A STUDY ON ENERGY EFFICIENT LIGHTING SYSTEMS IN INDUSTRIES

A THESIS SUBMITTED TOWARDS PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF TECHNOLOGY

IN

ILLUMINATION TECHNOLOGY AND DESIGN

Submitted by

Raktim Banerjee

Class Roll No.: 001931101027
Examination Roll No.: M6ILT22026

Under the guidance of

Dr. Debashish Das
Prof. Department of Architecture

Course affiliated to:

SCHOOL OF ILLUMINATION SCIENCE, ENGINEERING AND DESIGN

FACULTY OF INTERDISCIPLINARY STUDIES, LAW AND MANAGEMENT

JADAVPURUNIVERSITY

KOLKATA-700032

INDIA

JUNE 2022

M. Tech. (Illumination Technology and Design)
Course affiliated to
Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata, India

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"A STUDY ON ENERGY EFFICIENT LIGHTING SYSTEMS IN INDUSTRIES"** is a bonafide work carried out by **RAKTIM BANERJEE** under our supervision and guidance for partial fulfillment of the requirement of the degree of **M. Tech. (Illumination Technology and Design)** in School of Illumination Science, Engineering and Design, during the academic session 2019-2022.

THESIS ADVISOR

Prof. Dr. Debashish Das
Professor Faculty
Department of Architecture
Jadavpur University
Kolkata-700 032

DIRECTOR

Prof. Parthasarathi Satvaya
School of Illumination Science, Engineering and Design
Jadavpur University
Kolkata-700 032

DEAN -FISLM

Prof. Subenoy Chakrborty
FISLM, Jadavpur University
Kolkata-700 032

M. Tech. (Illumination Technology and Design)
Course affiliated to
Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata, India

CERTIFICATE OF APPROVAL **

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

Committee of final examination --

for evaluation of Thesis

** Only in case the thesis is approved.

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his /her **M. Tech. (Illumination Technology and Design)** studies during academic session 2019-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

NAME: RAKTIM BANERJEE

EXAMINATION ROLL NUMBER: M6ILT22026

THESIS TITLE: A STUDY ON ENERGY EFFICIENT LIGHTING SYSTEMS IN INDUSTRIES

SIGNATURE: DATE:

ACKNOWLEDGEMENT

A lot of inputs from various sources have gone into the making of this report and the analysis that has been carried out. Foremost, I take this opportunity to express my deep sense of gratitude and indebtedness to my university guide **Prof. (Dr.) Debashish Das,** Head of the Department of Architecture, Jadavpur University, for being a thoughtful and understanding guide for the project and his constant guidance and supervision.

I would like to acknowledge my sincere thanks to **Prof. Parthasarathi Satvaya**, Director of School of Illumination Science, Technology and Design, Jadavpur University, Kolkata, and his valuable suggestions and encouragements in carrying out this project work.

Also, I am thankful to the seniors and managers of **WIPRO Consumer care and Lighting, Delhi** for their co-operation in my project work. Finally, this thesis would not have been possible without the confidence, endurance and support of my friends with whom I share tons of fond memories. They have always been a source of inspiration and encouragement.

Last but not the least, I wish to convey my gratitude to my parents, whose love, teachings and support have brought me this far.

Date:

Place: --------------------------------------

Raktim Banerjee

ABSTRACT

With the rapid growth in industries, the development in its lighting systems has also become a major matter to be discussed upon. The idea is to control the lighting level in an energy efficient way, taking into account visual comfort and task management. Here in this paper, it has been tried to put forward the changes that overtook the conventional lighting systems and its results. With the discovery of LEDs, the industries underwent a revolution from within, incorporating technologies which was never thought of before its invention. To be precise, the LED lights can be implemented in every circumstantial condition, be it hazardous area, offices, manufacturing units, heat prone areas or frosted regions. Moreover, LEDs has improved the efficiency of energy consumption in industries. Keeping in mind these aspects of modern lighting designs with optimum use of energy and meeting visual satisfaction, this paper will guide further about the growth of industrial lighting systems along with the growth of the employees and infrastructure hand in hand.

CONTENT

Chapter 1

Evolution of Industrial Lightings

1.1. Incandescent Sources

An **incandescent light bulb**, **incandescent lamp** or **incandescent light globe** is an electric light with a wire filament heated until it glows. The filament is enclosed in a glass bulb with a vacuum or inert gas to protect the filament from oxidation. Current is supplied to the filament by terminals or wires embedded in the glass. A bulb socket provides mechanical support and electrical connections. Incandescent bulbs are manufactured in a wide range of sizes, light output, and voltage ratings, from 1.5 volts to about 300 volts. They require no external regulating equipment, have low manufacturing costs, and work equally well on either alternating current or direct current. As a result, the incandescent bulb became widely used in household and commercial lighting, for portable lighting such as table lamps, car headlamps, and flashlights, and for decorative and advertising lighting.

Thomas Edison began serious research into developing a practical incandescent lamp in 1878. Edison filed his first patent application for "Improvement in Electric Lights" on 14 October 1878. After many experiments, first with carbon in the early 1880s and then with platinum and other metals, in the end Edison returned to a carbon filament. The first successful test was on 22 October 1879, and lasted 13.5 hours. Edison continued to improve this design and by 4 November 1879, filed for a US patent for an electric lamp using "a carbon filament or strip coiled and connected ... to platina contact wires." Although the patent described several ways of creating the carbon filament including using "cotton and linen thread, wood splints, papers coiled in various ways," Edison and his team later discovered that a carbonized bamboo filament could last more than 1200 hours. In 1880, the Oregon Railroad and Navigation Company steamer, *Columbia*, became the first application for Edison's incandescent electric lamps (it was also the first ship to use a dynamo). This company didn't make their first commercial installation of incandescent lamps until the fall of 1880 at the Mercantile Safe Deposit Company in New York City, about six months after the Edison incandescent lamps had been installed on the Columbia.

More than 95% of the power consumed by a typical incandescent light bulb is converted into heat rather than visible light. Other electrical light sources are more effective.

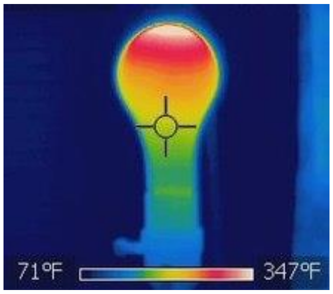


Fig. 1. Thermal image of an incandescent bulb. 22–175 °C = 71–347 °F.

For a given quantity of light, an incandescent light bulb consumes more power and emits more heat than a fluorescent lamp. In buildings where air conditioning is used, incandescent lamps' heat output increases load on the air conditioning system. While heat from lights will reduce the need to run a building's heating system, the latter can usually produce the same amount of heat at lower cost than incandescent lights.

Compared to other incandescent (non-halogen) light types, incandescent halogen lamps will emit the same amount of light using less power, and a more constant output over time, with little dimming.

Type	Overall luminous efficiency	Overall luminous efficacy (lm/W)
40 W tungsten incandescent	1.9%	12.6
60 W tungsten incandescent	2.1%	14.5
100 W tungsten incandescent	2.6%	17.5
Glass halogen	2.3%	16
Quartz halogen	3.5%	24
Photographic and projection lamps with very high filament temperatures and short lifetimes	5.1%	35
Ideal black-body radiator at 4000 K	7.0%	47.5
Ideal black-body radiator at 7000 K	14%	95
Ideal monochromatic 555 nm (green) source	100%	683

Table 1. efficacy of incandescent lamps

The spectrum of light produced by an incandescent lamp closely approximates that of a black body radiator at the same temperature. The basis for light sources used as the standard for colour perception is a tungsten incandescent lamp operating at a defined temperature.

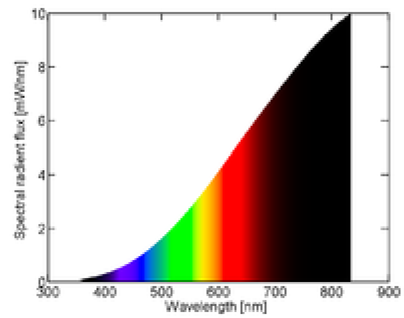


Fig. 2. Spectral power distribution of a 25 W incandescent light bulb

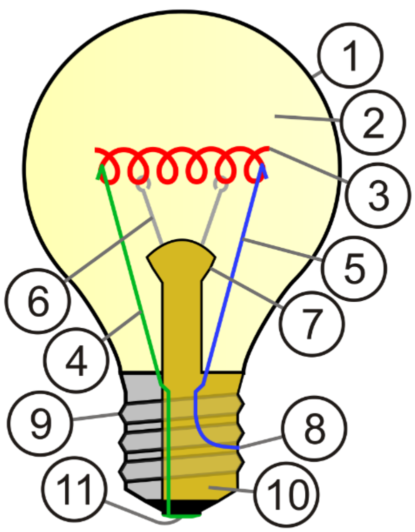


Fig. 3. Incandescent lamp parts

1. Outline of Glass bulb
2. Low pressure inert gas(argon, nitrogen, krypton, xenon)
3. Tungsten filament
4. Contact wire (goes into stem)
5. Contact wire (goes into stem)
6. Support wires (one end embedded in stem; conduct no current)
7. Stem (glass mount)
8. Contact wire (goes out of stem)
9. Cap (sleeve)
10. Insulation (vitrite)
11. Electrical contact

A parabolic aluminized reflector lamp (PAR lamp or simply PAR) is a type of electric lamp that is widely used in commercial, residential, and transportation illumination. It produces a highly directional beam. Usage includes theatrical lighting, locomotive headlamps, aircraft landing lights, and residential and commercial recessed lights. This lamp was first used in automobile industry in 1937.

1.2. Metal Vapour Sources

A metal-halide lamp is an electrical lamp that produces light by an electric arc through a gaseous mixture of vaporized mercury and metal halides (compounds of metals with bromine or iodine). It is a type of high-intensity discharge (HID) gas discharge lamp. Developed in the 1960s, they are similar to mercury vapor lamps,[1] but contain additional metal halide compounds in the quartz arc tube, which improve the efficiency and color rendition of the light. The most common metal halide compound used is sodium iodide. Once the arc tube reaches its running temperature, the sodium dissociates from the iodine, adding orange and reds to the lamp's spectrum from the sodium D line as the metal ionizes. As a result, metal-halide lamps have high luminous efficacy of around 75–100 lumens per watt, which is about twice that of mercury vapor lights and 3 to 5 times that of incandescent lights and produce an intense white light. Lamp life is 6,000 to 15,000 hours.

Metal-halide lamps are used for general lighting purposes both indoors and outdoors, such as commercial, industrial, and public spaces, parking lots, sports arenas, factories, and retail stores, as well as residential security lighting; automotive and specialty applications are further fields of usage. Metal-halide lamps are used in automobile headlights, where they are commonly known as "xenon headlamps" due to the use of xenon gas in the bulb instead of the argon typically used in other halide lamps.Metal-halide lamps consist of an arc tube with electrodes, an outer bulb, and a base.

Fig. 4. Metal Halide lamp

Arc tube

Inside the fused quartz arc tube, two tungsten electrodes doped with thorium are sealed into each end and an AC voltage is applied to them through molybdenum foil seals fused in silica. It is the arc between the two electrodes where the light is actually created.

Outer bulb

Most types are fitted with an outer glass bulb to protect the inner components and prevent heat loss. The outer bulb can also be used to block some or all of the UV light generated by the mercury vapour discharge, and can be composed of specially doped "UV stop" fused silica. Ultraviolet protection is commonly employed in single ended (single base) models and double ended models that provide illumination for nearby human use. Some high-powered models, particularly the lead-gallium UV printing models and models used for some types of sports stadium lighting do not have an outer bulb. The use of a bare arc tube can allow transmission of UV or precise positioning within the optical system of a luminaire. The cover glass of the luminaire can be used to block the UV, and can also protect people or equipment if the lamp should fail by exploding.

Base

Some types have an Edison screw metal base, for various power ratings between 10 and 18,000 watts. Other types are double-ended, as depicted above, with R7s-24 bases composed of ceramic, along with metal connections between the interior of the arc tube and the exterior. These are made of various alloys (such as iron-cobalt-nickel) that have a thermal coefficient of expansion that matches that of the arc tube.

Ballasts

The electric arc in metal-halide lamps, as in all gas discharge lamps has a negative resistance property; meaning that as the current through the bulb increases, the voltage across it decreases. If the bulb is powered from a constant voltage source such as directly from the AC wiring, the current will increase until the bulb destroys itself; therefore, halide bulbs require electrical ballasts to limit the arc's current. There are two types:

i. Inductive ballast - Many fixtures use an inductive ballast, also known as a magnetic ballast, similar to those used with fluorescent lamps. This consists of an iron-core inductor. The inductor presents an impedance to AC current. If the current through the lamp increases, the inductor reduces the voltage to keep the current limited.

ii. Electronic ballast - These are lighter and more compact. They consist of an electronic oscillator which generates a high frequency current to drive the lamp. Because they have lower resistive losses than an inductive ballast, they are more energy efficient. However, high-frequency operation does not increase lamp efficiency as for fluorescent lamps.

Because of the whiter and more natural light generated, metal-halide lamps were initially preferred to the bluish mercury vapor lamps. With the introduction of specialized metal-halide mixtures, metal-halide lamps are now available with a correlated color temperature from 3,000 K to over 20,000 K. Color temperature can vary slightly from lamp to lamp, and this effect is noticeable in places where many lamps are used.

1.3. Fluorescent Sources

A fluorescent lamp, or fluorescent tube, is a low-pressure mercury-vapor gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. A fluorescent lamp converts electrical energy into useful light much more efficiently than an incandescent lamp. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt, several times the efficacy of incandescent bulbs with comparable light output. For comparison, the luminous efficacy of an incandescent bulb may only be 16 lumens per watt.

Fig. 5. Fluorescent Lamps

Fluorescent lamp fixtures are more costly than incandescent lamps because, among other things, they require a ballast to regulate current through the lamp, but the initial cost is offset by a much lower running cost. Compact fluorescent lamps are now available in the same popular sizes as incandescents and are used as an energy-saving alternative in homes. Because they contain mercury, many fluorescent lamps are classified as hazardous waste.

All the major features of fluorescent lighting were in place at the end of the 1920s. Decades of invention and development had provided the key components of fluorescent lamps: economically manufactured glass tubing, inert gases for filling the tubes, electrical ballasts, long-lasting electrodes, mercury vapor as a source of luminescence, effective means of producing a reliable electrical discharge, and fluorescent coatings that could be energized by ultraviolet light. At this point, intensive development was more important than basic research.

In 1934, Arthur Compton, a renowned physicist and GE consultant, reported to the GE lamp department on successful experiments with fluorescent lighting at General Electric Co., Ltd. in Great Britain (unrelated to General Electric in the United States).

A fluorescent lamp tube is filled with a mix of argon, xenon, neon, or krypton, and mercury vapor. The pressure inside the lamp is around 0.3% of atmospheric pressure. The partial pressure of the mercury vapor alone is about 0.8 Pa (8 millionths of atmospheric pressure), in a T12 40-watt lamp. The inner surface of the lamp is coated with a fluorescent coating made of varying blends of metallic and rare-earth phosphor salts. The lamp's electrodes are typically made of coiled tungsten and are coated with a mixture of barium, strontium and calcium oxides to improve thermionic emission.

Fig. 6. FL filament

Fluorescent lamp tubes are often straight and range in length from about 100 millimetres (3.9 in) for miniature lamps, to 2.43 meters (8.0 ft) for high-output lamps. Some lamps have the tube bent into a circle, used for table lamps or other places where a more compact light source is desired. Larger U-shaped lamps are used to provide the same amount of light in a more compact area, and are used for special architectural purposes. Compact fluorescent lamps have several small-diameter tubes joined in a bundle of two, four, or six, or a small diameter tube coiled into a helix, to provide a high amount of light output in little volume.

The performance of fluorescent lamps is critically affected by the temperature of the bulb wall and its effect on the partial pressure of mercury vapour within the lamp.[32] Since mercury condenses at the coolest spot in the lamp, careful design is required to maintain that spot at the optimum temperature, around 40 °C (104 °F).

Using an amalgam with some other metal reduces the vapour pressure and extends the optimum temperature range upward; however, the bulb wall "cold spot" temperature must still be controlled to prevent condensing. High-output fluorescent lamps have features such as a deformed tube or internal heat-sinks to control cold spot temperature and mercury distribution. Heavily loaded small lamps, such as compact fluorescent lamps, also include heat-sink areas in the tube to maintain mercury vapor pressure at the optimum value.

1.4. Solid State Sources

Solid-state lighting (SSL) is a type of lighting that uses semiconductor light-emitting diodes (LEDs), organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) as sources of illumination rather than electrical filaments, plasma (used in arc lamps such as fluorescent lamps), or gas.

Solid state electroluminescence is used in SSL as opposed to incandescent bulbs (which use thermal radiation) or fluorescent tubes. Compared to incandescent lighting, SSL creates visible light with reduced heat generation and less energy dissipation. Most common "white LEDs" convert blue light from a solid-state device to an (approximate) white light spectrum using photoluminescence, the same principle used in conventional fluorescent tubes.

The typically small mass of a solid-state electronic lighting device provides for greater resistance to shock and vibration compared to brittle glass tubes/bulbs and long, thin filament wires. They also eliminate filament evaporation, potentially increasing the life span of the illumination device.

Solid-state lighting is often used in traffic lights and is also used in modern vehicle lights, street and parking lot lights, train marker lights, building exteriors, remote controls etc. Controlling the light emission of LEDs may be done most effectively by using the principles of nonimaging optics.

Solid-state lighting has made significant advances in industry. In the entertainment lighting industry, standard incandescent tungsten-halogen lamps are being replaced by solid-state lighting fixtures.

Philips Lighting ceased research on compact fluorescents in 2008 and began devoting the bulk of its research and development budget to solid-state lighting. On 24 September 2009, Philips Lighting North America became the first to submit lamps in the category to replace the standard 60 W A-19 "Edison screw fixture" light bulb, with a design based on their earlier "AmbientLED" consumer product.
General-purpose lighting requires a white light, emulating a black body at a specified temperature, from "warm white" (like an incandescent bulb) at 2700K, to "daylight" at around 6000K. The first LEDs emitted light in a very narrow band of wavelengths, of a colour characteristic of the energy band gap of the semiconductor material used to make the LED. LEDs that emit white light are made using two principal methods: either mixing light from multiple LEDs of various colours, or using a phosphor to convert some of the light to other colours. The light is not the same as a true black body, giving a different appearance to colours than an incandescent bulb. Colour rendering quality is specified by the

CRI, and as of 2019 is about 80 for many LED bulbs, and over 95 for more expensive high-CRI LED lighting (100 is the ideal value).
RGB or trichromatic white LEDs use multiple LED chips emitting red, green, and blue wavelengths. These three colours combine to produce white light. The colour rendering index (CRI) is poor, typically 25 – 65, due to the narrow range of wavelengths emitted. Higher CRI values can be obtained using more than three LED colours to cover a greater range of wavelengths.

Fig. 7. Parts of LED source

The second basic method uses LEDs in conjunction with a phosphor to produce complementary colours from a single LED. Some of the light from the LED is absorbed by the molecules of the phosphor, causing them to fluoresce, emitting light of another colour via the Stokes shift. The most common method is to combine a blue LED with a yellow phosphor, producing a narrow range of blue wavelengths and a broad band of "yellow" wavelengths actually covering the spectrum from green to red. The CRI value can range from less than 70 to over 90, although a wide range of commercial LEDs of this type have a colour rendering index around 82. Following successive increases in efficacy, which has reached 150 lm/W on a production basis as of 2017, this type has surpassed the performance of trichromatic LEDs. The phosphors used in white light LEDs can give correlated colour temperatures in the range of 2,200 K (dimmed incandescent) up to 7,000 K or more.
Tuneable lighting systems employ banks of coloured LEDs that can be individually controlled, either using separate banks of each colour, or multi-chip LEDs with the colours combined and controlled at the chip level. For example, white LEDs of different colour temperatures can be combined to construct an LED bulb that decreases its colour temperature when dimmed.

LED chips require controlled direct current (DC) electrical power and an appropriate circuit as an LED driver is required to convert the alternating current from the power supply to the regulated voltage direct current used by the LEDs.

LED drivers are essential components of LED lamps to ensure acceptable lifetime and performance of the lamp. A driver can provide features such as dimming and remote control. LED drivers may be in the same lamp enclosure as the diode array, or remotely mounted from the light-emitting diodes. LED drivers may require additional components to meet regulations for acceptable AC line harmonic current.

High temperature of LEDs can cause premature failure and reduced light output. LED lamps tend to run cooler than their predecessors since there is no electric arc or tungsten filament, but they can still cause burns. Thermal management of high-power LEDs is required to keep the junction temperature of the LED device close to ambient temperature, since increased temperature will cause increased current, more heating, more current, and so on until failure. LEDs use much less power for a given light output, but they do produce some heat, and it is concentrated in a very small semiconductor die, which must be cooled. LED lamps typically include heat sinks and cooling fins.

The term "efficiency droop" refers to the decrease in luminous efficacy of LEDs as the electric current increases above tens of milliamps (mA). Instead of increasing current levels, luminance is usually increased by combining multiple LEDs in one lamp. Solving the problem of efficiency droop would mean that household LED lamps would require fewer LEDs, which would significantly reduce costs.

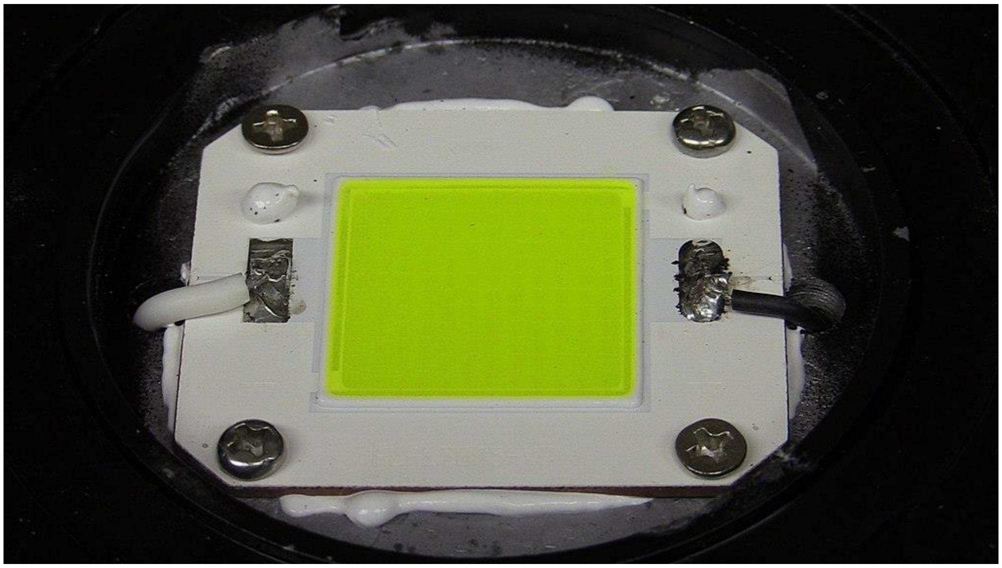


Fig. 8. COB LED

In addition to being less efficient, operating LEDs at higher electric currents produces high temperatures which compromise the lifetime of the LED. Because of this increased heating at higher currents, high-brightness LEDs have an industry standard of operating at only 350 mA, giving a good compromise between light output, efficiency, and longevity.

Early suspicions were that the LED droop was caused by elevated temperatures. Scientists proved the opposite to be true – that, although the life of the LED would be shortened, elevated temperatures actually improved the efficiency of the LED. The mechanism causing efficiency droop was identified in 2007 as Auger recombination, which was taken with mixed reaction. A 2013 study conclusively identified Auger recombination as the cause of efficiency droop.

Chapter 2

Existing Lighting Systems of Different Industries

2.1. Industries based on biological resources

Lighting equipment

a) Lamps: Light sources available for agriculture lighting applications include incandescent, fluorescent, low pressure sodium and high intensity discharge (HID). HID sources include mercury, metal halide and high-pressure sodium lamps.

i. **Incandescent Lamps** These lamps come in a variety of types and sizes. They are a high brightness source and should be used in appropriate luminaire to minimize glare. No auxiliary electrical equipment is required. These lamps can be dimmed.

ii. **Fluorescent Lamps** These lamps provide a large light source. Even though surface brightness is relatively low, fluorescent lamps should always be housed in a suitable luminaire to minimize glare. In high humidity environments or areas subject to wash down, gasketed or weatherproof housings are required to prevent corrosion and premature failure of the light system. Fluorescent lamps are available in different sizes, types, and colours, which can provide good colour rendering, cool or warm colours. Light output is highly dependent on operating temperature. At very high or extremely low ambient temperatures, light output drops. Cold start or low temperature starting ballasts along with an enclosure to maintain to temperature should be used in cold areas. Refer to IESNA Lighting Handbook, Part II Lighting Engineering, Chapter 6 Light Sources.

iii. **High Intensity Discharge Lamps** HID lamps are used both outdoors and indoors. Ballasts are required for their operation. HID lamps differ in their color rendering ability, generally being lower than fluorescent or incandescent lamps. These lamps are not suited to applications where lights operate intermittently for a short duration due to their slow warm up time.

b) Luminaires: Light is emitted from most lamps in many directions. A luminaire is designed to control the direction at which light is emitted so glare will be reduced and light directed more effectively on the objects to be seen. In most cases, luminaires should direct light downward to minimize losses. In some applications, it is desirable to have a portion of the light directed toward the ceiling. Some of the light striking a light coloured ceiling is reflected back to the visual tasks.

Luminaires control light distribution with reflectors (enamel, aluminum, glass, or plastic), refractors (glass or plastic diffusing lenses), or diffusers (glass or plastic diffusing shields). One or more of these devices might be used in the same luminaire. Reflectors and refractors direct light for more efficient utilization. Reflectors, refractors, and diffusing shields prevent glare. Refer to IESNA Lighting Handbook, Part II Lighting Engineering, Chapter 6 Light Sources.

