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SUSTAINABLE ENERGY OPTIMIZATION IN THE ADMINISTRATIVE BUILDING OF JOSEPH SARWUAN TARKA UNIVERSITY MAKURDI USING MATLAB-BASED LINEAR PROGRAMMING

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Abstract

Over the years, the increase in demand for sustainable electricity and rising energy costs in institutional buildings has necessitated the adoption of efficient energy management strategies. In this study, MATLAB-based linear programming approach for sustainable energy optimization in the Administration Building of Joseph Sarwuan Tarka University Makurdi (JOSTUM), Nigeria was explored. An energy audit was performed to determine the energy consumption characteristics of major office appliances. The energy consumption profiles and electricity costs were developed using appliance power ratings and operating schedules. Two objective functions (O1 and O2) were generated and optimized using the MATLAB Linprog solver to reduce energy consumption and operational costs while satisfying building operational requirements. The results showed that lighting systems, air conditioners and fans were the major energy-consuming loads. Optimization of appliance operation resulted in reductions in energy consumption across all load categories. Air-conditioning systems showed the highest energy-saving potential while lighting loads recorded substantial reductions in both energy consumption and operational costs. The study showed that MATLAB-based linear programming is an effective tool for optimizing energy consumption in institutional buildings. The developed framework provides a practical decision-support approach for reducing electricity costs and promoting sustainable energy management.

Keywords: Energy Optimization, MATLAB Simulation, Linear Programming, Sustainable Energy Management, Energy Efficiency

1.0 INTRODUCTION

In recent times, the increase in the demand for sustainable energy in institutional buildings has become a major challenge in both developed and developing countries. This is due to rapid technological advancement, increased dependence on electrical appliances and rising operational activities (Falcone, 2023). In most tertiary institutions, administrative buildings consume large amounts of energy for lighting, cooling systems, office equipment, communication devices, and other operational facilities required for effective administration (Almasri et al., 2024). However, several factors such as inefficient energy utilization, poor load management practices, and unstable power supply often result in excessive energy consumption, increased operational costs, and reduced system efficiency. In Nigeria, the problem of inadequate and unstable electricity supply has continued to affect the performance and sustainability of educational institutions. Most universities experience irregular grid supply, voltage fluctuations and increasing electricity tariffs (Bello et al., 2021). These amongst other experiences have forced institutions to adopt alternative power generation systems such as diesel generators and solar power to supplement energy demand. Over the years, there has been a growing need for sustainable electrical energy management strategies capable of minimizing energy wastage while improving system reliability and operational efficiency (Mishra and Singh, 2023).

Energy optimization has emerged as an effective approach for improving energy efficiency and reducing electricity costs in residential, commercial and institutional facilities (Diakaki et al., 2008). Optimization techniques enable efficient allocation and scheduling of electrical loads in order to achieve minimum energy consumption under defined operational constraints. Recently, mathematical modelling and computational tools such as MATLAB have gained wide applications in electrical energy analysis, simulation, forecasting, and optimization due to their flexibility, computational accuracy and their ability to handle complex engineering problems (Chukwunweike et al., 2024). Linear programming techniques, particularly the use of the Linprog optimization solver in MATLAB have proven effective for solving constrained optimization problems associated with electrical load management and energy distribution systems. Several studies have investigated energy optimization and demand-side management strategies in buildings using different optimization methods such as genetic algorithms, fuzzy logic, artificial neural networks and linear programming models (Kampelis et al., 2018). However, limited attention has been given to sustainable electrical energy optimization in institutional administrative buildings within developing countries. Particularly when under conditions of unstable grid supply and rising energy costs. Furthermore, there is insufficient integration of appliance-based energy profiling, power factor analysis, and optimization modelling within a unified framework for institutional energy management.

This study therefore focuses on the sustainable energy optimization of the Administrative Building of Joseph Sarwuan Tarka University using MATLAB-based linear programming techniques. The study evaluates the energy consumption profile of various load categories and office appliances, analyses electricity supply trends from 2020 to 2024, and investigates the relationship between reactive power and power factor within the building's electrical network.

