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Design of illumination system in an opencast coal mine – a case study

In large opencast mines, mining activities are needed to be performed overnight to meet production requirements. Hence, there is requirement of design of adequate and effective illumination systems at different workplaces in opencast mines in order to maintain high safety standards and quality of product. This paper presents design of illumination systems at different work places for an opencast coal mine with conventional and LED lighting. It also includes the comparative cost analysis of illumination systems with conventional and LED lightings based on annual power consumption. Illumination survey was conducted in a mechanized opencast coal mine-A and results obtained are also presented in this paper. The results showed 7.5% decrease in anual energy consumption by adopting illumination system with LED lightings over the conventional lightings. It was observed that the proposed illuminaton system design with LED lights consumed 27 MW less power per year and had better efficiency. Adopting LED based illumination system also reduces maintenance cost as it has long life and requires less maintenance and gives better light uniformity in the working areas.

Keywords: *Illumination survey, illuminance, coal mine, LED*

1. Introduction

Adequate lighting is very crucial for safety and production as it affects significantly efficiency and health of the individuals working in the mine. In many studies, if a task is performed in low or poor lighting condition, it may lead to strain and physical illness in an individual. Increase in production demand and increased mechanization in mining sector demands that lighting at work places should be adequate to reduce frequency of accidents, minimize human error. Good lighting at workplaces encourages enhanced visual performance, reduces accidents and human error, improved visual communication and tasks etc. Therefore, to achieve standards of illumination, a scientific approach needs to be followed. The basic motive of illumination design process is to identify visual needs of miners and meeting the standards set by concerned regulatory bodies at different workplaces of the mine. Hence, a suitable illumination system must be designed accounting these factors.

Martel and Sammarco (2017) performed a study on luminance measurement in an underground coal mine and conducted laboratory experiments and field testings at four rib locations to quantify various sources of variance in luminance measurement (measurement distance, angle offset of photometer, texture of rib, wetness of coal etc). Study result showed that there was –42.9% change in luminance when coal rib was wetted and 76% change when photometer perpendicularity was offset by 5^{o}. Study showed that field measurement of luminance is impractical as it is affected by various factors which are hard to control in the mine.

Tripathy and Chowdhury (2014) carried out illumination survey at different work places in Kusumnda OCP, SECL and data collected were analyzed. The results were found mostly 10 inadequate in most of the work places. Hence, new illumination system of that mine was designed by using DIALux software that complied with DGMS standards.

Lakshmipathy et al. (2014) carried out studies on design and development of optimum lighting parameters for haul roads in surface coal mines using MATLAB software programme. They made an attempt to develop a programme that gave a real time survey data of illumination in mines. The programme was developed on the MATLAB platform. The programme showed real time lux data, 3-D charts, 3-D graph, 2-D plot and source comparison table. The programme also read out the height of the mounting as well. They reported that the pole height may be varied from 12 to 16 meters for haul roads of around 12 meters width and emphasized that the lamp selection is made mainly based on efficacy and suitability to each situation. For long life and efficient penetration in dusty and foggy environment, it was observed that the high pressure sodium vapour lamps were giving very good performance in surface coal mine lighting. It was further stated that the energy efficient design has a tremendous impact on cost. However, final decision on lighting system to be installed should be based on total cost, that must include

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the initial cost of the installation as well as its operating and maintenance cost.

Pal et al. (2012) proposed design system of haul roads lighting for an opencast coal mine using green energy. A prototype board was also constructed and it showed fairly constant lumen output over varying input voltages.

Aruna and Jaralikar (2012) designed a lighting system for both mineral and overburden benches based on the minimum acceptable reflected light and the reflected uniformity ratio. The design was attempted with five different types of luminaires mounting at five different heights. Design of wet surface conditions ensured the minimum light level even under worst condition of surface reflectivity with marginal increase in cost.

By adopting new and energy-efficient technologies and introducing procurement practices that promote the purchase of these technologies, large energy and cost savings can be achieved. Considering the variable power quality conditions, selection of lamps that operate over a wide range of power parameters would significantly reduce the replacement costs of the lamps by reducing the failure rate, although it may entail a high initial investment cost. Further, good lighting can enhance visibility and safety, and helps to reduce consumption of electricity and reduction in costs, so as to free up resources for other pressing needs, thereby contributing to the improvement of the overall quality of life. The most important element of the illumination system is the light source that transforms electrical energy or power (in watts), into visible electromagnetic radiation or light (lumens). The rate of converting electrical energy into visible light is called “luminous efficacy” and is measured in lumens per watt. It is the principal determinant of the visual quality, cost and energy efficiency aspects of the illumination system (NYCGP, 2009).

Karmakar et al. (2005) developed a computer model for design and economic analysis of lighting system in an opencast mine. In this case the study revealed that one major issue in order to achieve all the required lighting standards was mounting heights. With low-wattage high pressure mercury vapour lamps, the pole height was kept lowered to achieve the necessary lighting standards.

Mayton (1991) performed an illumination study on mining operations in different surface mines and quaries in different regions of United States using visual task evaluation method, which was used by the CIE and the IES. In this study, Mayton found that illumination level was varied for different mines for the same task and equipment and suggested that illumination level and visibility can be improved by proper aiming of luminaires on dozers and loaders.

Cost of installation and maintenance of illumination system contributes significantly in operating cost of mining. Therefore, it is very important to design an illumination system with lower power consumption and low maintenance cost along with providing better lighting in the mine. Illumination system should be designed in the way that it consumes minimum electricity along with providing good illuminance level, better uniformity ratio etc.

2. Brief description of mine-A

Mine-A is located in the north-western part of the Ib valley in the State of Odisha (India). It has floor area of 279.52 ha and annual capacity of 13.0 MT/year. The map of mine is given in Fig.1

Fig.1 Satelite view of mine – a (Google maps)

3. Illumination survey in mine-A

Illumination survey was conducted in mine-A using Extech HD450 Luxmeter. Data was collected from illumination survey at Haul Road 1, Haul Road 2, OB Dump Yard, OB Face, working places of HEMM, Operator’s Cabin of machineries working in mine, Coal Dump Yard, Coal Face, Pumping Station, Manual Working Zone. Results of illumination survey is given in the Table 1.