A luminaire prevents water from striking hot lamps when used in damp locations, outdoor areas or areas which are washed. Weatherproof or gasketted housings are available for lamps used in humid environments, areas where water spray is a problem or when lamps are exposed to the weather.

c) Controls: Electric lighting systems in agricultural applications can be controlled electronically. There are several reasons for equipping a lighting system with an electronic control.

- Visual and Production Performance: match light intensity to the application. Occupant visual performance may depend on the quantity and quality of the light; for example, visually inspecting livestock for health or produce for quality purposes is a demanding visual task. The application may be specific to the reproductive, growth or behavioural needs of the plant or livestock.
- Energy Management: matches light application to demand; thereby, reducing unnecessary energy, time of use and/or demand charges.

A wide variety of controls are used in agricultural operations depending on the application. These controls include switches, dimmers, photosensors, occupancy sensors, and timers. The information provided in this section comes from IESNA Lighting Handbook, Part V Special Topics, Chapter 27 Lighting Controls. For details on any of the areas discussed, please refer to the Handbook.

d) Energy efficient Lighting: Switching control allows lights to be switched on and off manually with simple wall-box switches, or remotely with relays, switchable circuit breakers, a control system, or occupancy sensors. The choice of switching control will depend on the application. Local manual switching controls give control over light levels according to their needs or the tasks are inexpensive.

Central switching controls are well suited to scheduled activities such as occupation of a space during prescribed hours of the day and week. Control systems are ideal for applications with multiple zones and changing lighting requirements over time. Greenhouse operations, for example, employ lighting control systems to match light requirements to the crop being grown in a particular zone.

Occupancy or motion sensors are used in applications where lights are required only during occupancy of a space. These sensors are ideally suited to walkways, hallways, entrances to buildings, or to spaces where the user’s hands are not free to activate a switch.

e) Starting characteristics: The two starting characteristics that influence lamp selection are starting temperature and warm-up period.

Starting temperature generally is only important when selecting a lighting system for unheated spaces in cold climates, such as naturally ventilated structures. Incandescent and high-pressure sodium lamps perform well at cold temperatures (-29°C or colder). The minimum starting temperatures for standard fluorescent lamps and ballasts is 10°C. Ballasts are available that allow fluorescent lamps to start at -29°C.

Incandescent and halogen lamps do not have a warm-up period. Standard fluorescent lamps have a slight starting delay, but it is not significant in most applications. Quick starting ballasts can be purchased if required. All of the high intensity discharge lamps have a significant warm-up period. The warm-up period can range from 1 to 15 minutes.

f) Emergency lighting: The need for emergency lighting must be evaluated during the design phase of the building. If the facility does not have an automatic start generator, emergency lighting units may be required, to illuminate the exit passageways in the building(s) in the event of a power outage. Be sure to consult federal, state, provincial and local codes that may apply. NFPA (National Fire Protection Association) 101 - The Life Safety Code can be used as a reference along with the State Fire Marshal’s Office in the State where the facility will be built. Even if not required, the Engineer designing the building must always consider how to get people out of the building(s) in the event of an emergency. Auxiliary Generators must be installed in accordance with NFPA (National Fire Protection Association) 70, the National Electrical Code, NFPA 110 Standard for Emergency and Standby Power Systems and any other federal, state, provincial and local codes that may apply. The local electrical utility also must approve any installation and the equipment used. The appropriate NFPA, federal, state, provincial and local codes must be followed with regard to the installation of fuel tanks. In some instances, fuel tanks may be located inside the building, if the appropriate codes are followed and authorities such as State Fire Marshal's Offices are consulted. Be sure to check and see if the insurance company insuring the facility has any guidelines that must be met.

g) Codes: Many federal, state, provincial and local codes govern the use of lighting equipment. Some public health codes specify minimum illuminance levels required in processing plants, egg handling areas, milking and milk handling areas to maintain health standards. These required levels address the concern for proper sanitation and often are below those recommended for efficient performance of visual tasks.

Agriculture facilities include many types of environments, which may be wet, damp, corrosive, dirty, surrounded by combustible materials, or saturated with gasoline fumes. It is mandatory to follow the National Fire Protection Association Standard No. 70, National Electrical Code, and any local regulations that may be in effect when installing lighting equipment. Contact a local electrician, electric power supplier for assistance or refer to the Agricultural Wiring Handbook published by the National Food and Energy Council (US).

Lamp Type	Lamp Power (W)	CRI	Efficacy (lm/W)	Typical Lamp Life (hrs)
Incandescent	34 - 200	100	11 - 20	750 - 2,000
Halogen	50 - 150	100	18 - 25	2,000 - 3,000
Fluorescent	32 - 100	70 - 95	75 - 98	15,000 - 20,000
Compact Fluorescent	5 - 50	80 - 90	50 - 80	10,000
Metal Halide	70 – 1,000	60 - 80	60 - 94	7,500 - 20,000
High-pressure Sodium	35 – 1,000	20 - 80	63 - 125	15,000 - 24,000

Table 2. General Characteristics of Light Sources

Lighting Quantity

General Comments: The amount of the illumination needed in agriculture facilities varies depending on the type of production and the tasks performed in the work area. In response to the variability of lighting system requirements, this discussion is divided into several sections and subsections.

Livestock: Lighting system requirements vary with the housing and livestock type. The housing system and task will determine whether natural and or supplemental lighting is required. Dairy and Beef Cattle Facilities: In order to stimulate milk production, the lighting system must provide the following:

1) 150 lx of illuminance throughout the barn.
2) 16 to 18 hour continuous block of light.

Providing illuminance for 24 hours a day does not produce a sustainable increase in milkyield, and operating the lighting system more than necessary wastes energy. In addition to providing adequate levels and duration of illuminance for production, a high level of uniformity is required in the parlour pit, office, and milkroom washing area. These areas require high uniformity toper form demanding visual tasks.

Swine Facilities: Five footcandles are adequate and will be atleast twice as much light as typically is found in many older swine barns. Design is critical to maximize light efficiency and minimize overlit or underlit areas. Breeding/Gestation barns require lighting photoperiods from 14-16 hours per day, to bring on more quickly and extend breeding sow estrus. Nursery pigs, particularly those in SEW, should have 24 hours of light at low levels and higher levels for day time feeding, inspection, etc.

Work Area or Task	Illuminance (lx)
Parlour, pit and near udder	500
Parlour, stalls & return lanes	200
Parlour, holding area	100
Milk room, general	200
Milk room, washing	750-1,000
Stall barn, manger alley	100
Stall barn, milking alley	200
Drive-through feed alley	200

Table 3.Recommended Illuminance Levels for Dairy Livestock Facilities

Poultry Facilities: Broiler Houses Broiler chicks are placed into large houses inside which they move about freely. The structures may utilize natural light with artificial supplement or rely totally on artificial light. A low level of general lighting is required so the birds can find food and water during non daylight periods or for certain time periods each day in completely enclosed facilities. The light levels and photoperiod may be adjusted during the growing period to maximize growth and control losses. Light control is provided by a dimmer and timer system.

Breeder Barns Breeder birds are placed in separate facilities, which generally are totally enclosed blocking out all natural light. Artificial lighting on timing circuits controls the perceived day length. The hours of light per day stimulate reproduction and control the breeding process. The lights for production are on their own circuit. A separate lighting circuit provides general lighting for feeding, inspection and cleaning. Localized, higher intensity lighting is needed for record keeping, observation and adjustment of alarm and control systems and monitoring Equipment.

Laying Houses Artificial lighting systems control the perceived day length in order to extend the egg laying period during the year.

Egg Handling, Packing and Shipping General lighting is needed to keep the area clean and detect any unsanitary conditions. Higher intensity, task specific lighting is necessary to examine and grade eggs. In the loading platform and egg storage areas, general lighting is needed for operation of mechanical and loading equipment.

Raw Egg Processing General lighting must supply adequate light levels and uniformity to ensure that cleanliness requirements for a food preparation area are met.

Hatchery General lighting is needed for cleaning and easy movement of operators. Supplementary lighting is required for inspecting and cleaning inside incubators, and at dubbing stations to prevent cuts and injuries to chicks. Task specific lighting is necessary for sex sorting and should be provided in a closed area to prevent excessive luminance ratios between task area and the immediate surrounding area.

Poultry Processing Plant General lighting is needed for cleanliness, inspection and sanitation. Supplementary lighting is required to detect diseases and blemishes (vertical illuminance if the birds are hanging).

2.2. Industries Based on Natural Resources

In 1879 a practical incandescent filament lamp was patented. As a result light no longer depended on a fuel source. Many startling breakthroughs have been made in lighting knowledge since Edison’s discovery, including some with applications in underground mines. Each has inherent advantages and disadvantages. Current to energize the light sources may be either alternating (AC) or direct (DC). Fixed light sources almost always use alternating current whereas portable sources such as cap lamps and underground vehicle headlights use a DC battery. Not all light source types are suitable for direct current.

Fixed light sources

Tungsten filament lamps are most common, often with a frosted bulb and a shield to reduce glare. The fluorescent lamp is the second most common light source and is easily distinguishable by its tubular design. Circular and U-shaped designs are compact and have mining applications as mining areas are often in cramped spaces. Tungsten filament and fluorescent sources are used to light such diverse underground openings as shaft stations, conveyors, travelways, lunchrooms, charging stations, fuel bays, repair depots, warehouses, tool rooms and crusher stations.

The trend in mine lighting is to use more efficient light sources. These are the four high-intensity discharge (HID) sources called mercury vapour, metal halide, high-pressure sodium and low-pressure sodium. Each requires a few minutes (one to seven) to come up to full light output. Also, if power to the lamp is lost or turned off, the arc tube must be cooled before the arc can be struck and the lamp relit. (However, in the case of low-pressure sodium (Sox) lamps, restrike is almost instantaneous.) Their spectral energy distributions differ from that of natural light. Mercury vapour lamps produce a bluish white light whereas high-pressure sodium lamps produce a yellowish light. If colour differentiation is important in underground work (e.g., for using colour-coded gas bottles for welding, reading colour-coded signs, electrical wiring hook-ups or sorting ore by colour), care must be taken in the colour rendition properties of the source. Objects will have their surface colours distorted when lit by a low-pressure sodium lamp.

Mobile light sources

With working places spread out often both laterally and vertically, and with continual blasting in these working places, permanent installations are often deemed impractical because of the costs of installation and upkeep. In many mines the battery-operated cap lamp is the most important single source of light. Although fluorescent cap lamps are in use, by far the majority of cap lamps use tungsten filament battery-operated cap lamps. Batteries are lead acid or nickel cadmium. A miniature tungsten-halogen lamp bulb is often used for the miner’s cap lamp. The small bulb allows the beam to be easily focused. The halogen gas surrounding the filament prevents the tungsten filament material from boiling off, which keeps lamp walls from blackening. The bulb can also be burned hotter and hence brighter.

For mobile vehicle lighting, incandescent lamps are most commonly used. They require no special equipment, are inexpensive and are easy to replace. Parabolic aluminized reflector (PAR) lamps are used as headlights on vehicles.

Effects of Lighting on Accidents, Production and Health

One would expect that better lighting would reduce accidents, increase production and reduce health hazards, but it is not easy to substantiate this. The direct effect of lighting on underground efficiency and safety is hard to measure because lighting is only one of many variables that affect production and safety. There is well-documented evidence that shows highway accidents decrease with improved illumination. A similar correlation has been noted in factories. The very nature of mining, however, dictates that the work area is constantly changing, so that very few reports relating mine accidents to lighting can be found in the literature and it remains an area of research that has been largely unexplored. Accident investigations show that poor lighting is rarely the primary cause of underground accidents but is often a contributing factor. While lighting conditions play some role in many mine accidents, they have special significance in accidents involving falls of ground, since poor lighting makes it easy to miss dangerous conditions that could otherwise be corrected.

Until the beginning of the twentieth century, miners commonly suffered from the eye disease nystagmus, for which there was no known cure. Nystagmus produced uncontrollable oscillation of the eyeballs, headaches, dizziness and loss of night vision. It was caused by working under very low light levels over long periods of time. Coal miners were particularly susceptible, since very little of the light that strikes the coal is reflected. These miners often had to lie on their sides when working in low coal and this may also have contributed to the disease. With the introduction of the electric cap lamp in mines, miner's nystagmus has disappeared, eliminating the most important health hazard associated with underground lighting.

With recent technological advances in new light sources, the interest in lighting and health has been revived. It is now possible to have lighting levels in mines that would have been extremely difficult to achieve previously. The main concern is glare, but concern has also been expressed about the radiometric energy given off by the lights. Radiometric energy can affect workers either by acting directly on cells on or near the surface of the skin or by triggering certain responses, such as biological rhythms on which physical and mental health depends. An HID light source can still operate even though the glass envelope containing the source is cracked or broken. Workers can then be in danger of receiving doses beyond threshold limit values, particularly since these light sources often cannot be mounted very high.

2.3. Chemical Industries

LEDs for Hazardous Environment

In fact, LEDs can be used in environments where other technologies fail. They are capable of instant on and instant restrike to –40°C, and they require no warm-up time to be fully bright. LEDs do not produce any harmful UV or IR radiation, which are usually associated with other traditional lighting sources. While LEDs are a directional source of light—directed with optics and lenses, fluorescents need reflectors to direct the light, which loses efficiency as lumens get reduced. LED lighting needs very less maintenance as they have very long life and are well known for high performance. Maintenance in hazardous environments can be dangerous. This challenge can be resolved as LED lights come in sealed units as well which do not require changing for long period of time, and are protected against dust or gas. LED lighting provides 100% light output instantly on being switched on, which is an added advantage for hazardous environments.

LED luminaires for hazardous environments have to be waterproof as these places can be very humid. Keeping these luminaires light weight is another challenge for the designers; so they use plastics which can be used in different chemical environments. Polycarbonate is also used as it is resistant to UV and vibrations of heavy machinery. However, it is not resistant to chemicals, oils or other cleaning fluids. Manufacturers also use copper-free aluminum or stainless-steel to make the housing of the LED lights rugged for harsh environments, and to make them suitable for humid, cold and wet weathers. Sometimes extra coating and resistant proof paints are added to make the housing corrosion proof.

LED lighting technology offers many advantages over traditional HID technologies and appears to be the wave of the future. Properly selected and applied LED luminaires should result in reduced lifecycle costs, improved illumination levels and improved safety performance. Industrial LED luminaire development is only a short way into its maturity curve; however, evolution and product development is rapid as evidenced by the proliferation of products and manufacturers not well known in our industry. Applicable standards are also rapidly evolving. Great care should be taken in LED luminaire selection given the wide ranges of performance (variable wattages, photometric outputs, etc.) relative to design applications. Some existing facilities do not pay adequate attention to lighting; however, there are opportunities for improvement with new installation technologies that facilitate safer and more efficient access for maintenance. Innovative techniques can be very beneficial in studying and improving lighting awareness and performance. New LED luminaire technologies offer many concrete financial and environmental improvement opportunities.

2.4. Manufacturing Industries

Manufacturing and industrial facilities use massive amounts of energy. Consequently, it should come as no surprise that these buildings are also expensive to operate. A significant part of your facilities' cost of operation is a result of keeping the lights on. It is estimated that 40-60% of a commercial building's electric bill comes from lighting. If you're using conventional light fixtures, you may be consuming more energy—and paying—for way more than needed. Luckily, there's never been a better time to invest in new, energy efficient LED lighting solutions.

You should consider an LED lighting conversion or retrofit if your factory or warehouse still uses outdated lighting technology (e.g. metal halide, fluorescent, high-pressure sodium, high-intensity discharge). There are a number of factors unique to your facility that will increase the benefits provided from installing an LED lighting system.

Fig. 9. Manufacturing Industry

Number of Fixtures

The more lights you have in your factory or warehouse, the more you'll be able to take advantage of the benefits of an LED lighting upgrade. Light fixtures that count towards your total number include: high bay light fixtures, low bay light fixtures, dock lights, exterior security fixtures, and parking lot light fixtures. Each of these lighting types can be converted or retrofit with a more energy efficient LED fixture or LED bulb.

To maximize your energy savings, and better qualify for Federal and State rebate and incentive programs, your facility retrofit should have thirty or more new LED fixtures and lamps installed. If you're replacing only a few light fixtures at your facility, it may take a number of years before you start to see any savings on your utility bill.

24/7 Operations

In today's highly-productive environment, manufacturing facilities never sleep. While operating 24 hours a day increases capacity and productivity, it also upsurges your energy bill from having the lights on day-in and day-out. If you're using your lights at a high rate each week, utility companies are much more willing to provide incentives in order to help reduce your energy consumption (i.e. providing rebates to help offset the cost of a facility LED conversion or retrofit to lower energy usage).

Integrated Lighting Controls

In most factories, there are areas that are often not in use. LED fixtures with integrated occupancy sensors can control lighting levels in unoccupied areas of your facility to maximize energy savings. Once activity is detected, the light levels go up instantly (another benefit of LED lighting) to meet the required light levels for employees working in that area.

Once the sensors detect a period of inactivity, they turn the fixtures off or dim them to a preset level, achieving additional energy savings and extended lamp life. Some integrated occupancy sensors also include a daylight harvesting function, constantly measuring the light levels coming from other sources, and adjusts the lumen output accordingly.

Think Twice Before Investing in Cheap LEDs

Legacy lighting systems are expensive to operate, but buying cheap LEDs is not the way to go. Low-quality LEDs don’t sustain their advertised efficacy, life and light output that you expect, forcing you to buy again after a short period of time. The cheaper products might come at an unexpected price, and end up costing you up to three times the initial investment versus buying quality LED fixtures.

Vapour-Tight Requirements

Although dependent on industry, many factories and commercial spaces are semi-conditioned or non-conditioned spaces and may potentially be exposed to rain, ice, or other types of moisture. If these environments aren’t properly managed, it can lead to rust, corrosion, and other types of damage to your lighting over time. Luckily, there are many brands of industrial light fixtures that are specifically designed with vapor-tight fixtures to ensure bulbs and hardware continues to function properly.

High Ambient Temperature Requirements

As heat rises, hot air becomes trapped in the ceiling. Over time, it’s common to have ambient temperatures at the mounting height of the light fixture to reach 55°C up to 65°C, which can dramatically reduce the life of the fixture. It’s important to remember when selecting an LED fixture, that the product you select is intended to operate for many years. The only way to ensure you have a well-lit factory over that time is to make sure you’re installing LED fixtures designed and rated for high ambient temperatures.

Selecting the Best LED Fixture for Your Facility

High Bay Fixtures: Often used in factories and warehouses with ceilings approximately 25 feet and higher, high bay fixtures are used for vertical, as well as horizontal, lighting planes, and are functional with a variety of reflectors. While high bay lighting fixtures typically used fluorescent or metal halide bulbs in the past, LED high bay fixtures outperform these more conventional luminaires in a number of important ways (e.g. average lifespan, correlated-colour temperature (CCT), instantaneous on/off, dimming capabilities, directionality, efficiency, heat emissions and more).

Low Bay Fixtures: LED low bay lighting provides full-spectrum, crisp white light in factories and warehouses with low ceilings and mounting heights. Low bay LED luminaires deliver similar light levels to traditional metal halide and fluorescent fixtures but provide better uniformity and coverage.

Recessed Troffer Fixtures: Troffer fixtures are available in three standard sizes: 1’x4’, 2’x2’, and 2’x4’. While conventional troffer fixtures typically included T12 and/or T8 fluorescent lamps, with 2-4 lamps per fixture, LED solutions either consist of new LED fixtures or LED linear tube retrofits. Deciding which option is best will depend on your facility’s current operating conditions. LED troffer fixtures can be surface-mounted, pendant-mounted, or chain-hung. Choosing how to mount your troffer fixture depends on ceiling fit and desired light performance.

2.5. Textile and Apparel Industries

Sewing is the most important activity in garment manufacturing due to the multiplicity of machine types involved and amount of time taken by an operator in a given environment and factory condition, which goes on to define the quality of the garment. Having said that, the 1000 lux required at the needle point for quality work can be achieved using various lighting systems. Various types of lights with different lumens and colours are commonly available in the market but it is the incandescent bulbs and fluorescent tubelights which are most commonly used on the shopfloor, and among them fluorescent lights are used little more extensively in garment factories, giving a much needed clarity to the subject.

Fluorescent Tubelights on Lighting Frame and Ceiling

Fluorescent tubelights have been in use in the industry from the very beginning on the ceiling as well as in the lighting frame, typically constructed along the sewing line 8 feet above the floor level. T8 fluorescent tubelights are now commonly used on sewing floor as cool white colour is considered appropriate by apparel manufacturers since it lasts longer than traditional T12 and has greater lumen maintenance over time, besides being manufactured by numerous brands at competitive prices. One primary difference between T8 and T12 fluorescent tubelights is the size of the tubelights and their bases. While both tubelights come in standard lengths, commonly four feet, the number 8 or 12 refers to the difference in the diameter of the tubelights. T8 tubelights are one inch in diameter, while T12 tubelights have a larger diameter of one-and-a-half inch. According to Philips, a maker of light tubelights and lighting equipment, a T8 tubelight produces around 2600 lumens, while the T12 tubelight puts out around 2520 lumens. Over the time the tubelights begin to lose their intensity and brightness while T8 tubelights have a slower period of decrease, losing only 10 per cent of their initial brightness after 7,000 hours of use. In comparison, T12 tubelights can lose 20 per cent, or double the T8 loss, after the same number of hours.

Fig. 10. Textile Industry

Again in the same setup of a 30 sewing machine line, lights are removed from the lighting frame, along with the frame itself. The LED based needle lights at each sewing machine are the only source of light, which is complimented by CFL at the ceiling, 10 feet above the floor. CFL at ceiling is providing the ambient lighting at the shopfloor and LED needle lights are providing work lights at the sewing machine. Considering the distance from the needle point, the CFL lights of 50 watt each at the ceiling operating at 47% efficiency will produce approximately 80 lux, one LED needle light will produce 920 lux. So, the total lux generated at the needle point with the LED needle light and ceiling CFL lights would be 1000 lux. Therefore, 30 needle lights at the sewing machines and 15 CFL lights at ceiling will be required, and the power consumption for one hour would be a total of 765 watts, with each needle light consuming 0.5 watts and each CFL light consuming 50 watts.

2.6. Transport Industries

Lighting design can be the difference between effective infrastructure and missing the mark. Good lighting design brings many benefits including the prevention of night-time road accidents, the provision of a safe environment for both motorized and non-motorized users, assisting in the reduction of street crime and the fear of crime, as well as contributing to the local night-time economy. Innovations such as adaptive lighting, the application of LED light sources and control systems can reduce energy and carbon costs, while ensuring correct lighting performances. Innovations like weather and daylight adaptive lighting can make transportation safer, while reducing energy costs.

According to the top LED street lighting manufacturers, the influence of technological advancements has transformed the whole lighting domain. Innovative and smart lighting solutions like adaptive lighting, smart outdoor lighting, etc. not only ensure supreme performance but also reduce the energy costs and carbon emissions.

Roadways and Highways

Lighting is a primary safety measure that ensures safe transit on the roads and highways. It supports road safety by flourishing uniform illumination that improves night time visibility. This eventually minimizes the risk of unfortunate accidents on the roads. Furthermore, the leading commercial lighting manufacturers believe that using LED street lights can also contribute to the development of smart and empowered cities.

Railways and Metros

Lighting serves as a multi-purpose tool in busy places like railway stations and metro stations. Firstly, it aids in creating an impressive and functional environment that makes the visitors feel welcomed and assists them in finding the right passages and exit points. Secondly, proper lighting ensures passenger safety and security under all circumstances. It safeguards the people against mishaps and accidents on vulnerable places like stairs, escalators, concourse areas, and ticketing counters.

Fig. 11. Metro Railway

Airports

Airports are one of the highly-developed areas that undertake complex operations. Thus, the lighting systems in airports must take multiple factors into account. According to the best LED lighting manufacturers, airport authorities are required to ensure appropriate lux levels, operational efficiency, and uniformity, along with safety and emergency aspects. Lighting experts claim that the lux requirement on the terminals can range from 150 lux to 300 lux. However, exceptions can be made in some areas due to security concerns.

Chapter 3

Identification of issues and problems in Industrial Lighting

3.1. Lighting systems effecting Human Health

Changing lighting condition is a change process that influences performance via many routes. Wyon (1996) introduced a kind of step-by-step method to describe the relationship between an environmental change and performance in terms of specific mechanisms that explain the effects of the change. When these mechanisms are defined as chains of hypotheses, each of which must be true for the mechanisms to be valid, then we can test each link in the chain separately.

Light influences people via a visual and a non-image-forming (NIF, also called psycho-biological) path in the brain. The mechanisms that effect performance will be described with the chain approach. Human performance is directly linked to profitability in the industrial environment. Individual differences will influence the effect of the mechanisms. The change process itself will also be handled as a mechanism. The cost of the lighting change and the effects via customers also effect portability.

A literature search yielded several fields studies in which lighting change effects have been measured in an individual environment. Unfortunately, only few of the studies are well documented. Some are just used as an example in general papers. Most of them are old but still useful. In fig. 12 and 13 the results of all studies found in literature have been put together. Fig. 12 gives the increase in work output and Fig. 13 gives decrease in errors or rejects, as a function of task illuminance. The dotted lines connect the "before" and "after the change" situation for each individual study. The solid curves are drawn by calculating the average slope from the reported results as a function of the illuminance. The solid curves give the trend of the performance improvement (increase output decrease rejects), as has been found in the studies mentioned above and show that there is an effect of illuminance on performance.