2.0 MATERIALS AND METHODS

2.1 Study Area

This study was conducted at the Administrative Building of Joseph Sarwuan Tarka University. The building serves as the central administrative facility of the institution and accommodates several offices, conference rooms, administrative units, and service sections that require continuous electrical energy for daily operations. Electrical energy within the building is primarily utilized for lighting systems, air-conditioning units, desktop computers, printers, fans, refrigerators, photocopiers, and other office appliances necessary for administrative activities.

2.2 Data Collection

The data used for this study was obtained from the Administration Building through field measurements, equipment inventory assessment, electricity consumption records, and operational schedules of office appliances.

2.3 Energy Consumption Profiling

Energy consumption profiling was performed to evaluate the operational behaviour of electrical appliances within the building. The load demand profile was developed based on appliance operating schedules, rated capacities, and average daily usage duration. Furthermore, the relationship between power factor and reactive power within the Administration Building was investigated to assess the influence of reactive power demand on electrical system efficiency

2.4 MATLAB Modelling Approach

MATLAB R2013b was used for modelling and simulation of the electrical energy consumption characteristics of the Administration Building. The software environment was selected due to its computational efficiency, flexibility, and capability for solving engineering optimization problems. The optimization process was implemented using the Linprog solver in MATLAB. Linear programming was adopted to determine the optimal operating conditions of electrical appliances while satisfying predefined operational constraints such as appliance usage requirements, operational schedules, and load demand limitations.

The use of linprog solver was employed (See Equation 1).

$$Linprog: \frac{m}{x} \int_{x \leq ub}^{t} Such\ that\ \{A.x \leq bAeq.x = beqlb \leq x\} \quad (1)$$

- Min Etotal = i∈D∑Pi·ti·ui ENERGY
- Min Ctotal=i∈D∑Pi·ti·ui·c(t) COST

xi, t=energy consumption of appliance i during hour t

where;

i∈I{lighting, AC, fans, computers, printers, photocopier, refrigerator}

t =1,2,3…,24

Objective Function (Minimize Daily Energy Cost)

- min ∑t=1, 24 Ct (∑ix i,t) (2)

where;

Ct = electricity tariff at hour t (peak)

The Model Constrains are:

- Ax ≤ b – Operating Hours, Capacity, Demand Caps; (3)
- Aeq x = beq - Fixed Load (4)

- $Lb \leq x \leq ub$ – Appliance Power Limits (5)

To successfully optimize the necessary power consumption, all the energy loads were selected and grouped. This was due to their inherent large energy consumption which is as a result of their power factor configuration (low power factor in this case). The group includes;

a. Capacitive load: the appliances that falls into this category are Lightening bulbs, computer power packs, printer, photocopier
b. Inductive load: the appliances that fall into this category are television, air conditioner and fan.

3.0 RESULT AND DISCUSSIONS

3.1 Energy Consumption per Load Type

The energy consumption within the administrative building before optimization (kwh1) and after optimization (kwh2) is shown in Figure 1. The results showed variations in energy demand among the different load categories explored. This indicated the differences in the appliance ratings, operating durations and utilization patterns. Before optimization, air-conditioning systems recorded the highest energy consumption (approximately 33,000 kWh). A phenomenon which can be attributed to the relatively large power ratings of the units and their prolonged daily operation to maintain thermal comfort within offices (Aria and Akbari, 2014). The lighting systems on the other hand recorded the second-largest energy consumption (approximately 20,500 kWh). This can be attributed to the continuous illumination requirement during working hours spanning from the large number of offices, corridors, meeting rooms, and administrative spaces. Although individual lighting fixtures possess relatively low power ratings, their cumulative energy demand becomes substantial when operated for extended periods (Sharif and Hammad, 2019). Fan loads recorded approximately 12,200 kWh, indicating their extensive utilization as supplementary cooling devices. Furthermore, printers and photocopiers consumed approximately 7,700 kWh and 7,200 kWh respectively. This shows their contribution to total building energy demand. Refrigerators, computers, and televisions recorded smaller energy consumption values. However, their contribution remains important due to continuous or routine operation.

