example if a fire occurs and the power to the building is cut, there might be no means of escape for occupants.

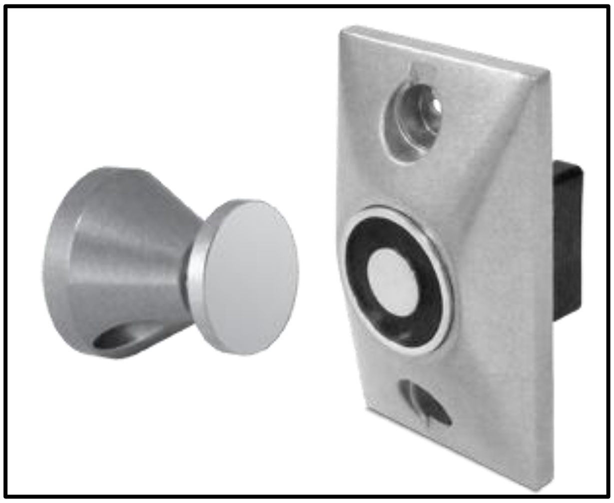


Fig. 3.8.4 Magnetic door holders.

3.8.4 CCTV Installation.

Closed-circuit television (CCTV) is the use of video cameras to transmit a signal to a specific place, on a limited set of monitors. It differs from broadcast television in that the signal is not openly transmitted, though it may employ point to point (P2P), point to multipoint, or mesh wireless links.

Though almost all video cameras fit this definition, the term is most often applied to those used for surveillance in areas that may need monitoring such as banks, casinos, airports, military installations, and convenience stores. Video telephony is seldom called "CCTV" but the use of video in distance education, where it is an important tool, is often so called.

3.8.4.1 Network camera

A network camera can be described as a camera and computer combined in one unit. It has a compression chip, an operating system, a built-in web server, FTP (File Transfer Protocol) server, FTP client, e-mail client, alarm management and much more. A network camera, unlike a web camera, does not need to be attached to a PC; it operates independently and connects, as with a PC, directly to an IP network. It can be placed wherever there is a wired or wireless network connection. The network camera captures and sends live images, enabling authorized users to locally or remotely view, store and manage video over a standard IP-based network infrastructure.

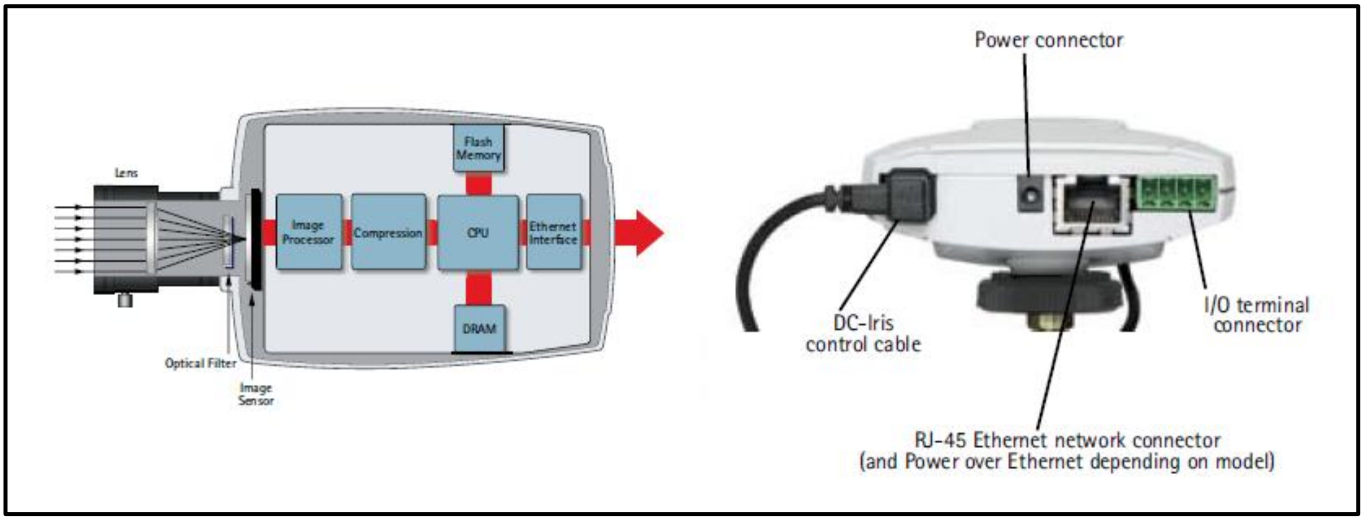


Fig. 3.8.5 Network camera.

3.8.4.2 Types of network cameras

Indoor or outdoor, Outdoor network cameras must have an auto iris lens to regulate how much light is received. Many outdoor cameras require a protective housing. Others may already be designed with a protective enclosure. Housings are also available for indoor cameras that require protection from harsh environments such as dust and humidity, and from vandalism or tampering.

Types (Fixed, fixed dome, PTZ (pan/tilt/zoom) or PTZ dome):

- **Fixed network cameras:** A fixed camera is one whose viewing angle is fixed once it is mounted. A fixed camera with a body and a lens represents the traditional camera type.

- **Fixed dome network cameras:** Fixed dome cameras, also called mini domes, essentially consist of a fixed camera that is pre-installed in a small dome housing. The camera can be easily directed to point in any direction.

- **Mechanical PTZ network cameras:** It can pan, tilt and zoom through manual or automatic control. In a manual operation, an operator can use a PTZ camera to follow, for instance, a person in a retail store. PTZ cameras are mainly used indoors and in applications where an operator is employed and where the visibility of the camera's viewing angle is desirable or not an issue. The optical zoom on PTZ cameras typically ranges from 10X to 26X. A PTZ camera can be mounted on a ceiling or wall.

- **PTZ dome network cameras:** PTZ dome network cameras can cover a wide area by enabling greater flexibility in pan, tilt and zoom functions. They enable a 360-degree, continuous pan, and a tilt of usually 180 degrees. PTZ dome cameras are ideal for use in discreet installations due to their design

Fig. 3.8.6 Types of network cameras.

3.9 Lighting Control

3.9.1 Introduction

Lighting controls have traditionally been used to create moods. Today, they are also used as part of a high quality energy efficient lighting system that integrates daylight and electric light sources to provide a comfortable and visually interesting environment for the occupants of a space. Electric lighting controls are appropriate for a wide variety of spaces, from restrooms to large open offices, from conference rooms to classrooms. They can be incorporated with daylighting to provide flexibility, energy savings, and ecological benefits. Although lighting controls are still most commonly used in commercial buildings, they are also increasingly being used in residential applications.

3.9.2 Description

Electric lighting controls are used in lighting design projects to achieve a high quality energy efficient lighting system. Specifying a layered, daylight-integrated lighting and control system gives the occupants control of the lighting while providing appropriate lighting levels, minimizing glare, balancing surface brightness, and enhancing the surrounding architecture.

Fig. 3.9.1 Various types of occupancy sensors and photo sensors.

When electric lighting controls are used properly, energy will be saved and the life of lamps and ballasts can be extended. Lighting controls will help reduce energy by:

- Reducing the amount of power used during the peak demand period by automatically dimming lights or turning them off when they are not needed.
- Reducing the number of hours per year that the lights are on.
- Reducing internal heat gains by cutting down lighting use, which allows for reduced HVAC system size and a reduction in the building's cooling needs.
- Allowing occupants to use controls to lower light levels and save energy.

A good lighting design includes a good controls design. Lighting controls play a critical role in lighting systems, enabling the user to manually or automatically:

- Turn the lights ON and OFF using a switch; and/or.
- Adjust light output up and down using a dimmer.

This basic functionality can be used to generate these benefits for the lighting owner:

- Flexibility to satisfy user visual needs; and
- Automation to reduce energy costs and improve sustainability.

Dimming controls can provide the lighting flexibility which is often required in multi-use rooms or rooms in which projectors are used. Exterior motion detectors and interior occupancy sensors can be used to turn lights on when people (including intruders) are present. Moreover, by tuning an environment for the individual occupant's or group's visibility, comfort and productivity can be improved.

3.9.3 Energy Codes

Most commercial building energy codes are based on the ASHRAE 90.1 energy standard or the International Energy Conservation Code (IECC), with the 2004 version of ASHRAE 90.1 being the current national energy standard. Both have mandatory requirements regarding energy codes, notably that indoor and outdoor lighting must be turned OFF automatically when it is not being used, and controls in enclosed spaces. IECC also requires light reduction control, ASHRAE 90.1 requires separate control of display lighting, and the latest generation of both requires separate control of daylight zones.

3.9.4 Control Zones

Power controllers allow control of connected lighting loads typically comprised of light fixtures. A group of light sources controlled simultaneously by a single controller is called a control zone. Control zones are a very important tool and decision point in control system design.

