Original Article

Optimizing Hospital Design for Energy Efficiency: Strategies to Minimize Energy Loss

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Abstract - Energy loss can be minimized through several ways, out of which the pre-designing and designing phases play a crucial role. An appreciable amount of electrical energy can be saved by performing a thorough design exercise for any concerned system. In this paper, a hospital ready to be constructed is considered, and practical design strategies have been implemented and proposed for establishing and improving energy efficiency, therefore paving a path for the mitigation of energy loss. The design outcomes show that energy efficiency can be considerably improved by taking considered steps, such as using high-star-rated appliances. This method helps reduce electricity consumption within the facility. Substituting 40W, 20W, and 5W lamps with 9W LED lamps for the concerned hospital can result in average energy savings of approximately 89.45%, 54%, and 39.95%, respectively. Upgrading to energy-efficient BLDC fans instead of conventional fans can result in an average energy savings of 62.59%. In the same way, opting for 5-star rated ACs over regular ones can help save approximately 29.28% of energy. The outcomes in this paper provide detailed insights into the energy-efficient design process and a sustainable energy management plan for a hospital, ensuring a consistent power supply for all medical instruments and appliances.

Keywords - Hospital Design, Electricity Load Balancing, Energy Efficiency, Power Distribution, Energy Loss Minimization, Hospital Energy Management, High Star-Rated Appliances, Power Consumption Reduction.

1. Introduction

Hospitals are critical public buildings that rely on good quality electrical power for life-saving medical services and diagnostic equipment - in addition to lighting, ventilation, and air-conditioning. Because of the 24/7 processes and various functional areas, including outpatient departments, operational theaters, emergency wards, ICUs/labs, and wards, etc., hospitals are one of the most energy-intensive building types. Ineffective electrical design due to lazy design can lead to the wastage of lots of energy, phase imbalances, and improper operation of the system. Accordingly, a detailed analysis of the lighting systems, fan technologies, and air-conditioning needs is essential for designing an efficient healthcare building. Although there are several studies dealing with energy efficiency in hospitals, the majority examine individual subsystems (e.g., lighting upgrades, HVAC retrofits, or overall building-level audits). To the best of our knowledge, such works generally do not support room-wise electrical load measurement or unify appliance-level efficiency with phase-wise power allocation. Moreover, most of the current processes are assumption-based, not specific to the real architectural shape of a potential health building. This lack of a decision-making platform restricts the application of energy demand reduction measures in a real scenario at an early stage, particularly in small- and medium-sized hospitals in developing countries. To fill this gap, the current work proposes a room-based investigation of lighting loads, including fan demand and air conditioning systems for a building that is under construction as a case study. Various lamp wattages, fan types, and AC star ratings are compared on an energy basis. Moreover, a weighted load distribution method is proposed to achieve equal inter-phase balancing (R-Y-B) that plays an important role in reducing energy loss and improving system stability. This investigation aims to provide architects, electrical engineers, and planners with some ideas about designing hospitals that are energy-efficient and operationally sustainable, as well as being comfortable for patients in an environmentally responsible way.

2. Literature Review

Energy performance in buildings has become a significant area of study due to rising environmental and economic pressures. X. Guo and Y. Wang demonstrated that critical parameters such as building envelope design, HVAC performance, and occupant behaviour significantly influence total energy consumption. Their Energy Plus-based multi-objective optimisation showed that temporary buildings can achieve up to 41% reduction in energy use through improved

design and early-stage planning [1]. Alotaiby and Krenyácz also noted that hospitals are among the most energy-intensive public facilities, with average consumption around 0.27 MWh/m², driven mainly by lighting, ventilation, and clinical equipment. Their study indicated that system-level measures such as refrigerant flow optimization and hybrid generation can substantially reduce the operational energy burden [7].

Lighting accounts for a significant share of hospital electricity use because medical spaces require high visual quality. Cesari et al. reported that enhancing fenestration design, increasing window-to-wall ratio, and applying daylight-linked dimming can lower lighting energy demand in patient rooms by up to 17%, underscoring the importance of daylight integration in healthcare facilities [2]. Montoya et al. highlighted the technological shift from incandescent and fluorescent lamps to LEDs and OLEDs, which has significantly improved energy efficiency and luminous efficacy in buildings [8].

Palacios Intriago et al. found that LED lamps offer better energy output, reduced environmental impact, and longer service life, which is particularly beneficial in hospitals where lighting operates for extended hours [3]. Comparative work by Khan and Abas showed that LEDs consistently provide the highest luminous efficacy and the lowest life-cycle energy cost among common lamp types, reinforcing their role as the preferred choice for hospital lighting retrofits [5]. Rahman et al. further demonstrated through a practical case study in Pakistan that replacing outdated lights and fans with efficient alternatives can produce substantial energy savings with short payback periods [6]. Papantoniou et al. advanced lighting efficiency by presenting adaptive lighting controllers using smart sensors in European hospitals, demonstrating that intelligent control can deliver efficient lighting without compromising patient comfort or visual performance [12].