After optimization, reductions were observed across all load categories. A 74% energy reduction was recorded for the air-conditioning energy demand (that is from approximately 33,000 kWh to about 8,600 kWh). This improvement indicates that a considerable portion of the initial energy consumption was associated with inefficient operating schedules and unnecessary equipment runtime. The optimization algorithm effectively minimized these inefficiencies by allocating operating periods more efficiently. Similarly, fan energy consumption reduced from approximately 12,200 kWh to 3,200 kWh, while lighting energy demand declined from about 20,500 kWh to 11,800 kWh. The reductions observed demonstrate that optimization-based energy management strategies can significantly improve building energy performance without necessarily compromising occupant comfort or administrative productivity (Hossian et al., 2023).

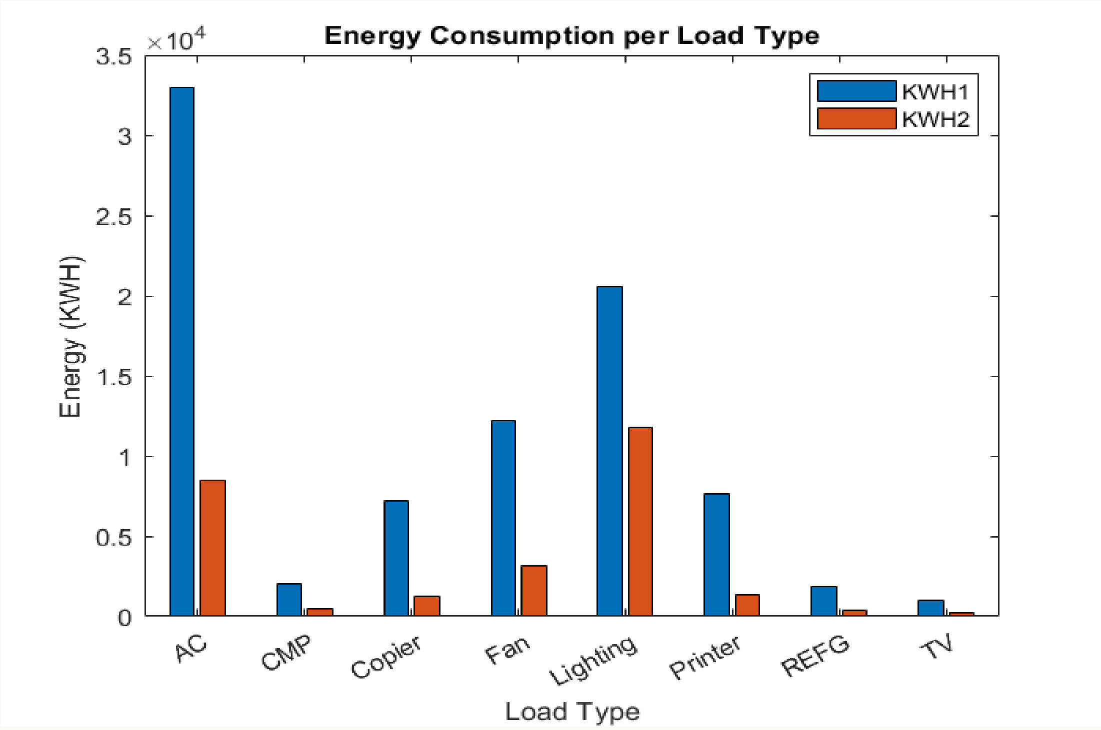

Figure 1: Energy Consumption Per Load Type

The results confirm the effectiveness of MATLAB-based linear programming in identifying optimal load operating conditions capable of minimizing overall electricity consumption. Furthermore, the findings suggest that the greatest energy-saving opportunities exist within cooling and lighting systems, which collectively account for the majority of the building's electricity demand.