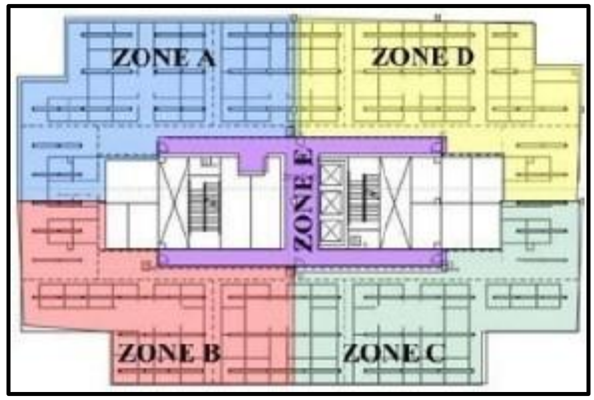


Fig. 3.9.2 Control zones diagram.

3.9.5 Control Strategies

Combining various inputs and outputs results in several unique control strategies available that can address visual needs, energy management and sustainability needs, or both. Manual control, occupancy sensing and time scheduling are the most common strategies, with daylight harvesting becoming important and demand response and task tuning still emerging. By networking controllers with multiple input devices, designers can build lighting control systems that can economically enact multiple strategies for maximum benefit.

- Manual control.
- Occupancy sensing
- Time scheduling
- Daylight harvesting
- Dimming
- Demand response

3.9.5.1 Types of Lighting Controls

3.9.5.1.1 Manual control

The most common form of electric lighting control is the on/off "toggle" switch. Standard on/off switches and relays can be used to turn groups of lights on and off together. Creative design options can be developed with this simple tool, if the circuiting is properly designed. For example, some of the lamps in each fixture can be switched together, every other fixture can be switched as a group, or lighting near the windows can be turned off when daylight is plentiful.

❖ ***How it works***

- Manual control is a simple strategy providing users the capability of choosing light levels in steps (switching) or over a wider range, with smooth transitions between levels (dimming). Manual control is driven by visual needs, although some energy is saved.
- Manual switching could be as simple as an ON/OFF switch up to bi-level switching schemes enabling users typically to choose full/50%/OFF and full/66%/33%/OFF using alternate ballasts, fixtures, rows or output levels offered by a light level switching (step dimming) ballast.
- Manual controls are highly suited to spaces requiring flexibility from the lighting system, such as private and open offices, meeting and education spaces, houses of worship, entertainment venues and other spaces.

❖ ***Energy savings***

- Private office: 22% energy savings
- Open office: 16% energy savings
- Classroom: 8% energy savings
- Retail: 15% energy savings

Fig. 3.9.3 Personal dimming controllers.

3.9.5.1.2 Occupancy sensing.

Occupancy sensors are devices that automatically turn the lights ON and OFF based on whether the sensor detects occupancy, resulting in energy cost savings.

Occupancy sensors are including passive infrared, ultrasonic, and dual technology sensors. Some sensors have settings that allow the specified to select between the functions (manual on instead of automatic on, for example). Note that sensor characteristics may vary considerably from manufacturer to manufacturer, so it is important to carefully evaluate the options for each device.

Fig. 3.9.4 Example of a ceiling-mounted occupancy sensor.

✓ ***Passive infrared sensors***

Passive infrared sensors (PIR) are triggered by the movement of a heat-emitting body through their field of view. Wall-box type PIR occupancy sensors are best suited for small, enclosed spaces such as private offices, where the sensor replaces the light switch on the wall and no extra wiring is required. PIR sensors cannot "see" through opaque walls, partitions, or windows so occupants must be in direct line-of-site of the sensor.

Fig. 3.9.5 Example of passive infrared sensors (PIR).

PIR occupancy sensors react to the movement of heat emitted by people in motion. These sensors detect motion within a field of view that requires a line of sight; they cannot "see" through obstacles. The sensor may detect motion through glass in some cases depending on the glass's infrared transmission characteristics.

The sensor's multi-faceted lens defines its coverage area as a series of discrete fan-shaped zones. As an occupant crosses these zones, motion is detected. As a result, PIR sensors are more sensitive to motion occurring lateral to the sensor. The sensor's lens also determines the size of motion it is best suited to detect.

The gaps between the coverage zones widen with distance, which results in decreasing sensitivity to motion proportional to distance from the sensor. Most PIR sensors are sensitive to full body movement up to about 40 ft. but are sensitive to hand movement, which is more discrete, up to about 15 ft.

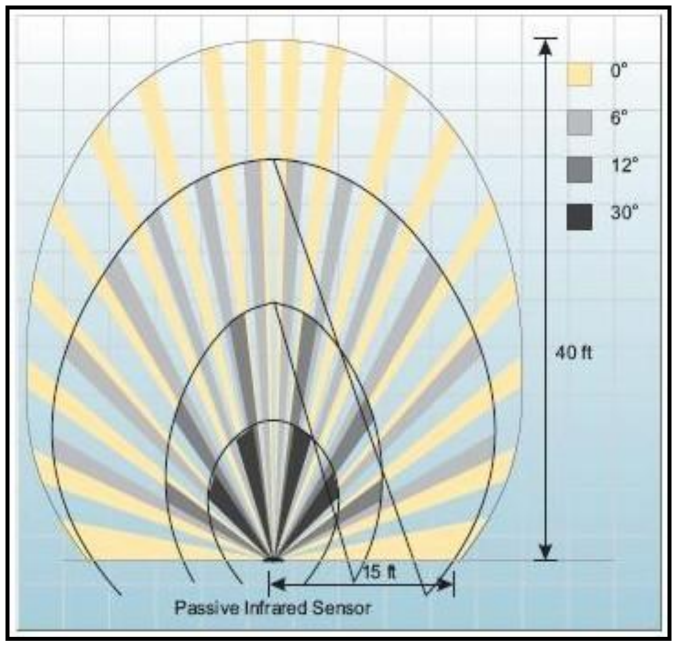


Fig. 3.9.6 PIR sensors coverage area

✓ ***Ultrasonic sensors***

Ultrasonic sensors emit an inaudible sound pattern that is disrupted by any moving object altering the signal returning to the sensor (Doppler shift). They are best suited for spaces where line-of-sight view to the occupant is not always available. This type of sensor detects very minor motion better than most infrared sensors and is often used in restrooms since the hard surfaces will reflect the sound pattern.

Fig. 3.9.7 Example of Ultrasonic sensors.

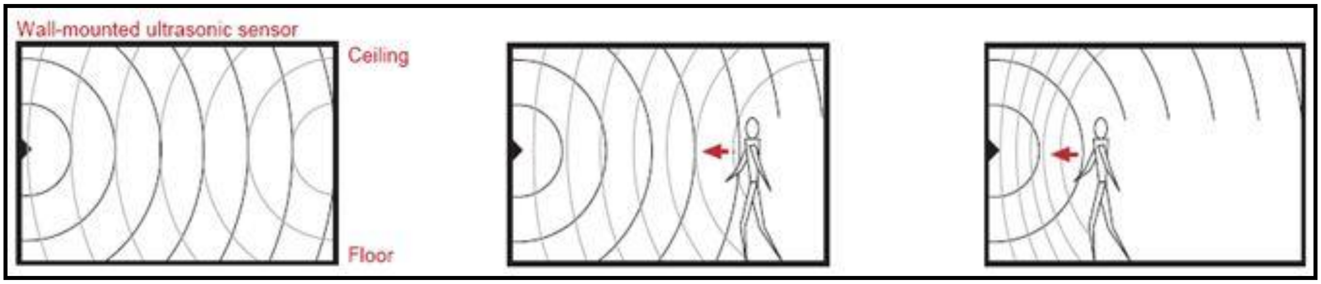


Fig. 3.9.8 Principle of operation of ultrasonic sensors.

Ultrasonic occupancy sensors emit an ultrasonic high-frequency signal throughout a space, monitor the frequency of the reflected signal, and interpret change in frequency as motion. Alternately, they can set up a standing wave and look for changes in both amplitude and frequency due to motion. The frequency of the waves is typically well above (32-40 kHz) what the normal ear can detect (20 kHz) to avoid incompatibilities with devices such as hearing aids. These sensors do not require a direct line of sight (coverage is volumetric), making them ideal for applications such as multiple public restroom stalls.

These sensors are highly sensitive, able to detect hand motion at a distance up to 25 ft. Shown here is a typical sensitivity pattern for a wall-mounted ultrasonic sensor. The sensor is most sensitive to motion occurring to and from the sensor.

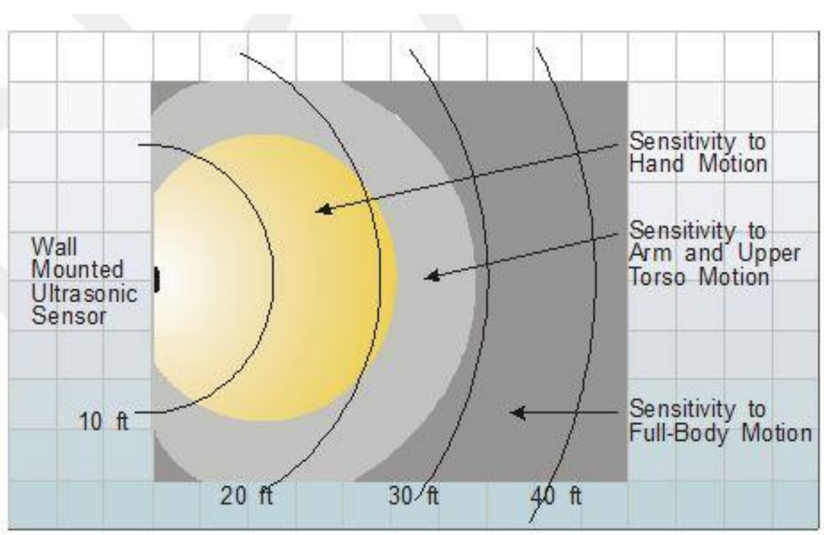


Fig. 3.9.9 Ultrasonic sensors coverage area.

