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Economic and Environmental Impact of IoT in the Energy Sector: A Study on Commercial and Residential Buildings in Bangladesh

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Abstract

Purpose*—In Bangladesh, where both commercial and residential buildings contribute significantly to energy demand, IoT solutions are gaining popularity. The study aims to determine the economic and environmental impact of the Internet of Things (IoT) in Bangladesh's energy sector.*

Design/Methodology/Approach*—This study employs an experimental research design, collecting data through observations and experiments in a specific office building setting between March and October 2019.*

Findings *– In March 2019, total electricity consumption was 231.73 kWh in four different upazilas of Khulna district, with the AC set to 20°C. Setting the AC to 24°C or 25°C can save 20-30% of energy, saving approximately 664 kWh from March to October. With 80% AC demand, the total energy saved amounts to 107,342,800 kWh, reducing about 129,885 tons of CO2 emissions.*

Research Implications*—The study enhances the understanding of IoT's role in optimizing energy use and reducing CO_2 emissions in property management.*

Practical Implications*—This study offers useful insights into adopting IoT to improve energy efficiency, lower costs, and promote sustainability.*

Originality/Value *– This research uniquely addresses IoT's impact on energy management in Bangladesh, highlighting its economic and environmental benefits.*

Keywords: IoT, sustainability, green energy, efficiency, eco-friendly, carbon emissions

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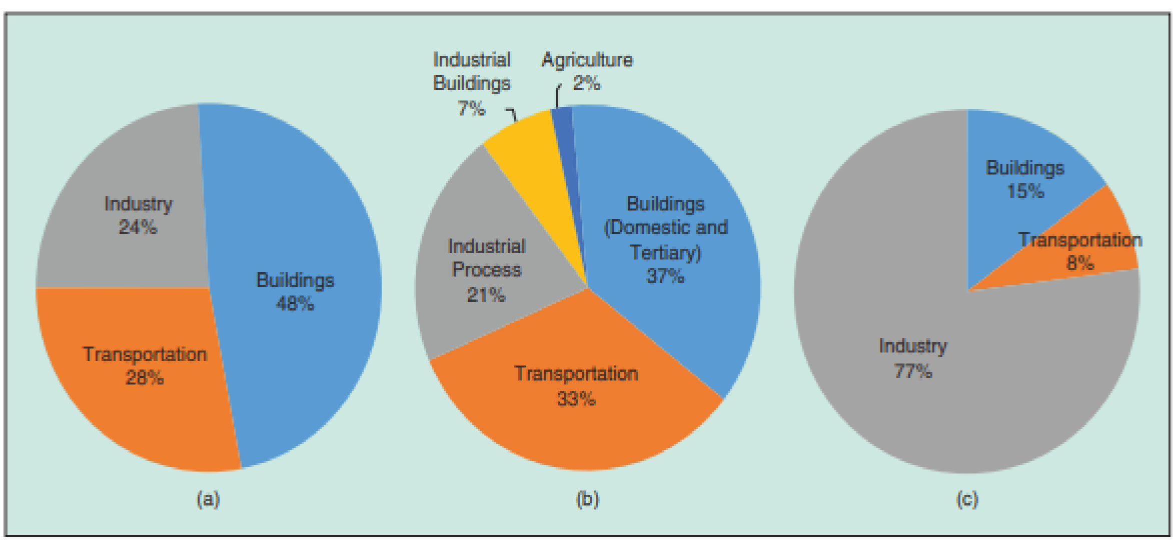
1. Introduction

Over the past decade, there has been a significant rise in energy consumption in buildings due to population growth, demand for building services and environmental quality, and global climate change. Buildings consume more than 40% of total primary energy in the US and EU (Cao *et al.*, 2016). Considerable energy savings may be accomplished in buildings if they are properly designed, built, and operated. Building energy efficiency may address energy shortages and carbon emissions, which pose a severe challenge to the environment (Santamouris and Vasilakopoulou, 2021). The Internet of Things (IoT) has emerged as a transformative technology across various industries. IoT has revolutionized the way commercial and residential buildings operate, particularly in energy management (Mathupriya *et al.*, 2020). By providing real-time data on consumption patterns, this system leads to more informed decision-making and automated adjustments based on usage. IoT systems can facilitate predictive maintenance, reducing downtime and costs associated with energy infrastructure. IoT in energy systems can lead to improvement in energy efficiency through real-time monitoring and predictive analytics (Borba *et al.*, 2019). IoT also has the potential to significantly reduce carbon emissions by optimizing energy use and integrating renewable energy sources. According to a report by the International Energy Agency (IEA), the widespread adoption of IoT in energy management could reduce global energy-related carbon emissions by up to 15% by 2040. Because of the high energy consumption, as shown in Figure 1, the building sector can provide the greatest potential for delivering significant cuts in emissions and costs globally (Yu, 2020).