3.2 Energy Consumption Profile per Office Appliances

Figure 2 presents the energy consumption profile of the major office appliances under sub-optimal and optimal power factor operating conditions. The results reveal that lighting systems constitute the largest energy-consuming load within the Administration Building, recording an energy consumption of approximately 20,500 kWh/month under sub-optimal power factor conditions. Following optimization, the energy consumption reduced to approximately 12,200 kWh/month (that is about 40.5%. reduction). Air-conditioning units recorded the second-highest energy demand decreasing from approximately 10,500 kWh/month under sub-optimal conditions to about 8,900 kWh/month after optimization. The relatively high energy consumption associated with air conditioners can be attributed to their continuous operation and high-power ratings, particularly under the climatic conditions of Makurdi where cooling requirements are substantial throughout much of the year. (Ni and Bai, 2017).

Fan loads exhibited a considerable reduction from approximately 4,800 kWh/month to 3,200 kWh/month following optimization. Similarly, printers and photocopiers recorded noticeable decreases in energy consumption, indicating that optimization measures improved the operational efficiency of office equipment. Refrigerators, televisions and computers consumed comparatively lower amounts of energy. However, reductions were still observed after optimization.

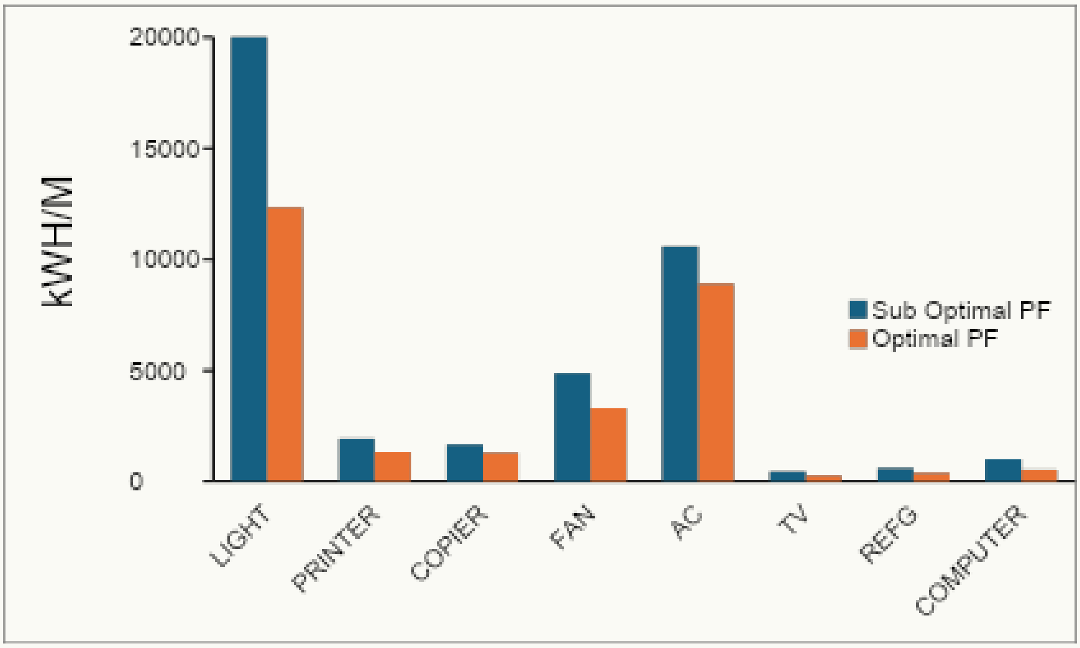

Fig 2: Energy Consumption Profile per Office Appliances

The overall decrease in energy consumption across all appliance categories demonstrates the effectiveness of power factor improvement and load optimization in reducing electricity demand (Avordeh et al., 2022). The results further indicate that lighting and air-conditioning systems possess the highest energy-saving potential and should therefore receive priority consideration in future energy management initiatives. The observed reductions can be attributed to improved utilization of electrical power, minimization of reactive power losses, and enhanced load scheduling achieved through the MATLAB-based optimization framework. These findings suggest that institutional buildings can achieve substantial energy savings without compromising operational functionality when effective energy management strategies are implemented.