✓ ***Dual-technology occupancy sensors (Acoustic detection)***

Dual-technology occupancy sensors use both passive infrared and ultrasonic technologies for less risk of false triggering (lights coming on when the space is unoccupied). Combining the technologies requires a more reliable, yet slightly larger and more expensive device.

Dual-technology sensors utilize two detection methods to increase reliability in applications where a higher degree of detection is desirable, such as classrooms and conference rooms.

Most manufacturers offer sensors that combine ultrasonic and PIR technologies. The lights are turned ON only when both technologies detect the presence of people, eliminating the possibility of false-ON triggering. Similarly, only one technology is needed to hold the lights ON, significantly reducing the possibility of false-OFF switching.

Fig. 3.9.10 Example of Dual-technology occupancy sensors.

Another type of dual-technology sensor combines PIR technology with acoustic detection, enabling the sensor to detect occupants via their motion or the noises they make. This method is effective in applications where there are obstructions and/or occupants that are not moving for long periods of time. The lights are only turned ON when the PIR technology detects initial motion, thus preventing false-ON switching. The lights are then turned OFF only when there is no detected occupant motion or occupant sound, thereby preventing false-OFF switching. The device's microphone is tuned to listen only for sounds caused by occupants, and distinguishes sharp variations from white noise. It is also known as passive dual-technology because no sound waves are emitted into the space. The primary manufacturer is Sensor Switch.

The coverage pattern/range for a PIR/acoustic sensor will always be the same as its PIR only counterpart. This is because lights will only turn ON through PIR. The acoustic dual technology provides overlapping detection of the PIR coverage area, but will not trigger lights initially ON. Additionally, because the sensor is not transmitting sound, the effective distance from occupants varies with the magnitude of the sound generated by the occupant and the acoustics of the space. Spaces with hard floors or very quiet rooms with little or no background noise will be more sensitive to small sounds. Additionally, advanced filtering is utilized to prevent noises from outside the PIR coverage area from keeping the lights ON indefinitely.

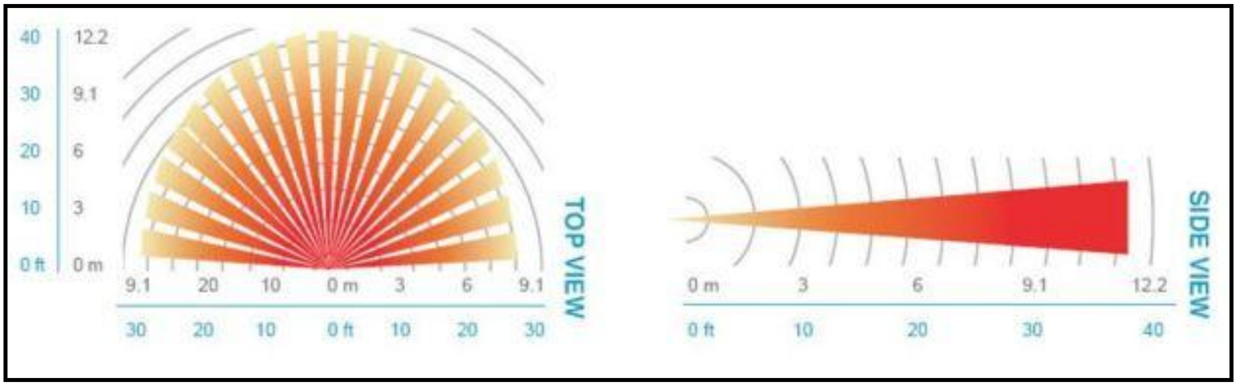


Fig. 3.9.11 Top & side view of acoustic detection sensors.

✓ ***Digital occupancy sensors***

The latest generation of occupancy sensor controls feature digital construction enabling a number of benefits, including onboard intelligence, self-commissioning, feedback (report on usage) and easier connections than allowed by traditional wiring methods.

In the digital control system shown to the right, all devices are connected using RJ45 low-voltage cables and plugged into the two-relay central controller, which senses the attached devices and automatically configures for optimal energy-saving operation.

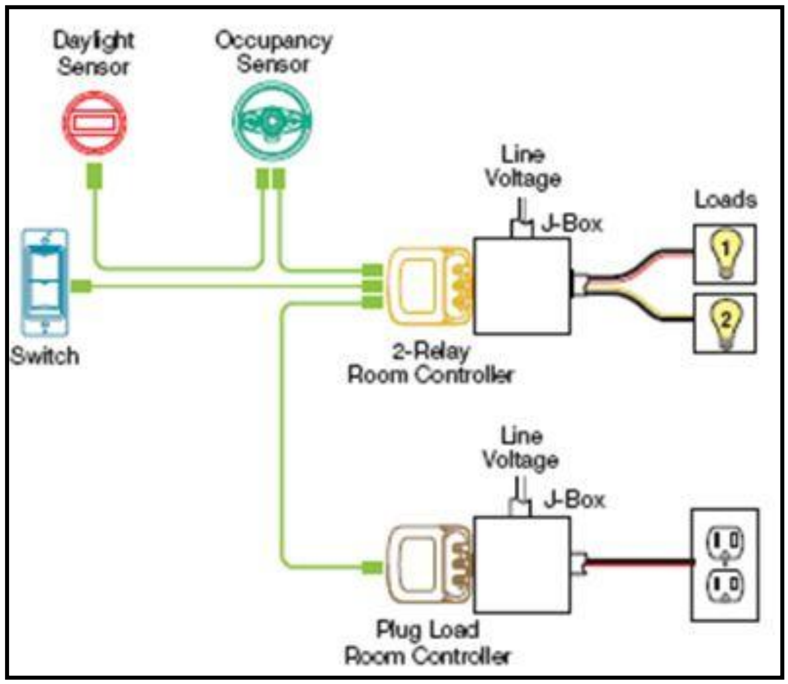


Fig. 3.9.12 Digital occupancy sensors.

❖ ***Operating Mode***

Traditional occupancy sensors turn the lights ON upon detecting the presence of people in the space. However, research has found that this approach saves less energy than requiring users to turn the lights ON manually.

The latest generation of energy codes is beginning to favor these so-called manual-ON occupancy sensors, also called vacancy sensors. Another option is to configure the lights for bilevel switching and turn the lights ON to 50%; the user must flip a switch to achieve 100%.

❖ ***How It Works***

Occupancy sensors serve three basic functions:

1. To automatically turn lights on when a room becomes occupied,
2. To keep the lights on without interruption while the controlled space is occupied, and
3. To turn the lights off within a preset time period after the space has been vacated.

If the device automatically turns the lights OFF but requires manual ON, it may be called a manual-ON occupancy sensor or a vacancy sensor. The sensor and power controller may be integral to the same unit, or they may be separate components.

Occupancy sensors are highly suited to smaller, enclosed spaces that are intermittently occupied, such as private offices, classrooms, conference rooms, copy and break rooms, restrooms and other spaces.

Occupancy sensor placement is very important to the successful implementation of the control design intent. Occupancy sensors must be located to ensure that they will not detect movement outside of the desired coverage area, through an open doorway, for example. Ultrasonic devices are sensitive to air movement and should not be placed near an HVAC diffuser, where air movement may cause false tripping.

Occupancy controls can be used in conjunction with dimming or daylight controls to keep the lights from turning completely off when a space is unoccupied, or to keep the lights off when daylight is plentiful and the room is occupied. This control scheme may be appropriate when occupancy sensors control separate groups of luminaires, or "zones", in a large space, such as in a laboratory or an open office area. In these situations, the lights can be dimmed to a predetermined level in one specific area when the space is unoccupied.

There are several different kinds of coverage patterns and mounting configurations for occupancy sensors, such as:

- Ceiling-mounted controls with 360° coverage
- Ceiling-mounted controls with elongated "corridor" coverage
- Wall-mounted controls with a fan-shaped coverage pattern
- Ceiling-mounted controls with a rectangular coverage pattern

Additionally, take note of the difference between each device's sensitivity to minor motion (working at a desk) vs. major motion (walking or half-step activity). The sensor manufacturer should provide coverage diagrams for both levels of activity. HID lamps do not work well with occupancy sensors because most HID lamps take a long time to start each time they are switched off.

❖ ***Energy Savings***

Occupancy sensing has been demonstrated to generate up to 38% lighting energy savings in private offices and 55% in classrooms. Energy savings are variable and will depend on occupancy patterns.

- Private office: 38% energy savings
- Classroom: 55% energy savings
- Open office (individual fixture control): 35% energy savings

Mounting Location	Sensor Technology	Angle of Coverage	Typical Effective Range*	Optimum Mounting Height
Ceiling	Ultrasonic	360º	500-2000 sq.ft.	8-12 ft.
Ceiling	PIR	360º	300-1000 sq.ft.	8-30+ ft.
Ceiling	Dual technology (PIR/ultrasonic)	360º	300-2000 sq.ft.	8-12 ft.