Modern hospitals can achieve deeper energy savings by integrating digital control and automation. Beucker et al. showed that Building Energy Management Systems (BEMS) can significantly reduce heating and electrical demand by dynamically coordinating energy use across building subsystems [9]. Their results highlight the environmental benefits of intelligent and automated energy management in extensive healthcare facilities.

The U.S. Department of Energy also emphasized the importance of combining energy efficiency with indoor health considerations. Their findings indicate that lighting quality, thermal comfort, and adequate ventilation directly affect both patient well-being and overall energy use, aligning with the principles of emerging "healthy building" frameworks [11]. Medical devices also represent a considerable portion of hospital electricity consumption. Rohde and Martinez reported that diagnostic equipment, ventilation systems, and sterilization units account for a substantial share of total

energy use in teaching hospitals, underscoring the need for effective equipment-level energy planning [4]. Anselm and Schick observed that modern anesthesia machines and specialized medical equipment can deliver meaningful reductions in energy demand, demonstrating that equipment selection plays a direct role in improving hospital energy efficiency [10].

2.1. Identified Research Gap
The literature shows strong interest in lighting systems, HVAC performance, digital management tools, and equipment-level efficiency. However, these studies generally explore each system separately. None of them:

- conduct a room-by-room analysis of lighting, fans, and AC loads, or
- Compare appliance ratings and technologies at the design stage while linking appliance-level choices to three-phase load balancing (R-Y-B).

As a result, there is no unified method that helps designers evaluate individual appliance performance together with the overall electrical load distribution of a hospital. The present study addresses this gap by analyzing lighting, fans, and ACs at the room level and proposing a weighted load-distribution approach to improve phase balancing and reduce energy losses.

3. Novelty
Earlier studies on hospital energy efficiency mainly focused on only one part of the system-for example, improving lighting layouts, making HVAC systems more efficient, or monitoring energy use through innovative-grid technologies. These works usually looked at each component separately and did not create a complete method that links the efficiency of individual appliances to the total electrical load of a real hospital. Also, many studies used general building models instead of room-by-room analysis based on an actual hospital's design.

What is new in this study is that it brings all these aspects together in one combined approach. Instead of studying only lighting or only HVAC, this work examines three significant electrical loads at the same time: lighting, fans, and air conditioners, across a realistic hospital layout.

It compares different lamp wattages, fan technologies (regular vs. BLDC), and AC star ratings at the room level, and includes practical wattage calculations and expected energy savings. The study also introduces a three-stage load distribution method that helps balance R-Y-B phase loads using optimized appliance scheduling. To the best of the authors' knowledge, no previous work has examined both appliance-level efficiency and overall load balancing together in a single framework.

4. Hospital: Energy-Efficient Design and Load Distribution Analysis

Figure 1 illustrates the complete methodology followed in this study, starting from room-wise data collection to load estimation, appliance comparison, and three-phase load distribution. This structured representation provides a clear overview of the analytical steps adopted to evaluate the energy-efficient electrical design for the proposed hospital. Figure 2 shows a simple block diagram of the proposed hospital electrical load design. It gives an overall view of the main stages involved, from room-wise data collection to appliance selection, load estimation, and three-phase load distribution. A new hospital planned at Nellore is considered for the analysis. The facility comprises a total of 29 rooms distributed across two floors.
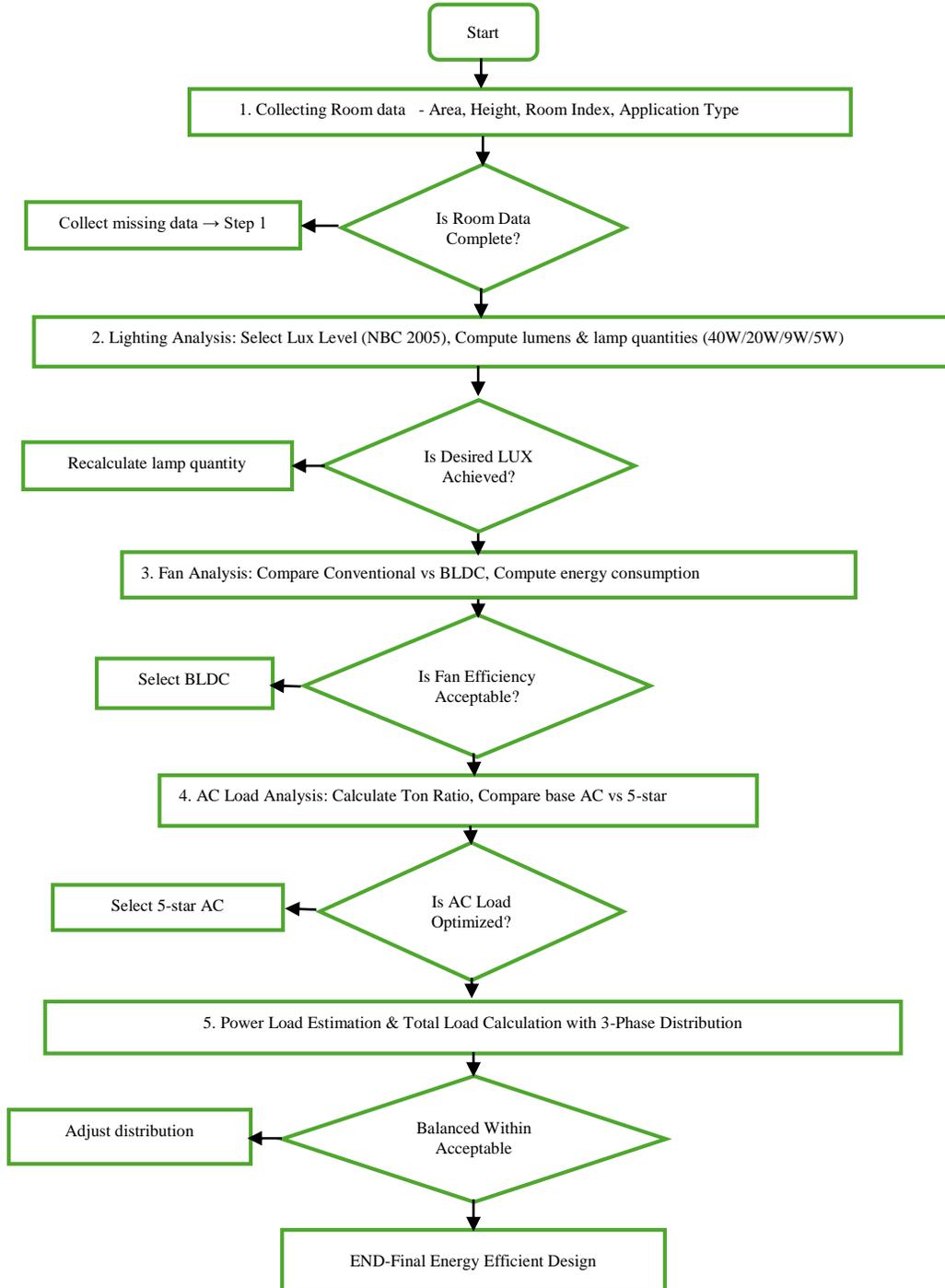