3.3 Electricity Cost for Each Appliance

Figure 3 illustrates the monthly electricity cost associated with the operation of various office appliances under sub-optimal and optimal power factor conditions. The results reveal a direct relationship between appliance energy consumption and electricity expenditure. Lighting systems incurred the highest electricity cost, amounting to approximately ₦530,000 under sub-optimal operating conditions. Following optimization, the cost reduced significantly to approximately ₦320,000, representing a reduction of nearly 40%. This substantial decrease highlights the economic benefits associated with energy-efficient operation and improved power factor management (Dashtaki et al., 2022). Air-conditioning systems represented the second-largest contributor to electricity expenditure, with operational costs reducing from approximately ₦275,000 to ₦230,000 after optimization. Fan loads similarly exhibited a notable reduction in cost from approximately ₦128,000 to ₦88,000. Printers and photocopiers also experienced significant decreases in operational expenses, further demonstrating the effectiveness of the optimization strategy.

Computers, refrigerators, and televisions accounted for relatively smaller portions of the total electricity expenditure. Nevertheless, the cumulative savings achieved across these appliances contribute meaningfully to overall reductions in building operating costs. The reduction in electricity cost observed after optimization can be linked to improved power factor conditions, reduced reactive power demand, and more efficient allocation of electrical loads. Improved power factor reduces current demand for the same useful power output, thereby minimizing electrical losses and lowering energy-related costs. From an economic perspective, the results demonstrate that optimization-based energy management can generate substantial financial savings for tertiary institutions. Such savings may be redirected toward infrastructure development, equipment upgrades, and other institutional priorities. The findings therefore underscore the importance of integrating energy optimization practices into institutional energy management policies.