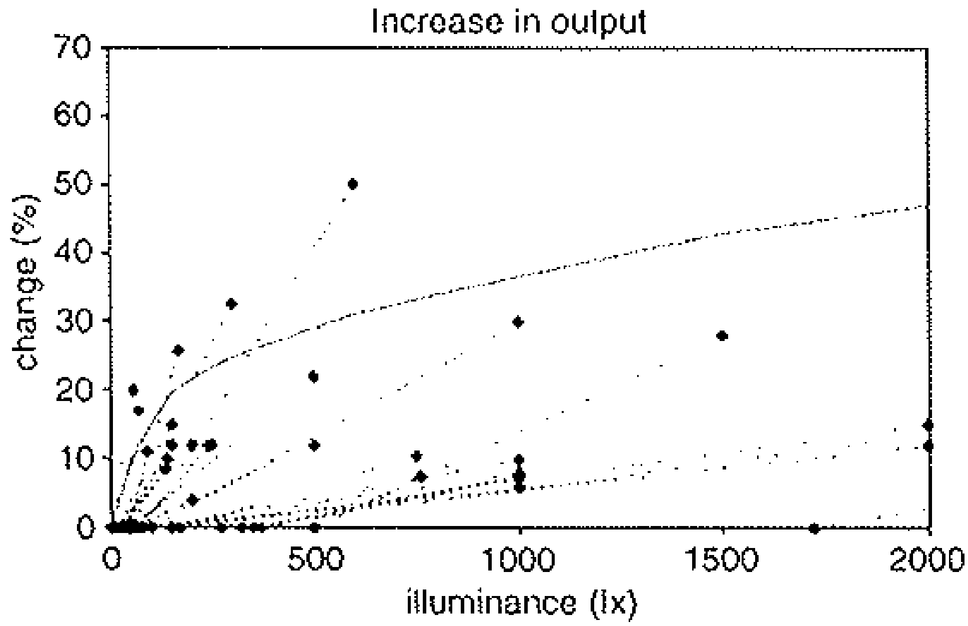


Fig. 12. Lighting change for work output. The dotted lines show the results of the individual tests and the solid curve shows the calculated average slopes

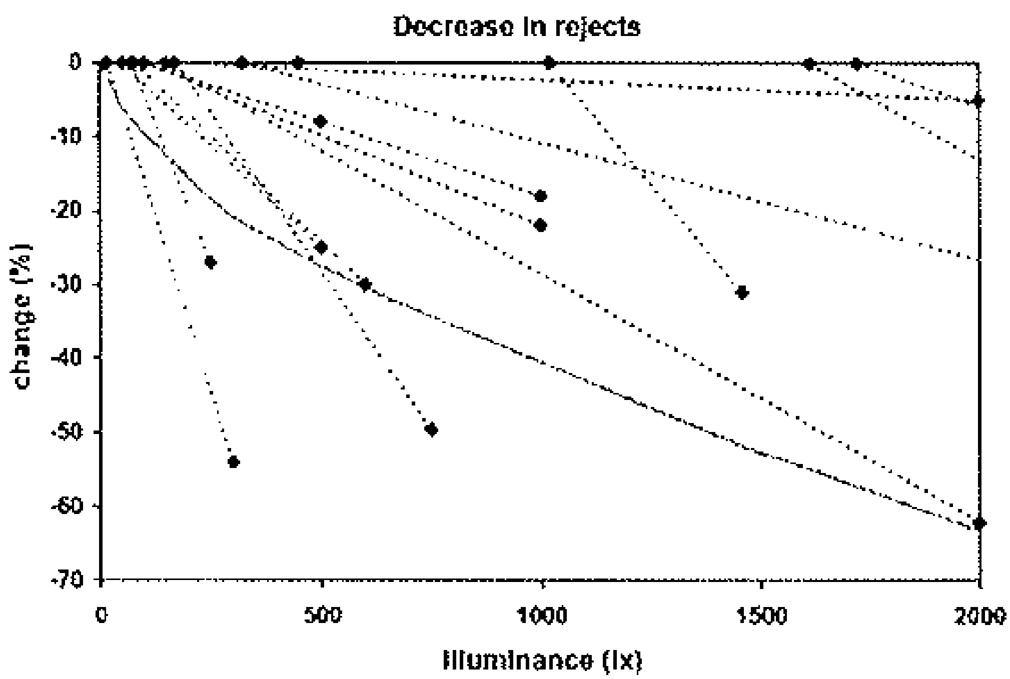


Fig. 13. Lighting change effects for rejects. The dotted lines show the results of the individual tests and the solid curve shows the calculated average slopes.

One should keep in mind that in experiments on human performance an increase in productivity could be caused by the so-called “Hawthorne Effect” The “Hawthorne Effect” (Mayo, 1933: Bloggs and Draper, 1996) is the effect that the study or evaluation itself has on people; the feeling of being observed and cared for can lead to improved performance. The Hawthorne effect was first established in the studies in the relay-assembly test room in the Hawthorne plant starting on 25.04.1927 and ending on 18.06.1932 (Parsons, 1974).

Many studies started with very low illuminances. This increases the uncertainty of the solid curves, which are averages. It is remarkable that even if the size and the reason for improving the performance is not clear, almost all individualstudies indicate improvement of performance after the lighting change. In most cases the illuminance has been increased, but this does not mean that illuminance is the only. or even the most important, factor behind the success.

The solid curves differ in the sense that the decrease in rejects shows a steeper slope than does the increase in output for illuminances above 300 lux. Although the results depend on (unknown) boundary conditions, such as initial quality level and process robustness. it could indicate that outputs are more strongly influenced by visual performance (just how well, we are able to see). When the illuminance is sufficient for the visual performance, the output increases. It is also possible that other factors block the increase in output. Many factories are producing more or less quantified amounts of products per time frame. depending on orders and contracts, or speed is determined by the machines employed: and even if the working environment offers possibilities to increase the number of products. it is not always done or desired. The ongoing decrease of rejects can be caused by another mechanism such as brain stimulation.

3.2. Mechanisms for the effects of a change of lighting

General introduction

A lighting change can be brought about by changing the artificial lighting or the daylight contribution. It has been indicated in the previous section that there is an effect lighting change on the performance of workers. Different mechanisms are responsible for this effect. A mechanism includes all the chains that can be created under one origin. The different origins are independent, and it is possible to find at least one chain that is specific only to this mechanism. When changing the lighting, it is possible to achieve increased performance via the following mechanisms:

1. Visual performance

When people can see the task better, they can perform better.

2. Visual comfort

Decreasing discomfort glare influences performance because of increased concentration.

3. Visual ambience

Lighting influences visual ambience, which being part of the working environment influences performance.

4. Interpersonal relationships

How people see each other influences how they feel about each other, which influences cooperation and productivity.

5. Biological clock

Light adjusts the biological clock. which controls the circadian rhythms and thus influences performance at certain times.

6. Stimulation

Light stimulates psychological and physiological processes, which enhances performance.

7. Job satisfaction

Improving lighting conditions might increase job satisfaction via task significance and autonomy, which influences performance.

8. Solving problems

Solving existing lighting problems, which are complained about, increases wellbeing and motivation, which enhances performance.

9. The Halo effect

The effect of the belief in the superiority of a new technology or product itself might result in enhanced performance.

10. Change process

Good change management increases the positive affect of the lighting change and diminishes negative effects

Mechanism 1, visual performance

A. Lighting influences visual performance.

B. Visual performance influences task performance.

C. Task performance influences total individual performance.

The first statement is obvious-we need light to be able to see. Visual performance is a quite-well studied topic in lighting. The relative visual performance model (RVP) (Rea and Quellette. 1991) is a model that has been developed during the past 20 years and that can predict visual performance in some tasks (Bailey et al., 1993: Eklund et al., 2001). Also, the lighting standards, such as the new European norm (EN 12464-1 Lighting for indoor workplaces), are mainly based on visual performance.

The effect of visual performance on task performance is not always clear. Visual performance has a different importance in different tasks. Some tasks do not need much light in order to be performed well visually. And task illuminance is not the only factor that influences visual performance-glare, spatial distribution. spectral composition, individual differences, and the task itself also play an important role in the impact of this mechanism.

Since the task is supposed to be a significant part of the work to be performed, the total performance of the individual worker will be influenced by the task performance.

3.3. Mechanism 2. visual comfort

A. Discomfort glare creates the sensation of pain or annoyance.

B. Pain and annoyance affect our possibilities to concentrate on the task.

C. Concentration level influences individual performance

Visual comfort might be compromised even if visual performance is still good. A typical example is discomfort glare that creates a sensation of annoyance without affecting visual performance A lighting change that improves visual comfort. such as a decrease of discomfort glare. yields a higher performance by reducing a disturbing factor present in the environment.

Mechanism 3. visual ambience

A. Lighting influences the working environment via visual ambience.

B. The working environment influences wellbeing and feelings.

C. Positive effect increases individual performance.

Boyden (1971) distinguishes "survival needs" and "well-being needs" in humans. The survival needs are mostly fulfilled in a working environment, but failure to

satisfy well-being needs produces psychosocial maladjustment and stress-related ill nesses. One of the needs mentioned is: "A visual environment that is interesting, that has aesthetic integrity, and in which a certain amount of change meaningful to the observer is taking place". Lighting is directly linked to this need.
Many significant effects of positive, pleasant feelings have been reported in literature. Important work-related results of positive mood arc, for example: the inclination to help others, positive effects on memory, more efficient decision making. increased innovation and creative problem-solving tendencies. All these are direct links to better individual performance (Isen and Baron, 1991).

According to this chain, the illuminated environment influences performance via positive mood and not only via better visual performance (mechanism 1). It is difficult to estimate the size of the effect of this mechanism in increased overall performance in real industrial environments. Anyway it has been shown that the physical environment affects performance by influencing the effectiveness of teamwork in industry (Sundström and Altman, 1989).
Mechanism 4. interpersonal relationships

A. Light influences a person's appearance.
B. A person's appearance influences interpersonal relationships.
C. Interpersonal work relationships influence team
The characteristics of light influencing communication and interpersonal relationships are luminance, spatial distribution and spectral composition. The (vertical) illuminance (or luminance) determines how well the other person's face and expressions can be seen. The direction of the light has an influence on the shadows, which can change the expression observed, and the spectral composition is important for the colour rendering (e.g. of the skin colour). The colour of the skin is a signal of health and mood. Skin and clothes look different under different lighting: consequently, people with different skin tones prefer different lamps.
Visual performance plays a role here, but in this mechanism the emphasis lies on how the other person appears, not on how well he or she can be seen. Appearance influences interpersonal relationships, which in turn have several effects on performance. Body language and appearance provide an important part of the information for the interpersonal relationship. It has been shown that interpersonal relationships influence the effectiveness of teamwork (Sundström et al., 1990).

The light level also has an effect on conversational sound level (Veitch and Kaye, 1988), which then influences the interpersonal relationships. The change in conversational sound levels depending on light level is not connected directly to visual performance.

Mechanism 5. horological clock

Chain S

A. Light exposure influences the biological clock.

B. The biological clock influences the circadian rhythms.

C. The circadian rhythms influence individual performance of shift workers.

Circadian rhythms are changing patterns that have a period of approximately 24 hours. Examples of circadian rhythms are body temperature, alertness. and hormonal rhythms such as melatonin and cortisol. Circannual (annual) rhythms also influence our body processes. Our biological clock is located in the suprachiasmatic nucleus, and ocular light synchronizes it (Brainard and Bernecker. 1995). Without daily light exposure, the free running period of our circadian system would be more than 24 hours. Recent studies, by Brainard et al. (2001). in which melatonin suppression was measured, show that the spectral sensitivity curve of the photo-biological system peaks at around 460 mm. To achieve maximum effects, one has to use cither high photopic lighting levels or lamps that produce more light of wavelengths around 460 mm. According to the Dawson et al. (1995). bright light has been shown to be "superior" to melatonin administration in controlling the biological clock.

The biological clock needs to be set if we want to perform well outside the normal daytime (e.g. after travelling across several time zones and during night shifts). Travelers are familiar with desynchronization of their biological clock and the local time so-called jetlag. Shift workers face the same problem when they are trying to work while their body clock says it is time to sleep. The effect of light on the circadian rhythm depends on the time of the day (Czeisler et al., 1988). Bright (or photo biologically effective) light late in the evening. before the body temperature minimum. will delay our circadian rhythms, whereas light in the early morning, after the body temperature minimum. will advance the rhythms. Timing, intensity, spectral distribution, spatial distribution and duration of the light exposure together with individual factors define how large the phase shift is. Light influencing the circadian rhythms is supposed to be one element to improve the quality of life and the performance of shift workers. In case studies, where bright

light during the night shift has been used, increased performance has been observed.
It is assumed that daytime workers can also benefit by increased lighting levels, especially in the morning and during the so-called "post lunch dip" (van den Beld, 2002). For example. light exposure in the morning affects cortisol levels in humans (Scheer and Buijs, 1999), The light/dark cycle sets the amplitude of the hormonal rhythms (Jewett et al. 1994), and when the hormonal rhythms are stronger. we sleep better and are more alert-when we are awake. Being not so sleepy when we are awake then naturally also improves our performance (Dinges and Kribbs. 1991).

Mechanism . stimulation effects

For the direct stimulation effects, two chains are described. Chain 6a

A. Lighting level and colour temperature influencemood.

B. Better mood increases individual performance (see mechanism 2).

Chain 6b

A. Increased lighting level decreases sleepiness measured as EEG delta waves.

B. Sleepiness influences individual performance.

Light has several direct and indirect stimulation effects on our psychological (example chain 6a) and physiological (example chain 6b) processes. The increase of daylight in springtime, for example, creates well-known positive mood effects. Studies (Knez, 1995, 1997: McCloughan et.al. 1999) have shown that the lighting level and colour temperature also influence our mood in doors. The problem with mood and colour temperature is that personal differences are so big that finding general rules is difficult. Higher lighting levels also influence the electroencephalogram (EEG). keeping us more alert and less sleepy (Daurat et al., 1993: Küller and Wetterberg, 1993).

The Yerkes Dodson law (Yerkes and Dodson. 1908), which is also called the arousal theory, suggests that the relationship between arousal (sensory stimulation) and human performance varies systematically following the so-called "in verted U" function. Higher arousal means higher performance. until a certain level is reached above which increased arousal starts to influence performance negatively. Lighting is supposed to be a rather mikl arousal agent. Lighting is supposed to increase human performance, especially when arousal moves from low to medium levels and the task is not very difficult (Gifford, 1988). Many industrial jobs have repetitive tasks where this mechanism might cause effects. To be able to maximize benefits out of this mechanism we should install an adjustable lighting installation, because after adaptation to the changed circumstances the effect is probably not so strong (Gifford et al., 1997).

A study by Tops et al. (1998) shows a relationship between the illuminance at the working plane and the length of continuous presence in an office This was explained by an arousing capacity of light, which increases with increasing lighting levels. A number of researchers have supported the hypothesis that lighting directly and positively influences the arousal state (Bingr, 1991) An Improvement in attention and concentration between 15:00h and 17:00h in a 2500 lux condition as compared with a 500 lux condition has been reported by Grünberger et al. (1993). An alternative explanation is that high light levels slow the rate of tiring among subjects, as has been found with visual tasks (see Boyce et al., 1989 for a review). Assuming that with higher lighting levels people tire more slowly, it follows that they are able to stay longer in the office before having to leave for a break.

Mechanism 7. job satisfaction

Two chains are described.

Chain 7a

A. Improved lighting gives the employee a signal that his work is significant.

B. Perceived task significance influences job satisfaction.

C. Job satisfaction influences individual job performance.

Chain 7b

A. Opportunity to control lighting conditions increases the feeling of autonomy.

B. Autonomy influences job satisfaction.

C. Job satisfaction influences individual job performance.

This mechanism (both chains) has an influence only for cases where task significance or autonomy influence job satisfaction. In those industrial jobs where this is not the case improved lighting will have no effect via this mechanism

In an often-used job satisfaction model presented by Hackman and Oldham (1976), the focus lies on five core jobs characteristics, which are task identity, feedback, skill variety task significance and autonomy. Lighting change has an effect on tusk significance and autonomy. The fact of having a new lighting installation itself gives the employee the message that he and his job are important. The lighting installation might also have features that increase the feeling of autonomy, such as individual control options or level and or colour temperature Studies that have been done in the Office environment have shown that the possibility to control the lighting is preferred by people (Moore et al., 2002; Escuyer and Fontoynont, 2001; Maniccia et al., 1999). In industry, people have fewer possibilities to control their environment, which might mean that lighting controls arc even more important for them than for office workers.

According to a meta-analysis made by Tait et al. (1989), job satisfaction correlates moderately well with life satisfaction (r= 0.44). There is also a moderate correlation between job satisfaction and job performance (r= 0.30) (Judge et al., 2001b). In any case, the strength and even direction of the correlation between job satisfaction and job performance in the individual cases is not totally clear. For example, an older meta-analysis gave a much weaker correlation (r= 0.17) (laffaldano and Muchinsky. 1985). Job satisfaction also influences absenteeism and turnover. The average correlation is weak but significant, generally in the r=-0.25 range (Judge et al., 2001a).

Mechanism 8. problem solving

Two chains are described.

Chain 8a

A. Solving problems that employees complain about increases well-being and motivation.

B. Well-being and motivation influence individual performance (see mechanism 2).

Chain 8b

A. Employing high-frequency ballasts instead of magnetic ones limits flicker.

B. Flicker causes fatigue and eyestrain and results in lower sustained performance.

C. Decreasing fatigue and eyestrain increases individual performance.

The original lighting installation might have "quality" problems such as glare. bad colour rendering, stroboscopic effects, noise from ballasts, wrongly located luminaires, difficult control of luminaires, etc., which are causing complaints and difficult working conditions. "Repairing" these kinds of problems has direct positive results via two routes. Firstly, repairing conditions gives a signal to employees that they are being listened to by the employers and that they have influence, which increases their motivation (chain 8a). Secondly, that getting rid of the problems improves the physical working environment and gives the employees the opportunity to work effectively (chain 8b).

Chain 8a influences performance in the same way as the chains described under mechanism 7 (viz. changing environmental conditions shows the employee that his job is significant and that it is worthwhile to improve conditions). In this mechanism, the reason for the change comes from the employee, and a reaction to his demands will give him feelings of autonomy and importance.

Lighting might also cause other problems. A typical, but not visual-performance-related example is flicker from magnetic ballasts causing problems such as headaches (Wilkins et al., 1998). When the magnetic ballasts are replaced by electronic ballasts, the problems disappear. And as in chain 8b, getting rid of those problems influences performance: for example, in the form of reduced absenteeism. Health-related things are not the only beneficial outcomes of using electro nic (high-frequency) ballasts. A study by Veitch and Newsham (1998) shows that task performance is also better when electronic ballasts are employed.

Mechanism 9. The Halo effect

Chain 9

A. People have positive presumptions about good lighting.

B. Their presumptions influence individual performance.

The term "the halo effect" was first used by Thorndike (1920). It describes how a person's first impression influences the total judgment of that person. The halo effect can be applied to people as well as to things. Sometimes the subjects of technological intervention believe that a new technology is wonderful, and that belief is the real cause of improved performance (Bloggs and Draper, 1996). The beliefs can be like those tested by Veitch et al. (1993): "Brighter light leads to greater productivity" or "People feel happier when working under light that is similar to natural daylight." It is not important whether or not these beliefs are well founded. The origin of these beliefs might be anything. In many cases the halo effect increases the positive effect of the lighting change on individual and organizational performance.

Mechanism 10. change process

Chain 10

A. Lighting change is a change process.

B. Change management influences the results of the change process.

C. Results of the change process influence individual performance.

A change of lighting is a management intervention, which can be done in different ways. The way the change process is managed influences the results (Pascale et al., 1997). Changing the working environment can lead to a change in work output. The most common basic advice to managers since the early studies of participative change management (Coch and French, 1948) has been to involve and or inform people about the change. Even though a better environment is most probably well accepted, there is always the possibility of the negative mechanism called "resistance to change" if the change process is not well handled. Involving people in the lighting change could be accomplished by giving them the possibility to influence the lighting installation. Those involved could be kept informed simply by telling them the reason for the change in advance (lower energy consumption, flicker-free installation, better lighting for performing tasks, etc).

Chapter 4

Energy efficient codes and standards

4.1. IS 6665(1972)

This Indian Standard was adopted by the Indian Standards Institution on 8 August 1972, after the draft finalized by the Illuminating Engineering Sectional Committee had been approved by the Electrotechnical Division Council. This code covers the principles and practice governing good lighting for various industrial premises. It recommends the levels of illumination and quality requirements to be achieved by general principles of lighting.

Industrial lighting encompasses seeing tasks, operating conditions and economic conditions. Visual tasks may be classified as either small or very large; dark or light; opaque, transparent or translucent; specular of diffuse surfaces; flat or contoured shapes. With each of the various task conditions, lighting should be suitable for adequate visibility in developing raw materials into finished products. Physical hazards exist in manufacturing processes and, therefore, lighting should contribute to the utmost as a safety factor in preventing accidents. The speed of operations may be such as to allow only minimum time for visual perception and, therefore, lighting should be a compensating factor to increase the speed of vision.

A good industrial lighting should take into account:

- adequate quantity of illumination, and
- good quality of illumination.

Quantity of Illumination- The utilitarian goal of a lighting system is to provide for optimal performance of a given task. A starting point will be the determination of relationship between illumination and performance, but the final recommendation has to take into consideration other factors such as avoidance of fatigue, physiological and psychological effects, economics, etc. Desirable criteria for determining the quantity of illumination are:

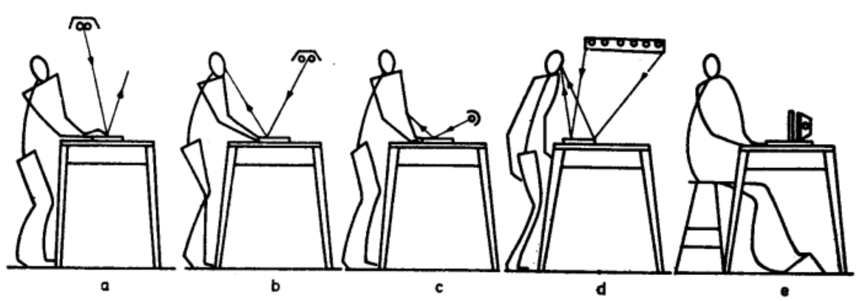
a) adequacy for preventing occupational eye-strain and the risk of accidental injury due to bad visibility;
b) adequacy for creating an agreeable luminous environment; and

c) adequacy for different satisfactory levels of visual performance, each standard being applicable to a particular range of visual task.

Quality of Illumination-Quality of illumination pertains to the distribution of brightness in the visual environment. The term is used in a positive sense and implies that all brightness should contribute favourably to visual performance, visual comfort, ease of seeing, safety and aesthetics for the specific visual task involved. Glare, diffusion, direction, uniformity, colour, luminance and luminance ratios all have a significant effect on visibility and the ability to see easily, accurately and quickly. Certain seeing tasks such as discernment of fine details require much more careful analysis and higher quality illumination than others. Areas where seeing tasks are severe and performed over long periods of time require much higher quality than where seeing tasks are casual or of relatively short duration.

Permanent Supplementary Artificial Lighting (PSAL)-This refers to artificial lighting provided for use in daytime to supplement natural daylight.

Supplementary Lighting- Difficult seeing tasks often require a specific amount or quality of lighting which cannot readily be obtained by standard general lighting methods. To solve such problems supplementary luminaires often are used to provide higher illumination levels for small or restricted areas. Also they are used to furnish a certain luminance, or colour, or to permit special aiming or positioning of light sources to produce or avoid highlights or shadows to best portray the details of the task.



a — Luminaire located to prevent reflected glare; reflected light does not coincide with angle of view.
b — Reflected light coincides with angle of view.
c — Low-angle lighting to emphasize surface irregularities.
d — Large-area surface source and pattern are reflected toward the eye.
e — Transillumination from diffuse source.

Fig. 14. Examples of placement of Supplemented Luminaires

TABLE 2 RECOMMENDED VALUES OF ILLUMINATION AND LIMITING VALUES OF GLARE INDEX

(*Clause* 5.1)

L Io.	Industrial Buildings and Processes	Average Illumination lux	Limiting Glare Index
1.	*General Factory Areas*		
	a) Canteens	150	—
	b) Cloakrooms	100	—
	c) Entrances, corridors, stairs	100	—
2.	*Factory Outdoor Areas*		
	Stockyards, main entrances, exit roads, car parks, internal factory roads	20	—

Table 4. Examples of illumination levels from IS 6665 (1972)

4.2. IS 3646-1 (1992)

This code (Part 1) covers the principles and practice governing good lighting in buildings and relates chiefly to the lighting of ‘working areas’ in industrial, commercial and public buildings, hospitals and schools.

The lighting of an interior should fulfil three functions. It should:

a) ensure the safety of people in the interior,
b) facilitate performance of visual tasks, and
c) aid the creation of an appropriate visual environment.

Safety is always important but the emphasis given to task performance and the appearance of the interior will depend on the nature of the interior. For example, the lighting considered suitable for a factory tool room will place more emphasis on lighting the task than on the appearance of the room, but in a hotel lounge the priorities will be reversed. This variation in emphasis should not be taken to imply that either task performance or visual appearance can be completely neglected. In almost all situations the designer should give consideration to both these aspects of lighting.

Lighting affects safety, task performance and the visual environment by changing the extent to and the manner in which different elements of the interior are revealed. Safety is ensured by making any hazards visible. Task performance is facilitated by making the relevant details of the task easy to see. Different visual environments can be created by changing the relative emphasis given to the various objects and surfaces in an interior. Different aspects of lighting influence the appearance of the elements in an interior indifferent ways. However, it should always be remembered that lighting design involves integrating the various aspects of lighting into a unity appropriate to the design objectives.