Fig. 1 Methodology flow chart for energy-efficient hospital energy design

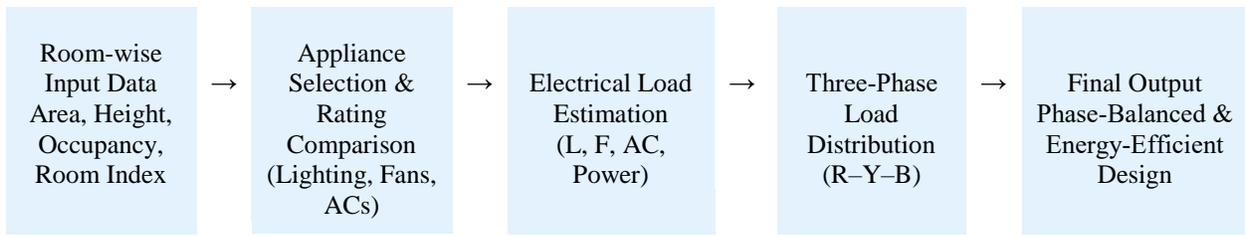| Room-wise Input Data Area, Height, Occupancy, Room Index | → | Appliance Selection & Rating Comparison (Lighting, Fans, ACs) | → | Electrical Load Estimation (L, F, AC, Power) | → | Three-Phase Load Distribution (R–Y–B) | → | Final Output Phase-Balanced & Energy-Efficient Design |

Fig. 2 Block diagram of the proposed energy-efficient hospital electrical load design framework

The principal rooms on the ground floor include the generator room, pharmacy, waiting hall, consultation rooms, emergency room, laboratory, scanning room, and associated service spaces.

The first floor consists of the nurse station, ICU, waiting hall, general ward, operation theatre, laboratory, and other supporting areas. The application-wise room details for both floors are provided in Tables 1 and 2, respectively.

Table 1. Application - wise room details - ground floor

R. No	Room Application	Area (Sqm)	Height (M)	Room Index
R1	Generator Room	3.93	2.70	0.36
R2	Pharmacy	5.20	2.70	0.42
R3	Waiting Hall	18.46	2.70	0.78
R4	OP-2	12.99	2.70	0.66
R16	Scanning Room	3.86	3.00	0.33
R5	Toilet	2.01	2.70	0.24
R6	OP-1	5.22	2.70	0.42
R7	Open Area	6.82	2.70	0.45
R8	Emergency Room	10.89	2.70	0.61
R9	Toilet	3.24	2.70	0.33
R10	Not Usable			
R11	Lab	5.94	2.70	0.43
R12	Toilet	1.62	2.70	0.22
R13	Toilet under the ramp	1.62	2.70	0.22
R14	Waiting Hall	29.58	2.70	0.77
R15	Front open area	11.60	2.70	0.60