Wall switch	Ultrasonic	180º	275-300 sq.ft.	40-48 in.
Wall Switch	PIR	170-180º	300-1000 sq.ft.	40-48 in.
Corner wide view	PIR and dual technology (PIR/ultrasonic)	110-120º	To 40 ft.	8-15 ft.
Corner narrow view	PIR	12º	To 130 ft.	8-15 ft.
Corridor	Ultrasonic	360º	To 100 ft.	8-14 ft.
High mount	PIR	12-120º	To 100 ft.	To 30 ft.
High mount corner	Dual technology (PIR/ultrasonic)	110-120º	500-1000 ft.	8-12 ft.
High mount ceiling	Dual technology (PIR/ultrasonic)	360º	500-1000 ft.	8-12 ft.
Luminaire-integrated	PIR, ultrasonic	360º	To 12 ft.	8-12 ft.
Luminaire-attached	PIR	360º, aisle	To 40 ft.	20-40 ft.
***Sensitivity to minor motion may be substantially less than noted above, depending on environmental factors.**				

Table 3.9.1 Occupancy sensor characteristics.

3.9.5.1.3 Time scheduling

Scheduling adjusts the output of the lighting system based on a time event implemented using a time-clock, which may be implemented using software-based intelligence built into the control system. At certain times, controlled lights will turn ON, OFF or dim to save energy or support changing space functions.

Scheduling is highly suitable for larger, open spaces that are regularly occupied as well as spaces that are intermittently occupied but where the lights must remain ON all day for safety or security reasons. Local override (time extension) wall controls are often used to allow for irregular use of the space.

Clock switches turn lights on or off for a specific period of time. They are especially useful for turning off photocell-activated exterior lighting late at night (as long as that lighting is not needed after a certain time).

Fig. 3.9.13 Time scheduling units.

Centralized controls can be used to automatically turn on, turn off, and/or dim lighting at specific times or under certain load conditions. This type of control can be used in a conference room or on a building-wide scale. Centralized control strategies can also integrate lighting controls with other building systems such as mechanical or security systems.

Distributed controls are based on digital communication protocols. These systems are local, or integral, to the luminaire itself, not housed in a central cabinet or enclosure. They integrate with building automation or energy management system. A Digital Addressable Lighting Interface (DALI) system provides a means of control which can speak to an individual ballast or groups of ballasts. The "control wiring" is independent of the "power wiring" and provides the highest degree of flexibility available at this time. When space configuration or occupant needs change, the system can respond by reassigning the ballasts accordingly.

3.9.5.1.4 Daylight Harvesting

Daylight harvesting entails using a photo sensor to monitor light levels and adjust electric light output to maintain a target light level, saving energy.

Automatic daylight harvesting dimming control is better suited for spaces where occupants work stationary tasks, luminaires are installed in the field of view, and/or where daylight availability fluctuates frequently throughout the day.

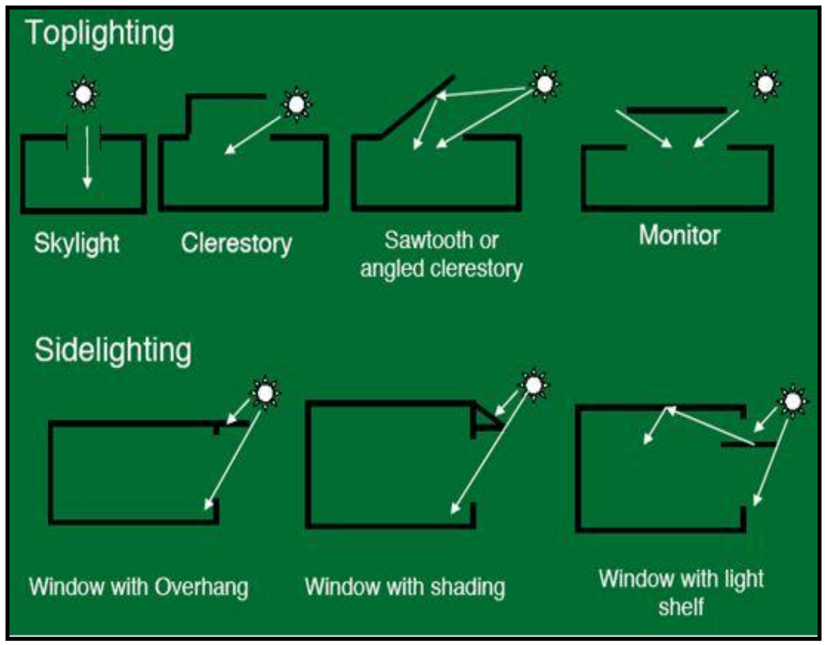


Fig. 3.9.14 Principle of Daylight harvesting.

daylight may enter a building via top lighting (e.g., skylight) or side lighting (e.g., window) apertures. Good daylight design enables diffuse daylight to serve as a primary source of general illumination, while avoiding glare and heat gain.

❖ ***How It Works***

Daylight harvesting is a control strategy that utilizes a photo sensor with a power controller to switch or dim lighting in response to available daylight. As light levels rise above a target threshold due to daylight contribution, the photo sensor signals the controller to reduce light output, saving energy.

❖ ***Energy Savings***

Daylight harvesting has been demonstrated to generate up to 70% lighting energy savings in private offices and 50% in classrooms. Energy savings are typically variable and will depend on application characteristics such as daylight availability in the space.

- Open office: 40% energy savings.
- Private office: 50% (manual blinds) to 70% (manual blinds used optimally, or automatic shading) energy savings.
- Classroom: 50% energy savings.

Daylight harvesting is highly suitable for lighting zones adjacent to windows and clerestories and under skylights and roof monitors—anywhere daylight is consistent and plentiful. The strategy is particularly favored in LEED and other projects seeking to maximize energy savings beyond energy code.

❖ ***Daylight Control***

Automatic window shades, blinds or other devices can dynamically reduce direct glare and heat gain. Using the same control station, users can override automatic control functions and set both daylight and electric

❖ ***Designing for Daylight***

Daylight should be provided where people need it most. Since daylight often does not enter the space uniformly, however, visualize it as gradients in a pattern, with each gradient representing an area of consistent daylight availability.

Each of these areas in turn presents an opportunity to separately zone the general lighting for daylight harvesting.

This may require designing lighting circuits to support separate control of general lighting, such as separately circuiting the first one or two rows of light fixtures parallel to daylighting windows.

Energy savings occur by automatically switching the lights OFF or proportionally reducing electric light levels continuously (dimming) in response to variable daylight levels.

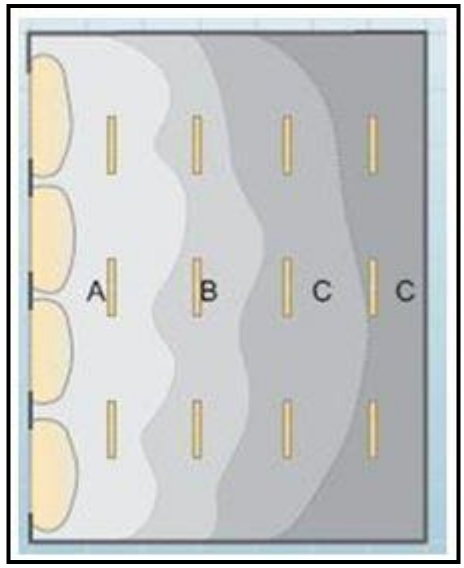


Fig. 3.9.15 zone of general lighting for daylight harvesting.

❖ ***Daylight Availability***

The energy savings potential for daylight harvesting in a given application will depend largely on daylight availability, including:

1. Daylight penetration into the space-in other words, how much of the task area receives daylight.
2. Quantity of daylight in the space--in other words, what is the density of illumination on the task area in foot-candles.
3. Duration of daylight availability during the day--that is, for how long each day the task area receives high, consistent enough daylight levels to warrant daylight harvesting control.

❖ ***Typical System***

Automatic daylight harvesting control systems are comprised of a photosensor that measures light levels and shares this information with a controller, which decides, using its algorithm, whether the lighting load should be switched or dimmed. In some cases, the ballast and the controller may be the same unit.

Daylight harvesting controls can be effective in virtually any type of facility where the lights operate much of the time and where ample daylight is present.

Spaces with skylights and corridors, private offices and open cubicles near windows—particularly those with task lighting—are good candidates for daylight harvesting.

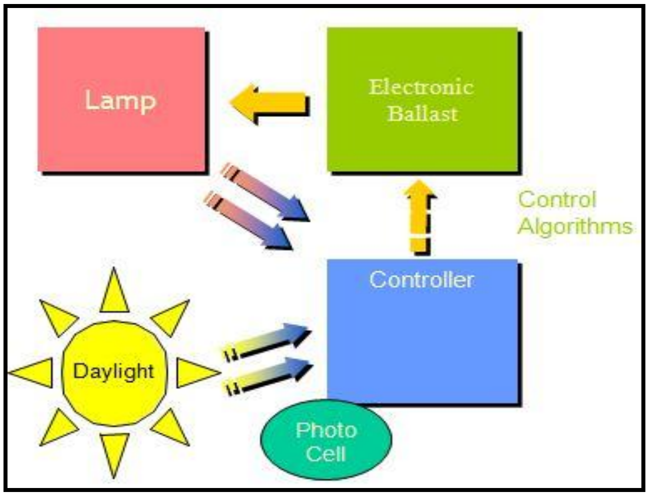


Fig. 3.9.16 Daylight harvesting control systems.