4. Design of illumination system

Based on illumination requirements at different workplaces in the mine, appropriate illumination designs were developed for different workplaces. From the survey data, it was found that present illumination system is not adequate; hence, a new system of illumination was designed for places in the mine where illumination levels were inadequate. The illumination system was designed with both conventional and LED lights for energy efficiency analysis of illumination system. The design of illumination systems was performed with the help of DIALux evo 8.2. Virtual Philips luminaires (HPSV and LED) of different power and luminous flux were used for illumination design.

4.1 Design of illumination system with conventional luminaires [9]

4.1.1 Haul road illumination design

An illumination design model was simulated for haul road with length and width of 1 km and 20 m respectively with dual

Table 1: Illumination survey in Mine-A [9]

Location of illumination survey	Minimum Illuminance standards by DGMS (in lux)		Illuminance level (average) (in lux)		Remarks
	Horizontal	Vertical	Horizontal	Vertical	
Haul Road 1	10	-	11.03	-	Satisfactory
Haul Road 2	10	-	1.48	-	Unsatisfactory
OB dump yard	15	25	1.4 (At 30m distance)	3.0 (At 30m distance)	Unsatisfactory
OB face	15	25	9.27 (At 30m distance)	12.13 (At 30m distance)	Unsatisfactory
Coal dump yard	15	25	0.4 (At 30m distance)	0.7 (At 30m distance)	Unsatisfactory
Coal face	15	25	4	6	Unsatisfactory
Manual working zone	10	-	16	-	Satisfactory
Pumping station	40	-	21	-	Unsatisfactory
Work place of HEMM	15	25	Satisfactory		
Operators cabin of machineries	50 (At all places)		Satisfactory in all HEMM (Except in dozer)		

row offset pole arrangement, 15m pole height, 1.5m overhang, 1.5m boom length and 169W Philips HPSV lamp. Luminaire specifications and results of model are depicted in Tables 2 and 3 respectively. From simulation, lux value grid and Isolux diagram were produced and depicted in Figs.2 and 3 respectively.

Table 2: Luminaire specifications

Make and type Model	Philips (HPSV)SGS102 FG 1×SON-TPP150W TP P3X
Luminous efficiency	103.6 lm/W
Lamp wattage	169 W
Luminous flux	17500 lm

Table 3: Results of illumination system model

Parameter	Value
Illuminance level, E_m	11.5 lux
Uniformity ratio, U_o	0.66
Optimum pole spacing	40 m
No. of poles required	49
Power requirement	8281 W

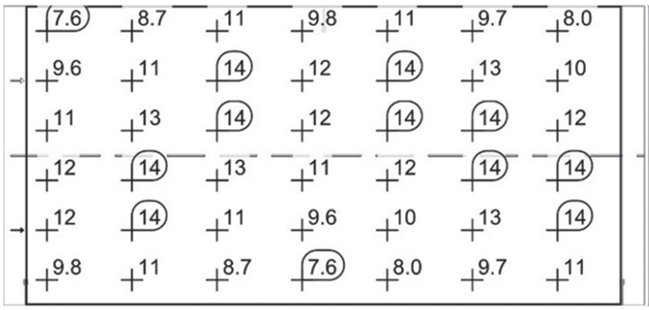


Fig.2 Lux value grid

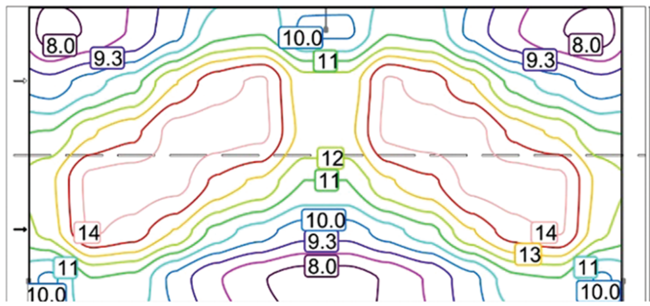


Fig.3 Isolux diagram

4.1.2 *OB dump yard illumination design*

Approximate area of OB dump yard was 150 m × 300 m. As per illumination requirement of mine, illumination design model for OB dump yard was simulated. Total of 48 luminaires (each at 50° angle) used on 14 different poles (each with height of 25 m) at different positions on OB dump yard where, 4 luminaires on a pole in half circular manner at edges of dump yard and 2 luminaires on a pole at each corner. Layout of poles in OB dump yard are depicted in Fig.4. Luminaire specifications are given in Table 4. 3D CAD model for the illumination design of dump yard is given in Fig.5. Isolux diagram and false colour diagram were produced from simulation and depicted in Figs.6 and 7 respectively.

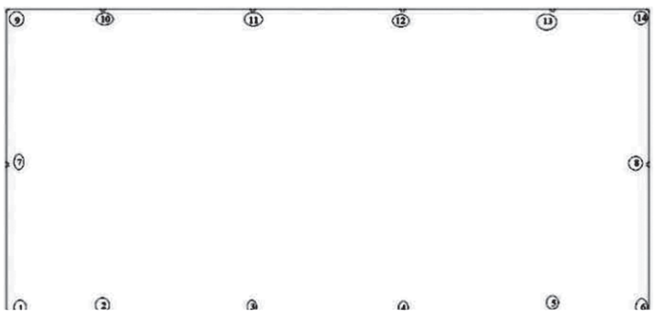


Fig.4 Layout of poles in illumination design of OB dump yard

4.1.3 *Pump station illumination design*

Water pump was placed on a platform of 5m × 5m in the mine. Height of pump house assumed to be 5m for design