Table 2. Application-wise room details – first floor

R. No	Room Application	Area (Sqm)	Height (M)	Room Index
R1	Small Room (Nurse Station)	1.90	3.00	0.22
R2	Waiting Hall	8.62	3.00	0.49
R3	ICU	18.46	3.00	0.70
R4(a)	ICU Toilet-1	1.72	3.00	0.22
R4(b)	ICU Toilet-2	1.72	3.00	0.22
R5	General Ward	11.53	3.00	0.54
R6	General Ward Wash Area	1.98	3.00	0.21
R7	General Ward Toilet-1	1.76	3.00	0.22
R8	General Ward Toilet-2	1.76	3.00	0.22
R9	Open area	11.69	3.00	0.50
R10	Waiting area	15.19	3.00	0.64
R11	Ramp area	7.09	3.00	0.39
R12	OT	10.40	3.00	0.54
R13	Toilet	3.24	3.00	0.30
R14	Lab	5.94	3.00	0.39

Based on the attained Room Index (RI) and desired lux level as per NBC 2005, the category-wise total quantity of lights required for illuminating the rooms floor-wise is furnished in Tables 3 and 4, respectively. From Table 3, it is clear that within the rooms belonging to the ground floor, the total quantity of 40W, 20W, 9W, and 5W lamps required is

28, 47, 68, and 172, respectively, and the total circuit watts are 1120W, 940W, 612W, and 860W, respectively. Besides, the relevant total Energy Consumption Per Hour (kWh) is 1.12, 0.94, 0.612, and 0.86, respectively.

From this, it is clear that the total quantity of 5W lamps required exceeds that of 9W, 20W, and 40W lamps. However, the total circuit watts are more with a 4W lamp, followed by 20W, 5W, and 9W lamps.

Table 3. Projected quantity of different capacities of lights-ground floor

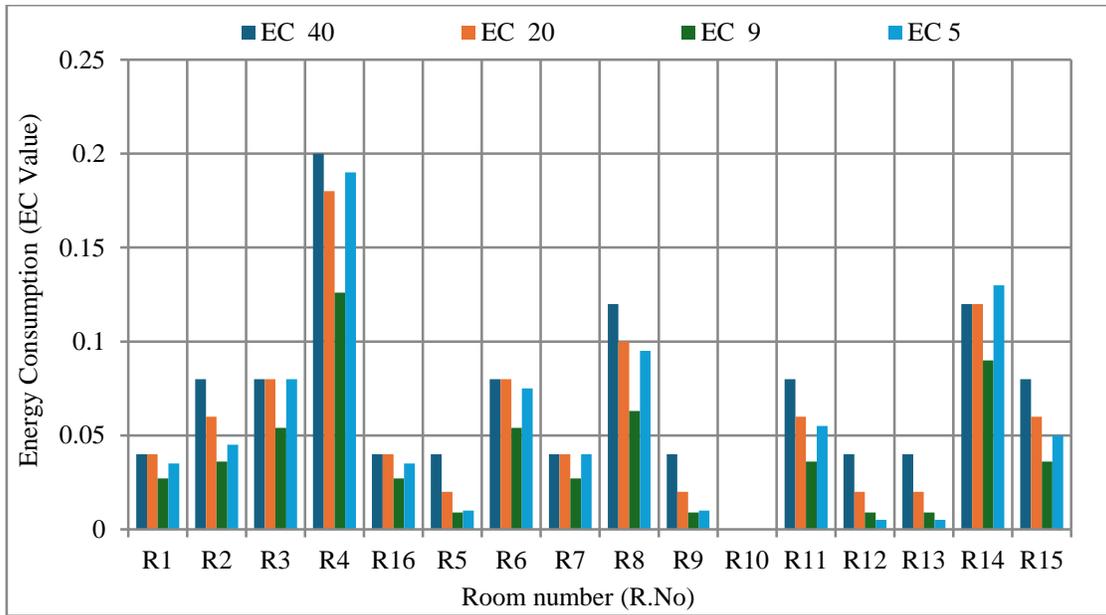| R. No	Lux	40W LED	20W LED	9W LED	5W LED
R1	300	1.00	2.00	3.00	7.00
R2	300	2.00	3.00	4.00	8.00
R3	300	4.00	8.00	12.00	32.00
R4	100	1.00	1.00	1.00	1.00
R5	300	3.00	5.00	8.00	20.00
R6	100	1.00	1.00	1.00	2.00
R7	100	1.00	1.00	1.00	2.00
R8	100	1.00	1.00	1.00	2.00
R9	150	2.00	3.00	4.00	11.00
R10		0	0	0	0
R11	300	2.00	3.00	4.00	11.00
R12	100	1.00	1.00	1.00	1.00
R13	100	1.00	1.00	1.00	2.00
R14	150	3.00	6.00	10.00	26.00
R15	150	2.00	3.00	4.00	10.00

Fig. 3 Total hourly Energy Consumption (EC) by different capacities of lamps-GF

Table 4. Estimated quantity of different capacities of lights-first floor

R. No	Lux	40W LED	20W LED	9W LED	5W LED
R1	500	1.00	2.00	3.00	6.00
R2	150	1.00	2.00	3.00	8.00
R3	300	4.00	8.00	12.00	32.00
R4(a)	100	1.00	1.00	1.00	1.00
R4(b)	100	1.00	1.00	1.00	1.00
R5	300	3.00	5.00	8.00	20.00
R6	100	1.00	1.00	1.00	2.00
R7	100	1.00	1.00	1.00	2.00