❖ ***Ideal Applications***

If the entire space is uniformly skylighted (as in the skylighted space shown here, with properly spaced skylights covering about 3-5 percent of the floor area), energy savings can accrue on the entire lighting load. More commonly, daylight harvesting applies only to the perimeter zone of a windowed installation, where typically general lighting within two window heights (distance from floor to top of window) deep into the space is suitable for daylight harvesting.

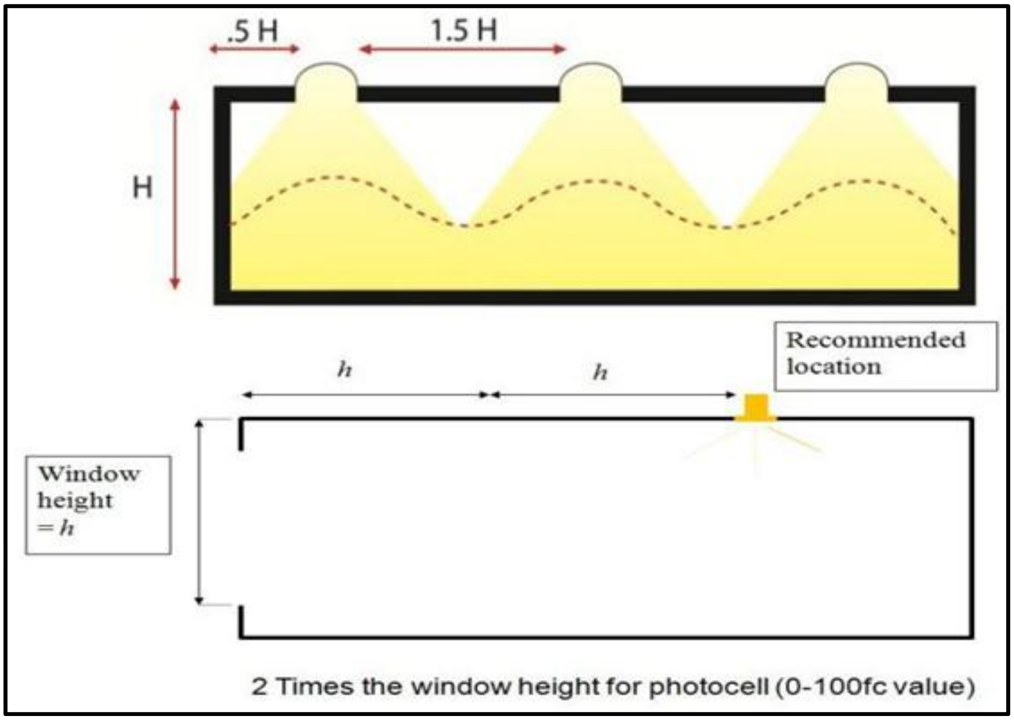


Fig. 3.9.17 Ideal Applications of daylight harvesting.

For side lighted spaces, a traditional rule of thumb was that a primary daylight zone can be established up to 15 ft. deep from a window, and a secondary zone 15-25 ft. deep into the space. This thinking is changing, as reflected in the latest generation of energy codes and standards, to a depth of 1 x window height (floor to top of window) for a primary daylight zone, and 2 x window height for a secondary daylight zone.

❖ ***Control Zoning, Energy Codes***

Energy codes and standards are now beginning to regulate the minimum size of control zones.

ASHRAE 90.1-2010, for example, defines a sidelighted daylight zone as:

WIDTH = window width plus 2 ft. on either side, limited only by 60+ in. partitions, by

DEPTH: one window height (distance from floor to top of window), limited only by 60+ in. partitions.

Contiguous windows produce a single daylight zone. Any electric lighting in the daylight zone must be controlled separately from other general lighting in the space.

Some codes recognize a secondary zone that goes beyond the boundaries of the primary zone; daylight harvesting in the secondary zone may result in power adjustment credits the designer can use to increase the lighting power density for the controlled load.

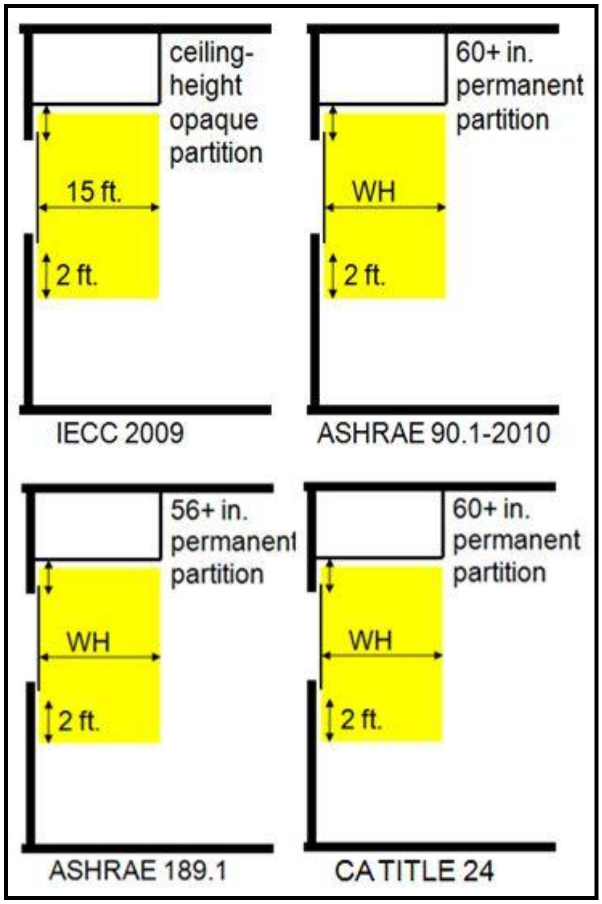


Fig. 3.9.18 Control zones.

3.9.5.1.5 Dimming

❖ ***Purpose of Dimming***

Dimming provides greater flexibility from the lighting system, enabling users to have more control over their lighting conditions to support visual needs, and enabling enactment of energy management strategies that can reduce energy costs.

✓ Step Dimming

Step dimming provides a limited choice of light levels, with one or more preset increments between OFF and full output. Typically, there is no fade between lighting states, so while technically the approach is dimming, the visual effect is the lights are switched to a lower state.

This approach is typically implemented for fluorescent and HID systems, using a special ballast, in spaces where a sudden light level change will not be irritating to users, and it is desirable to achieve uniform light level reduction from the lamps without separately circuiting/ controlling alternate lamps or luminaires.

✓ Continuous Dimming

Continuous dimming enables users to raise and lower light levels over a specified range, with smooth transitions between levels. This provides a higher degree of flexibility for manual dimming control driven by application needs such as A/V presentation, mood setting and so on. It also enables light output to be automatically reduced to save energy without irritating occupants, and is therefore the control method of choice for automatic control strategies in spaces occupied by people performing stationary tasks

❖ *Light Level and Perception*

As lamps are dimmed, light output decreases but the human eye may perceive a higher light output and light level than is actually present. This is because the human eye overcompensates for diminished light level by allowing more light to enter into its pupil. For example, dimming to 25% appears to be about 50% of full light level. The effect is predictable according to the square law, which defines the theoretical relationship between light level and perceived brightness:

Perceived Light (%) = 100 x square root (Measured Light (%)/100)

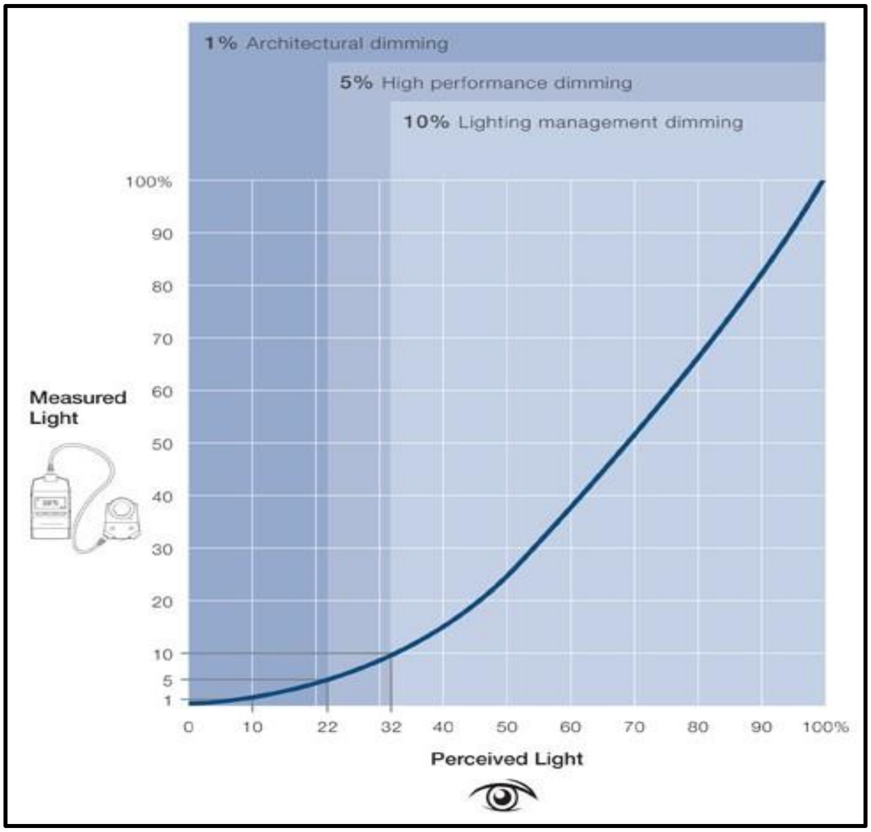


Fig. 3.9.19 Measured light vs. Perceived light.