7.6 Assembly Shops			
7.6.1 Rough work for example, frame and heavy machine assembly	200-300-500	3	The lighting of vertical surface may be important
7.6.2 Medium work, for example, engine assembly, vehicle body assembly	300-500-750	2	
7.6.3 Fine work, for example, office machinery assembly	500-750-1 000	1	Localized lighting may be useful
7.6.4 Very fine work, for example, instrument assembly	750-1 000-1 500	1	Local lighting and optical aids are desirable
7.6.5 Minute work, for example, watch making	1 000-1 500-2 000	1	Local lighting and optical aids are desirable

Table5. Examples of illumination levels from IS 3646 (1992)

23 GENERAL BUILDING AREAS			
23.1 Entrance			
23.1.1 Entrance halls, lobbies, waiting rooms	150-200-300	2	
23.1.2 Enquiry desks	300-500-750	2	Localized lighting may be appropriate
23.1.3 Gatehouses	150-200-300	2	
23.2 Circulation Areas			
23.2.1 Lifts	50-100-150	—	
23.2.2 Corridors, passageways, stairs	50-100-150	2	
23.2.3 Escalators, travellators	100-150-200	—	
23.3 Medical and First Aid Centres			
23.3.1 Consulting rooms, treatment rooms	300-500-750	1	
23.3.2 Rest rooms	100-150-200	1	
23.3.3 Medical stores	100-150-200	2	
23.4 Staff Rooms			
23.4.1 Changing, locker and cleaners rooms, cloakrooms, lavatories	50-100-150	—	
23.4.2 Rest rooms	100-150-200	1	
23.5 Staff Restaurants			
23.5.1 Canteens, cafeterias, dining rooms, mess rooms	150-200-300	2	
23.5.2 Servery, vegetable preparation, washing-up area	200-300-500	2	

Table 6. Examples of illumination levels from IS 3646 (1992)

4.3. BEE_ECBC (2017)

Bureau of Energy Efficiency had launched Energy Conservation Building Code (ECBC) 2007 to establish minimum energy performance standards for buildings in India. Buildings consume significant proportion of our energy resources and the ECBC is an essential regulatory tool to curb their energy footprint. Energy efficient technologies and materials that were aspirational in the years preceding launch of

ECBC are now commonly available in Indian markets. Accordingly, ECBC 2017has been revised to incorporate advanced technologies.

Additional parameters included are related to renewable energy integration, ease of compliance, inclusion of passive building design strategies and, flexibility for the designers. One of the major updates to the code is inclusion of incremental, voluntary energy efficiency performance levels. ECBC 2017 is one of the first building energy codes to recognize beyond code performance. There are now three levels of energy performance standards in the code. In ascending order ofefficiency, these are ECBC, ECBCPlus and SuperECBC. The adherence to the minimum requirements stipulated for ECBC level of efficiency would demonstrate compliance with the code. Other two efficiency levels are of voluntary nature. This feature was added to prepare the building industry for meeting energy efficiency standards in coming years and give sufficient time to the market to adapt.

ECBC 2017 is technology neutral. Energy efficiency requirements have been framed to provide architects and engineers artistic and technical freedom as long as minimum efficiency requirements are fulfilled.

Provisions for installation of renewable energy generation systems are mandatory in ECBC 2017. Buildings compliant with the updated code must be ready for installation of renewable energy systems. Proportion of total electricity demand to be met through renewable energy systems increases with the efficiency level the project aspires to.

Passive designs strategies like daylight and shading are mandatory in ECBC 2017.Objective for this change is to encourage design with passive strategies to be the norm for buildings in India. Building energy codes are hinged on climate responsive buildings that use local natural resources and climatic conditions to their advantage.

Surface Type	*Reflectance*
Wall or Vertical InternalSurfaces	50%
Ceiling	70%
Floor	20%
Furniture (permanent)	50%

Table 7. Default Values for Surface Reflectance

Source: ECBC 2017

Building Area Method

Determination of interior lighting power allowance (watts) by the building area method shall be in accordance with the following:

Determine the allowed lighting power density for each appropriate building area type from Table 6-1 for ECBC Buildings, from Table 6-2 for ECBC+ Buildings and from Table 6-3 for SuperECBC Buildings.

a) Calculate the gross lighted carpet area for each building area type.
b) The interior lighting power allowance is the sum of the products of the gross lighted floor area of each building area times the allowed lighting power density for that building area type.

Building Type	***LPD (W/m2)***	***Building Area Type***	***LPD (W/m2)***
Office Building	9.50	Motion picture theatre	9.43
Hospitals	9.70	Museum	10.2
Hotels	9.50	Post office	10.5
Shopping Mall	14.1	Religious building	12.0
University and Schools	11.2	Sports arena	9.70
Library	12.2	Transportation	9.20
Dining: bar lounge/leisure	12.2	Warehouse	7.08
Dining: cafeteria/fast food	11.5	Performing arts theater	16.3
Dining: family	10.9	Police station	9.90
Dormitory	9.10	Workshop	14.1
Fire station	9.70	Automotive facility	9.00
Gymnasium	10.0	Convention center	12.5
Manufacturing facility	12.0	Parking garage	3.00
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 8.1. *Interior Lighting Power for ECBC Buildings – Building Area Method*
Source: ECBC 2017

Building Area Type	***LPD (W/m2)***	***Building Area Type***	***LPD (W/m2)***
Office Building	7.60	Motion picture theatre	7.50
Hospitals	7.80	Museum	8.20
Hotels	7.60	Post office	8.40
Shopping Mall	11.3	Religious building	9.60
University and Schools	9.00	Sports arena	7.80
Library	9.80	Transportation	7.40

Dining: bar lounge/leisure	9.80	Warehouse	5.70
Dining: cafeteria/fast food	9.20	Performing arts theater	13.0
Dining: family	8.70	Police station	7.90
Dormitory	7.30	Workshop	11.3
Fire station	7.80	Automotive facility	7.20
Gymnasium	8.00	Convention center	10.0
Manufacturing facility	9.60	Parking garage	2.40
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 8.2. *Interior Lighting Power for ECBC+ Buildings – Building Area Method*
Source: ECBC 2017

Building Area Type	***LPD (W/m2)***	***Building Area Type***	***LPD (W/m2)***
Office Building	5.0	Motion picture theater	4.7
Hospitals	4.9	Museum	5.1
Hotels	4.8	Post office	5.3
Shopping Mall	7.0	Religious building	6.0
University and Schools	6.0	Sports arena	4.9
Library	6.1	Transportation	4.6
Dining: bar lounge/leisure	6.1	Warehouse	3.5
Dining: cafeteria/fast food	5.8	Performing arts theater	8.2
Dining: family	5.5	Police station	5.0
Dormitory	4.6	Workshop	7.1
Fire station	4.9	Automotive facility	4.5
Gymnasium	5.0	Convention center	6.3
Manufacturing facility	6.0	Parking garage	1.5
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 8.3. *Interior Lighting Power for SuperECBC Buildings – Building Area Method*
Source: ECBC 2017

Chapter 5

Efficiency of Present Industrial Lighting Systems

5.1. Introduction to Energy Efficiency

Energy-efficient lighting is usually the lowest life-cycle cost option. Lighting is widely used in everyday life. It is a significant factor contributing to our quality of life and productivity of our workforces. Artificial illumination extends the productive day, enabling people to work in homes, offices, buildings and factories.

Payback time of energy-efficient lighting varies depending on equipment and energy costs. It ranges from less than one year (for direct retrofit of a light source) to two to three years for a complete lighting system overhaul. The latter requires higher investments but will render higher annual savings in return.

We currently consume 2,900 TWh of electricity per year for lighting. This is equivalent to five times the total national consumption of Germany. Over the next two decades lighting services are projected to rise by approximately 50 per cent relative to current levels of demand.

By 2030, these policy measures would reduce electricity demand for lighting to 2,160 TWh per year, saving up to 640 TWh of electricity, according to the UNEnvironment model. This slight savings in step with such a large increase in lighting service is due to a widespread shift from conventional lighting technologies like incandescent, halogen and fluorescent lamps to lighting products based on light-emitting diodes (LEDs).

This period of technology transition from old to new products is an opportunity to governments. They can introduce cost-effective policy measures across all lighting applications yielding substantial savings and accelerating the adoption of LED-based lighting. By 2030, governments could save up to 640TWh of electricity, according to the UN Environment model. This is up to 23 per cent of the projected (no new policy) demand. In terms of CO_2 emissions, governments could avoid upwards of 390million metric tonnes annually. Taken on a cumulative basis, between 2015 and 2030 theCO_2 savings would be up to 3.3gigatonnes of avoided

CO_2.The guidance provided in this document is meant to be flexible, rather than prescriptive. It can be applied to a diverse range of lighting applications, including indoor lighting in public, commercial and residential buildings and outdoor lighting as in the case of urban and rural street lights and parking lots.

UN Environment encourages countries to follow a five-stage integrated policy approach for transforming their respective markets towards higher energy efficiency:

i. **Standards and Regulations (MEPS1)** — cover a collection of related requirements defining which products can be sold and those that should be blocked from the market. Standards and regulations form the foundation from which to ensure the success of any efficient lighting transition strategy.

ii. **Supporting Policies** —are necessary to ensure the smooth implementation of standards and regulations, and to achieve a broad public acceptance. Supporting policies include labelling schemes and other market based instruments, often initiated and promoted by regulatory incentives, and information and communication campaigns that inform end users in order to change or modify their behaviour.

iii. **Finance and Financial Delivery Mechanisms** —addressing high first-cost challenges with efficient light sources, looking at economic instruments and fiscal instruments and incentives, such rational electricity prices and tax breaks. Also consider financing incentive mechanisms that help address the initial incremental costs such as through dedicated funds, electric utility on-bill financing, and pay-as-you save schemes based on shared savings transactions through Energy Service Companies.

iv. **Monitoring, Verification and Enforcement (MVE)** —successful market transition depends on effective monitoring (i.e. verify product efficiency), verification (i.e. verify declarations of conformance); and enforcement (i.e. actions taken against noncompliant suppliers) of the regulations (MEPS). Enhancing the capacity of various countries and the sharing of information and skills between countries and across regions provides an effective means through which to promote best practice, quickly and thoroughly.

v. **Environmentally Sound Management of Lighting Products** — mercury and other hazardous substance content standards should be established in line with global best practice in order to minimize any environmental or health impact. Special attention should be given to the development of a legal framework for environmentally sound, end-of-life activities. In order to support governments in promoting energy efficiency and removing obsolete and energy intensive lighting technologies from their markets, United for Efficiency has developed a step-by-step guide called “Fundamental Policy Guide: Accelerating the Global Adoption of Energy Efficient Products”. This guide offers an overview of the key elements required to transform a national appliance market towards more energy efficient products through the application of the U4E Integrated Policy Approach. The Fundamental Policy Guide is cross-cutting for all United for Efficiency priority products including lighting, residential refrigerators, air conditioners, distribution transformers and electric motors.

5.2. Why leapfrog to energy-efficient lighting?

Many countries and economies promote energy-efficient lighting solutions in their national markets. They do this through a combination of regulatory measures, supporting policies, and financing mechanisms. Many countries, including Argentina, Brazil, Ecuador, Ghana, Jordan, the Russian Federation, Senegal, South Africa, and Tunisia, are working to take such action in their respective lighting markets.48 developing and emerging countries have completed, with the support of U4E, national or regional efficient lighting strategies. These countries have policies in place to phase-out inefficient incandescent lamps by the end of 2016.

The accelerator depicts a scenario where countries follow the integrated policy approach. They realise the benefits of energy-efficient lighting through efficient-lighting policies would take effect in 2020. In 2030, the annual global electricity savings for lighting reaches 640 TWh per year. This reduction in power equates to$360 billion in avoided investment in 290large coal-fired power plants.6 The savings would be enough electricity to provide new grid-connections to over 300 millionhouseholds7, each consuming 2,000 kWh/year. The CO2 emission savings from this global transition to efficient lighting would be 390 megatonnes per year in 2030.8 In addition the electricity savings result in over $50 billion in consumer savings on their electricity bills.

The expected cumulative savings are significant. The cumulative savings of the energy-efficient lighting policy scenarios relative to the business as usual case between now and 2030 are 5,400 TWh of global electricity. The cumulative avoided emissions from this transition to efficient lighting globally are 3.3

gigatonnes of avoided CO2. This is equivalent to over three times the current GHG emissions of Germany. Within the non-OECD group, Asia stands out as the region with the highest gains in electricity savings and avoided CO2 emissions. Many other global programmes and activities help find mechanisms to cost effectively mitigate climate change.

This includes country commitments through Intended Nationally Determined Contributions (INDCs), the UN Framework Convention on Climate Change's Conference of the Parties XXI (COP21) emission reduction targets, the SEforALL Lighting Accelerator, the Clean Energy Ministerial Global Lighting Challenge's 10 billion lamps announcement, GEF projects implemented by the World Bank and others, the Super-efficient Equipment and Appliance Deployment (SEAD) Global Efficiency Award Medal for Lighting.

The work promoting efficient lighting in each country should touch upon and draw from these programmes and initiatives. Most importantly, it should establish a more sustainable, energy-efficient and better-quality national lighting market for that specific country.

5.3. Lighting Technologies

This section provides a high-level overview of lighting technologies. The objective is to help ensure a good understanding of the technologies being considered within the scope of any lighting regulations. The lighting technologies are classified into incandescent lighting, fluorescent lighting, high-intensity discharge lighting and LED lighting. In addition, this section provides a summary of common lighting controls systems.

Incandescent lighting: Originally developed in the late 1800s, incandescent lamps produce light by passing electrical current through a tungsten metal wire suspended in an inert atmosphere inside a glass bulb. The electric current causes the filament to heat up so much that it glows and produces visible light and a lot of heat. Halogen lamps are an improvement over incandescent (offering better efficacy, and a slightly longer bulb life).

Fig. 15. Incandescent Lamp

These lamps contain a small quantity of halogen (iodine or bromine) inside a filament capsule that re-deposits evaporated tungsten back onto the filament, preventing the blackening of the filament capsule and increasing the lamp lifetime.

CHARACTERISTIC	INCANDESCENT TYPICAL QUANTITY	HALOGEN TYPICAL QUANTITY
LUMINOUS EFFICACY RANGE	8-17 lm/W	11-21 lm/W
LAMP LIFETIME	1,000-1,500 hr	2,000-3,000 hr
COLOUR RENDERING INDEX (RA)	100	100
CORRELATED COLOUR TEMPERATURE	2,600-2,800 K	2,800-3,200 K
DIMMABLE?	Yes	Yes

Table 9. Incandescent and halogen lighting typical performance specification

Advantages of incandescent and halogen:

- Low purchase price;
- Highest colour rendering;
- No control gear needed;
- Easily dimmed;
- Universal operating position.

Disadvantages of incandescent and halogen:

- Low efficacy (lots of wasted electricity);
- Short lifetime, typically
  1,000 hours incandescent
  3,000 hours halogen;
- High operating costs (i.e. electricity use);
- High operating temperature.

Fluorescent lighting: CFLs are direct retrofits for incandescent lamps, which incorporate an electronic ballast and phosphor-lined glass tube. An electrical arc is struck at the tube's electrodes, causing the mercury atoms to emit ultraviolet (UV) light, exciting the phosphor coating and emitting visible light. CFLs were developed in the 1970s, and are essentially a miniaturised version of a linear fluorescent lamp (LFL). Compared to incandescent lamps, CFLs use approximately 75 per cent less electricity while producing the same amount of light and last about ten times longer.

Linear fluorescent lamps operate in the same manner as described for CFLs. Table 3 provides more details. They do not incorporate a ballast, and thus require a dedicated fixture incorporating a ballast to operate. Linear fluorescent lamps are typically classified by their tubular diameter (most common are: T12 = 38mm, T8 = 25mm, T5 = 16mm) and by their length and wattage.

Fig. 16. Fluorescent Lamp

CHARACTERISTIC	CFL TYPICAL QUANTITY	LFL TYPICAL QUANTITY
LUMINOUS EFFICACY RANGE	50 - 70 lm/W	80 - 110 lm/W
LAMP LIFETIME	6,000 - 15,000 hr	15,000 - 30,000 hr
COLOUR RENDERING INDEX (RA)	70 - 85	60 - 95
CORRELATED COLOUR TEMPERATURE	2,500 - 6,500 K	2,700 - 6,500 K
DIMMABLE?	If dimmable ballast	If dimmable ballast

Table 10. Fluorescent lighting typical Performance specification

Advantages of fluorescent:

- Low running costs;
- High efficacy;
- Long operating life;
- Very good to excellent colour rendering.

Disadvantages of fluorescent:

- Control gear (ballast) required for operation;
- Frequent switching can shorten life;
- Dimming requires special ballast;

- Contains mercury.

High intensity discharge lighting: High intensity discharge (HID) lighting produces light from an electrical arc contained within a capsule of gas which is sealed inside a bulb. HID lights require a ballast to start and operate, which regulates the voltage supplied to the capsule of gas. Light is produced by the electrical arc passing through a metal vapour; however, HID bulbs only produce 5 per cent of their light when first started, and require several minutes to achieve full brightness. If an HID lamp is switched off, it must cool before a new arc can be re-struck in the capsule and light produced.

HID lighting has several variants, but the main ones are mercury vapour (white light, least efficacious), high pressure sodium (orange light, very efficacious), and metalhalide (white light, range of efficacies). Table 4 provides more details. HID lighting is commonly found in outdoor lighting applications such as street lighting, are a flood lighting and sports stadium lighting. HID lighting is also found indoors in places such as large retail outlets, warehouses and manufacturing facilities.

Fig. 17. HID Lamp

CHARACTERISTIC	MERCURY VAPOUR TYPICAL QUANTITY	HIGH PRESSURE SODIUM QUANTITY	METAL HALIDE TYPICAL QUANTITY
LUMINOUS EFFICACY RANGE (INITIAL)	45 - 55 lm/W	105-125 lm/W	80-100 lm/W
LAMP LIFETIME	20,000 hr	20,000 - 24,000 hr	10,000 - 20,000 hr
COLOUR RENDERING INDEX (RA)	15 - 50	25	65-85
CORRELATED COLOUR TEMPERATURE	3,900 - 5,700 K	2,000 - 2,100 K	4,000 - 5,000 K
DIMMABLE?	If dimmable ballast	If dimmable ballast	If dimmable ballast

Table 11. High intensity discharge lighting typical performance specification

Advantages of HID lighting:

- Low running costs;
- High efficacy for high pressure sodium and metal halide lamps;
- Long operating life –typically 20,000 hours;
- High flux in a small package;
- Range of colour rendering, with metalhalide able to achieve excellent colour.

Disadvantages of HID lighting:

- Control gear (ballast) required for operation;
- Re-strike after operation can take time;
- Can be several minutes to reach full brightness;
- Frequent switching can shorten life;
- Dimming requires special ballast;
- Contains mercury.

Fig. 18. LED lamps and an LED luminaire

LED lighting: LEDs offer unique characteristics that make them a compelling source of light. They are compact, have long life, resist breakage and vibration, offer their best performance in cold operating environments, are instant-on and some models are dimmable. Depending on the drive circuit and LED array in a particular light source, LEDs can also be adjusted to provide different coloured light or colour temperatures of white. Unlike incandescent and fluorescent lamps, LEDs are not inherently white light sources. Instead, LEDs emit nearly monochromatic light, making them highly efficient for coloured light applications such as traffic signal and exit signs. To be used as a general light source, white light is needed, by combining different LEDs or using a phosphor. Figure 8 shows the different ways that white light can be achieved with LEDs.

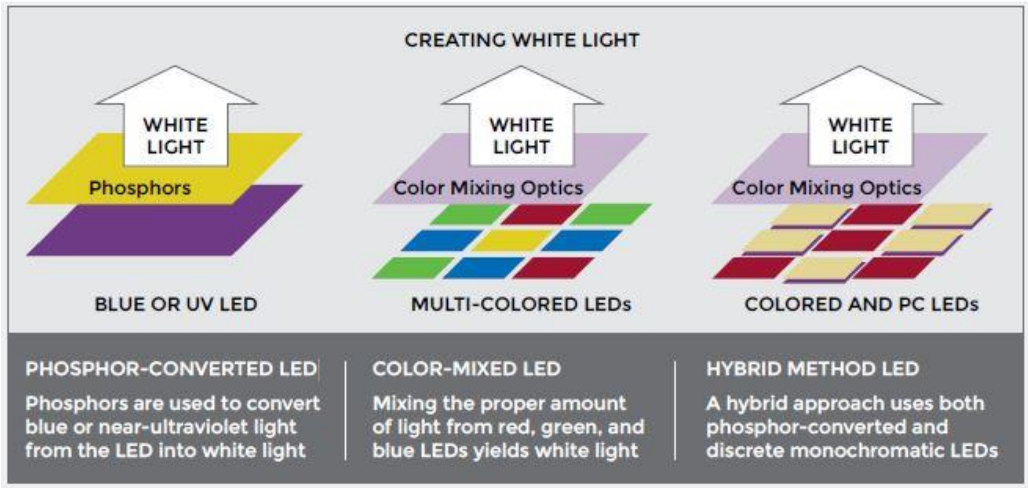


Fig. 19. Producing white light with LEDs

Figure 9 shows the projected market average efficacies of various types of commercial LED lamps and luminaires, as used by the US Department of Energy in their recent report calculating the energy savings potential of solid-state lighting. The trend for increasing efficacy also means users tend to get more and better quality light at a lower running cost. That is, the higher energy efficiency of the LED sources translates into lower energy bills and greater reductions in CO2 emissions.

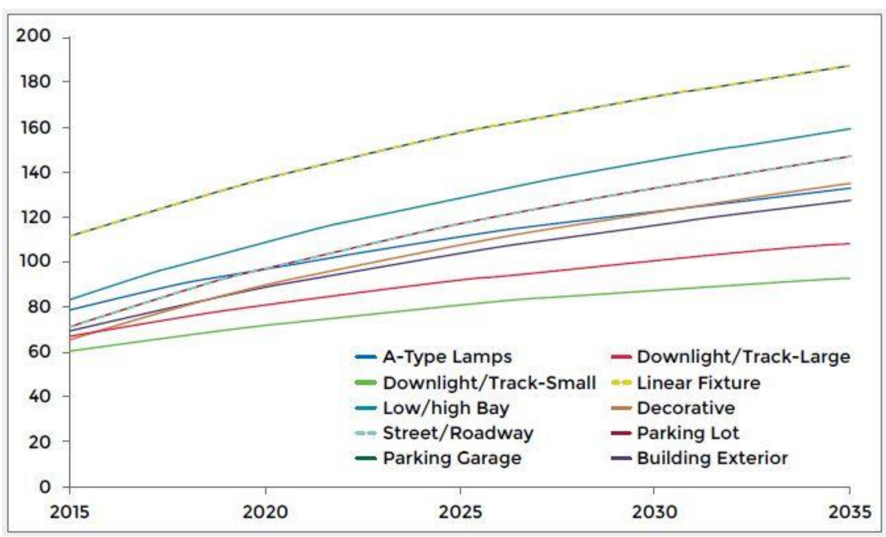


Fig. 20. Market average LED lamp and luminaire efficacy projections

Figure 10 shows average global retail price of a LED and CFL replacement lamp for a 60W incandescent.LED costs fall rapidly, then slow in 2017,reaching near parity with CFLs in 2020.Actual LED pricing in a given country may vary from these levels. They depend on, for example, volume of imports and consumer demand.

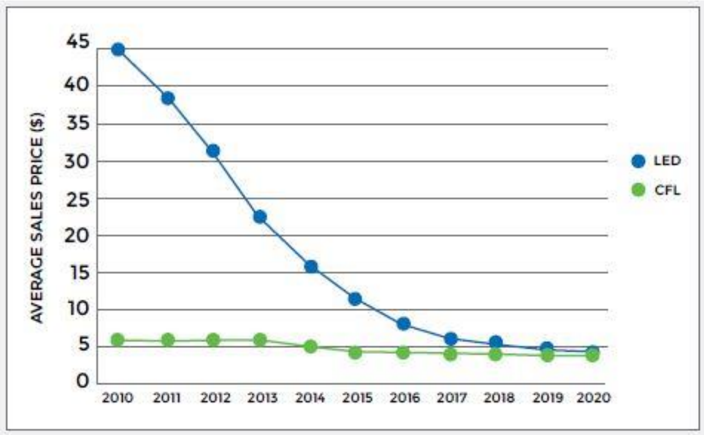


Fig. 21. LED vs. CFL Retail Price for a 60W replacement lamp15

CHARACTERISTIC	MERCURY VAPOUR TYPICAL QUANTITY	HIGH PRESSURE SODIUM QUANTITY	METAL HALIDE TYPICAL QUANTITY
LUMINOUS EFFICACY RANGE (INITIAL)	45 - 55 lm/W	105-125 lm/W	80-100 lm/W
LAMP LIFETIME	20,000 hr	20,000 - 24,000 hr	10,000 - 20,000 hr
COLOUR RENDERING INDEX (RA)	15 - 50	25	65-85
CORRELATED COLOUR TEMPERATURE	3,900 - 5,700 K	2,000 - 2,100 K	4,000 - 5,000 K
DIMMABLE?	If dimmable ballast	If dimmable ballast	If dimmable ballast

Table 12. Light emitting diode (LED) lighting typical performance specification

Advantages of HID lighting:

- Highest efficacy light sources available;
- Lowest running costs;
- Very long operating life – typically more than 20,000 hours;
- High flux in a small package, good for optical control;
- Can offer excellent colour rendering;
- Instant on, instant re-strike, dimmable;
- Contains no mercury

Disadvantages of HID lighting:

- Control gear (driver) required for operation;
- Higher relative first costs (but competition is driving prices down);
- Needs good thermal design because waste heat is conducted, not projected

5.4. Lighting Controls

A combination of a lighting controls system and energy-efficient lamps and luminaires produces the best possible outcome in terms of lighting performance in a building. Lighting controls systems can save a further 20 – 40 per cent of energy consumption for lighting. They constantly monitor use and ambient light levels, and only run lighting when it is needed.

Some of the strategies in use today for lighting controls systems include:

- **Time clocks and photocells (light sensors)**—offering simple, reliable and cost-effective ways of adding the most basic of controls to a lighting system;
- **Occupancy sensors as well as sound and heat-sensing technology**—are used to detect the presence of people and turn the lights off when an illuminated space is unoccupied. These systems incorporate intelligence into the designs to avoid false or too frequent turning off for the light fixtures. Occupancy sensors can gather data to optimise building utilisation;
- **Dimming technologies**—including manual dimming switches and more sophisticated technology that automatically reduces light output according to the availability of daylight or other ambient light. Dimming of some lamps and luminaires (e.g. CFLs, LEDs) can be accomplished, provided the ballast enables dimming;
- **Day lighting sensors**—adjust luminaire light output levels in areas near windows in response to natural outdoor light entering the building. Day lighting controls are available in continuous dimming and stepped reduction of lighting levels;
- The most sophisticated lighting controls systems are characterised by automated lighting management systems, offering centralized computer control of lighting systems;
- Personalized lighting setting, e.g. via mobile apps, to enhance comfort and user experience.