R8	100	1.00	1.00	1.00	2.00
R9	150	2.00	3.00	4.00	11.00
R10	150	2.00	3.00	5.00	13.00
R11	150	1.00	2.00	3.00	7.00
R12	500	4.00	7.00	11.00	30.00
R13	100	1.00	1.00	1.00	2.00
R14	300	2.00	3.00	4.00	11.00

The hourly vitality utilization by distinctive lights is presented in Figure 3. From the figure, it is obviously evident that by installing 68 No. 9W lamps, the total energy consumption per hour is 0.612 kWh, which is much less than that of other capacity lamps. The percentage savings in relative energy consumption that can be achieved relative to 40W, 20W, and 5W lamp is 83%, 53.6% and 40.5% respectively. From Table 4, it is clear that within the rooms belonging to the first floor, the total quantity of 40W, 20W, 9W, and 5W lamps required is 26, 41, 59, and 148, respectively, and the total circuit watts are 1040W, 820W, 531W, and 740W, respectively. Besides, the relevant Total

Energy Consumption Per Hour (kWh) is 1.04, 0.82, 0.53, and 0.74, respectively. From this, it is clear that the total quantity of 5W lamps required is more, followed by 9W, 20W, and 40W lamps. However, the total circuit watts are more with a 40W lamp, followed by 20W, 5W, and 9W lamps. The hourly energy consumption by different lamps is illustrated in Figure 4. From the figure, it is obviously evident that by installing 59 No. 9W lamps, the total energy consumption per hour is 0.53 kWh, which is much less than that of other capacity lamps. The percentage savings in relative energy consumption that can be achieved relative to 40W, 20W, and 5W lamps are 95.9%, 54.4% and 39.4% respectively.
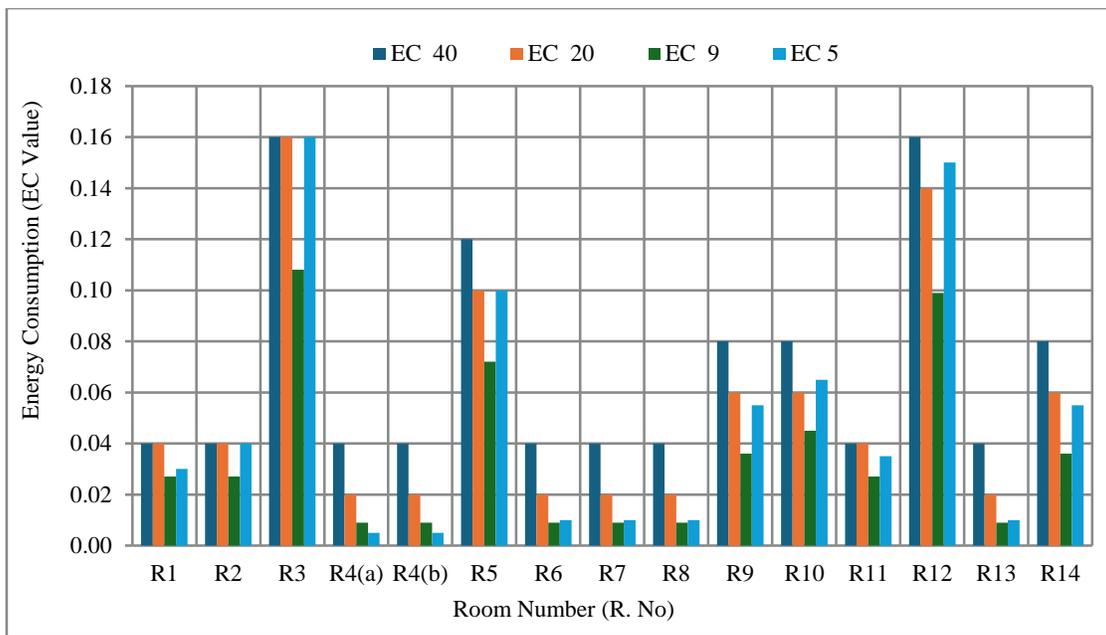

Fig. 4 Total hourly Energy Consumption (EC) by different capacities of lamps- FF

Table 5. Estimated quantity of ceiling fans – GF

R. No	Option-1: Ceiling / Exhaust Fan			Option-2: BLDC Fan		
	Wattage	Qty	Circuit Watts	Wattage	Qty	Circuit Watts
R1			0			0
R2	52	1	52	26	1	26
R3	52	2	104	26	2	52
R4	52	1	52	26	1	26
R5	25	1	25	25	1	25
R6	52	1	52	26	1	26
R7	52	1	52	26	1	26
R8	52	1	52	26	1	26
R9	25	1	25	25	1	25