✓ Linear fluorescent lamp dimming

Fluorescent lamps are dimmable using dimmable ballasts, which are designed to respond to control signals by changing the current flowing through the lamp, which reduces both lamp output and power. Linear fluorescent lamps should be "seasoned" prior to dimming for 12 hours at 100% output per NEMA guidelines, or per manufacturer instructions.

✓ Led dimming

LED lighting is theoretically very friendly to dimming control. As shown in this graph, reducing LED device internal temperatures extends service life. Because dimming reduces internal temperatures, it can extend lamp life while also delaying color shift (towards blue) that occurs over time with phosphor-coated LEDs.

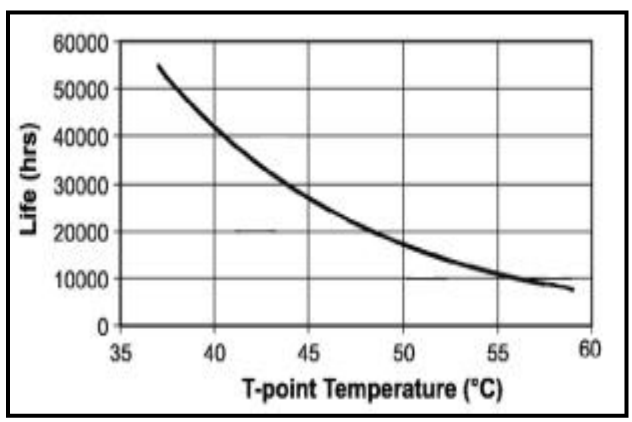


Fig. 3.9.20 Life vs. Temperature

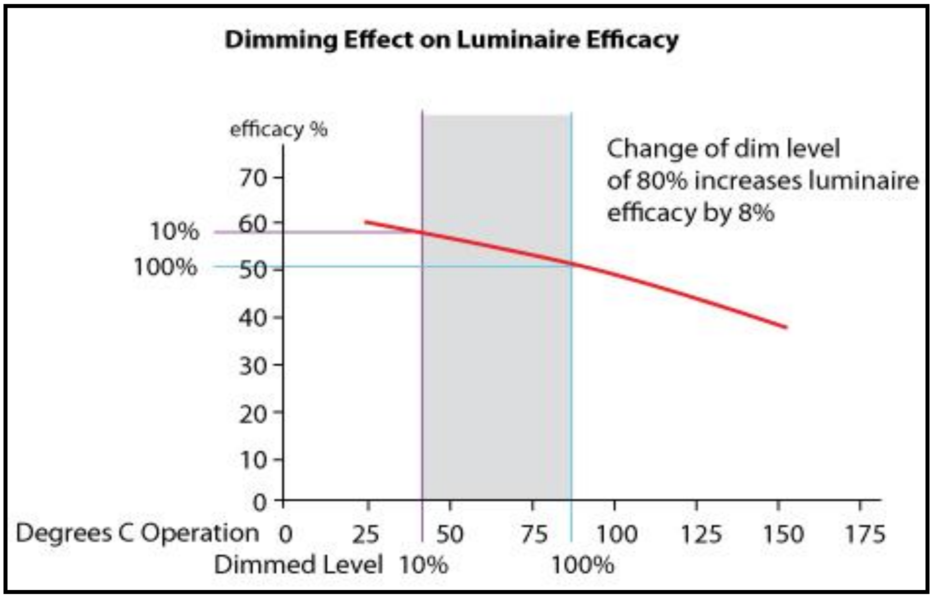


Fig. 3.9.21 Dimming effect on luminaire efficacy.

Dimming results in light output that is proportional to electrical input; an LED operating at 50% of its rated power will produce roughly 50% of its initial rated light output. As a result, efficacy (lumens/W) is stable across the dimming range until the low end, when efficacy actually increases due to dimming reducing internal temperatures, producing higher light output. While this is obviously positive in terms of efficiency, it also means that for manual dimming, light output and dimmer setting may drift out of proportion at the dimming range's low end. Some higher-end products compensate for this effect.

❖ ***Dimming System, Distributed Controllers***

And another type of dimming system uses distributed micro panels within a digital communication architecture instead of a centralized panel or networked ballasts. With this approach, the micro panels are distributed close to the loads they control, and can provide switching or dimming of standard analog dimming ballasts. In this executive office, a two-relay dimming room controller is configured for automatic-ON to 50%/automatic-OFF operation for the pendant luminaires and manual-ON operation for the whiteboard lighting, with all lighting dimmable using 0-10VDC ballasts and digital dimmers with four-scene personal remote.

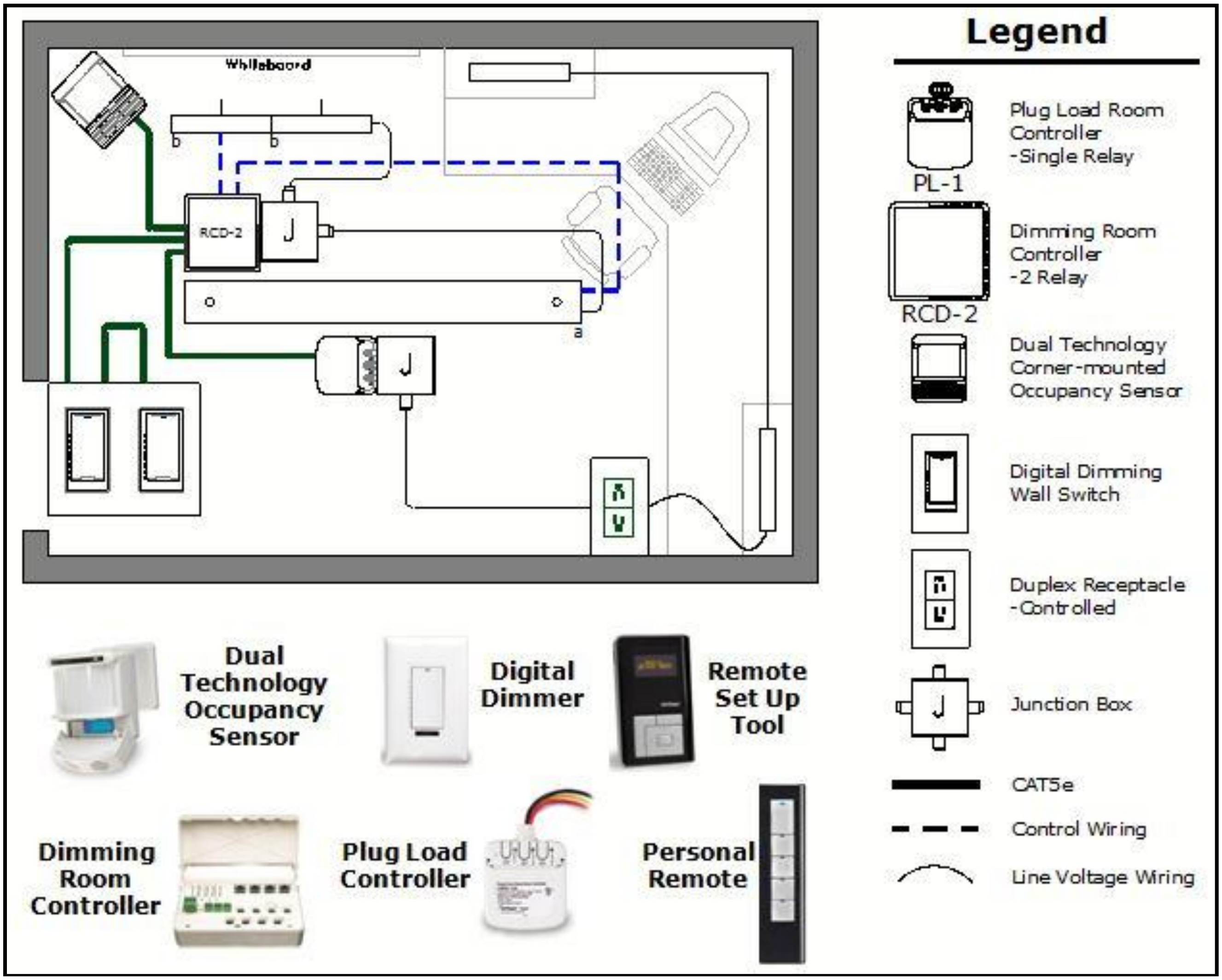


Fig. 3.9.22 Dimming controller parts.