Source: Yu (2020)

Figure 1: The energy consumption by sector for (a) the United States, (b) the European Union, and (c) China

Energy consumption in Bangladesh has been rapidly increasing due to industrialization, urbanization, and rising household demand (Figure 2). Electricity consumption grew from around 31 terawatt-hours (TWh) in 2010 to over 90 TWh in 2023, with the government achieving an electrification rate exceeding 97% (Uddin *et al*., 2019). This surge in demand has put immense pressure on the country's energy infrastructure, which is heavily reliant on natural gas, accounting for over 60% of electricity generation. However, depleting domestic gas reserves has led to increased reliance on imported liquefied natural gas (LNG) and coal, raising concerns over energy security and environmental sustainability (Islam *et al*., 2014).

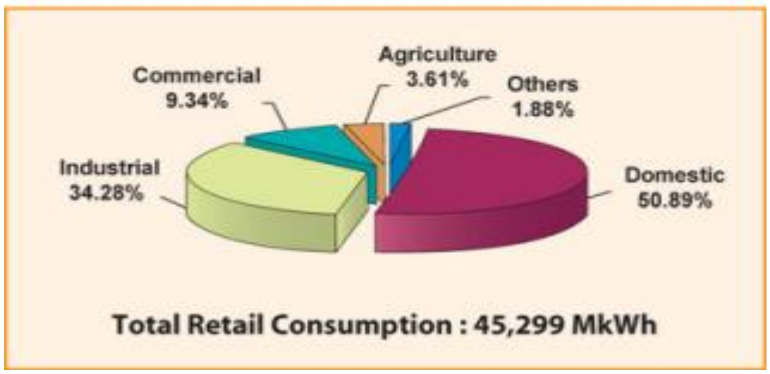


Figure 2: Sector-wise energy consumption in Bangladesh

Source: BPDB

Despite government efforts to promote renewable energy, solar and wind power contribute less than 5% to the energy mix, underscoring the need for greater diversification. The commercial and residential sectors are among the largest consumers of electricity (Halder *et al*., 2015). In commercial buildings, energy demand has surged due to the expansion of service industries, while in residential areas, the increasing use of air conditioners and modern appliances has significantly raised electricity usage (Islam and Khan, 2017). According to the Sustainable and Renewable Energy Development Authority (SREDA), air conditioning accounts for up to 50% of total energy consumption in urban households during peak summer months, further straining the power grid. One of the key challenges Bangladesh faces is energy inefficiency, with transmission and distribution (T&D) losses estimated at 10-12%, well above global averages

(Abdulrazak *et al.*, 2021). These losses highlight the need for modernization, and the Internet of Things (IoT) presents a promising solution. IoT technologies, including smart meters and connected devices, can optimize energy consumption by providing real-time data, predictive maintenance, and automated control to reduce energy waste and costs (Wei *et al.*, 2016). IoT adoption in commercial and residential buildings can also enhance energy efficiency by allowing users to monitor and adjust their energy use dynamically (Siddique *et al.*, 2021). To tackle these issues, the Bangladesh government has launched several initiatives aimed at improving energy sustainability. Vision 2041, for instance, targets generating 40% of the country's electricity from renewable sources by 2041, with solar power expected to play a pivotal role. The National Solar Energy Action Plan seeks to generate 4,000 megawatts (MW) of electricity from solar by 2030 (Hasan *et al*., 2019). As energy demand continues to rise, leveraging IoT technologies could significantly contribute to optimizing energy use and reducing both economic costs and environmental impacts (Marinakis and Doukas, 2018). Integration of IoT into the energy management of commercial and residential buildings can provide the opportunity to address energy inefficiencies (Mahbub, 2020). This dual focus on economic and environmental benefits underscores the critical role IoT can play in ensuring a greener, more efficient energy future for the country (Joshua, 2020).