Table 4: Luminaire specifications

Make and type	Philips (HPSV)
Model	MVP506 1×SON-TPP400W A25-WB
Power	433 W
Luminous flux	56500 lm
Luminous efficacy	130.45 lm/W

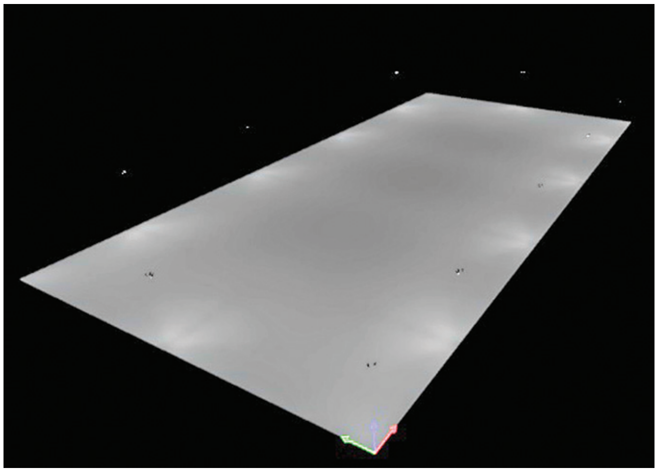


Fig.5 3D CAD model of illumination design of OB dump yard

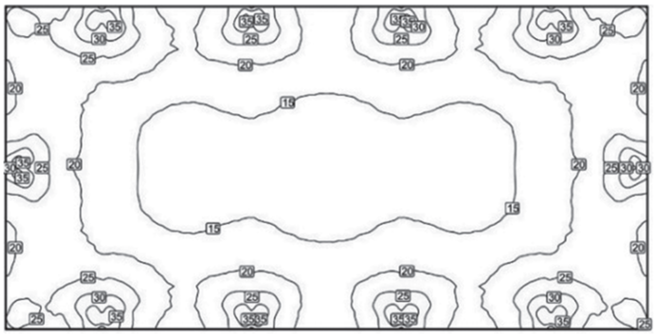


Fig.6. Isolux diagram

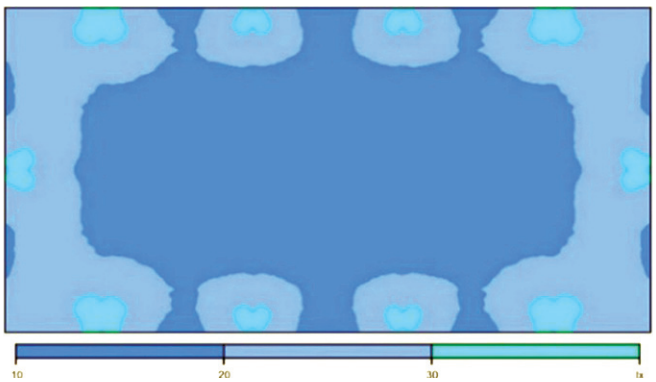


Fig.7 False color diagram

purpose. To get appropriate illuminance level at pump station, an illumination design model was simulated for pump station with two Philips HPSV lamps of 61 W at height of 4.8 m. Luminaire specifications are given in Table 6. 3D CAD model of illumination design is depicted in Fig.8. Isolux diagram and

Table 5: Results of illumination system model

Parameters	Value
Average horizontal illuminance	19.8 lux
Total luminaires used	48
Total wattage requirement	20784 Watts

Table 6: Luminaire specifications

Make and type	Philips (HPSV)
Model	SGS101 FG 1×SON-TPP50W TP P2
Power consumption	61 W
Luminous flux	4400 lm
Luminous efficacy	72.13 lm/W

Table 7: Results of illumination system model

Average Illuminance level	Minimum Illuminance level	Maximum illuminance level	Total wattage requirement
41.4 Lux	23.9 Lux	45.3 Lux	122 Watts

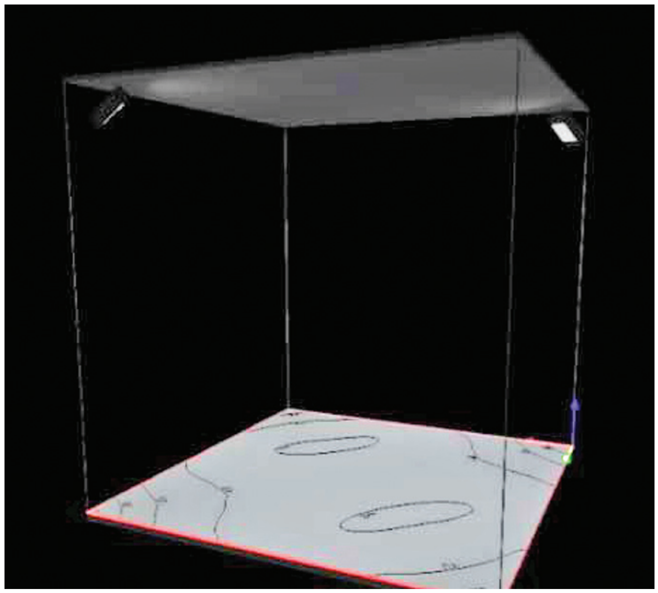
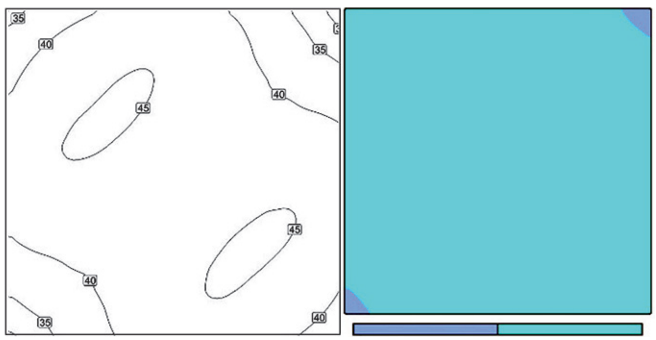


Fig 8 3D CAD model of illumination design of pump station



(a) Isolux diagram (b) False color diagram

Fig.9 Illuminance level at surface of pump station

false color diagram were produced from simulation and are predicted in Fig.9(a) and 9(b) respectively.