❖ ***Design Questions***

- What do you want the system to do once it's installed? How complex is the application need?
- What is the alternative?
- How many zones will be controlled?
- What is the connected load and load type for each zone?
- How many master control and other control stations will be needed?
- Where will the master control and other control stations be located?
- What other integration must be achieved—such as theatrical consoles, A/V, shades/blinds, etc.—and how? Are these systems compatible and how?
- Are there emergency lighting circuits?
- Where are the dimming panels going to be located?
- What is the budget?

❖ ***Locate Equipment On Plans***

Make sure the controls are easy to locate and to access. Don't put them in a closet that might be locked. Make sure the controlled lighting can be seen from the control panel or switch location. Otherwise, occupants will have to yell to each other, "Is that good? Is it dim enough?" If the controls adapt to the normal behavior of people, they will be accepted. If not, they will be rejected and bypassed. Make the control scheme simple and intuitive for even the most basic operation. If controls aren't simple, they will not be used. Controls should make sense and provide flexibility to all users.

❖ ***Dimming Range For CFL And Fluorescent***

The dimming range expresses how low the ballast can dim the lamps. A lamp with a dimming range of 100% to 5%, for example, can dim from full light output to 5% of full light output. Dimmable T8 ballasts can dim down to as low as 3%, T5HO ballasts as low as 1%, and dimmable CFLs to as low as <3%. A number of factors may affect actual dimming range in a field installation, such as voltage to the ballast, ambient temperature, lamp life used/remaining and lamp seasoning.

❖ ***Dimming and Switching***

Dimming: Dimming is continuous over the dimmable ballast's range, allowing a wide range of light output.

Dimming is relatively expensive due to the inclusion of dimmable ballasts, but the smooth, gradual changes in light output are not intrusive to occupants.

Switching: Switching may be circuited to offer a choice of two lighting and power levels —50% and 100%, or thre—33%, 66% and 100%.

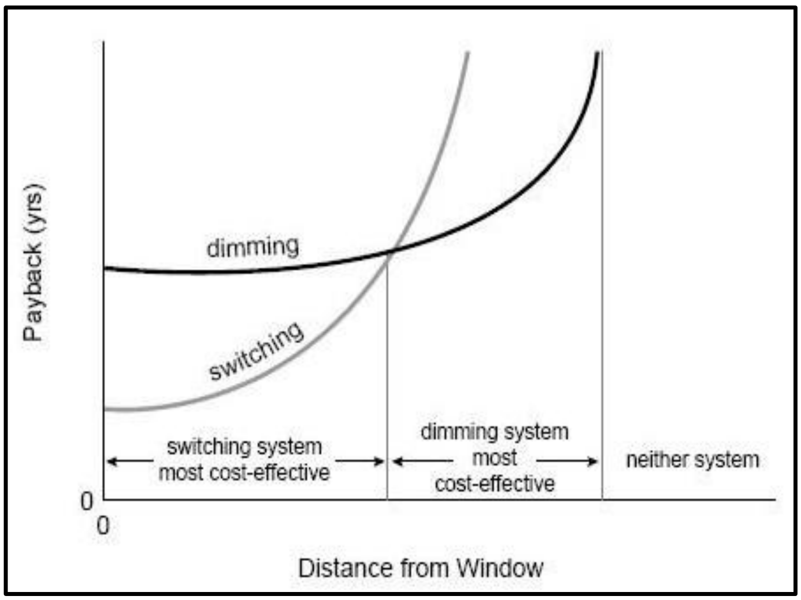


Fig. 3.9.23 Dimming/Switching payback chart.

Although the cost of dimmable ballast is falling, dimming can cost about twice as much as switching, but dimming is preferable for many applications because it is more acceptable to occupants. Sudden changes in light output can be disruptive, limiting application. If switching is selected and occupant acceptance is an issue, multi-level switching may be preferable because it offers smaller changes in light output. According to the New Buildings Institute, in high-ceiling applications, users generally do not notice changes in light level that are less than one-third of the current light level.

daylight Harvesting Strategy	Dimming	Switching
Typical Equipment Types	Photosensor, dimmable ballast, dimmer, dimming panel	Photosensor, switch (usually low-voltage relay), ballast, control, power-packs (if individual fixture control/zoning by fixture is desired)
Light Levels	Continuous dimming from 100% to 5-10%, or stepped dimming from 100% to one or more levels	ON/OFF switching (100% and 0%), bi-level switching (100%, 50% and 0%) or multi-level switching (100%, 66%, 33% and 0%) by switching groups of lamps or fixtures (by circuit) or individual fixtures (using a power-pack)
Advantages	Smooth transitions between light levels, greater control accuracy, more options for integration with personal control strategy, greater occupant acceptance, higher energy savings in spaces where daylight levels are highly variable and/or close to electric light levels	Lower initial cost (although more ballasts may be required than equivalent dimming strategy), easier to commission, higher energy savings in spaces with high, consistent amounts of daylight
Disadvantages	Higher initial cost, dimming ballasts less efficient than the most efficient non-dimming ballast, more sophisticated commissioning	Less occupant acceptance , less control accuracy
Occupants	More effective in spaces with occupants performing stationary or critical tasks such as offices, where changes in light output should be virtually unnoticed	More effective in spaces with occupants performing non-stationary, non-critical tasks such as hallways and atria, where abrupt changes in light output will be minimally intrusive
Daylight Levels	More effective if daylight provides only portion of required light level in space or daylight contribution is variable; dimming can respond to fluctuating conditions without being intrusive	More effective if daylight provides consistent, large contribution (2-3 times greater than minimum electric light levels); in climates with clear skies, fixtures can be shut off and remain off for hours
Lamp and Fixture Visibility	Fixtures can be mounted in normal field of view, lamps can be visible to occupants	More effective in spaces where fixtures are mounted high and not in normal field of view; occupants should have limited view of lamps and instead primarily view illuminated surfaces, such as with indirect fixtures

Table 3.9.2 Dimming and Switching.

❖ ***IECC recognizes four methods of light level reduction control:***

- Controlling all lamps or fixtures (e.g., dimming).
- Dual switching alternate rows, fixtures or lamps.
- Switching middle lamp independent of outer lamps (3-lamp fixtures).
- Switching each fixture or each lamp.

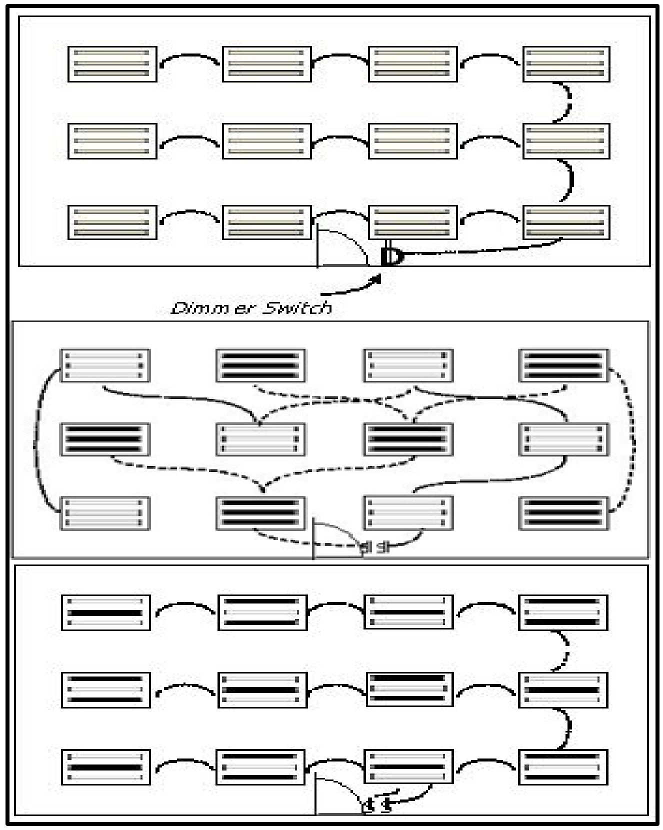


Fig. 3.9.24 Methods of light level reduction control.

3.9.5.1.6 Demand Response

In this energy management strategy, the control system responds to a signal from the local utility to reduce electric load during a grid emergency. The owner receives financial incentives such as special rates in return.

Dimming is ideally suited to demand response, as it enables lighting load reduction without turning the lights OFF.

3.9.5.2 Selecting the Appropriate Lighting Controls

There are many guides and services available for designing lighting control systems. Some controls manufacturers will actually do a controls layout on the building plans or even on electronic drawing files, free of charge or for a nominal fee. If you prefer to do the controls layout yourself, it is advisable that you provide a written "sequence of control" which describes the design intent and a "performance specification" which describes the performance characteristics of individual components. Further, some coordination with the selected controls manufacturer will help to avoid surprises during construction and commissioning.

If you know how you would like the controls scheme to work, but you are not sure what equipment to choose or how it should be connected electrically, explain your ideas to the manufacturer's technical support personnel. Chances are they will be able to help you work out the details.

The table below provides control ideas for several different room types and usage patterns. Some additional links to help on manufacturers' web sites are provided below the table.