In Bangladesh, where both commercial and residential buildings contribute significantly to energy demand, the adoption of IoT solutions is gaining momentum. IoT devices and systems can provide real-time data monitoring, automated energy management, and predictive maintenance, leading to substantial reductions in energy waste and costs (Singh et al., 2022). The integration of IoT systems in smart buildings could contribute to the country's commitment to environmental sustainability, as outlined in its Intended Nationally Determined Contributions (INDCs) to the Paris Agreement. With commercial and residential buildings responsible for a large share of energy consumption, leveraging IoT offers a clear path toward a greener energy future (Alsamhi *et al*., 2019). This study explores the dual impact of IoT in Bangladesh's energy sector, focusing on economic benefits, such as cost savings and enhanced energy efficiency, and environmental advantages, including reduced carbon emissions and conservation of natural resources. As energy demand continues to grow with the country's economic development, integrating IoT in both commercial and residential buildings presents an opportunity to address sustainability challenges while promoting smarter, greener energy use. This study aims to provide insights into the potential of IoT to revolutionize energy management in Bangladesh and contribute to broader goals of sustainable development.

2. Literature Review

Several studies provided an analysis of the possible economic benefits of IoT solutions in the energy field, with special emphasis on cost reduction as a result of increased efficiency in the energy sector (Ntafalias *et al.*, 2024). Smart metering, smart thermostats, and smart sensors designed in the field of IoT help observe and regulate the usage of power in a real-time network (Rohayani *et a*l., 2024). These devices help control energy consumption, hence minimizing wastage and, consequently, the costs incurred. In small commercial buildings, it was observed that the installation of an IoT-based energy management system could cut operational costs by about 30% (Shrouf *et al*., 2014). This efficiency is achieved through the timing of energy usage during periods of peak demand and low usage, the use of automation and other effective features, and the anticipation and control of equipment failures, hence avoiding the need for expensive repairs (Syed *et al*., 2021). The economic benefits of IoT in the context of energy applications, cost-effectiveness, and frequent ROI forecasts for both the producers' and the consumers' side have been pointed out. IoT devices are financially effective by using less energy in the long run and sparing appliances from premature wear through proper monitoring (Houston *et al*., 2017). According to Mehmood *et al*. (2017), although IoT requires a huge initial investment in infrastructure, the cost of overhead could be recovered from the bills of energy in two to three years. In the industrial segment, IoT-based preventive maintenance management enables a 20–50% decrease in production downtime, which leads to economic benefits (Syah., 2016).

IoT continues to disrupt industries characterized by rigid structures in one way or another by creating new business models, such as energy as a service (EssaS). EaaS makes it possible for companies to sell management of energy through IoT data based on service rather than ownership of the energy infrastructure (Hastik *et al*., 2015). This shift minimizes initial capital investment requirements from the business side while enabling energy service providers to grow their enterprises exponentially (Jonsson *et al*., 2011). IoT also favors distributed generation, like microgrids, that would allow communities or companies to produce and regulate their power more efficiently. In terms of impacts, it is the saving of energy in the energy sector that is affected through IoT technology, resulting in the lowering of carbon footprints. IoT enables more exact control of energy consumption to eliminate losses (Anthony Jnr., 2021). Smart grids and smart meters enable the user to manage and control their consumption in real-time, therefore reducing the overall demand. IoT-type systems can minimize global energy use by up to 15% by the year 2030 (Mehmood *et al*., 2017). All these cuts bear a direct proportion to the reduction of carbon footprint in residential as well as commercial facilities (Hossein *et al*., 2020).

Reducing the dependency on non-renewable energy sources is critical, where IoT has a particularly important role. In this solution, IoT enables users to specifically manage and enhance the operations of renewable energy structures like solar power plants and wind power plants (Bedi *et al*., 2018). Pahuja and Kumar (2024) reflected that IoT-integrated energy management systems could monitor energy generation and utilization for the give-and-take of renewable energy. These systems also assist in the management of variability, which is a major issue of the integration of renewable electricity into existing grid infrastructures. Intelligent energy storage, in addition to distribution through IoT, enhances energy sustainability (Arshad *et al*., 2017). IoT has the potential to contribute to the fight against climate change and hence acts as an advantage to the environment.

Thus, IoT technologies become effective in reducing greenhouse gas emissions by maximizing energy usage as well as encouraging the efficiency of the same (Liu and Ansari, 2019). Smart grids based on IoT can decrease greenhouse gas emissions by 12 percent in developed countries by 2030. In addition, through IoT, energy systems help monitor energy consumption patterns that can help policymakers devise measures that can decrease emissions even further (Adhikari and Gianey, 2019). This is especially important now, particularly when the whole world is in the process of trying to reverse global warming. The higher initial cost is needed to support IoT despite apparent economic and environmental gains in the long run. Some of the main issues associated with the smart-metabolization of IoT technologies often stem from the inability of entrepreneurs and consumers to invest in connected devices because of the costs of purchasing and installing connected devices (Abir *et al*., 2021). Besides, to maintain the smooth working of IoT systems, continuous upgrades are needed, while software updates come with additional expenses. Bedi *et al.* (2016) have shown that if the government does not incentivize the use of IoT or provide subsidies, then the energy sector may not increase the IoT adoption rate, particularly in the developing world.