4.1.4 OB and coal face illumination design

Due to blasting and constant movement of coal and OB face in mine, it is not possible to design an effective lighting system with static luminaire position. So, movable/mobile light tower arrangement was used for simulation assuming 30m as safe distance from coal/OB face or loading point. Height of tower was 15m with seven luminaires positioned on tower in half-circular manner at 70^{o} angle. 3D CAD model, isolux diagram and lux grid diagram for horizontal illuminance level are depicted in Figs.10, 11 and 12 respectively. Luminaire specifications and results of model are given in Tables 8 and 9 respectively.

TABLE 8: LUMINAIRE SPECIFICATIONS

Make and type Model	Philips (HPSV) MVP506 1×SON-TPP250W A25-WB
Power	276 W
Luminous flux	33200 lm
Luminous efficacy	120.65 lm/W

TABLE 9: RESULTS OF ILLUMINATION SYSTEM MODEL

Distance from tower	Illumination level (Horizontal)	Illuminance level (Vertical)
10 m	55 Lux	45 Lux
20 m	33 Lux	42 Lux
30 m	15 Lux	29 Lux
Total power consumption	1932 W	

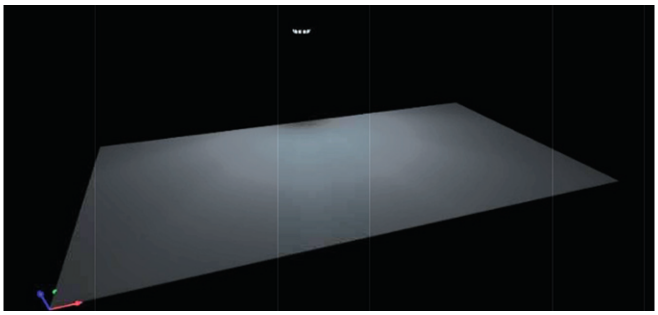


Fig.10 3D CAD model for mobile tower lighting system

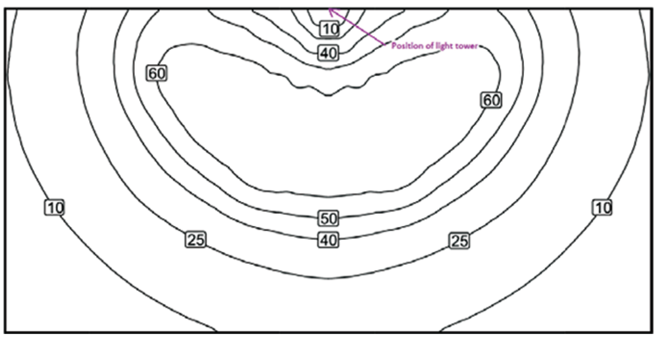


Fig.11 Isolux diagram (horizontal illuminance) for mobile tower lighting system

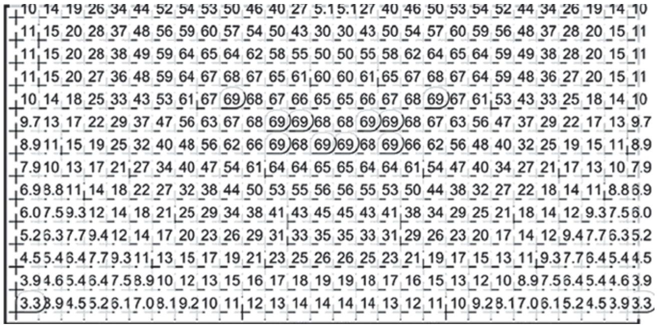


Fig.12 Lux grid diagram (horizontal illuminance) for mobile tower lighting system

4.1.5 Coal dump yard illumination design

Area of coal dump yard was approx. 500 m × 400 m. As per illumination requirement of mine, Illumination design model for coal dump yard was simulated. Luminaire specifications and luminaire arrangement are given in Tables 10 and 11 respectively. Layout of poles in dump yard and 3D CAD model are depicted in Figs.13 and 14 respectively. From simulation of illumination design model, Isolux diagram and false color diagram were produced and depicted in Figs.15 and 16 respectively.

TABLE 10: LUMINAIRE SPECIFICATIONS

Make and type Model	Philips (HPSV) MVP506 1×SON-TPP400W A25-WB
Power	433 W
Luminous flux	56500 lm
Luminous efficacy	130.48 lm/W

TABLE 11: LUMINAIRE ARRANGEMENT

Total luminaire used	138
Total no. of poles	34
Angle of luminaire	55^{o}
Height of poles	25 m

TABLE 12: RESULTS OF ILLUMINATION SYSTEM MODEL

Parameters	Value
Average horizontal Illuminance	15.2 lux
Minimum Illuminance	10.2 lux
Maximum Illuminance	31.8 lux
Total wattage requirement	59754 Watts

4.2 DESIGN OF ILLUMINATION SYSTEM WITH LED LIGHTS [9]

4.2.1 Haul road illumination design

Illumination design model was simulated with dual row offset pole arrangement, 20m pole height, 1m overhang, 1m boom length and 199W Philips LED light. Luminaire specifications and results of model are depicted in Tables 13 and 14 respectively. From simulation, lux value grid and Isolux diagram were produced and depicted in Figs.17 and 18 respectively.