Advantages of lighting controls:

- Improves the overall performance of an energy-efficient lighting system, achieving even greater energy savings;
- Lowers running costs;
- Provides automated performance of systems, does not require constant human interaction (i.e. “set it and forget it”);
- Can gather useful data on performance, usage and even predictive.

Disadvantages of lighting controls:

- Higher first cost in purchase of additional equipment for an installation;
- Higher installation and commissioning costs, due to time to set the controls system correctly;
- To manage the system effectively, may require expert consultants or training of staff;
- Unless owner-occupied, there could be limited incentive for controls.

5.5. Contribution of Daylight

Daylight was the primary source of interior lighting in the pre-industrial world. Daylight was still an integral part of illumination systems well into the industrial age. Early industrial buildings were day lit out of necessity rather than productivity or aesthetic considerations. The introduction of high-performance glazing materials, the advent of controllable industrial lighting, along with an enhanced knowledge of the advantages of daylighting has brought back the popularity of daylighting for industrial buildings. Today we recognize the high-performance attributes of daylighting. Architects and lighting designers are borrowing from yesterday’s designs, while incorporating modern materials, technologies, and ideas to bring daylight into industrial environments. The benefits of these designs include improved productivity, worker health, energy savings, and enhanced aesthetics. In the 1970s and 1980s, three coinciding events led to the boarding up of windows and skylights, and a virtual temporary end to designing industrial buildings with daylighting. These factors were rising fuel prices, improved process

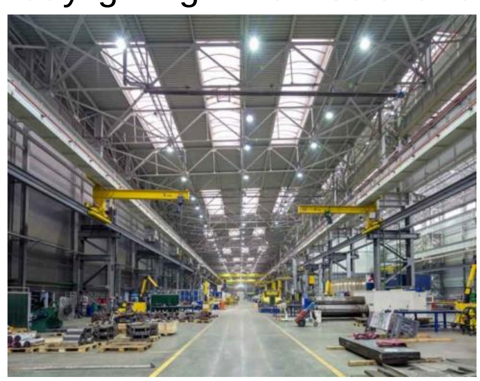


Fig. 22. Daylight in industries

efficiencies, and the advance of fluorescent and high intensity discharge lighting technologies.

Ironically, the concerns over fuel prices that helped shelve daylighting were also a major factor in its return. During the 1970s and early 1980s, Europe, Asia, Australia and the United States experienced an amazing effort to develop practical solar energy systems. Passive solar buildings were at the forefront of this movement, and in an effort to heat space with solar energy, architects began to design commercial and industrial buildings with glazing oriented toward the winter sun. Many existing buildings that had previously had the glazings on all orientations covered over were now having selected areas opened back up to the winter sun. The desire to bring solar energy into the buildings as a source of heat was in advertently reintroducing daylighting.

Advancements in many materials and techniques are meeting these challenges (Heschong Mahone 1999).

- **Improved Glazing Materials.** As one segment of the solar energy industry developed insulating window treatments, the glass manufacturers began developing higher performance glazing. Multiple layers of glass became common, while other developments included Low-E (emissivity) coatings and Low-E membranes installed between glass layers, such as Heat Mirror. Today, there is an amazing selection of high-performance glazing materials available for daylight design. These include materials with a low “U” value, tinted glass for reduced heat gain, materials that offer reflectance of UV and IR rays, and glazing assemblies that include auto-adjusting shading features.
- **Advanced Gasketing for Operable Windows.** Widely recognized as one of the biggest mistakes of modern architecture was the loss of operable windows. Total reliance on mechanical ventilation is not only energy intensive, but also further removes workers from the natural environment.
- **Improved Adjustable Blinds.** Controlling glare is one of the most significant challenges in daylight design. Adjustable blinds have seen many improvements over the last two decades, including new materials and automatic controls that respond to incoming sunlight. For practical reasons however, blinds are typically restricted to “clean” manufacturing areas, as well as office areas, within industrial facilities.

- **Revitalized and New Architectural Design Ideas.** History shows that indirect daylighting was developed over 3,000 years ago. Early daylit industrial building took advantage of indirect sunlight through the use of standard monitors, saw tooth monitors, and clerestories. Although rarely sophisticated designs, these systems typically included the reflecting of at least some of the light off of solid architectural surfaces before it was delivered to the workplace, thus softening the effect and reducing debilitating glare. Better technology has allowed for a resurgence in these old techniques. Today, daylight control techniques also include monitors, clerestories, and skylights. Added to this mix of design approaches are: dedicated vertical visual glass (windows) and dedicated daylight glass (above line of sight), reflective light shelves, redirected beam. daylighting, and movable baffles and louvers (New Buildings Institute 2001, Weidhaas 1981).
- **Longitudinal Monitors.** This design feature is essentially a penthouse that runs the length of the building, straddling the main roofs ridgeline. Typically, vertical glazing covers both sides of the monitor, with some monitors also incorporating skylights. The daylight is introduced above the workers normal line of sight. Morning and afternoon sunlight is usually reflected off of architectural surfaces, further reducing glare.
- **Saw Tooth Monitors.** These rooftop architectural features are shaped like saw teeth, with the vertical planes being glazed to allow daylight to reflect off of the angled opposite surface bringing indirect light into the space.
- **Clerestories.** These are essentially sections of vertical glazing that are incorporated into the design, high on the wall, above the main story that they are illuminating.
- **Skylights.** We are all familiar with skylights, but new designs offer advanced glazings, integral diffusers, reflective wells/shafts, and movable baffles.
- **Dedicated Visual and Daylight Glass.** Window walls are a nice architectural feature in that they introduce both daylight and a visual connection to the outdoor environment. Glare and heat gain/loss are of course problems. Increasingly, architects are distinguishing between visual

and daylighting glass. Asking one window to provide both elements is a difficult, sometimes impossible, task.

- **Reflective Light Shelves.** These architectural features redirect daylight to provide a diffuse indirect source. Interior or exterior light shelves are typically associated with vertical glazing. Often the most effective light shelves direct light upward to be reflected again off of a light-coloured ceiling surface.
- **Redirected Beam Daylighting.** In reality, all indirect forms of daylighting take advantage of redirected beams. However, the term has come to be used to describe systems that do not include visual sight lines to the outdoors. For this reason they are usually used in conjunction with visual glass. Redirected beam systems can be integral architectural site-built features, or can be manufactured products to be site installed. These systems often include a series of reflective surfaces and also may include refractive diffusing lenses in their illumination delivery systems.
- **Movable Baffles and Louvers.** Although sometimes hard to distinguish from shade and blind systems, louvers and baffles are used to control and direct incoming daylight. Some louver/baffle systems are automatically controlled by astronomical time clocks or photo-sensors that track the sun’s path.

There are several cutting-edge daylighting technologies presently in the works, some of which will no doubt have dramatic effects on the way we light buildings. A few of the most interesting concepts are discussed below.

- **Fibre Optic Delivery of Daylight**. Fibre optic cable can deliver light from any source. Typically, projection boxes of 250 watts and up are used to generate the light delivered through the optic cables. A few companies are presently working on fibre optic daylight delivery systems that they hope can efficiently deliver daylight exactly where it is needed. Some type of collector/concentrator device would act as the projection box, and the delivery would be similar to other fibre optic systems. Current fibre optic systems do not deliver the light efficiently, and cannot deliver full spectrum light over great distances.
- **Hybrid Daylight and Electric Lighting Fixtures.** At least one manufacturer is developing hybrid lighting fixtures that combine daylight

and artificial light in the same delivery vehicle. A roof penetration (skylight) delivers natural light to multiple light fixtures containing fluorescent lamps. An internal sensor controls dimmable ballasts within each fixture, reacting to the amount of available light.

- **Light-Bending Glazings**. Several glass manufacturers are working on glazing materials that incorporate elements that actually bend the rays of light. Different versions would be available that could, as an example, direct high angle sunlight back upwards to be bounced off the ceiling, while low angle sun would be reflected back out to reduce heat gain and glare.

5.6. Measures taken

1) **Mandatory Star Rating, Fluorescent Tubes, Bureau of Energy Efficiency, India-** India's energy labelling programme offers significant benefits to consumers, enabling them to reduce their energy bills by providing critical information on energy use at the time of purchase. The Bureau of Energy Efficiency (BEE), Government of India, is working to promote the efficient use of energy and its conservation across India. The number of stars can vary from 1 to 5, with more stars indicating higher energy efficiency and more savings for consumers. The illustration below is the BEE Star Rating Plan for Fluorescent Lamps.

Fig. 23. BEE star rating

BEE STAR RATING PLAN					
STAR RATING	★	★★	★★★	★★★★	★★★★★
Lumens per Watt at 0100 hrs of use	<61	>=61 & <67	>=67 & <86	>=86 & <92	>=92
Lumens per Watt at 2000 hrs of use	<52	>=52 & <57	>=57 & <77	>=77 & <83	>=83
Lumens per Watt at 3500 hrs of use	<49	>=49 & <54	>=54 & <73	>=73 & <78	>=78

Table 13. BEE star rating plan

2) **Energy Star, Department of Energy and Environmental Protection Agency, US-** ENERGY STAR is a US Environmental Protection Agency (EPA) voluntary program helping businesses and individuals save money and protect the planet's climate by promoting highly energy-efficient products.

Fig. 24. BEE star rating

ENERGY STAR was established in 1992, under the authority of the Clean Air Act Section 103(g), which directed the EPA “to develop, evaluate, and demonstrate nonregulatory strategies and technologies for reducing air pollution.” The Energy Policy Act of 2005 amended the statute directing the Department of Energy and the EPA to manage a voluntary program to identify and promote energy– efficient products and buildings in order to reduce energy consumption, improve energy security, and reduce pollution through voluntary labelling. Now in its 23rd year, the ENERGY STAR programme has boosted the adoption of energy-efficient products, practices, and services through valuable partnerships, objective measurement tools, and consumer education.

3) **A Communications Campaign About Efficient Lighting, Zambia-** ZESCO, the utility company serves Zambia, launched a “Switch and Save” campaign urging customers to lower their usage by turning off lights and appliances whenever they are unneeded. The company encourages its clients to save power to ensure they can have enough power for everyone.

4) **I LED the Way—UJALA India Communications Campaign, India-** In India, a communications campaign is being run to help underpin the national work of the Energy Efficiency Services Limited (EESL) promoting LED lighting. The programme uses on-line resources, advertising and other means of outreach to engage the public to participate in this national programme to promote LED lighting. The programme promotes national pride, with the slogan “Join a Movement to Make India Brighter and Smarter!”. The programme focuses on affordability and lowering people’s electricity bills, encouraging them to take advantage of the UJALA (Unnat Jyoti by Affordable LEDs for All) scheme by EESL, which offers LED lighting at lower prices thanks to the programmes robust and large bulk-procurement scheme. The campaign also encourages programme participants to promote the scheme, instructing them to tell others you switched to a smarter lighting solution and say I led the way!

Fig. 25. UJALA India

5) **Regional Efficient Lighting Strategy, Central America-** Central American countries are developing a regional communications programme

tosupport the replacement of incandescent lights in low-income sectors through transitionto efficient lighting. The programme will focus on low-income sectors. It will use print,broadcast, and billboard posters to inform the public about energy-efficient lighting. The broad regional communications strategy is combined with guidelines aligned with each country's particular characteristics.

Fig. 26. Regional Efficient Lighting strategy, Central America

Chapter 6

Case Studies

6.1. G.A. Braun North Syracuse, NY

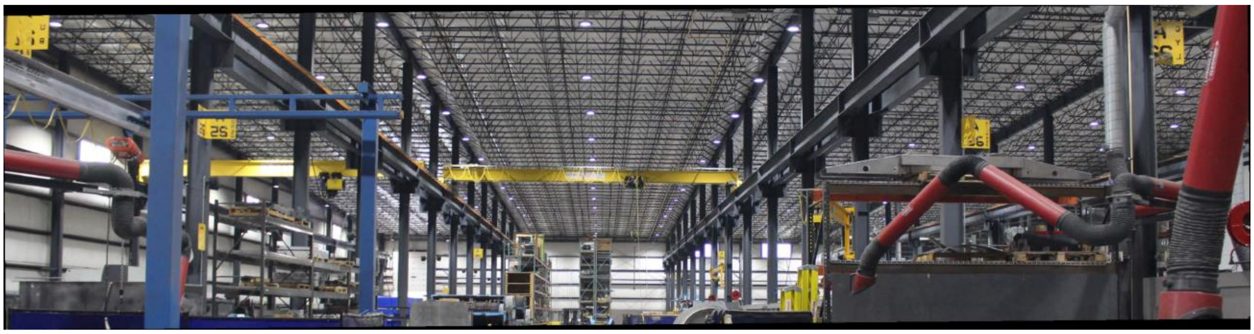


Fig. 27. G.A. Braun workshop

"We'd just switched our existing facility over to T5 fluorescents about 4 years earlier but that was already becoming a problem," David Welsh, director of operations, said, "The T5s were a maintenance nightmare. The bulbs dimmed after the first year, and they were so cheaply made the bulbs would sometimes actually fall right out of the fixture."

Unfortunately, the T5s weren't cheap to maintain. With six bulbs per fixture, plus two starters, the systems were very expensive to replace and repair. Braun was spending about $6,800 a year to change out T5 bulbs, not to mention the storage and disposal of the tubes was also an issue.

As the bulbs dimmed and failed, visibility inside the facility dwindled quickly, which created a quality assurance problem.

As the addition neared completion, Braun installed 9 LED fixtures from 4 different suppliers throughout the facility to test their output and durability, including Dialight's 18K Vigilant High Bay fixtures.

Taking advantage of a $60,000 rebate from NYSERDA for the retrofit project and a $70,000 rebate from National Grid for the new construction, Braun installed 320 retrofit and 276 new construction fixtures, for a total of 596 Dialight 18K Vigilant industrial LED high bays. In the new facility, Braun opted to add Dialight's wireless network controls to operate the lights automatically. This way, if someone forgets to turn the lights off at the end of the shift, they're programmed to go off automatically at a designated time, reducing burn time, energy waste and electricity cost.

In addition to enjoying an outstanding quality of light and better visibility, Braun has also realized a substantial savings beyond the utility rebates. The company is saving $51,000 a year in electricity alone, plus nearly $7,000 in maintenance costs by eliminating the need to constantly replace the T5 bulbs and fixtures. And, they no longer have to worry about lights randomly falling from the ceiling for an added safety bonus.

Installation Snapshot

- Commercial laundry and textile equipment manufacturer – North Syracuse, NY
- Hindered by ineffective and cheap T5 fluorescents
- Replaced 320 T5 fluorescents with Vigilant® High Bays
- Installed a total nearly 600 Dialight LED High Bays in existing 155,000 SQ FT and new 100,000 SQ FT facility
- Saved $6,800 /year on LABOR & MAINTENCE COSTS
- Saved $ 51,000/year in ENERGY COSTS
- Redeemed $130,000 in ENERGY REBATES for installing LEDs

Fig. 28. LED High bay

Fig. 29. G.A. Braun workshop

6.2. North Dakota Mill

Fig. 30. North Dakota Mill

Recently, due to growing demand for its high-quality milled product, North Dakota Mill expanded, adding 75,000 square feet of additional space for cleaning and tempering the wheat, plus a 7-story tall structure to house a new milling unit. Given the complexity of the overhead structures—spouts, stainless steel supply lines and other equipment—production operations manager Chris Lemoine recognized the potential for lighting to be a challenge inside the new facility.

“We had already begun changing out from high-pressure sodium and mercury vapor to LED fixtures throughout the facility, and we knew we needed classified fixtures that would safeguard against the risk of combustion or explosion due to dust inside the facility,” Lemoine said.

Looking for the safest, most efficient, economical and maintenance-free solution possible, Lemoine and the team at Fusion Automation turned to Dialight’s class leading industrial LED lighting fixtures to illuminate the new structure. Working with the team at Fusion Automation, they designed an optimal lighting plan that would accommodate the maze of pipes and other obstacles, with lighting mounted overhead and vertically on the walls, as needed. Not only have the Dialight LED fixtures allowed the team to optimize the lighting placement for maximum light efficacy, but they’ve also provided an outstanding work environment with superior clarity.

In addition to eliminating the hassle and expense of lighting maintenance, the Dialight LEDs make for a much safer environment, enabling workers to clearly spot tripping hazards, overhead fixtures, etc. to safeguard against potential hazards. The high CRI and visual clarity also improves quality assurance. In the event of discoloration, or problems with the “dress” of the flour product, operators can immediately detect the problem, whereas the orange glow of mercury vapor lights made this distinction very difficult to spot.

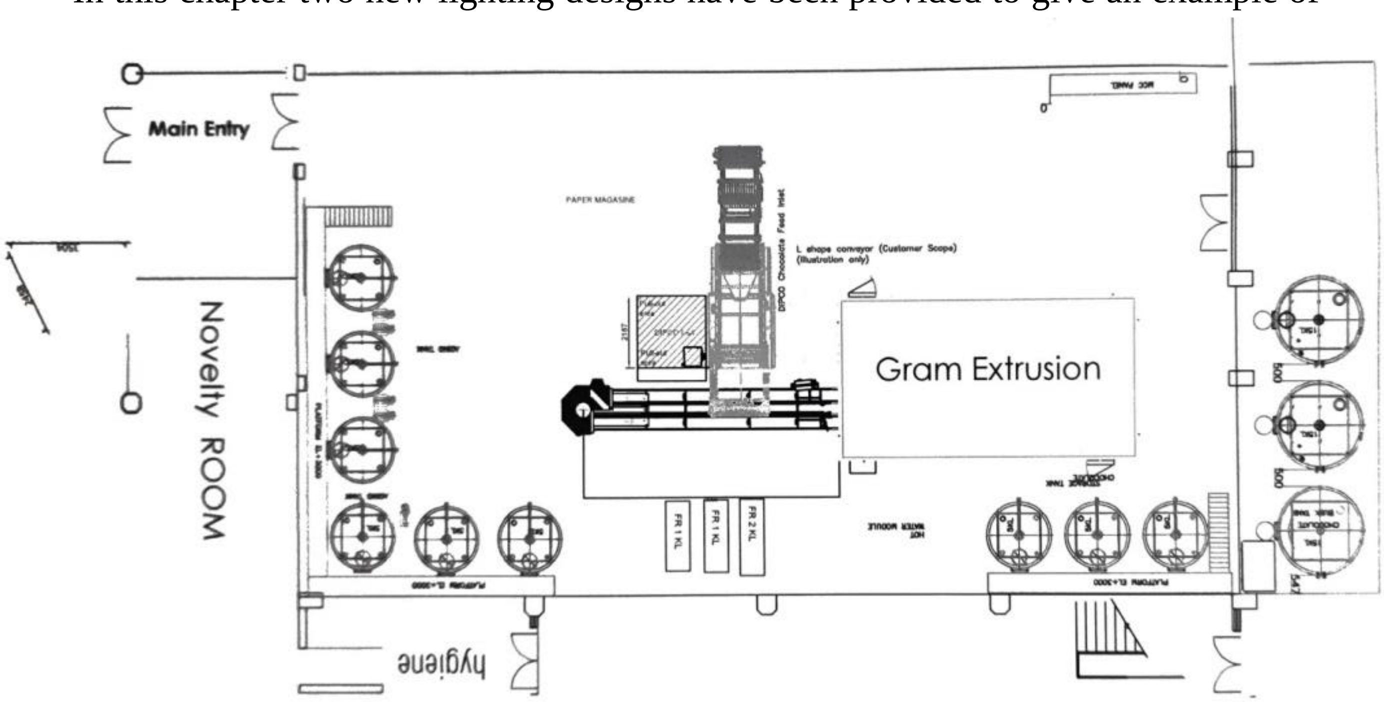
Fig. 31. North Dakota Mill

Chapter 7

Design proposals

7.1. Introduction

In this chapter two new lighting designs have been provided to give an example of



efficient industrial lighting system. Keeping an account of the knowledge provided in the previous chapters, all the parameters and standards have been analyzed and observed. The result gives an idea of how the new technology can change the overall costing and energy conservation statistics.

The two designs provided here are of a goods manufacturing unit in Uttar Pradesh, India and a food factory in Haryana, India.

7.2. Food Factory

1. Plan

Fig. 32. Food Factory plan

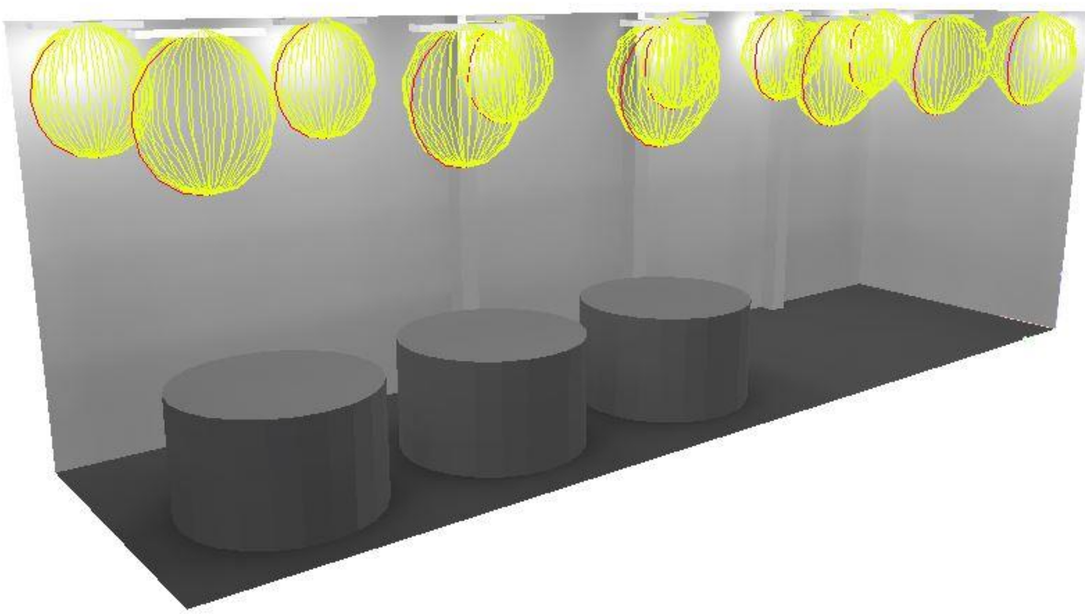


Fig. 33. Food Factory-Chocolate Bulk Tanks

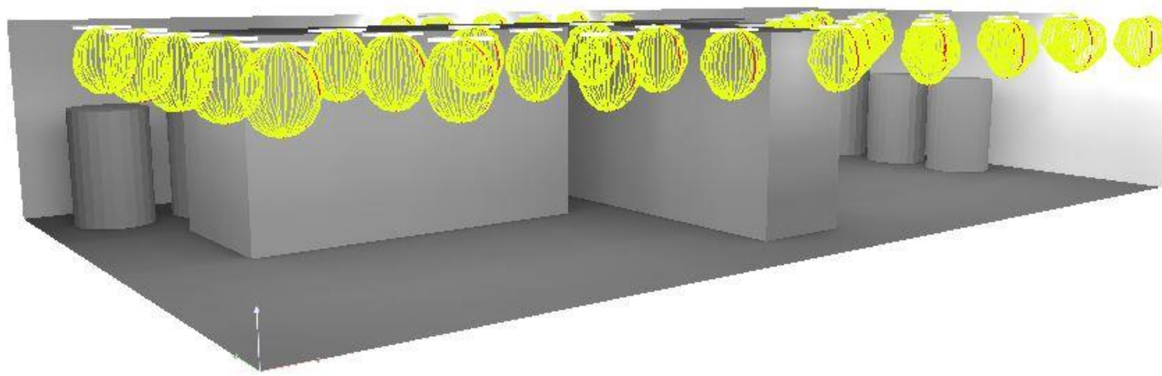


Fig. 34. Food Factory- Hot Water Module

Food Manufacturing Unit:

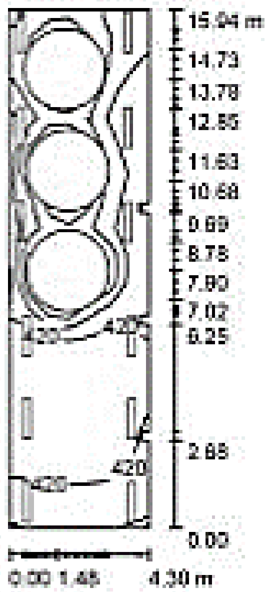
i. Chocolate Bulk Tank Facory
ii. Hot Water Module with Gram Extrusion

2. Existing Designs

Sl. No.	Area	Lux level as per IS 3646-1	Existing Lux level
1	Chocolate Bulk Tank Room	300 lx	392 lx
2	Hot Water Module with Gram Extrusion	300 lx	319 lx

Types of lights used: FTL

3. Design reports



Height of Room: 5.500 m, Mounting Height: 5.500 m, Light loss factor: 0.80

Values in Lux, Scale 1:205

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	392	223	482	0.568
Floor	20	256	24	418	0.093
Ceiling	80	235	140	571	0.595
Walls (16)	50	373	61	3867	/