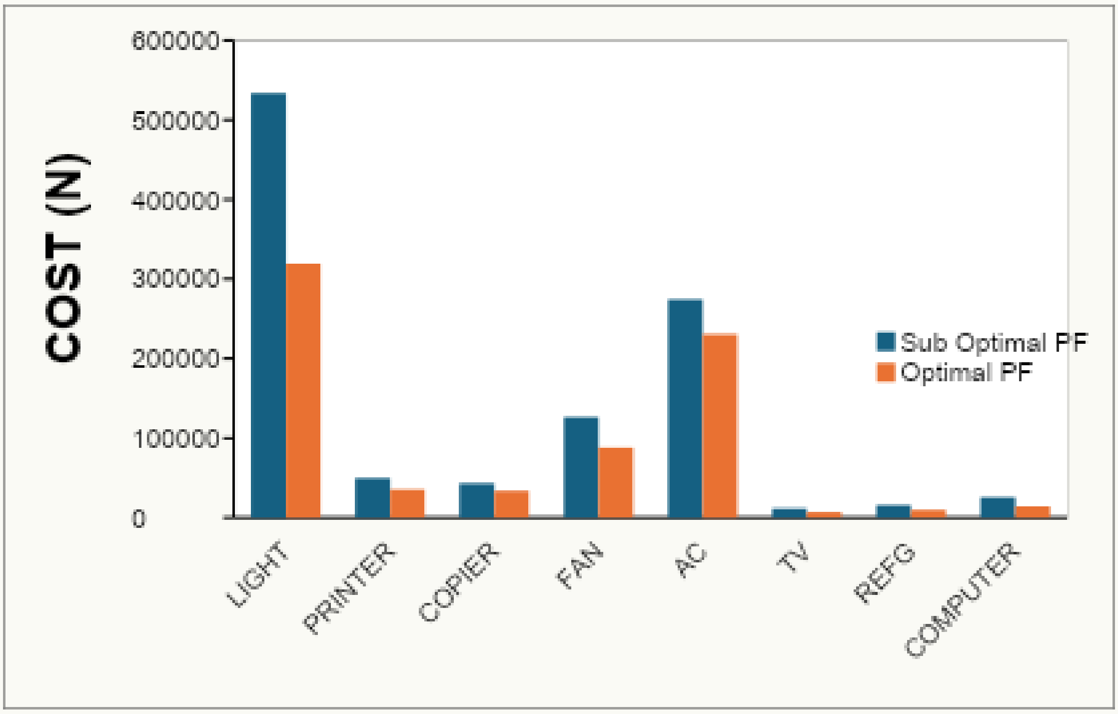

Figure 3: Electricity Cost for Each Appliance

3.4 Simulation and Optimization for O_1 and O_2

The simulation and optimization results obtained for Objective Function O_1 across the various load categories showed consistent improvements in the performance index (see Figure 4). For air-conditioning systems, the O_1 value increased from approximately 0.80 to 0.83 after optimization. Similar improvements were observed for computers, where the value increased from about 0.52 to 0.56, and for photocopiers which improved from approximately 0.74 to 0.78. Fan systems exhibited an increase from 0.64 to 0.67 while lighting loads improved from approximately 0.57 to 0.62. Furthermore, printer loads recorded one of the largest improvements (increasing from approximately 0.68 to 0.72). Refrigerators and television systems also experienced positive changes (increasing from 0.60 to 0.63 and from 0.57 to 0.61 respectively). The consistent enhancement across all load categories indicates that the optimization framework was capable of improving operational efficiency regardless of appliance type.

The average improvement achieved under O_1 was approximately 5–9%, depending on the load category. Although the magnitude of improvement appears moderate, the cumulative effect across all appliances can result in substantial reductions in annual energy consumption and operating costs. The results show that the optimization algorithm effectively improved load utilization while maintaining operational requirements within the building. Furthermore, the relatively larger improvements observed for lighting and computer systems suggest that these loads possess greater flexibility for optimization through operational scheduling and demand management techniques.