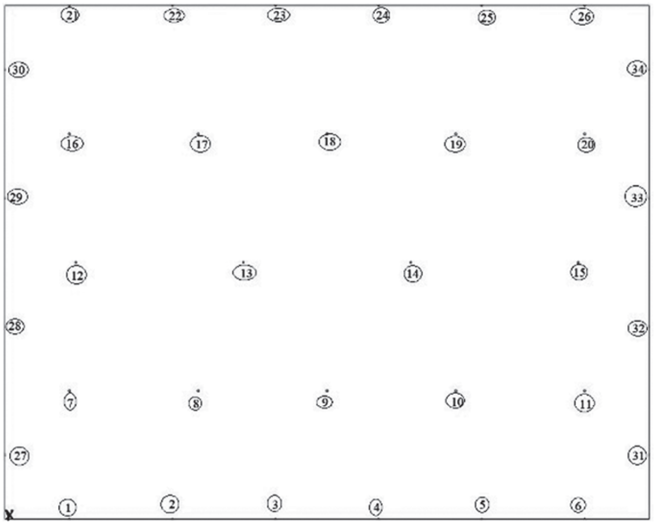


Fig.13 Layout of poles in illumination design of coal dump yard.

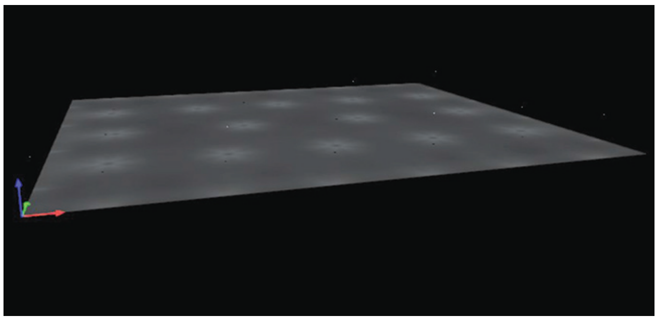


Fig.14 3D CAD model of illumination design of coal dump yard

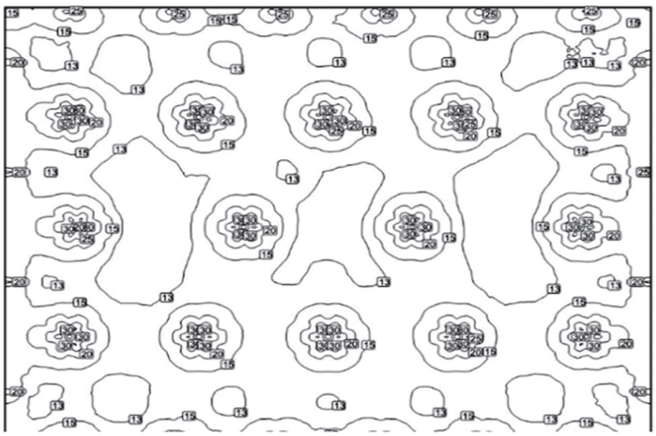


Fig.15 Isolux diagram

Fig.16 False color diagram

TABLE 13: LUMINAIRE SPECIFICATIONS

Make and type	Philips (LED)
Model	BVP506 GCA T25 1×ECO226-3S/757 DC
Luminous efficiency	119.6 lm/W
Lamp wattage	199 W
Luminous flux	23800 lm

TABLE 14: RESULTS OF ILLUMINATION SYSTEM MODEL

Parameter	Value
Illuminance level, E_m	11.11 lux
Uniformity ratio, U_o	0.69
Optimum pole spacing	70 m
No. of pole requirement	29
Total wattage requirement	5771 W

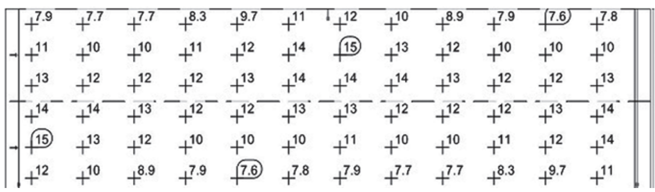


Fig.17 Lux value grid

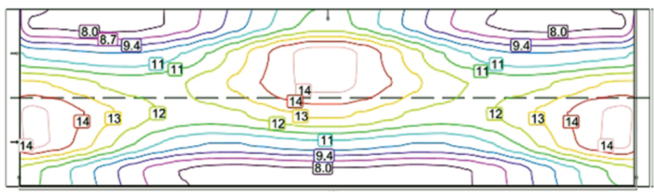


Fig.18 Isolux diagram

4.2.2 OB dump yard illumination design

Illumination design model for OB dump yard was simulated with Philips LED lamps. Total of 32 luminaires (each at 70^o angle) used on 13 different poles (each with height of 25 m) at different positions on OB dump yard where, 3 luminaires on a pole in half circular manner at edges of dump yard and 2 luminaires on a pole at each corner and at middle of dump yard (Fig.19). Layout of pole arrangement in OB dump yard is depicted in Fig.19. 3D CAD model of illumination design for OB dump yard is given in Fig.20. Luminaire specifications are given in Table 15. Isolux diagram and false color diagram were produced from simulation and depicted in Figs.21 and 22 respectively.