Space Type	Typical Use Pattern	If...	Then...
Cafeterias or Lunchrooms	Occasionally occupied	Daylighted	Consider daylight-driven dimming or on/off control
		Occupied occasionally	Consider ceiling-mounted occupancy sensor(s). Make sure minor motion will be detected in all desired locations.
Classroom	Usually occupied	Multiple tasks like overhead projectors, chalkboard, student note taking and reading, class demonstrations	Consider manual dimming
	Occasionally occupied	Occupied by different groups of students and teachers daily	Consider ceiling- or wall-mounted occupancy sensor(s) and manual dimming. Make sure that minor motion will be detected.
		Lights left on after hours	Consider centralized controls and/or occupancy sensors.
Computer Room	Usually unoccupied	Lights are left on all the time	Consider occupancy sensors with manual dimming. Be sure that minor motion will be detected and that equipment vibration will not falsely trigger the sensor.
Conference Room	Occasionally occupied	Multi-tasks from video-conferencing to presentations	Consider manual dimming (possibly preset scene control)
		Small conference room	Consider a wall box occupancy sensor
		Large conference room	Consider ceiling- or wall-mounted occupancy sensor(s). Be sure that minor motion will be detected in all desired locations.
Gymnasium or Fitness	Usually occupied	Requires varied lighting levels for activities	Consider manual dimming and occupancy sensors. Be sure that the HVAC system will not falsely trigger the sensor.
	Occasionally occupied	Requires varied lighting levels for activities	Consider ceiling- and wall-mounted passive infrared occupancy sensors.

			Be sure that the coverage areas of the sensors are sufficiently overlapped to keep the lights on when the room is occupied.
		Daylighted	Consider daylight on/off control.
Health Care—Examination Rooms	Occasionally occupied	Different lighting needs for examination	Consider manual dimming.
		Small areas	Consider a wall box occupancy sensor.
Health Care—Hallways	Usually occupied	Daylighted	Consider automatic daylight-driven dimming.
		Requires lower lighting level at night	Consider centralized controls to lower lighting levels at night.
Hotel Rooms	Occasionally occupied	Used primarily in the late afternoon through evening for sleeping and relaxing	Consider manual dimming.
Laboratories	Usually occupied	Daylighted	Consider automatic daylight-driven dimming in combination with occupancy sensors.
Laundry Rooms	Occasionally occupied	Requires high light levels, yet lights are usually left on	Consider occupancy sensors.
Libraries—Reading Areas	Usually occupied	Daylighted	Consider automatic daylight-driven dimming. Occupancy sensors may be appropriate.
		Lights left on after hours	Consider centralized controls.
Libraries—Stack Areas	Occasionally occupied	Stacks are usually unoccupied	Consider ceiling-mounted sensor(s).
Lobby or Atrium	Usually occupied but no one "owns" the space	Daylighted and lights should always appear on	Consider automatic daylight-driven dimming.
		It isn't a problem if lights go completely off in high daylight	Consider automatic daylight-driven dimming or on/off control.
		Lights are left on all night long, even when no one is in the area for long periods	Consider occupancy sensors. Be sure that minor motion will be detected in all desired areas.
Office, Open	Usually occupied	Daylighted	Consider automatic daylight-driven dimming.
		Varied tasks from computer usage to reading	Consider manual dimming.

		Lights left on after hours	Consider centralized controls and/or occupancy sensors.
Office, Private	Primarily one person, coming and going	Daylighted	Consider manual dimming, automatic daylight-driven dimming, or automatic on/off.
		Occupants are likely to leave lights on and occupants would be in direct view of a wall box sensor	Consider a wall box occupancy sensor. Add dimming capabilities if appropriate.
		Occupants are likely to leave lights on and partitions or objects could hide an occupant from the sensor	Consider a ceiling- or wall-mounted occupancy sensor. Add dimming capabilities if appropriate.
Photocopying, Sorting, Assembling	Occasionally occupied	Lights are left on when they are not needed	Consider an occupancy sensor. Be sure that machine vibration will not falsely trigger the sensor.
Restaurant	Usually occupied	Daylighted	Consider automatic daylight-driven dimming.
		Requires different lighting levels throughout the day	Consider manual dimming (possibly preset scene dimming).
		Requires different lighting levels for cleaning	Consider centralized control.
Restroom	Any	Has stalls	Consider a ceiling-mounted ultrasonic occupancy sensor for full coverage.
		Single toilet (no partitions)	Consider a wall switch occupancy sensor.

Table 3.9.3 Control ideas for several different room types

✓ **PIR**

PIR sensors require a line of sight between the sensor and the primary task area; there should be no obstructions, such as a door swinging open. In the left office, the sensor has an unobstructed line of sight to the task area, in this case the desktop. In the right office, the occupant's body is blocking the sensor's view of the task area, in this case the laptop keyboard, and therefore an ultrasonic or dual-technology (PIR/acoustic) sensor would be recommended to minimize false-OFF switching.

✓ **Ultrasonic**

Ultrasonic sensors emit high-frequency sound waves into the space and detect occupancy from changes in the frequency of returning reflections, or they may set up a standing wave and measure both frequency shift and amplitude. They can be installed on ceilings or walls, including as a wall switch replacement, typically in indoor applications. Although they are an active technology (emit energy into the space), properly designed devices will not interfere with local devices such as hearing aids. They are well suited to applications requiring greater sensitivity and reliability, open indoor spaces, and spaces with obstacles. Suitable applications include open offices, private offices, bathrooms, classrooms and conference rooms.

✓ **Dual Technology**

For spaces where line of sight to occupants is blocked by obstructions or where occupants are not moving for long periods of time, sensors that utilize dual-technology can be effective.

The two types of dual-technology sensors are PIR/ultrasonic and PIR/acoustic. These sensors can be more effective at preventing false-OFF switching than PIR sensors, and preventing false-ON switching than ultrasonic sensors.

3.9.6 Switching and Lamp Life

Incandescent, halogen and LED light sources are friendly with frequent switching, which has no undesirable impact on lamp life. Fluorescent and HID lamps experience additional wear and tear during startup, however. As the operating cycle (expressed in hours/start) decreases, energy savings increase (see graphic, revealing results of a Lighting Research Center study) but lamp life decreases, particularly for popular instant-start systems.

For an optimal balance, lamp manufacturers recommend a minimum time/start of 15 to 20 minutes.

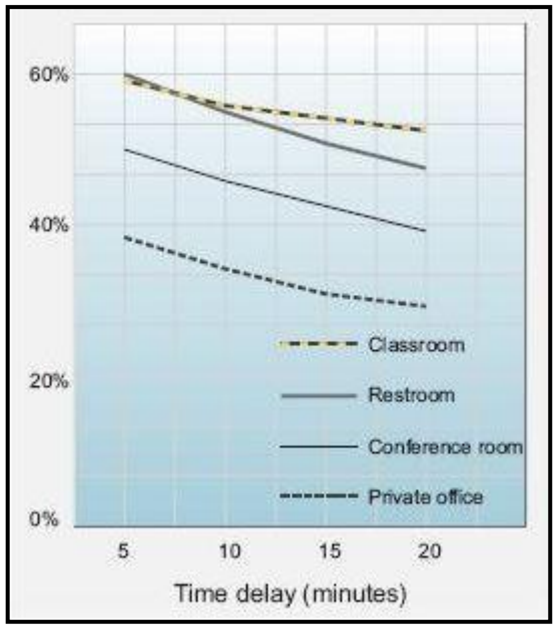


Fig. 3.9.14 Lamp Life diagram.

3.9.7 Economic Analysis of Lighting Control Systems

Lighting controls are cost-effective, especially when one considers long-term life-cycle costs along with initial costs. Lighting controls can add approximately $0.50-$1.00 per square foot initially. Payback periods vary widely by project and are difficult, at best, to predict accurately. That does not take into account the savings from reduced energy use and HVAC reduction.

The easiest way to do an economic analysis of lighting controls is to use an "effective energy charge (EEC)," which is a cost per kWh number derived by dividing the entire electricity bill (in dollars) by the total amount of energy used during that billing period (in kWh). The potential savings per controlled fixture is calculated as follows:

$$\$\ \textbf{Savings per year} = \{(\textbf{Wb} \times \textbf{HPYb} \times \textbf{PFb})] - [(\textbf{Wf} \times \textbf{HPYf} \times \textbf{PFf})\} \times (\textbf{EEC})$$

Where:
$\mathbf{W_b}$ is the baseline watts of the controlled fixture(s).
$\mathbf{HPY_b}$ is the baseline number of hours per year that the fixture is on.
$\mathbf{PF_b}$ is the baseline power fraction for the fixture or fixtures (use 1 for full power).
$\mathbf{W_f}$ is the final watts of the controlled fixture(s) (i.e. after retrofit or redesign).
$\mathbf{HPY_f}$ is the final number of hours per year that the fixture is on (i.e. after controls are installed that turn the lights off when they are not needed, such as occupancy sensors or centralized controls).
$\mathbf{PF_f}$ is the final power fraction for the fixture(s) (i.e. if a fixture will be dimmed to an annual average of 50%, use .5. For low dimming levels, the energy usage fraction is slightly higher than the dimming percentage due to ballast losses.).
EEC is the "effective energy charge" in $/kWh.

This method of calculating annual dollar savings is an approximate estimate because is does not allow you to calculate the exact changes in demand charges—demand charges have been wrapped up into the "effective energy charge."

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