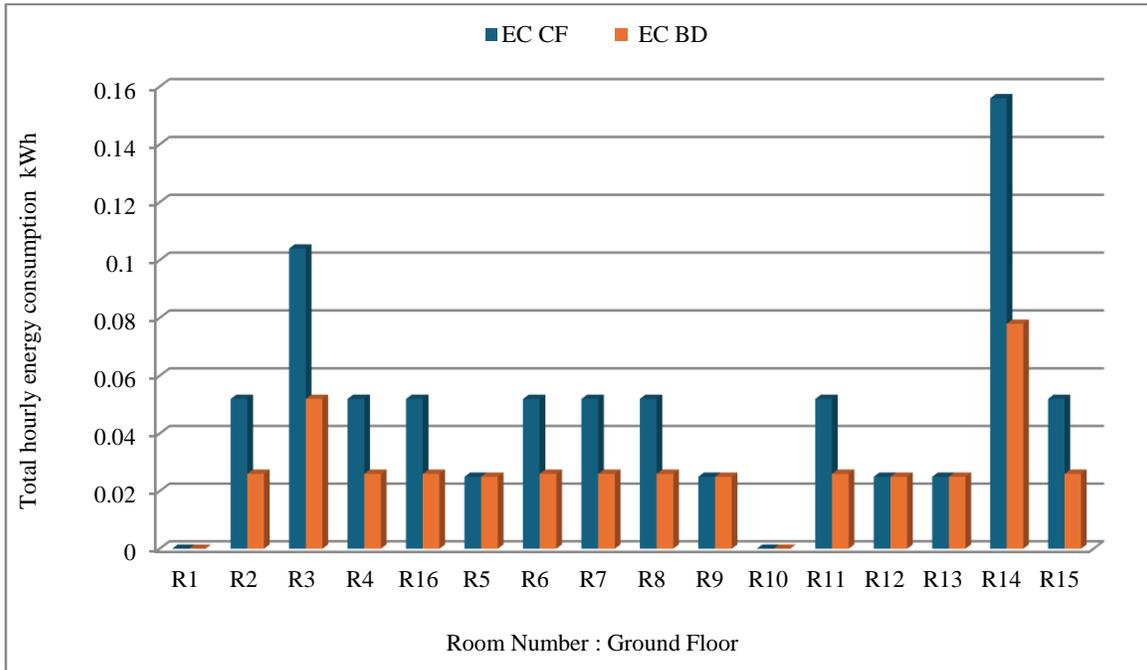|						
R10						
R11	52	1	52	26	1	26
R12	25	1	25	25	1	25
R13	25	1	25	25	1	25
R14	52	3	156	26	3	78
R15	52	1	52	26	1	26
R16	52	1	52	26	1	26
Total		17	776		17	438

Fig. 5 Total hourly Energy Consumption (EC) by Ceiling Fans (CF) and BLDC Fans (BD): GF

The floor-wise estimated quantity of Ceiling Fans required is furnished in Tables 5 and 6, respectively, and the total hourly Energy Consumption (EC) by Ceiling fans is depicted in Figures 5 and 6, respectively.

From Table 5 and Figure 5, it is clear that the total number of conventional 52 W ceiling fans (option-1) required is 13, and the 25W exhaust fans required are 4. The total circuit watts are 776W, and the hourly energy consumption is 0.776 kWh.

However, by opting for efficient BLDC fans (option 2) instead of conventional fans, the total circuit watts and the hourly energy consumption get reduced to 438W and 0.438 kWh, respectively. The relative percentage savings in energy consumption that can be achieved is 77.16.

From Table 6 and Figure 6, it is clear that the total number of conventional 52 W ceiling fans (option-1) required is 8, 50W wall-mounted fans required are 2, and 25W exhaust fans required are 5. The total circuit watts are 641W, and the hourly energy consumption is 0.641 kWh. However, by opting for efficient BLDC fans (option 2) instead of conventional fans, the total circuit watts and the hourly energy consumption get reduced to 433W and 0.433 kWh, respectively. The relative percentage savings in energy consumption that can be achieved is 48.03. The floor-wise estimated quantity of ACs required is furnished in Tables 7 and 8, respectively.

From these tables, it is obvious that the energy savings that can be achieved by opting for 5-star rated ACs are about 29.28% as compared to those of conventional ACs.

As per the requirement and nature of the hospital, all the power loads, viz anesthesia machine, surgical suction machine, short wave diathermy machine, heart rate monitor, laparoscopy machine, ECG machine, blood analyzer, dome LED, OT light, standard sockets, etc, of appropriate rating are considered for progressing the study.

The total capacity of the power load within GF and FF is 12,056 W and 12,697 W, respectively, and the estimated energy consumption per hour is 12.05 kWh and 12.70 kWh, respectively.