4.2.3 Pump station illumination design

To get appropriate illuminance level at pump station, an

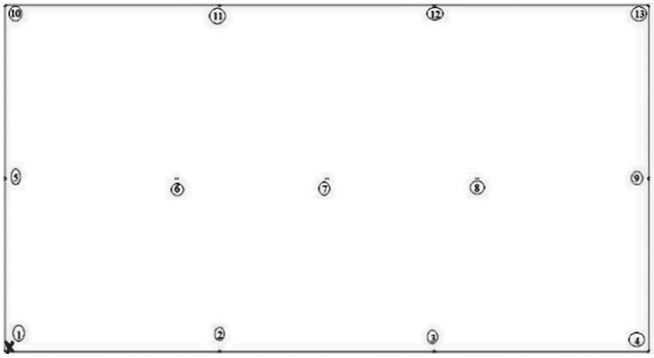


Fig.19 Layout of poles in illumination design of OB dump yard

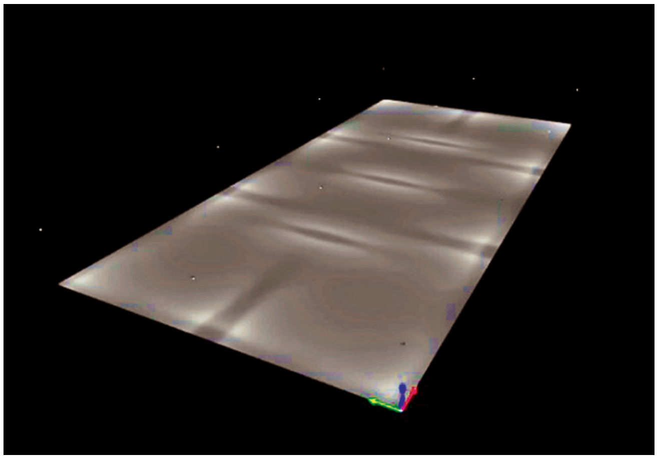


Fig.20 3D CAD model of illumination design of OB dump yard

TABLE 15: LUMINAIRE SPECIFICATIONS

Make and type Model	Philips (LED) BVP651 T25 1×LED800-4S/757 DW10
Power	540 W
Luminous flux	66345 lm
Luminous efficacy	122.9 lm/W

TABLE 16: RESULTS OF ILLUMINATION SYSTEM MODEL

Parameters	Value
Average Horizontal Illuminance	19.8 lux
Total luminaires used	32
Total wattage requirement	17280 Watts

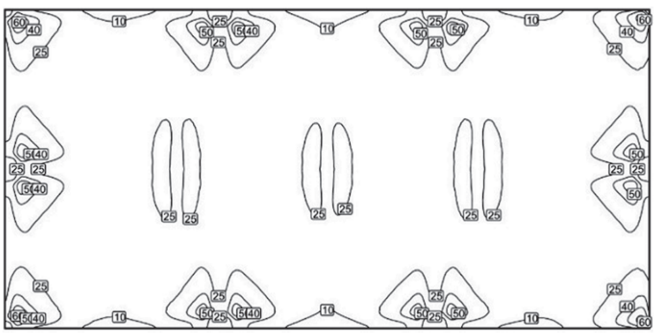


Fig.21 Isolux diagram

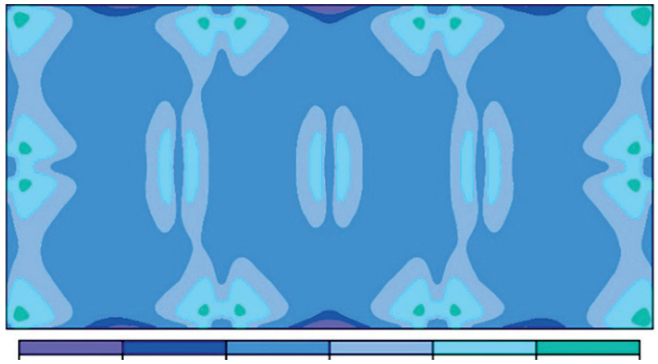


Fig.22 False color diagram

TABLE 17: LUMINAIRE SPECIFICATIONS

Make and type Model	Philips (LED) BGP322 T50 1×GRN21-3S/657 DC
Power consumption	17 W
Luminous flux	2200 lm
Luminous Efficacy	129.41 lm/W

TABLE 18: RESULTS OF ILLUMINATION SYSTEM MODEL

Average Illuminance level	Minimum Illuminance level	Maximum illuminance level	Power consumption
40.6 Lux	20 Lux	49 Lux	34 W

illumination design model was simulated for pump station with two Philips LED lamps of 17 W at height of 3.8 m. Luminaire specifications are given in Table 17. 3D CAD model of illumination design is depicted in Fig.23. Isolux diagram and false color diagram were produced from simulation and are predicted in Figs.24(a) and 24(b) respectively.

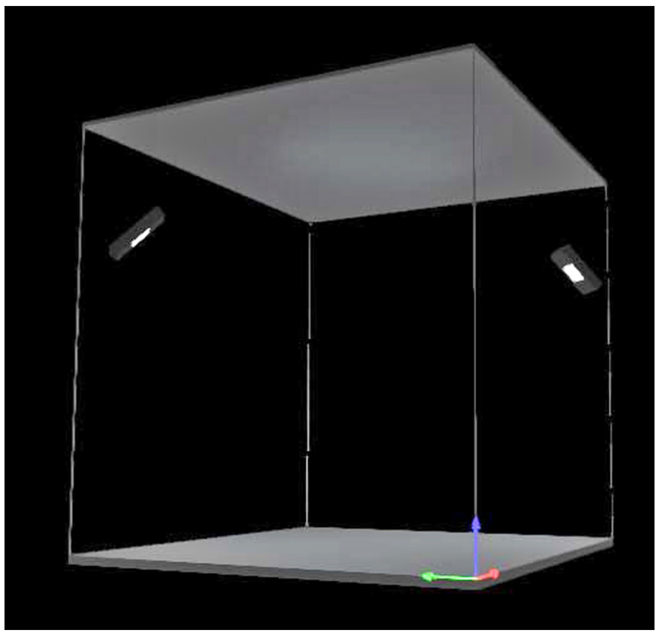
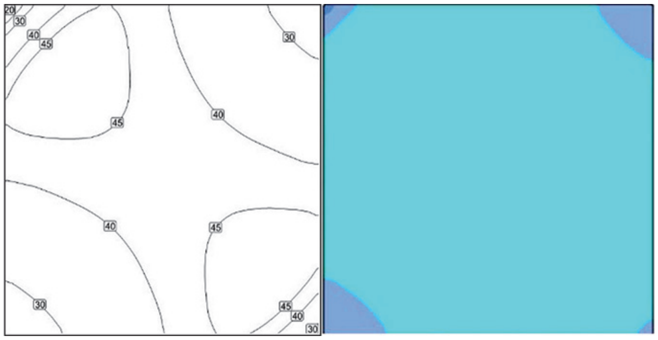


Fig.23 3D CAD model of illumination design of pump station



(a) Isolux diagram (b) False color diagram

Fig.24 Illuminance level at surface of pump station

4.2.4 OB and coal face illumination design

Illumination design with movable/mobile light tower arrangement was simulated assuming 30m as safe distance from Coal/OB face or loading point. Height of tower was 15m with five luminaires positioned on tower in half-circular manner at 70^{o} angle. 3D CAD model, isolux diagram and lux grid diagram for horizontal illuminance level are depicted in Figs.25, 26 and 27 respectively. Luminaire specifications and results of model are given in Tables 19 and 20 respectively.