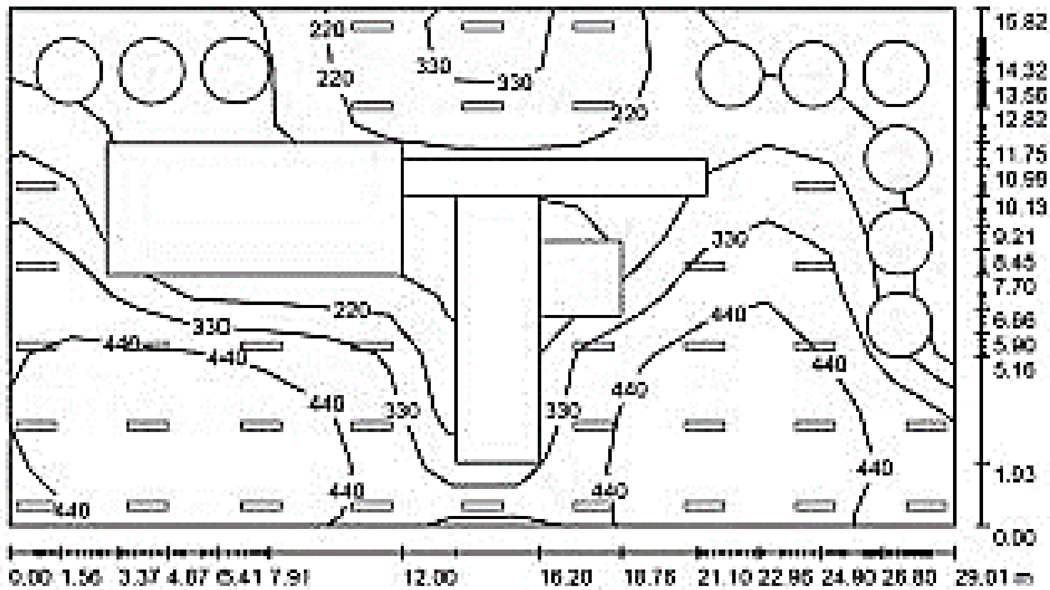
Workplane:
Height: 0.760 m
Grid: 19 x 7 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 1.052, Ceiling / Working Plane: 0.608.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	TECHNICAL CONSUMER PRODUCTS, INC. PC43A332UNIH POWER CAGE MIRO4 INCLUDES WIRE GUARD (1.000)	7215	8850	108.0
			Total: 86576	Total: 106200	1296.0

Specific connected load: 18.98 W/m² = 4.85 W/m²/100 lx (Ground area: 68.27 m²)



Height of Room: 5.200 m, Mounting Height: 5.200 m, Light loss factor: 0.80

Values in Lux, Scale 1:208

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	319	24	530	0.074
Floor	20	228	3.00	478	0.013
Ceiling	80	91	12	531	0.129
Walls (4)	50	229	15	1708	/

Workplane:

Height: 0.760 m
Grid: 15 x 9 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.756, Ceiling / Working Plane: 0.279.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	35	TECHNICAL CONSUMER PRODUCTS, INC. PC43A332UNIH POWER CAGE MIRO4 INCLUDES WIRE GUARD (1.000)	7215	8850	108.0
			Total: 252514	Total: 309750	3780.0

Specific connected load: 8.24 W/m² = 2.58 W/m²/100 lx (Ground area: 458.94 m²)

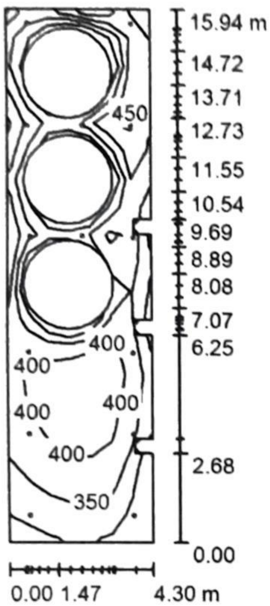
4. Proposed Designs

Sl. No.	Area	Lux level as per IS 3646-1	Existing Lux level	Achieved Lux level
1	Chocolate Bulk Tank Room	300 lx	392 lx	**324 lx**
2	Hot Water Module with Gram Extrusion	300 lx	319 lx	**353 lx**

Types of lights used: LED Midbay light & LED 2"X2" Clean room light

5. Design report

CHOCOLATE BUKL TANK (OUTER) / Summary



Height of Room: 5.500 m, Mounting Height: 5.500 m, Light loss factor: 0.80

Values in Lux, Scale 1:205

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	378	255	495	0.675
Floor	10	226	11	388	0.049
Ceiling	50	121	71	634	0.583
Walls (16)	30	341	62	39789	/

Workplane:

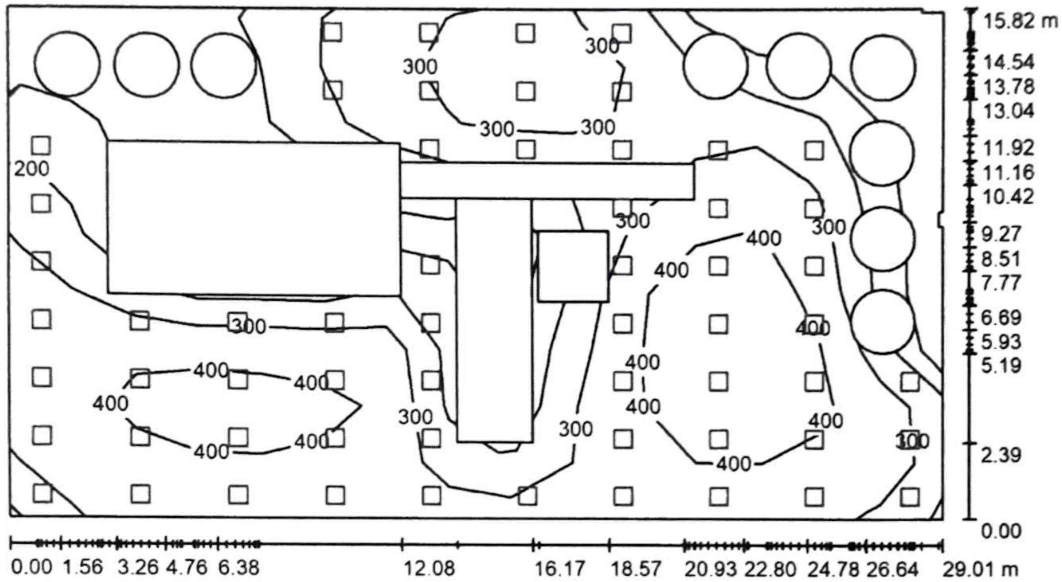
Height:	0.760 m
Grid:	19 x 7 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.999, Ceiling / Working Plane: 0.322.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	15	Wipro Lighting LE09-671-XXX-57-XX (1.000)	7000	7000	55.0
			Total: 104995	Total: 105000	825.0

Specific connected load: 12.18 W/m² = 3.22 W/m²/100 lx (Ground area: 67.75 m²)



Height of Room: 5.200 m, Mounting Height: 5.200 m, Light loss factor: 0.80

Values in Lux, Scale 1:208

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	296	13	474	0.045
Floor	10	210	1.49	437	0.007
Ceiling	50	41	6.61	96	0.163
Walls (10)	30	170	7.97	791	/

Workplane:

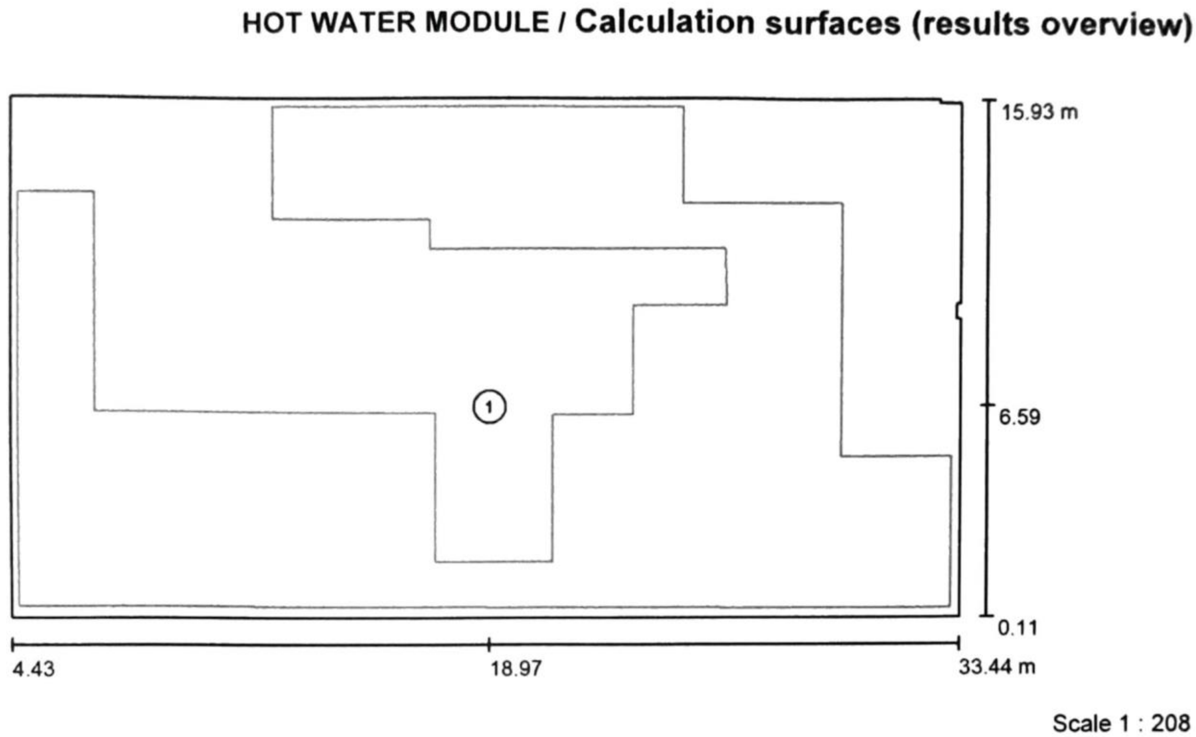
Height:	0.760 m
Grid:	15 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.602, Ceiling / Working Plane: 0.136.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	59	Wipro Lighting LC20-551-XXX-57-G2 Bottom Opening Clean Room Luminaire with LED (1.000)	4200	4200	42.0
			Total: 247821	Total: 247800	2478.0

Specific connected load: 5.40 W/m² = 1.83 W/m²/100 lx (Ground area: 458.69 m²)



Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Calculation Surface 4	perpendicular	64 x 32	353	124	477	0.350	0.259

6. Observations

- The LPDs (Light Power Density) of the existing designs of the industry:

Total power consumption = 5076 W

Total area = 576.44 m²

LPD = 8.81 W/m²

- As per the results of the proposed designs, the observed the LPDs (Light Power Density) of the industry:

Total power consumption = 3303 W

Total area = 576.44 m²

LPD = 5.73 W/ m²

- Total power saved:

(5076 - 3033) W = **2043 W**

7.3. Goods Manufacturing Unit

1. Plan

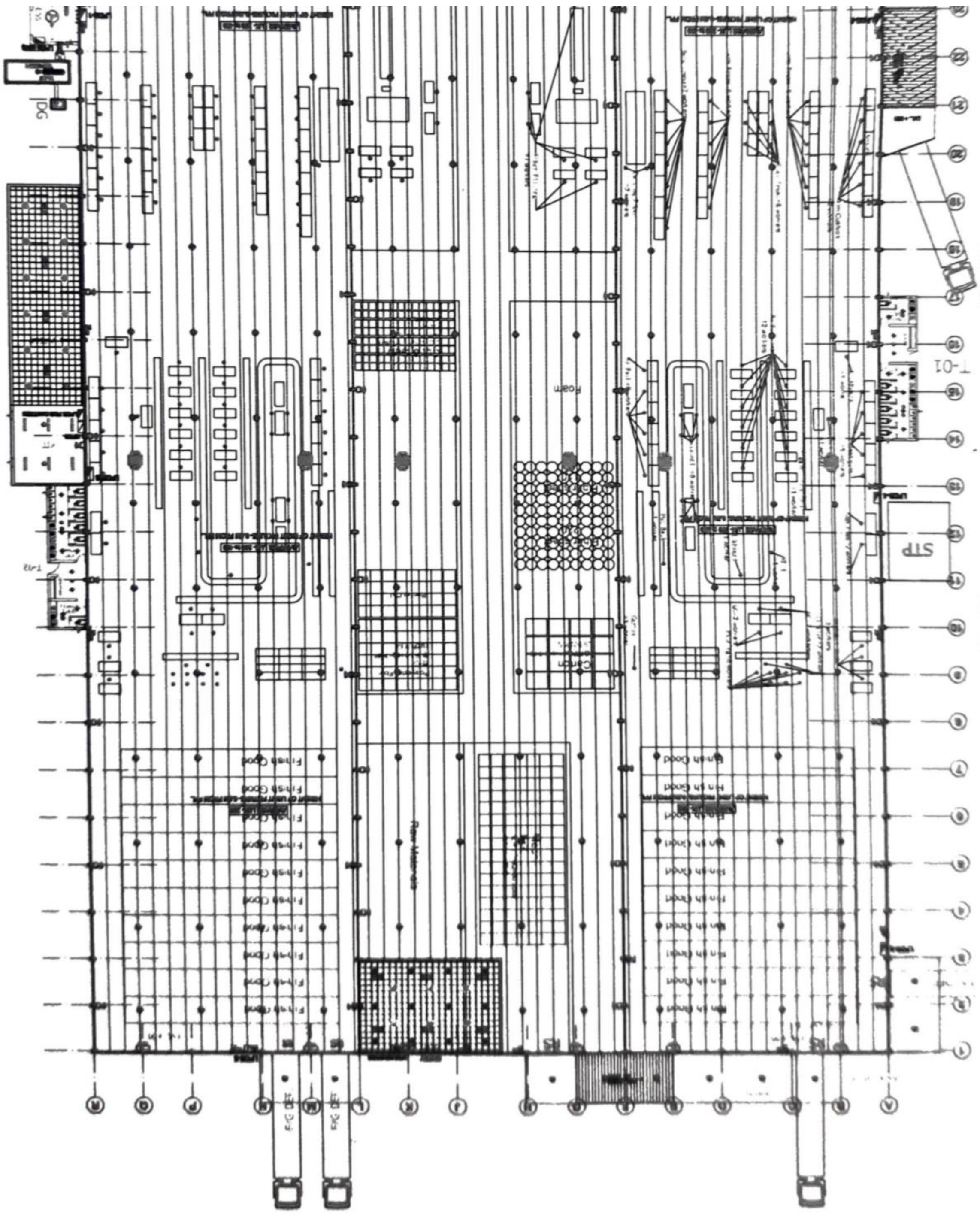


Fig. 35. Goods Manufacturing Unit plan

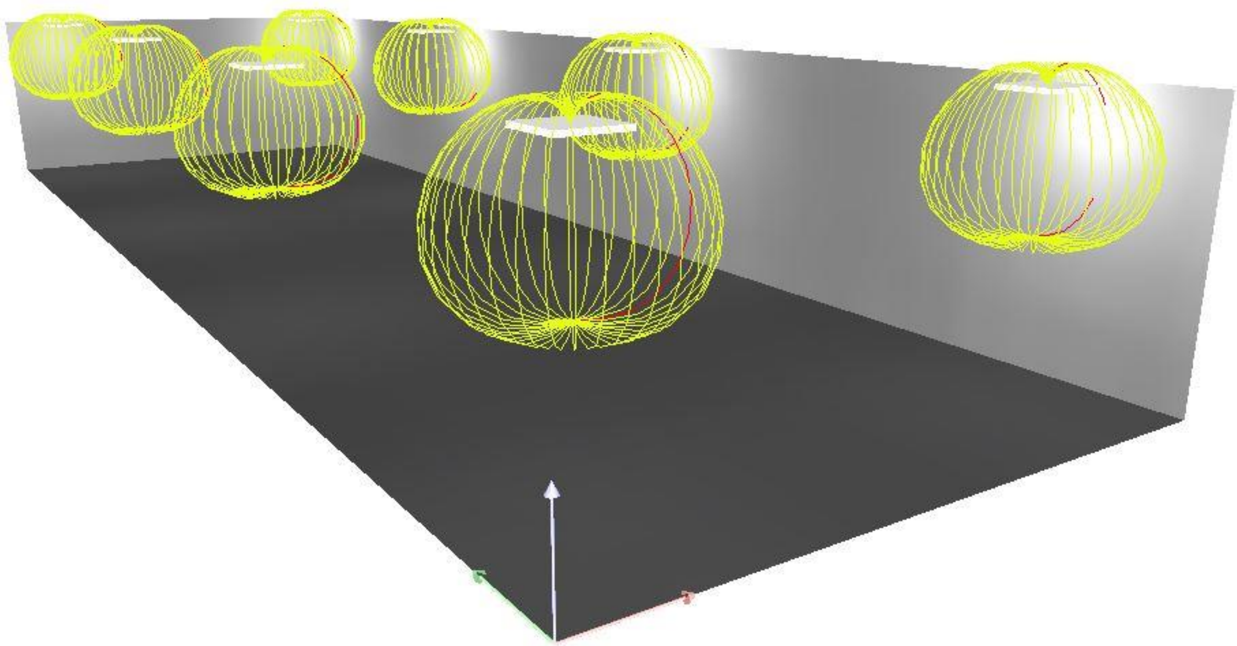


Fig. 36. Goods Manufacturing Unit- Canteen

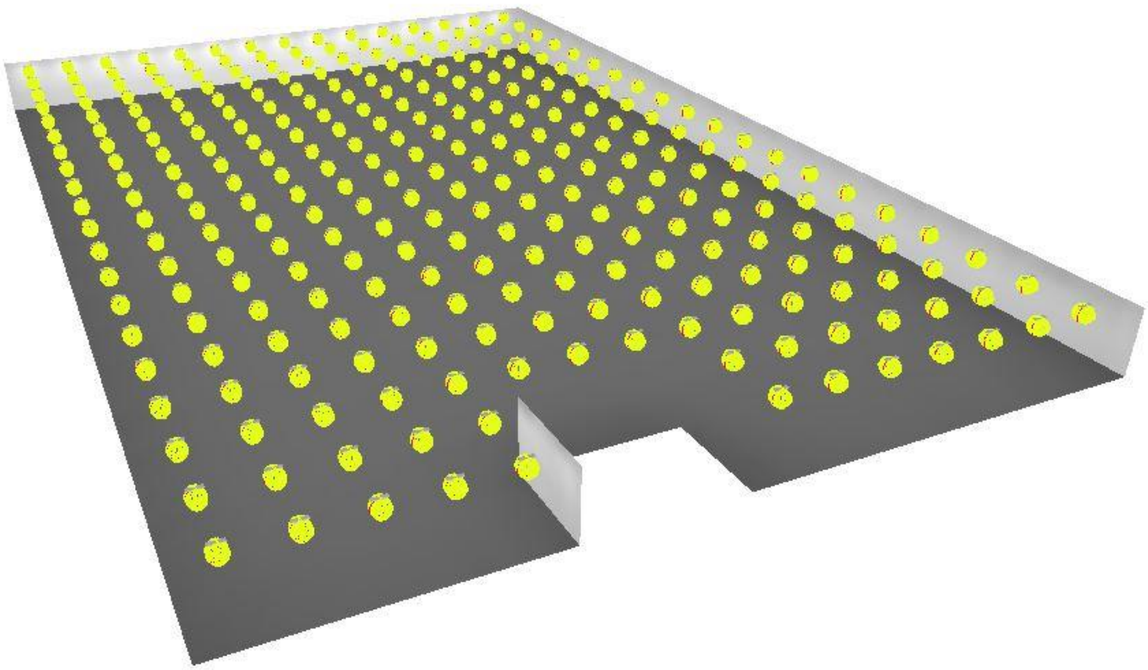


Fig. 37. Goods Manufacturing Unit- Manufacturing and Storage area

Goods factory:

i. Entry/Exit
ii. First Aid Room
iii. Toilets
iv. Potable Water Area
v. Reception
vi. Kitchen
vii. Canteen
viii. LT Panel room
ix. Acomp Room
x. Manufacturing and Storage Area

2. Existing Designs

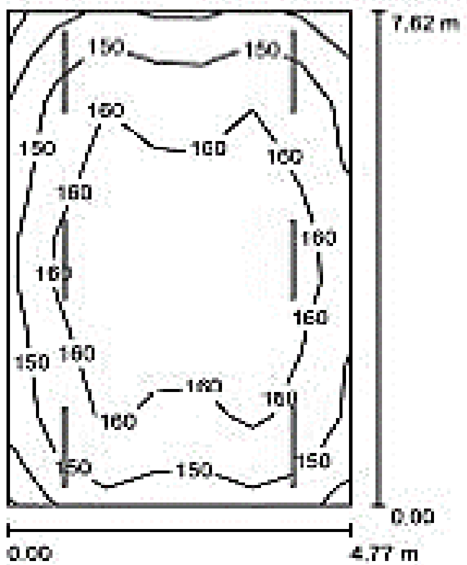
Sl. No.	Area	Lux level as per IS 3646-1	Existing Lux level
3	Entry/Exit	150 lx	141 lx
4	First Aid Room	150 lx	158 lx
5	Toilets	100 lx	96/136 lx
6	Potable Water Area	150 lx	193 lx
7	Reception	200 lx	266 lx
8	Kitchen	200 lx	244 lx
9	Canteen	200 lx	220 lx
10	LT Panel room	150 lx	149 lx
11	Air Compressor Room	100 lx	105 lx
12	Manufacturing and Storage Area	300 lx	262 lx

Table 14. Existing light level

Types of lights used: FTL, HID, Diffused FL

3. Design reports

First Aid / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:56

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	158	129	171	0.817
Floor	20	133	103	148	0.773
Ceiling	80	123	45	2649	0.363
Walls (4)	50	140	70	478	/

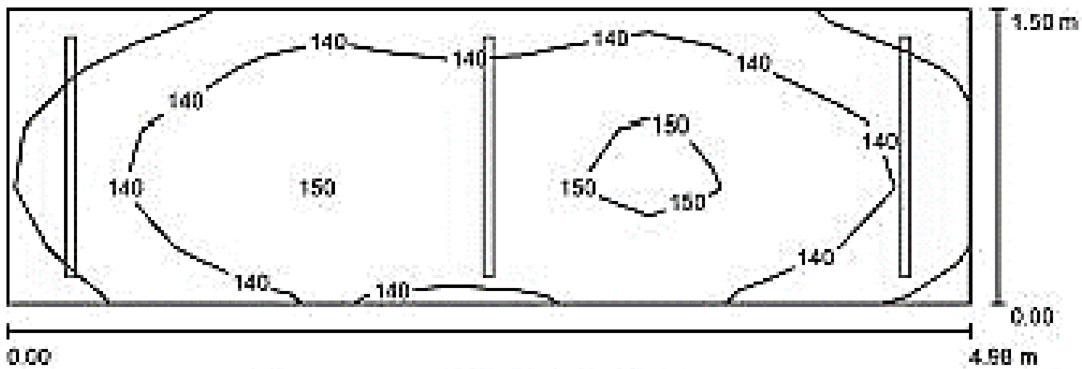
Workplane:
Height: 0.760 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.009, Ceiling / Working Plane: 0.779.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TCPI na (1.000)	2088	2088	26.1
			Total: 12529	Total: 12529	156.6

Specific connected load: 4.31 W/m² = 2.73 W/m²/100 lx (Ground area: 36.35 m²)

Entry / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:36

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	141	123	154	0.867
Floor	20	99	86	107	0.865
Ceiling	80	225	32	2579	0.143
Walls (4)	31	152	33	975	/

Workplane:
Height: 0.760 m
Grid: 15 x 5 Points
Boundary Zone: 0.000 m

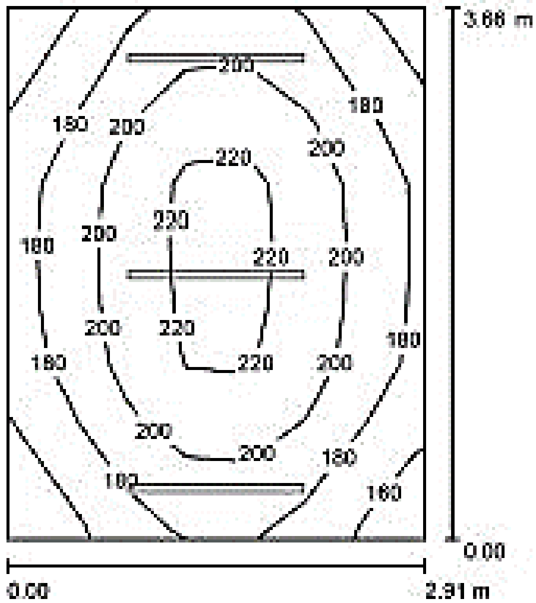
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.290, Ceiling / Working Plane: 1.593.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	TCPI na (1.000)	2088	2088	26.1
			Total: 6264	Total: 6264	78.3

Specific connected load: 10.48 W/m² = 7.41 W/m²/100 lx (Ground area: 7.47 m²)

Drinking Water Area / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:47

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	193	151	226	0.783
Floor	20	147	118	165	0.803
Ceiling	80	204	77	2606	0.376
Walls (4)	50	170	76	894	/

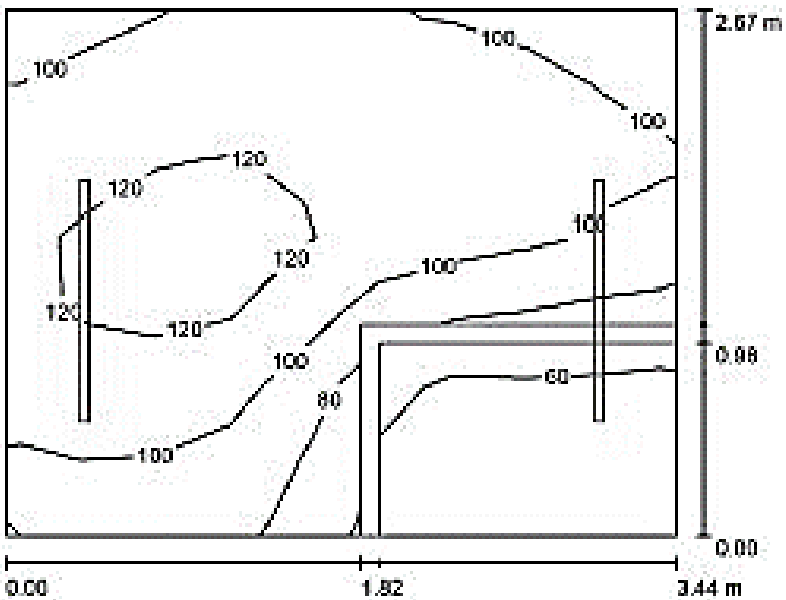
Workplane:
Height: 0.750 m
Grid: 7 x 9 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.999, Ceiling / Working Plane: 1.052.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	TCPl na (1.000)	2088	2088	26.1
			Total: 6264	Total: 6264	78.3