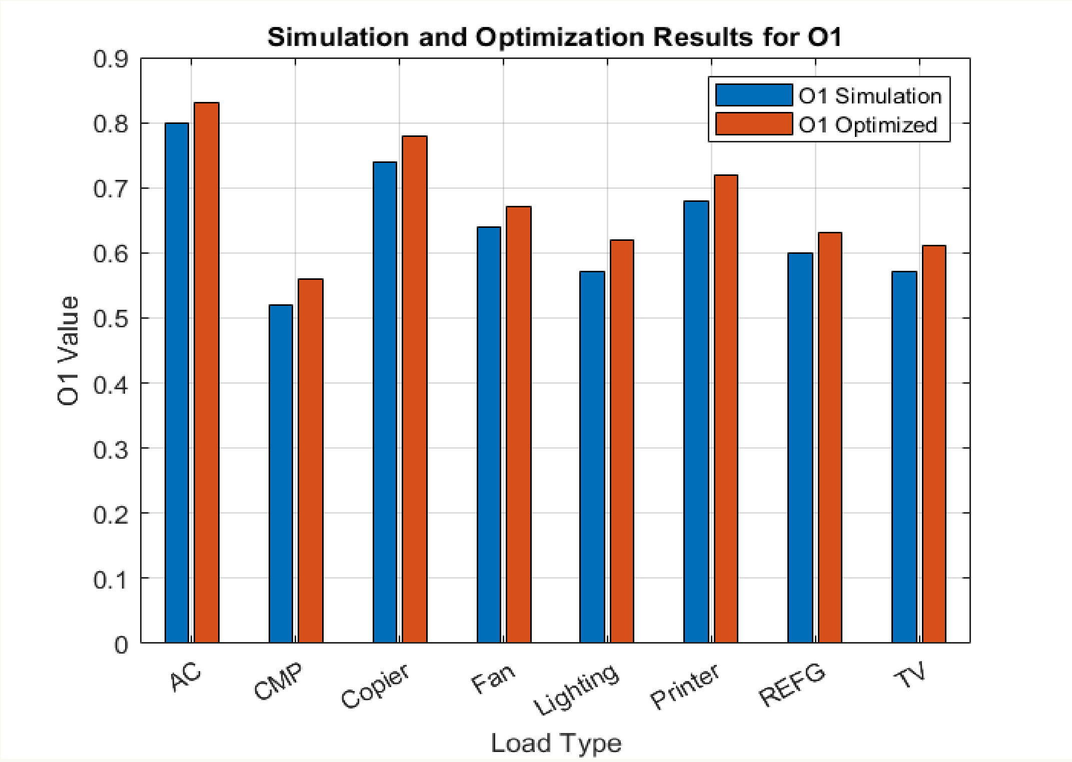

Figure 4: Simulation and Optimization O1

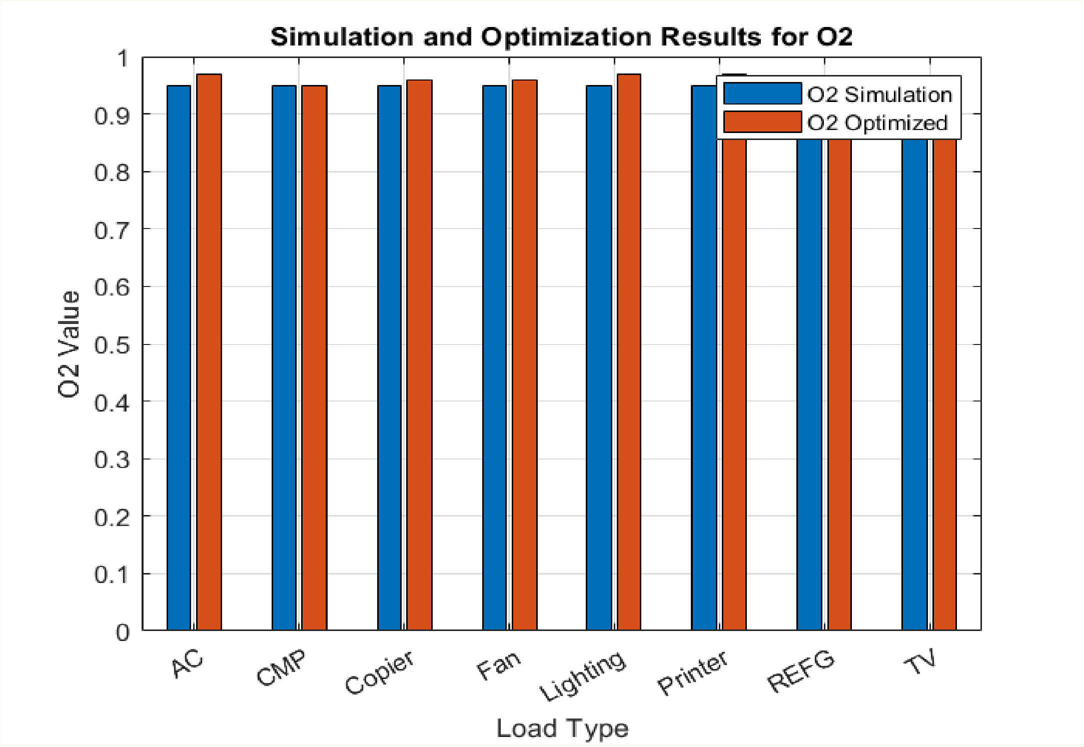

Figure 5: Simulation and Optimization O2

On the other hand, figure 5 presents the simulation and optimization results for Objective Function O_2. Unlike O_1, the O_2 values were already relatively high before optimization, with most load categories exhibiting values close to 0.95. However, further improvements were achieved after optimization thereby enhancing the system performance. Air-conditioning systems improved from approximately 0.95 to 0.97, while photocopiers increased from approximately 0.95 to 0.96. Lighting loads improved from 0.95 to 0.97, and printer systems increased from approximately 0.95 to 0.97. Refrigerators and television systems also recorded slight but consistent improvements. The smaller improvements observed for O_2 compared with O_1 are expected because the baseline values were already close to the upper performance limit. In optimization studies, improvements become increasingly difficult to achieve as the system approaches optimal operating conditions.