Table 6. Estimated quantity of ceiling fans – FF

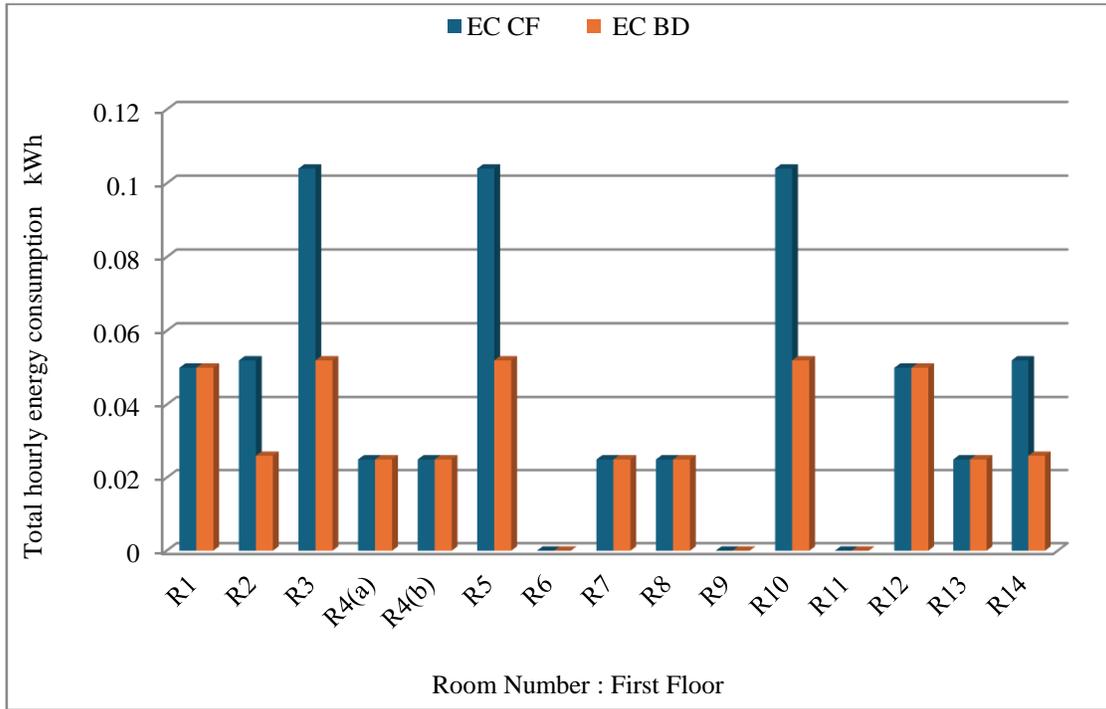| R. No	Option-1: Ceiling/Exhaust Fan			Option-2: BLDC Fan		
	Wattage	Qty	Circuit watts	Wattage	Qty	Circuit watts
R1	50	1	50	50	1	50
R2	52	1	52	26	1	26
R3	52	2	104	26	2	52
R4(a)	25	1	25	25	1	25
R4(b)	25	1	25	25	1	25
R5	52	2	104	26	2	52
R6			0			0
R7	25	1	25	25	1	25
R8	25	1	25	25	1	25
R9			0			0
R10	52	2	104	26	2	52
R11			0			0
R12	50	1	50	50	1	50
R13	25	1	25	25	1	25
R14	52	1	52	26	1	26
Total		15	641		15	433

Fig. 6 Total hourly Energy Consumption (EC) by Ceiling Fans (CF) and BLDC fans (BD): FF

Table 7. Estimated AC load - GF

	Room Application	Area (SFT)	Desired TR	Proposed TR	Star Rating (Opt-1)	Power Consumption in kW (1.4kW/TR) Opt-1	Star Rating (Opt-2)	Power Consumption in kW (0.99kW /TR) Opt-2
R4	OP-2	144.38	1.20	1.50	Base	2.1	5	1.485
R6	OP-1	58.00	0.48	1.00	Base	1.4	5	0.99
R11	Lab	66.00	0.55	1.00	Base	1.4	5	0.99
Total (GF)						4.9		3.465

Table 8. Estimated AC load - FF

	Room Application	Area (SFT)	Desired TR	Proposed TR	Star Rating (Opt-1)	Power Consumption in kW (1.4kW /TR) Opt-1	Star Rating (Opt-2)	Power Consumption in kW (0.99kW/TR) Opt-2
R2	Waiting Hall	95.81	0.80	0	Base	0	5	0
R3	ICU	205.14	1.71	2	Base	2.8	5	1.98
R12	OT	115.50	0.96	1	Base	1.4	5	0.99
R14	Lab	66.00	0.55	0	Base	0	5	0
Total (FF)						4.2		2.97

4.1. Load Distribution

The total connected load of the hospital is 33195 W, which includes a total lighting load of 2007 W, an AC load of 6435 W, and the power load of 24753 W, respectively. For adequate distribution of the power, a load distribution exercise has been performed, and utmost care has been taken to uniformly distribute the load among the three phases using an 8-way distribution model, which consists of one incoming and seven outgoing paths, as shown in Figure 7.

The optimal deviated load between RY, YB, and BR is about 40W, 50W, and 10W, respectively. The percentage load sharing among the three 3-phases is revealed in Figure 8.

From this figure, it is evident that the percentage load shared by R and B phases is equal; however, the load shared by the Y phase is relatively 1% more compared to the other two phases, and is acceptable.