Specific connected load: 7.35 W/m² = 3.81 W/m²/100 lx (Ground area: 10.65 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:35

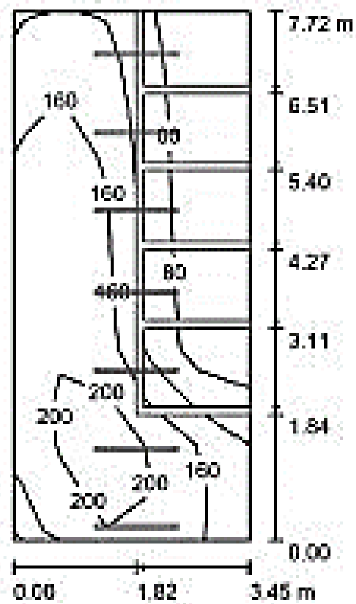
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	96	45	129	0.468
Floor	20	67	19	91	0.288
Ceiling	80	147	44	2685	0.301
Walls (4)	50	106	12	706	/

Workplane:
Height: 0.750 m
Grid: 9 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.290, Ceiling / Working Plane: 1.503.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	TCPI na (1.000)	2088	2088	26.1
			Total: 4176	Total: 4176	52.2

Specific connected load: 5.68 W/m² = 5.94 W/m²/100 lx (Ground area: 9.18 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:100

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	136	54	226	0.393
Floor	20	96	18	167	0.189
Ceiling	80	172	54	2646	0.315
Walls (4)	50	135	12	1582	/

Workplane:
Height: 0.760 m
Grid: 5 x 11 Points
Boundary Zone: 0.000 m

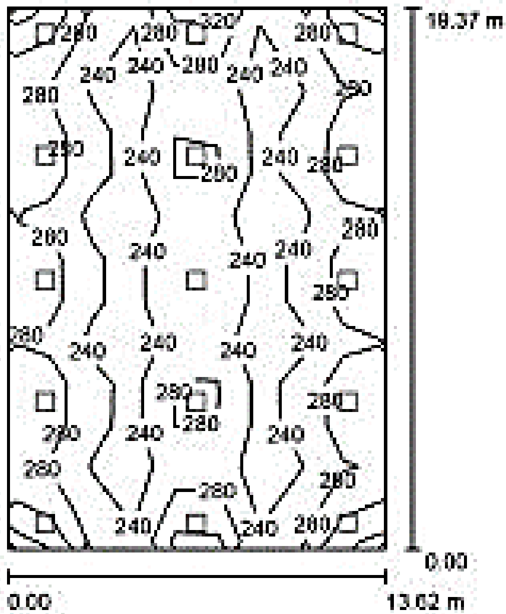
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.123, Ceiling / Working Plane: 1.234.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	7	TCPI na (1.000)	2088	2088	26.1
			Total: 14617	Total: 14617	182.7

Specific connected load: 6.86 W/m² = 5.03 W/m²/100 lx (Ground area: 26.63 m²)

Reception / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:249

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	266	201	360	0.756
Floor	20	246	210	274	0.854
Ceiling	80	152	57	3400	0.374
Walls (4)	50	254	148	872	/

Workplane:
Height: 0.760 m
Grid: 13 x 9 Points
Boundary Zone: 0.000 m

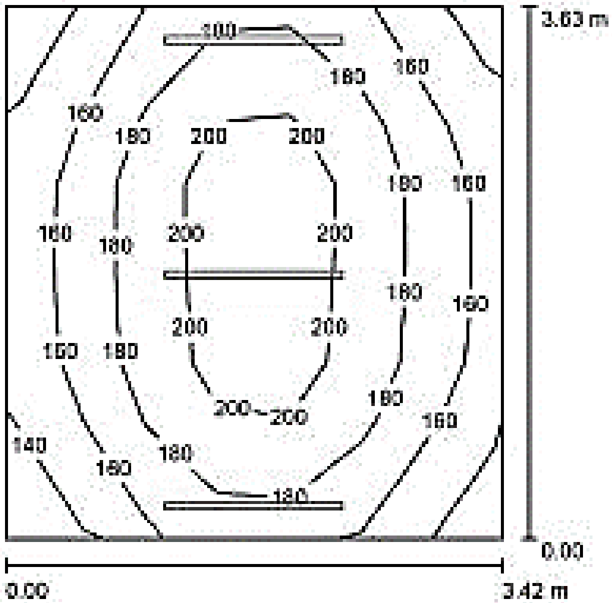
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.059, Ceiling / Working Plane: 0.567.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	15	TCPI na (1.000)	7096	7096	88.7
			Total: 106437	Total: 106437	1330.5

Specific connected load: 5.04 W/m² = 1.90 W/m²/100 lx (Ground area: 263.82 m²)

Drinking Water Area / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:47

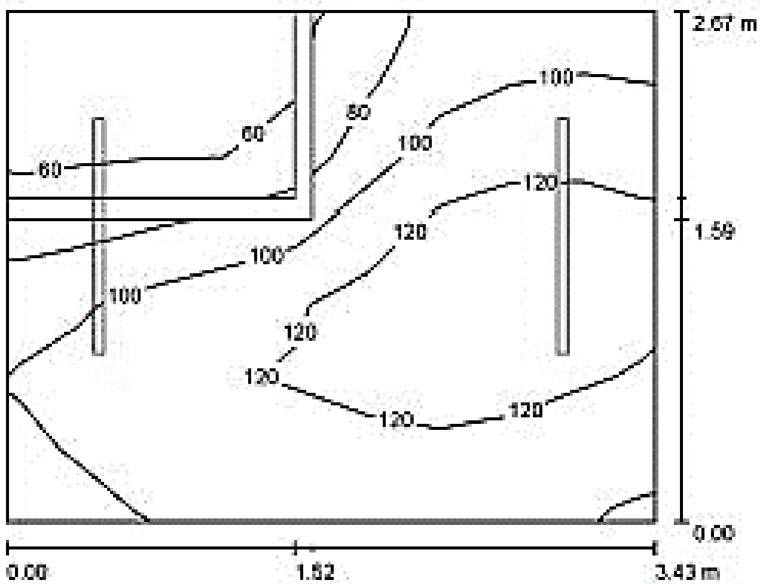
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	176	132	210	0.754
Floor	20	136	109	155	0.800
Ceiling	80	177	59	2289	0.332
Walls (4)	50	153	68	1367	/

Workplane:
  Height: 0.760 m
  Grid: 9 x 7 Points
  Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.971, Ceiling / Working Plane: 1.000.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	TCPI na (1.000)	2088	2088	26.1
			Total: 6264	Total: 6264	78.3

Specific connected load: 6.31 W/m² = 3.59 W/m²/100 lx (Ground area: 12.41 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:35

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	99	47	134	0.474
Floor	20	69	21	94	0.302
Ceiling	80	153	47	2534	0.305
Walls (4)	50	106	11	558	/

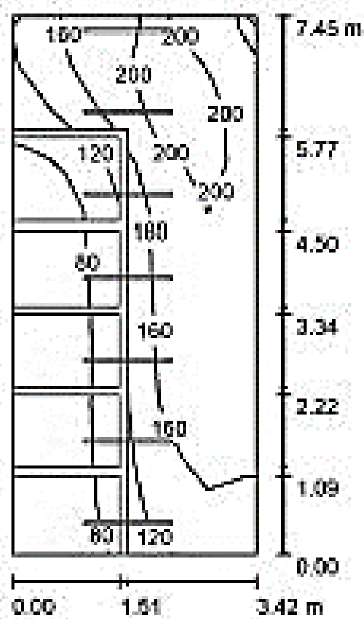
Workplane:
Height: 0.760 m
Grid: 9 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.254, Ceiling / Working Plane: 1.504.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	TCPI na (1.000)	2088	2088	26.1
			Total: 4176	Total: 4176	52.2

Specific connected load: 5.70 W/m² = 5.73 W/m²/100 lx (Ground area: 9.16 m²)

Male Toilet 2 / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:96

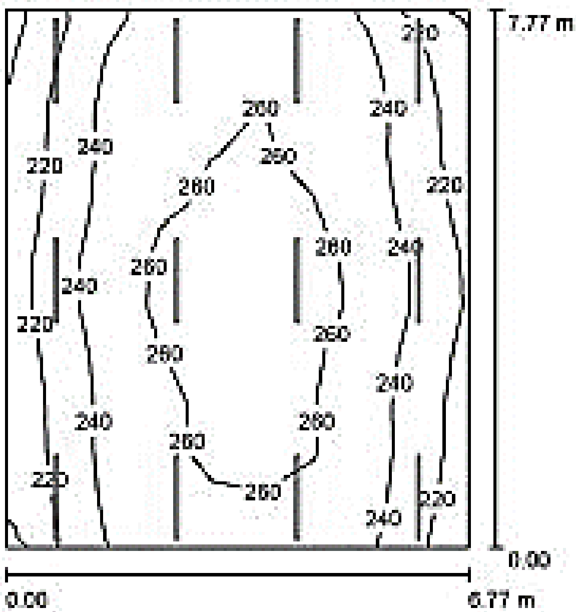
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	130	52	232	0.402
Floor	20	98	20	169	0.206
Ceiling	80	182	55	2795	0.303
Walls (4)	50	141	15	1622	/

Workplane:
Height: 0.760 m
Grid: 5 x 11 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.170, Ceiling / Working Plane: 1.297.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	7	TCPI na (1.000)	2088	2088	26.1
			Total: 14617	Total: 14617	182.7

Specific connected load: 7.17 W/m² = 5.52 W/m²/100 lx (Ground area: 25.48 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80	Values in Lux, Scale 1:100

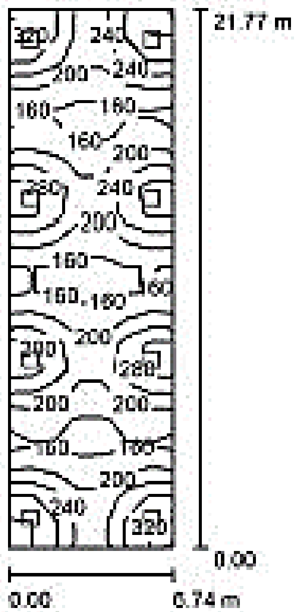
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	244	197	270	0.806
Floor	20	213	173	239	0.813
Ceiling	80	176	66	2658	0.374
Walls (4)	50	214	114	1187	/

Workplane:
Height: 0.760 m
Grid: 11 x 9 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.971, Ceiling / Working Plane: 0.717.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	TCPI na (1.000)	2088	2088	26.1
			Total: 25057	Total: 25057	313.2

Specific connected load: 5.95 W/m² = 2.44 W/m²/100 lx (Ground area: 52.60 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:280

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	220	141	329	0.639
Floor	20	195	152	245	0.776
Ceiling	80	146	49	3456	0.334
Walls (4)	50	216	101	916	/

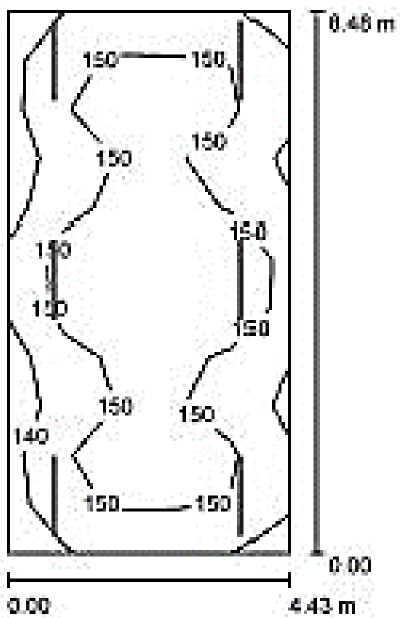
Workplane:
- Height: 0.750 m
- Grid: 21 x 7 Points
- Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 1.136, Ceiling / Working Plane: 0.666.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	8	TCPI na (1.000)	7096	7096	88.7
			Total: 56766	Total: 56766	709.6

Specific connected load: 4.84 W/m² = 2.20 W/m²/100 lx (Ground area: 146.73 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:109

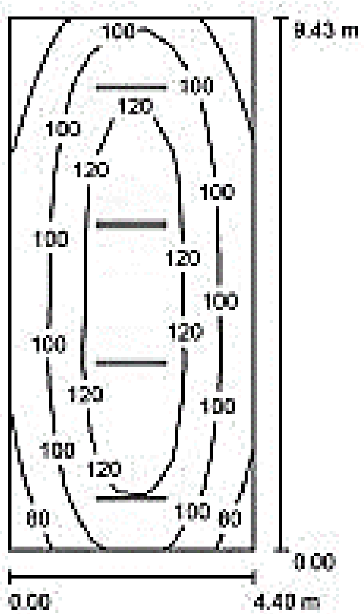
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	149	136	162	0.913
Floor	20	126	104	139	0.825
Ceiling	80	120	42	2645	0.349
Walls (4)	50	136	67	769	/

Workplane:
Height: 0.760 m
Grid: 5 x 11 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.039, Ceiling / Working Plane: 0.796.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	TCPI na (1.000)	2088	2088	26.1
			Total: 12529	Total: 12529	156.6

Specific connected load: 4.17 W/m² = 2.79 W/m²/100 lx (Ground area: 37.57 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:122

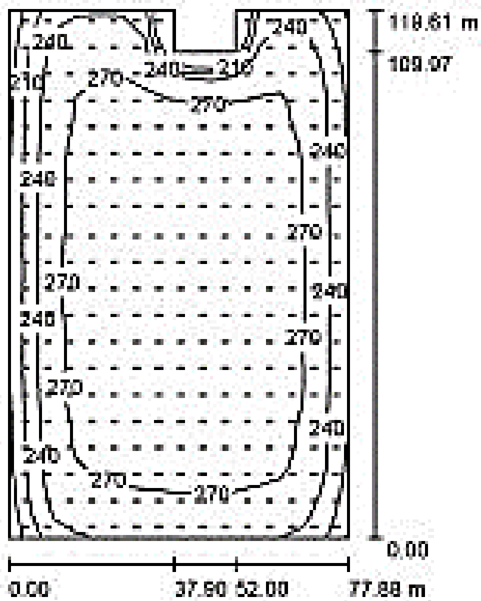
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	105	68	134	0.645
Floor	20	88	60	106	0.678
Ceiling	80	70	28	2609	0.397
Walls (4)	50	76	45	217	/

Workplane:
Height: 0.760 m
Grid: 17 x 9 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.785, Ceiling / Working Plane: 0.666.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	TCP1 na (1.000)	2088	2088	26.1
			Total: 8352	Total: 8352	104.4

Specific connected load: 2.52 W/m² = 2.40 W/m²/100 lx (Ground area: 41.49 m²)



Height of Room: 6.500 m, Mounting Height: 6.500 m, Light loss factor: 0.80

Values in Lux, Scale 1:1536

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	262	177	288	0.677
Floor	20	257	140	287	0.547
Ceiling	80	69	46	515	0.662
Walls (8)	50	163	87	298	/

Workplane:
Height: 0.760 m
Grid: 15 x 23 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.632, Ceiling / Working Plane: 0.273.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	294	TECHNICAL CONSUMER PRODUCTS, INC. PL4WA432UNIH POLAR BAY ENCLOSED & GASKETTED WHITE REFL. 4' 32W T8 4 LAMP HBF (1.000)	9566	11800	147.0
			Total: 2812460	Total: 3469200	43218.0

Specific connected load: 4.71 W/m² = 1.80 W/m²/100 lx (Ground area: 9179.30 m²)

4. Proposed Designs

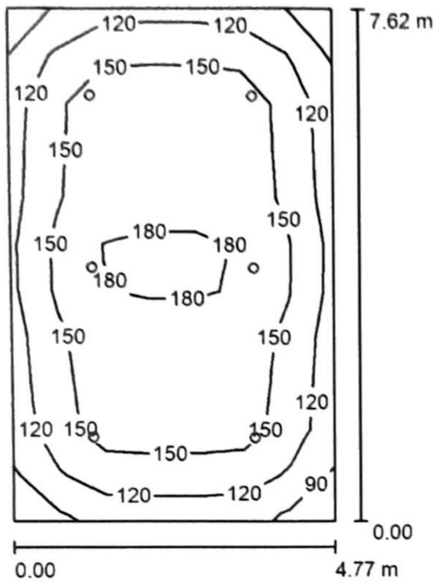
Sl. No.	Area	Lux level as per IS 3646-1	Existing Lux level	Achieved Lux level
3	Entry/Exit	150 lx	141 lx	**156 lx**
4	First Aid Room	150 lx	158 lx	**190 lx**
5	Toilets	100 lx	96/136 lx	**158 lx**
6	Potable Water Area	150 lx	193 lx	**175 lx**
7	Reception	200 lx	266 lx	**223 lx**
8	Kitchen	200 lx	244 lx	**232 lx**
9	Canteen	200 lx	220 lx	**268 lx**
10	LT Panel room	150 lx	149 lx	**153 lx**
11	Air Compressor Room	100 lx	105 lx	**100 lx**
12	Manufacturing and Storage Area	300 lx	262 lx	**340 lx**

Table 15. Proposed light level

Types of lights used: LED Downlights, LED Battens, LED 2”X2” & LED High bays

5. Design Reports

First aid / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:98

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	147	82	190	0.557
Floor	20	125	63	161	0.505
Ceiling	50	20	14	24	0.703
Walls (4)	30	61	14	104	/

Workplane:

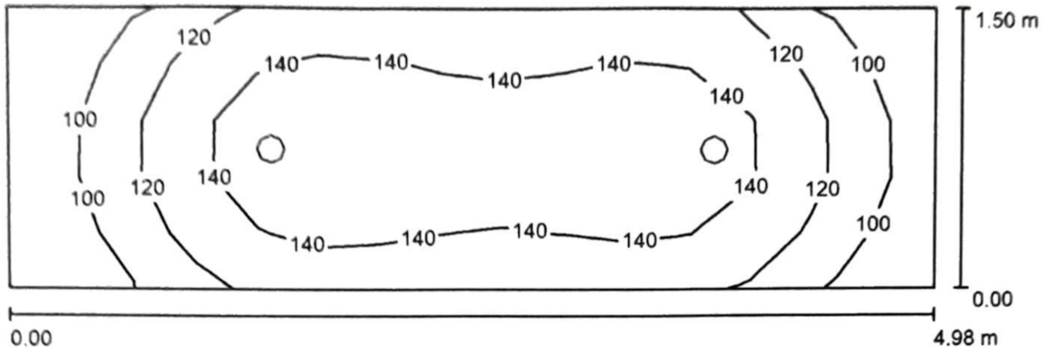
Height: 0.760 m
Grid: 7 x 11 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.412, Ceiling / Working Plane: 0.138.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 9002	Total: 9000	90.0

Specific connected load: 2.48 W/m² = 1.68 W/m²/100 lx (Ground area: 36.35 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:36

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	128	81	156	0.630
Floor	20	91	60	109	0.661
Ceiling	50	20	13	25	0.662
Walls (4)	30	65	14	215	/

Workplane:

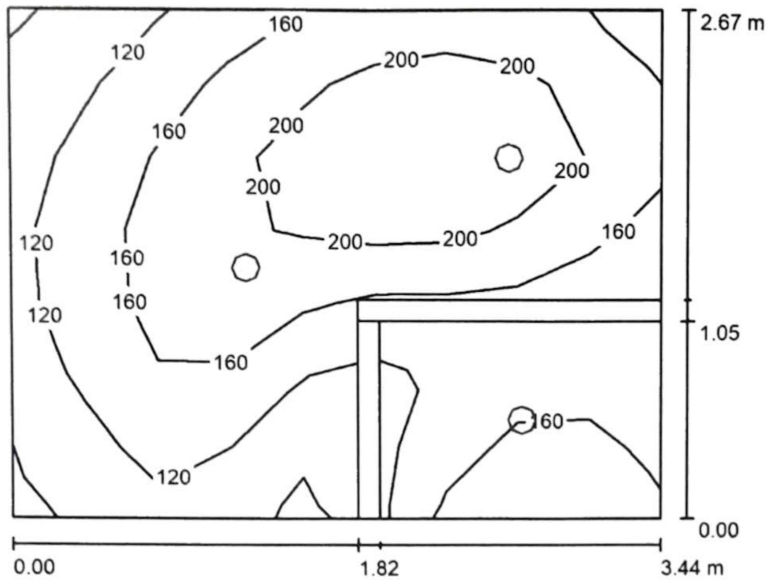
Height: 0.760 m
Grid: 15 x 5 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.580, Ceiling / Working Plane: 0.153.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 3001	Total: 3000	30.0

Specific connected load: 4.02 W/m² = 3.14 W/m²/100 lx (Ground area: 7.47 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:35

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	159	70	238	0.441
Floor	20	102	8.79	160	0.086
Ceiling	50	27	14	38	0.529
Walls (4)	30	86	7.17	381	/

Workplane:

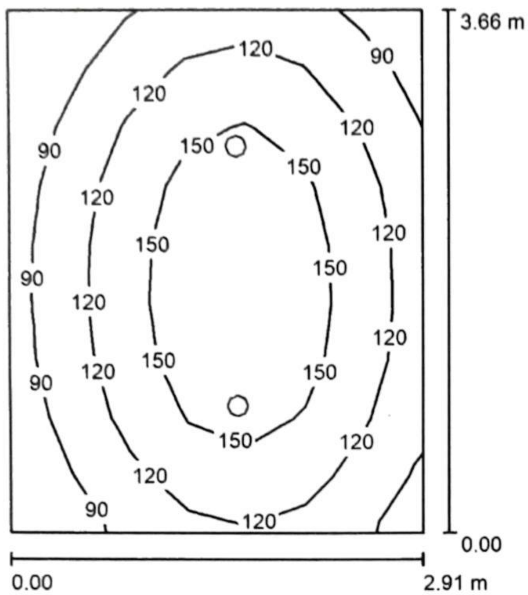
Height:	0.760 m
Grid:	9 x 7 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.604, Ceiling / Working Plane: 0.167.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 4501	Total: 4500	45.0

Specific connected load: 4.90 W/m² = 3.08 W/m²/100 lx (Ground area: 9.18 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:47

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	125	65	175	0.519
Floor	20	94	53	121	0.567
Ceiling	50	16	9.95	19	0.628
Walls (4)	30	55	11	164	/

Workplane:

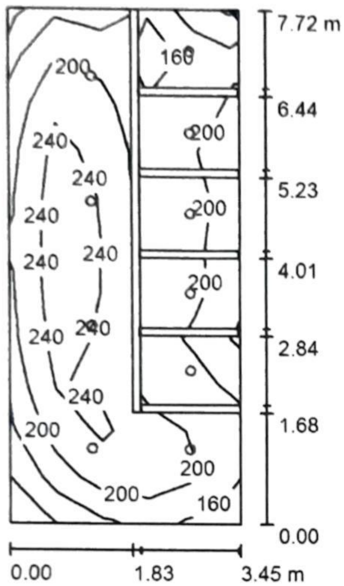
Height: 0.760 m
Grid: 7 x 9 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.454, Ceiling / Working Plane: 0.126.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 3001	Total: 3000	30.0

Specific connected load: 2.82 W/m² = 2.25 W/m²/100 lx (Ground area: 10.65 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:100

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	206	119	296	0.576
Floor	20	125	11	222	0.085
Ceiling	50	36	21	47	0.573
Walls (4)	30	109	15	358	/

Workplane:

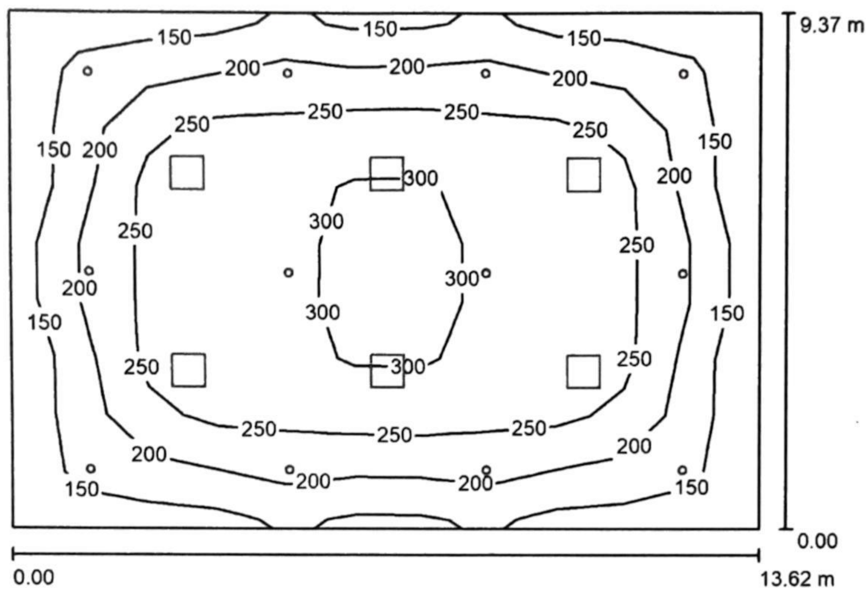
Height:	0.760 m
Grid:	5 x 11 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.592, Ceiling / Working Plane: 0.180.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	10	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 15003	Total: 15000	150.0

Specific connected load: 5.63 W/m² = 2.73 W/m²/100 lx (Ground area: 26.63 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:121