TABLE 19: LUMINAIRE SPECIFICATIONS

Make and type	Philips (LED)
Model	BGP323 T35 1×ECO287-3S/657 DW
Power	243 W
Luminous flux	30100 lm
Luminous efficacy	123.9 lm/W

TABLE 20: RESULTS OF ILLUMINATION SYSTEM MODEL

Distance from tower	Illumination level (Horizontal)	Illumination level (Vertical)
10m	67 Lux	80 Lux
20m	41 Lux	63 Lux
30m	16 Lux	31 Lux
Total power requirement	1215 W	

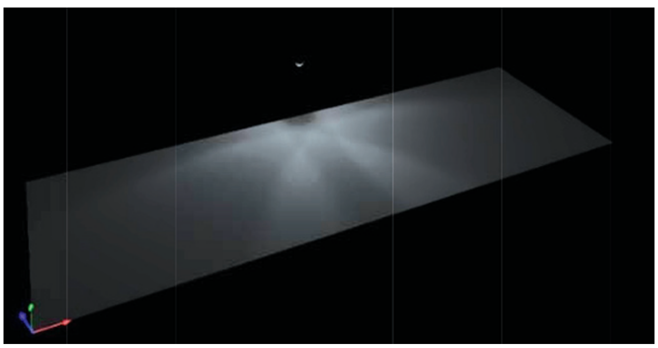


Fig.25: 3D CAD model for mobile tower lighting system

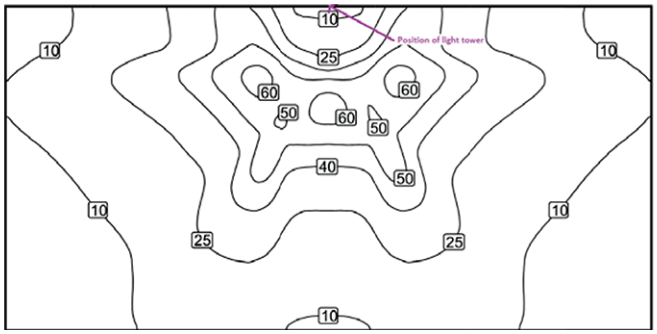


Fig.26 Isolux diagram (horizontal illuminance) for mobile tower lighting system

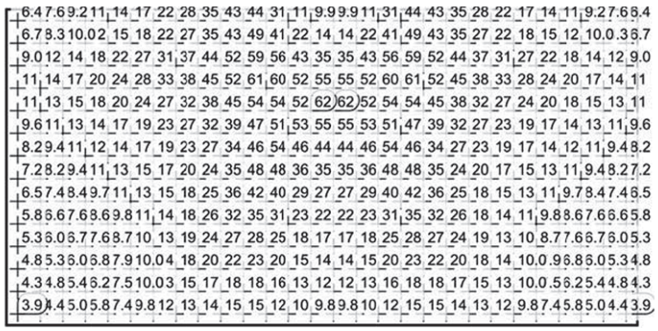


Fig.27 Lux grid diagram (horizontal illuminance) for mobile tower lighting system

4.2.5 Coal dump yard illumination design

Illumination design model for coal dump yard was simulated. Luminaire specifications and luminaire arrangement are given in Tables 21 and 22 respectively. Layout of poles in dump yard and 3D CAD model are depicted in Figs.28 and 29 respectively. From simulation of illumination design model, Isolux diagram and false color diagram were produced and depicted in Figs.30 and 31 respectively.

TABLE 21: LUMINAIRE SPECIFICATIONS

Make and type	Philips (LED)
Model	BVP651 T25 1×LED800-4S/757 DW10
Power	540 W
Luminous flux	66345 lm
Luminous efficacy	130.49 lm/W

TABLE 22: LUMINAIRE ARRANGEMENT

Total luminaire used	122
Total no. of poles	39
Angle of luminaire	70^{o}
Height of poles	25 m

TABLE 23: RESULTS OF ILLUMINATION SYSTEM MODEL

Parameters	Value
Average Horizontal Illuminance	19.7 lux
Total wattage requirement	65880 Watts