3.5 Percentage Energy Savings for Each Appliance

The percentage energy savings analysis revealed varying levels of energy reduction among the different appliances after optimization. Air-conditioning systems achieved the highest energy savings due to improved operational scheduling and reduced unnecessary operating periods. Lighting systems also recorded significant energy savings following optimization of operational duration and improved load management. Desktop computers, printers, photocopiers, and fans exhibited moderate reductions in energy consumption after optimization. Appliances with continuous operational patterns such as refrigerators showed relatively smaller percentage savings due to their essential operational requirements.

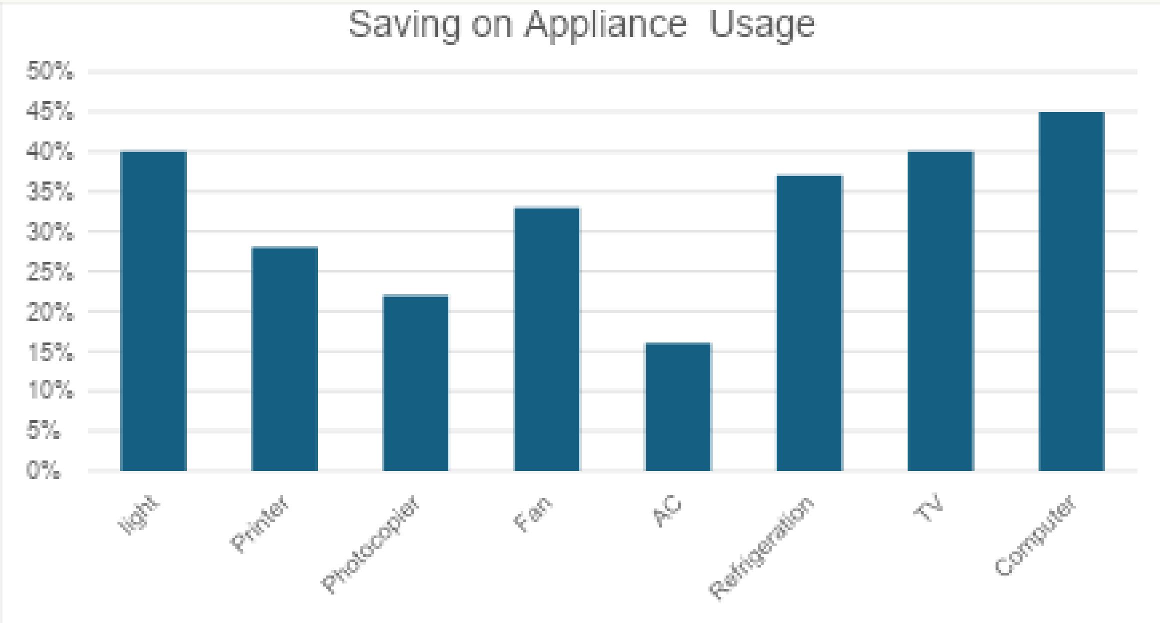

Figure 6: Percentage Energy Savings for Each Appliance

The results demonstrated that substantial reductions in institutional electricity consumption can be achieved through appliance-level optimization and effective load management strategies. The overall percentage energy savings confirmed the effectiveness of the developed MATLAB-based optimization model for sustainable electrical energy management in institutional administrative buildings.

4. CONCLUSION

This study developed a MATLAB-based linear programming framework for sustainable electrical energy optimization in the Administration Building of Joseph Sarwuan Tarka University. The results revealed that lighting systems, air-conditioning units, and fan loads were the major contributors to the building's electricity consumption and operational costs. Energy consumption profiling and cost analysis provided a clear understanding of appliance-level energy demand and identified significant opportunities for energy conservation.

The optimization results obtained from Objective Functions O1 and O2 demonstrated the effectiveness of the proposed framework in reducing energy consumption and electricity costs while maintaining operational requirements. The achieved energy savings confirm that MATLAB-based linear programming is a practical and reliable tool for improving energy efficiency and supporting sustainable energy management in institutional buildings. The framework can serve as a decision-support tool for facility managers and may be extended to other university and public-sector buildings seeking to enhance energy performance and reduce operating expenses.

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