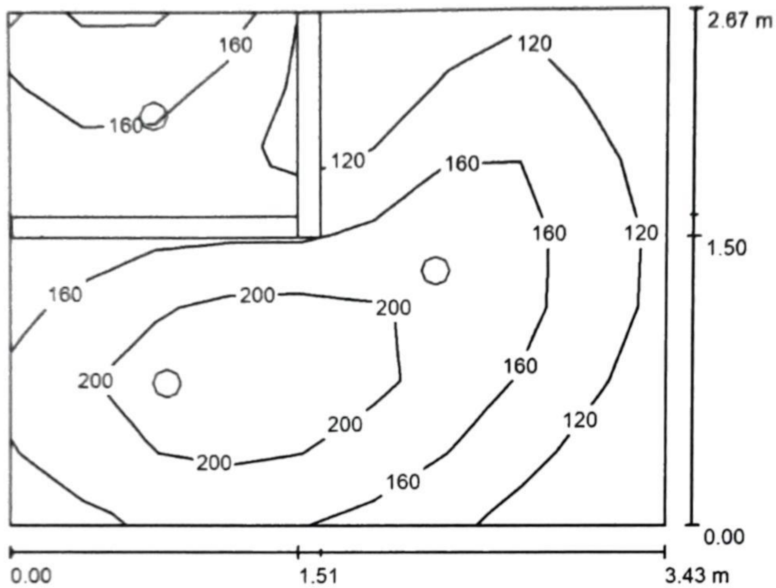
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	223	119	323	0.531
Floor	20	205	82	285	0.403
Ceiling	50	36	22	45	0.614
Walls (4)	30	89	24	157	/

Workplane:
Height: 0.760 m
Grid: 11 x 9 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.380, Ceiling / Working Plane: 0.159.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
2	6	Wipro Lighting CRCO10R038HP57GL1 LED 2X2 Luminaire suitable for Recessed on Grid/POP ceiling (1.000)	3640	3640	36.3
			Total: 39843	Total: 39840	397.6

Specific connected load: 3.12 W/m² = 1.39 W/m²/100 lx (Ground area: 127.62 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:35

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	158	81	235	0.517
Floor	20	101	7.71	154	0.076
Ceiling	50	27	14	42	0.523
Walls (4)	30	86	7.57	460	/

Workplane:

Height: 0.760 m
Grid: 9 x 7 Points
Boundary Zone: 0.000 m

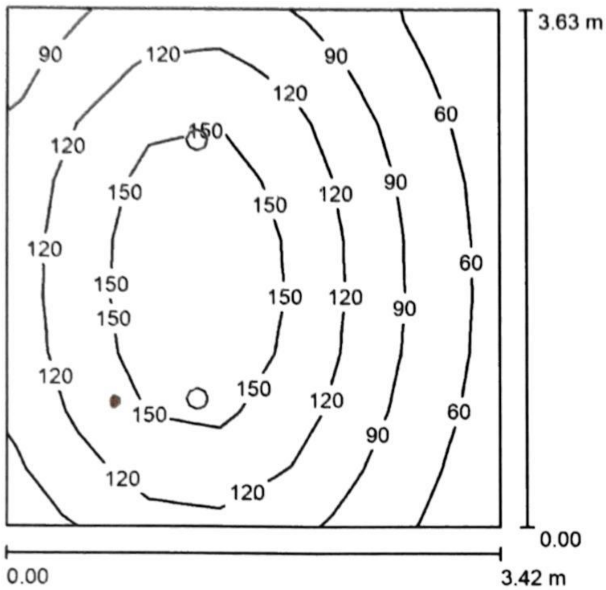
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.613, Ceiling / Working Plane: 0.169.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 4501	Total: 4500	45.0

Specific connected load: 4.93 W/m² = 3.12 W/m²/100 lx (Ground area: 9.13 m²)

Drinking water / Summary



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:47

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	114	45	174	0.395
Floor	20	87	42	119	0.476
Ceiling	50	14	8.51	18	0.591
Walls (4)	30	48	10	166	/

Workplane:

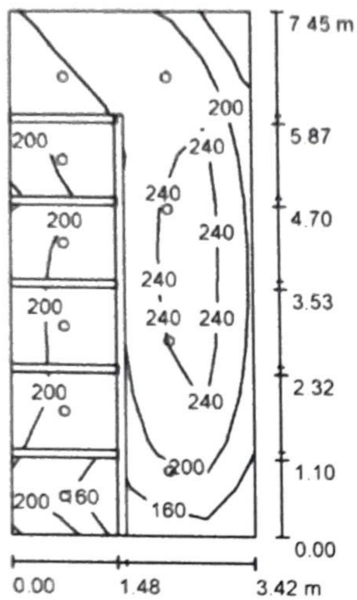
Height:	0.760 m
Grid:	7 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.439, Ceiling / Working Plane: 0.126.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 3001	Total: 3000	30.0

Specific connected load: 2.42 W/m² = 2.12 W/m²/100 lx (Ground area: 12.40 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:96

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	208	121	286	0.583
Floor	20	126	13	222	0.105
Ceiling	50	38	23	49	0.595
Walls (4)	30	115	14	358	/

Workplane:

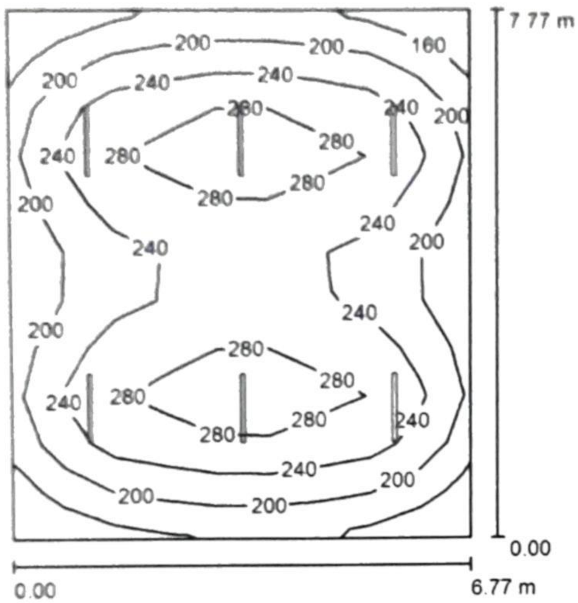
Height: 0.760 m
Grid: 5 x 11 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.618, Ceiling / Working Plane: 0.185.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	10	LD06-171-XXX-57-XX (1.000)	1500	1500	15.0
			Total: 15003	Total: 15000	150.0

Specific connected load: 5.89 W/m² = 2.84 W/m²/100 lx (Ground area: 25.46 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:100

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	232	135	313	0.580
Floor	20	198	113	248	0.572
Ceiling	50	73	36	5110	0.499
Walls (4)	30	144	77	252	/

Workplane:

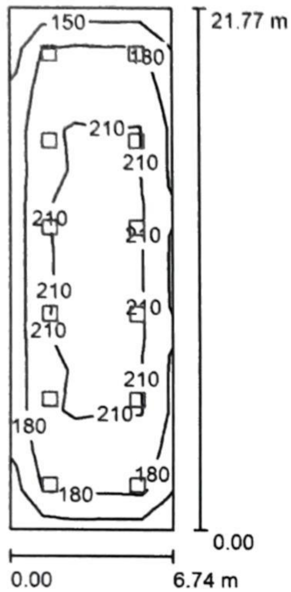
Height	0.760 m
Grid	9 x 11 Points
Boundary Zone	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.658, Ceiling / Working Plane: 0.313.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	WIPRO LIGHTING LE23-491-XXX-57-XX (1.000)	4000	4000	40.0
			Total: 23999	Total: 24000	240.0

Specific connected load: 4.56 W/m² = 1.96 W/m²/100 lx (Ground area: 52.60 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:280

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	199	138	268	0.694
Floor	20	174	82	213	0.470
Ceiling	50	32	23	42	0.711
Walls (4)	30	99	22	174	/

Workplane:

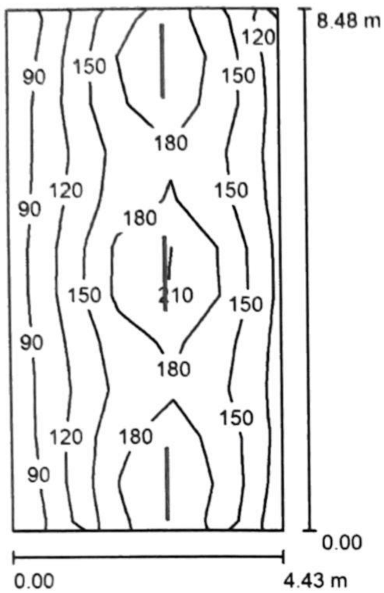
Height:	0.760 m
Grid:	5 x 13 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.494, Ceiling / Working Plane: 0.166.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	12	Wipro Lighting CRCO10R038HP57GL1 LED 2X2 Luminaire suitable for Recessed on Grid/POP ceiling (1.000)	3640	3640	36.3
			Total: 43678	Total: 43680	435.1

Specific connected load: 2.97 W/m² = 1.49 W/m²/100 lx (Ground area: 146.73 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:109

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	153	84	224	0.551
Floor	20	125	72	165	0.578
Ceiling	50	61	21	4759	0.339
Walls (4)	30	100	40	916	/

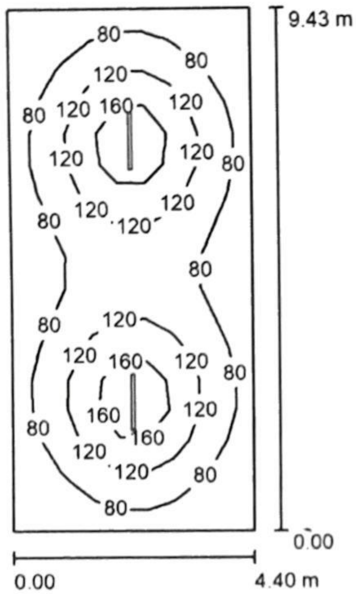
Workplane:		**UGR**	Lengthways-	Across	to luminaire axis
Height:	0.760 m	Left Wall	23	23	
Grid:	11 x 5 Points	Lower Wall	24	26	
Boundary Zone:	0.000 m	(CIE, SHR = 0.25.)			

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.715, Ceiling / Working Plane: 0.400.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	3	Wipro Lighting LL24-541-XXX-57-XX Batten Type LED Luminaire - 4FT LED Batten (1.000)	4399	4400	40.0
			Total: 13196	Total: 13200	120.0

Specific connected load: 3.20 W/m² = 2.10 W/m²/100 lx (Ground area: 37.52 m²)



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:122

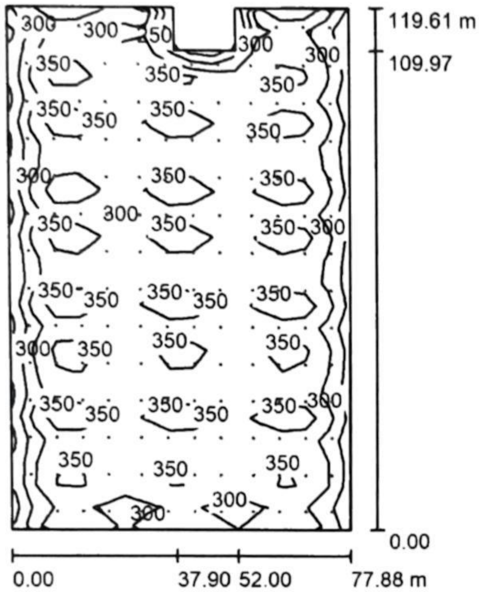
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	99	44	194	0.440
Floor	20	82	41	122	0.496
Ceiling	50	29	12	3128	0.426
Walls (4)	30	52	21	87	/

Workplane:
Height: 0.760 m
Grid: 17 x 9 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.537, Ceiling / Working Plane: 0.287.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	WIPRO LIGHTING LE23-491-XXX-57-XX (1.000)	4000	4000	40.0
			Total: 8000	Total: 8000	80.0

Specific connected load: 1.93 W/m² = 1.94 W/m²/100 lx (Ground area: 41.46 m²)



Height of Room: 6.500 m, Mounting Height: 6.500 m, Light loss factor: 0.80

Values in Lux, Scale 1:1536

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	322	191	423	0.591
Floor	20	317	82	393	0.259
Ceiling	50	59	34	78	0.582
Walls (8)	30	86	30	430	/

Workplane:

Height:	0.850 m
Grid:	23 x 15 Points
Boundary Zone:	0.000 m

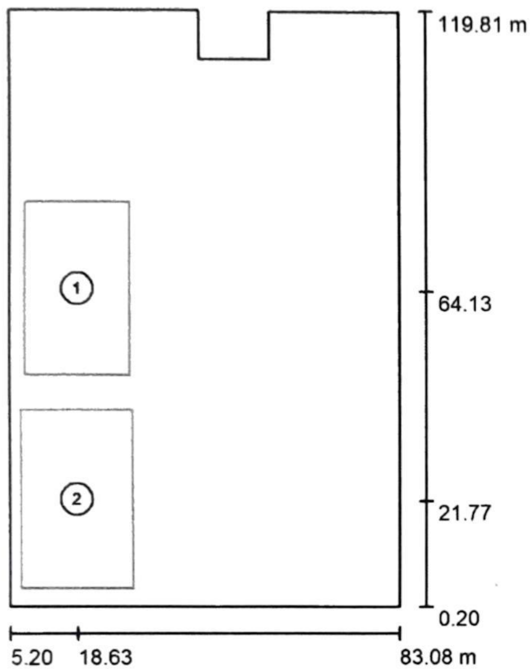
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.245, Ceiling / Working Plane: 0.184.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	166	WIPRO ENTERPRISES (P) LTD LH21-212-090-57-X1 UNO HIGHBAY LIGHT LUMINAIRE (1.000)	20800	20800	160.0
			Total: 3452866	Total: 3452800	26560.0

Specific connected load: 2.90 W/m² = 0.90 W/m²/100 lx (Ground area: 9172.42 m²)

Manufacturing & storage area / Calculation surfaces (results overview)



Scale 1 : 1362

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Production area 1	perpendicular	9 x 15	340	255	429	0.750	0.594
2	Production area 2	perpendicular	7 x 19	340	249	429	0.731	0.579

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	340	249	429	0.73	0.58

6. Observations

- The LPDs (Light Power Density) of the existing designs of the industry:

Total power consumption = 46693.6 W

Total area = 9715.62 m²

LPD = **4.81 W/m²**

In both cases, energy is consumed more than the standard recommendation.

- As per the results of the proposed designs, the observed the LPDs (Light Power Density) of the industry:

Total power consumption = 28402.7 W
Total area = 9715.62 m²

LPD = **2.92 W/m²**

- Total power saved:

(46693.6 - 28402.7) W = **18290.9 W**

7.4. Energy Savings

Overview of observations:

Sl. No.	Factory	Existing LPD (W/m²)	Achieved LPD (W/m²)	LPD as per ECBC (W/m²)
1	Food Factory	8.81	**5.73**	6.00
2	Goods Factory	4.81	**2.92**	6.00

Comparative Observations:

Sl. No.	Factory	Wattages Saved - (a)	Hours/ Year – (b)	Total Power saved - (a)*(b)	Total Units saved per Year
1	Food Factory	2043 W	8760 hrs	17,896,680	**17897**
2	Goods Factory	18290.9 W	8760 hrs	160,228,248	**160228**

Overview

1. Existing designs consisted of conventional lighting systems in both the factories.
2. Just by changing them to LED energy efficient lighting, the power consumption is reduced.
3. Also the illumination level meets the optimum level required and follows the standards.
4. Hence, a total of **17,897 kWh** and **160,228 kWh,** or units, of power is being saved per year for Food factory and Goods manufacturing unit respectively.
5. This, in turn, saves an approximate amount of **1.5 Lakhs** and **13.5 Lakhs** of rupees respectively (considering a commercial rate of Rs. 8.4 per kWh).

Chapter 8

Conclusion

8.1. Scopes of improvement

- **Proper evaluation of input power:** High power industrial lights (anything 100W or above) are prone to power supply failure. Proper drivers are needed to fix the problem, like driver with high power factor, better PWM system etc.
- **LED dimmer functioning:** flickering of light is a major concern over a long time. The PWM dimmer induces flicker in LED lights due to short bursts if electricity. CCR dimmers are preferred in industries for steady supply, which requires more improvement.
- **Low quality lamps and fixtures:** low price for lamps and fixtures do not offer true benefit of quality. Industry owners need to understand the worth of technology within lamps and luminaire manufacturing
- Proper designing: over lighting cause light pollution and low lighting causes accidents and health issues. Appropriate illumination and proper distribution is recommended.

8.2. Conclusion

- Explained the role and need of efficient industrial lighting systems. Efficient industrial lighting reduces energy wastage and light pollution.
- Shown how lighting influences human health and nature in industrial work fields, Issues faced and the solution with modern lighting systems. Explained the mechanisms for the effects of a change of lighting.
- Presented some designs with modern lighting design techniques to show betterment in terms of design, lighting and economy. With the proposed design, it is shown that powers as much as 2043 W and 18290.9 W can be reduced from new lighting designs in the food factory and the goods manufacturing unit respectively.

8.3. Future Avenues of Work

- A great scope of improvement is available in utilization of daylight harvesting, solar energy and renewable sources to reduce energy conservation and go eco-friendly.

Bibliography

i. https://en.wikipedia.org/wiki/Incandescent_light_bulb
ii. https://en.wikipedia.org/wiki/Metal-halide_lamp
iii. https://en.wikipedia.org/wiki/Fluorescent_lamp
iv. https://www.iloencyclopaedia.org/part-xi-36283/mining-and-quarrying/item/605-lighting-in-underground-mines
v. https://www.wsp.com/en-GL/services/lighting-design-for-transport-infrastructure
vi. https://greenbusinesslight.com/case-studies/
vii. https://www.dialight.com/resource/g-a-braun/
viii. https://energyperformancelighting.com/manufacturing-industrial-lighting/
ix. https://apparelresources.com/technology-news/manufacturing-tech/technology-lighting-sewing-floor/
x. https://www.wiprolighting.com/blog/importance-of-lighting-in-transport-infrastructure
xi. https://www.dialight.com/resource/g-a-braun/
xii. https://www.dialight.com/resource/north-dakota-mill/
xiii. Henri Juslen and Ariadne Tenner, 2005. Mechanisms involved in enhancing human performance by changing the lighting in the industrial workspace, International Journal of Industrial Ergonomics 35 (2005) 843-855
xiv. SP 72 (2010): National Lighting Code 2010 [ETD 24: Illumination Engineering and Luminaries]
xv. Lighting Systems for Agricultural Facilities, American Society of agricultural and Biological Engineers, ASAE EP344.3 JAN2005
xvi. IS 6665 (1972): Code of practice for industrial lighting [ETD 24: Illumination Engineering and Luminaries]
xvii. IS 3646-1 (1992): Code of practice for interior illumination, Part 1: General requirements and recommendations for welding interiors [ETD 24: Illumination Engineering and Luminaries]
xviii. Benazeer Hassan K. Ibrahim, June -2017, LED Lighting for Petro-chemical Industries, International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 06
xix. Accelerating the Global Adoption of Energy-Efficient Lighting, UN Environment – Global Environment Facility, United for Efficiency (U4E), 2017. U4EPolicyGuide Series
xx. W. F. Little, E. H. Salter, May 1959, Lighting for the Past 25 Years and the Future
xxi. Bureau of Energy Efficiency, June 2017, Energy Conservation Building Code, FSC© C084365-COC- 003187, Ministry of Power, Government of India
xxii. Bailey, L. Clear, R., Berman, S., 1993. Size as a determinant of reading speed. Journal of the Illuminating Engineering Society 22. 102 117.

xxiii. Baker. T... 1995. Use of circadian lighting system to improve might shift alertness and performance at the USNRC's headquarters operations center. Aus American Nuclear.Society International Topical Meetings, 17 20 September 1995.

xxiv. Begemann. SILA.. van den Beld, GJ.. Tenner. A.D., 1997. Daylight, artificial light and people in an office environment, overview of visual and biological responses, International Journal of Industrial Ergonomics 201, 231 239.

xxv. Biner, P.M.. 1991.Effects of lighting-induced arousal on the magnitude of goal valence. Personality and Social Psychology Bulletin 17-12), 219 226.

xxvi. Bitterli. F. 1955. Lacht und arbeit Bulletin SchweizerischerElektrotechnischerVerein 46 (12). 559-563.

xxvii. BloggsX.. Draper, SW. 1996. http: www.psy.gla.aeuksteve XXXX html (accessed 5.07.2002).

xxviii. Boyce. PR. 2003, Lighting research for interiors; the beginningof the end or the end of the beginning. Proceedings 25th CIEsession. San Diego, 2003, vol. 1. pp. 34-42.

xxix. Boyce. P.R.. Berman. S.M.. Collins. B.L.. Lewis. A.L, Rea. MS. 1999, Lighting and Human Performance: A Review Washington, DC. Lighting Equipment Division, National Electrical Musalacturers Association.

xxx. Boyce, P.R. Beckstead. JW... Eklund, N.H. Strobel. R.W.Bea. M.S. 1997. Lighting the Graveyard shift: the influenceof a daylight-simulating skylight on the task performanceand mood of night-shift workers. Lighting Research andTechnology 29 (3) 105 134.

xxxi. Boyden. S. 1971, Biological determinants of optimal health. In: Vorster, DJ.M. (Ed.). The Human Biology of Environ mental Change Proceedings of a Conference held in Blantyre Malawi, 5-12 April 1971. International Biology Program, London.

xxxii. Brainard, G.C, Bernecker, CA, 1995. The effects of light on human physiology and behaviour. Proceedings CIE Session. New Delhi, 1995.

xxxiii. Brainard. GC. Hanifin, J.P.. Byrne, B. Glickaman, G. Gerner. E. Rollag, M.D., 2001. Action spectrum formelatonin regulation in humans: evidence for a novelcircadian photoreceptor. The Journal in Neuroscience 21(16), 6405 6412.

xxxiv. Buchanan, T.L.. Barker, K.N.. Gibson, J.T. Jiang, B.C.. Pearson, R.E., 1991. Illumination and errors in dispensing. American Journal of Hospital and Pharmacy 48, 2137-2145.

xxxv. Cajochen, C., Zeitzer, J.M., Creisler, C.A.. Dijk. DJ, 1999.Dose response relationship for light intensity and alertness and its ocular and EEG Correlates of human alertness Sleep Research Online 2 (Suppl. 1), 517.

xxxvi. Carlton. B. 1980 Industrial lighting must be tailored to real life working conditions. Electrical Times, issue 4562 (14 March) (1980).

xxxvii. Coch, L. French, J.PR. 1948. Overcoming resistance to change. Human Relations 1, 512 532 Crouch. CL. 1967. Working and living in a luminous environment, Transactions of the Illuminating Engineering Society 12 (1), 41-53.

xxxviii. Caisler, CA., Allan, J.S., Kronauer, R.E... Dulfy. J.F., 1988. Strong circadian phase resetting in man is effected by bright light suppression of circadian amplitude Sleep Research 17, 367.

xxxix. Daurat. A.. Aguirre, A.. Foret. J. Gonnet. P. Keromes, A.. Benoit, O. 1993. Bright light affects alertness and performance rhythms during a 24-h constant routine. Physiology and Behaviour 53, 929-936.

xl. Dawson. D.. Encel, N. Linhington. K. 1995. Improving adaptation to simulated night shift: timed exposure to bright light versus daytime melatonin administration. Sleep 18 (1) 11 21.

xli. Dinges. D. Kribbs, N.B. 1991. Performing while sleepy: effects of experimentally-induced sleepiness. In: Monk. T. (Ed.), Sleep, Sleepiness and Performance. Wiley, Chichester UK.

xlii. Eklund. N.. Boyce. R. Simpson. S.N.. 2001. Lighting and sustained performance modeling data-entry task performance. Journal of the Illuminating Engineering Society 30 (2), 126 141.

xliii. Escuyer. S., Fontoynont, M., 2001. Lighting controls; a field study of office workers reactions. Lighting Research and Technology 33 (2), 77-96

xliv. Fontoynoot. M.. 2002. At daytime performance and well being. Proceedings. Symposium Healthy Lighting 20 November. 2002. Eindhoven.

xlv. Gifford. R.. 1988. Light, decor, arousal, comfort, and communication. Journal of Environmental Psychology 8, 177-189.

xlvi. Gifford. R., Hinc. D. Veitch. J., 1997. Meta-analysis for environment-behaviour and design research. illuminated with a study of lighting level effects on office task performance. In: Moore. G.T. Marans. R.W. (Eds.). Advances in Environment, Behaviour, and Design, vol. 4. Plenum Press. New York, pp. 223-253.

xlvii. Goldstern. N., Putaoky, F., 1931. Die wirtschaftliche Beleuchtung von Wchstuhlen, neuearbeitstechnische Untersuchun gen. Licht und Lampe 22, 5-9 25-28.

xlviii. Grünberger, J. Linzmayer, L. Dietzel. M., Saletu, B., 1993. The effect of biologically active light on the noo- and thymopsyche on psychophysiological variables in healthy volunteers International Journal of Psychophysiology 15. 27 37

xlix. Hackman, J.R. Oldham, G.R.. 1976 Motivation through the design of work: test and theory. Organizational Behaviour and Human Performance 16, 250-279.

l. Härmä, M., 1995. Sleepiness and shiftwork: individual differences. Journal of Sleep Research 4 (Suppl. 2). 37 61.

li. Iaffaldano. M.R. Muchinsky. P.M.. 1985. Joh satisfaction and jah performance: a meta-analysis, Psychological Bulletin 97. 251-273

lii. Isen, A. Baron, R. 1991. Positive affect as a factor in organizational hehavior. In: Cummings, LI, Stow, R.M. (Eds.) Research in Organizational Behavior, vol. 13. p. 1-54

liii. Jewelt M. Kronauer, R.E. Creisler. C.A 1994. Phase amplitude resetting of the human circadian pacemaker via bright light: a further analysis. Journal of Biological Rhythms 9, 295 314.

liv. Judge. T. Parker. S.. Colbert. A. Heller, D. Ilies, R., 2001. Job satisfaction: a cross-cultural review. In: Anderson, N... Ones. D.S., Sinangil. ILK., Viswesvaran, C. (Eds.). Hand book of Industrial. Work & Organizational Psychology, vol. 2. Sage Publications Ltd, London.

lv. Judge. T.A.. Thoresen, CJ. Bono, J.E. Patton, G.K.. 2001b. The job satisfaction-job performance relationship, a quantitative and quantitative review. Psychological Bulletin 127. 376 407.