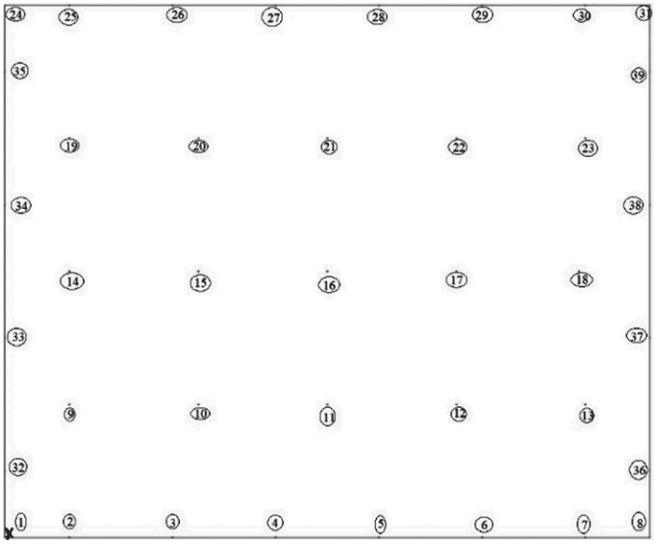


Fig.28 Layout of poles in illumination design of coal dump yard

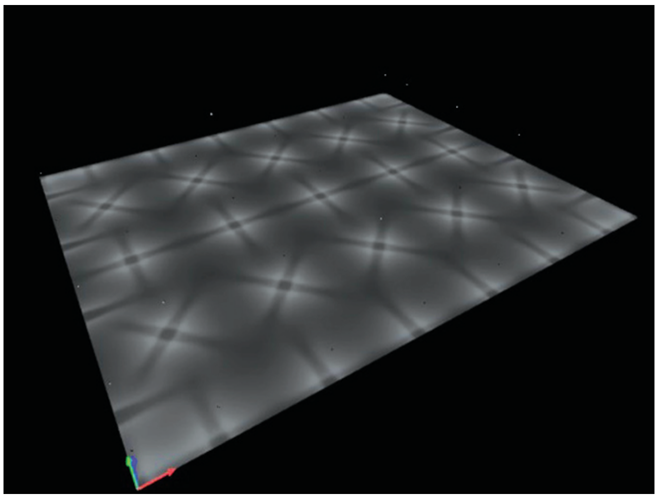


Fig.29 3D CAD model of illumination design of coal dump yard

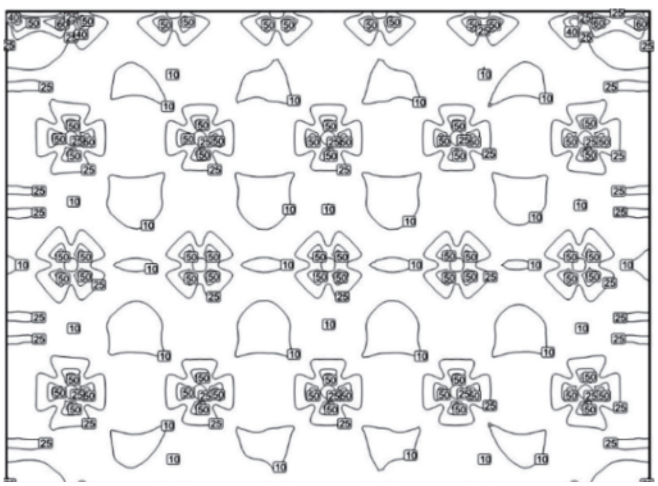


Fig.30 Isolux diagram

TABLE 24: POWER CONSUMPTION AND AVERAGE ILLUMINANCE LEVEL OF ILLUMINATION DESIGN WITH CONVENTIONAL AND LED LAMPS [9]

	Traditional lamps	LED Lamps
	Power consumption	Power consumption
Haul road	8281 W	5771 W
OB dump yard	20784 W	17280 W
Pump station	122 W	34 W
OB and coal face	1932 W	1215 W
Coal dump/stack yard	59754 W	59754 W (conventional)
Total power consumption/hour	90873 W	84054 W

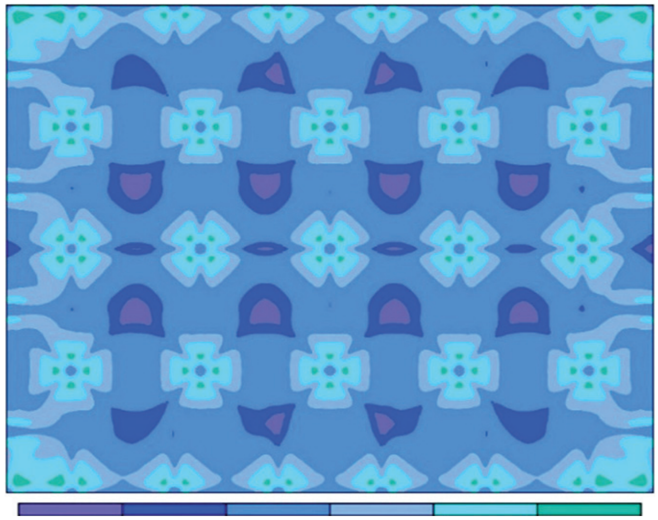


Fig.31 False color diagram

5. Summary of illumination design at mine-A

It was found that lighting system with LED lights consumes more power compared to lighting system with conventional lights for coal dump yard. So, Illumination design with conventional lights had been adopted for coal dump yard. Also adopted for energy consumption and cost calculations.

Assuming total number of working days in a year are 330 and lampsare lighted during working days only and lighting time for illumination system in the mine per day as 12 hours (6 PM to 6 AM), annual energy consumption for illumination design with

- Conventional lamps,
  - = 90873 W/hour×12 hours/day×330 days/year
  - = 359,857,080 W/year ≈ 360 MW/year
- LED lamps,
  - = 84054 W/hour×12 hours/day×330 days/year
  - = 332,853,840 W/year H” 333 MW/year

Therefore, annual energy saving by adopting LED lighting system,

= (359,857,080 W/year – 332,853,840 W/year)

= 27,003,240 W/year H” 27 MW/year

Percentage decrease in energy consumption,

= (27 MW/360 MW) ×100

= 7.5 %

6. Conclusions

In this paper, illumination system was designed for different work places in an opencast coal mine with both conventional and LED lightings. Power consumption of designs were calculated per year basis for illumination system with both conventional and LED lightings. It was observed that power consumption with LED lightings is less than power consumption with conventional lightings at most work places except at coal dump yard which have very large area (400m × 500m) and power consumption with LED lights (65880 W) and with conventional lights (59754 W). Uniformity was found to be better in case of illumination system with traditional lights. Annual power consumption of designed illumination system with conventional lights was 360 MW per year and with LED lights was 333 MW per year. So, illumination system design with LED lights consumes approx. 27 MW less power (7.5 %) per year and have better efficiency.

Lower power consumption directly reduces electricity cost of mine and so operating cost of mining activities. In addition, LED lights have long life and requires less maintenance, also decreases maintenance cost of illumination system.

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