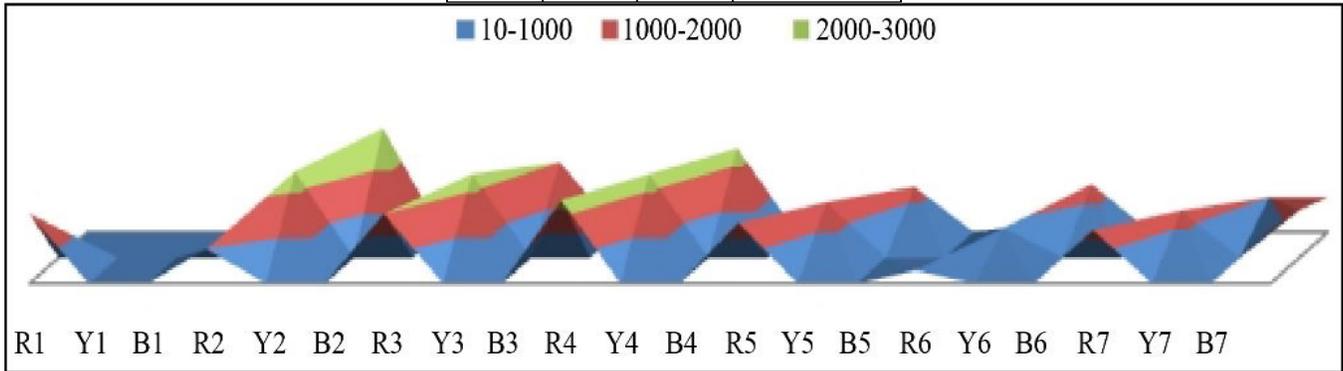| R	Y	B	Total (W)
11055	11095	11045	33195

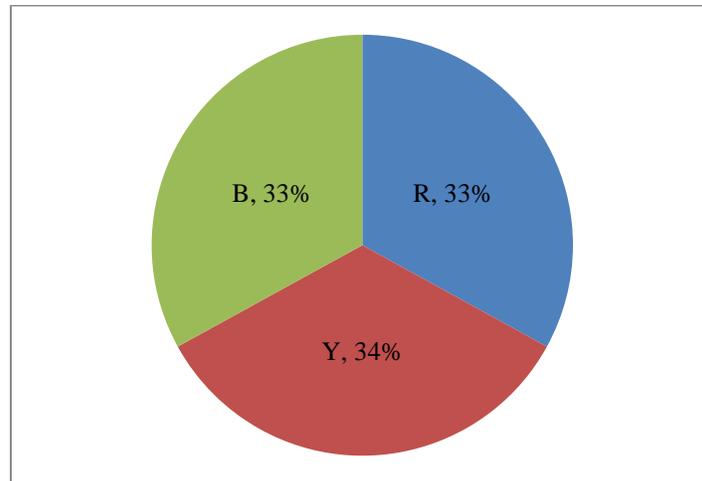**Fig. 7 Three-phase load distribution**

Fig. 8 Percentage load sharing among three phases

5. Conclusion

The new hospital to be constructed at Nellore for conducting the research study is under consideration. The hospital consists of two floors and 29 rooms in total. Considering the hospital development, the need for different facilities, and the need for essential electrical-powered equipment apart from the usage of normal electricals, general testing, and screening objectives towards healthcare are done for every possible effort. More work has been rendered in improving the rate of energy savings and creating standards of energy efficiency for each appliance category.

The total connected load of this concerned hospital, with 2007 W as total lighting load, 6435 W total AC load, and 24753 W power load, stands 33195 W with the proposed energy-saving design method. The eight-way distribution of electricity connection has been achieved by adopting power load distribution models and splitting the load equally for every phase. Furthermore, the possible percentage of load shares attained for the R phase and Y phase is similar, as R is slightly less. Moreover, the load share by the Y phase is just one percent more compared to the other two phases, making it the right option. Further, the deviation is very low as it is a negligible one and even it is tolerable. Considering the fact there are numerous hospitals and medical facilities in every part of the street, at least in the case of new additions, this design consideration can be adopted, no doubt that in reducing just the energy quantity consumed vastly in the medical sector and carrying out a massive amount of energy loss via distribution side, this one possibility cost and energy-saving can be implemented concluding a considerable quantity. The improved results obtained in this study are mainly due to the way electrical loads are analysed and planned during the design stage. In many earlier works, lighting systems, cooling systems, or power loads are studied separately, which leads to approximate or assumption-based decisions. In the present work, lighting, fan, air-conditioning, and power loads are evaluated together at the room level using actual requirements. This helps avoid unnecessary over-sizing and improves accuracy in total load estimation.

Further, equipment efficiency is considered before installation, rather than after operation. The addition of three-phase load distribution at the planning stage also improves performance, as phase imbalance is a common issue that is rarely addressed in reported hospital energy studies. Because of this combined and design-focused approach, better energy efficiency and more stable electrical operation were achieved compared to methods commonly reported in the literature.

Acknowledgments

Data Availability

The data that support the findings of this study are available from the corresponding author upon request.

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