The vast amounts of data generated by IoT devices raise concerns regarding privacy and security (Jayakumar *et al*., 2016). IoT systems in the energy sector collect sensitive information about energy consumption patterns, which could lead to privacy breaches if accessed by unauthorized parties. There are also concerns about IoT systems' security, as they are susceptible to hacking and cyber-attacks (Moudgil *et al*., 2023). Moness and Moustafa (2016) highlighted the need for robust cybersecurity measures to protect IoT infrastructure from potential threats. Ensuring the security and privacy of IoT data is critical to gaining user trust and promoting widespread adoption (Miorandi *et al*., 2022).

The future of IoT in the energy sector, particularly in residential and commercial buildings, is poised for significant advancements (Mishra *et al*., 2022). The expansion of intelligent energy grids. IoT will enable two-way communication between energy producers and consumers, allowing for real-time monitoring and management of energy consumption. This means that buildings can adjust their energy usage dynamically based on pricing, demand, and availability of renewable energy, optimizing overall efficiency and reducing costs (Nizetic *et al.*, 2020). Another significant trend is the deeper integration of IoT with renewable energy sources, such as solar panels and energy storage systems (Bekara, 2014).

IoT can manage these systems in both residential and commercial settings to ensure that energy is used optimally and stored when necessary. This will help reduce dependency on the traditional power grid and increase the use of cleaner, renewable energy sources (Farhan *et al*., 2018). The use of predictive analytics and machine learning will also grow. IoT devices will continuously collect and analyze data on energy usage, allowing systems to predict future energy needs and identify inefficiencies. IoT sensors in buildings can anticipate changes in energy demand and adjust HVAC or lighting systems in real time, improving energy efficiency and reducing waste (Wei *et al*., 2017). Building automation will become more advanced, and IoT systems will control energy use based on real-time data from sensors (El-Afifi *et al*., 2024).

Heating, cooling, lighting, and even appliances automatically adjust according to occupancy, weather, and other factors, ensuring energy is used only when and where needed. Edge computing will enhance the responsiveness of IoT systems by processing data locally rather than sending it to a central server (Sarkar and Debnath, 2021). This allows faster decision-making and improves the efficiency of energy management systems, particularly in large commercial buildings (Verma and Prakash, 2019). Additionally, it will strengthen the cybersecurity of IoT networks by reducing vulnerabilities. IoT will play a crucial role in sustainability efforts. It will monitor the condition and lifecycle of building materials and energy systems, encouraging maintenance, recycling, and reduced waste. IoT can track resource usage in commercial buildings, helping businesses meet sustainability goals by reducing energy consumption and minimizing their environmental impact (Alcaraz *et a*l., 2023).

3. Material and methods

In this study, the exploratory research method is applied to analyze the economic and environmental consequences of IoT in the energy sector of commercial and residential buildings in Bangladesh. The study employs an experimental research design; the study collects data both through observations and experiential experiments to capture real-world total energy consumption as affected by IoT technologies. The research collects cross-domain data from building data, energy price data, meteorological parameters, and end-user data. Data were collected from a specific office building setting between March and October 2019. The schedule was selected with a focus on seasonal changes, as the period that was chosen may greatly influence the energetic consumption in the building because of the conditions, including temperature, humidity, and light.

There were different IoT devices, which included sensors for monitoring heating, cooling, lighting systems, and overall electrical power intake of Acs in the buildings. IoT devices offered actual time consumption information about energy, which was recorded and analyzed consistently (Figure 3). Different types of sensors are required to capture various parameters for effective monitoring of ACs. Temperature sensors capture the ambient and output air temperature to maintain the desired level of cooling. Humidity sensors are equally important, as

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they track indoor humidity levels to ensure comfort and energy efficiency at an optimum. Air quality sensors monitor pollutants, CO_2, and other parameters that help maintain a healthier indoor environment. Energy consumption sensors provide valuable inputs on the power usage of AC units, thus helping in efficiency and cost improvements. Pressure sensors measure refrigerant pressure to identify possible leaks or inefficiencies within the system. Besides, vibration sensors detect abnormal vibrations in compressors and fans, which could mean the call for maintenance to prevent breakdown. All these sensors combined allow for comprehensive monitoring and management of AC systems in buildings.

The experiments were conducted in a controlled office environment equipped with IoT-based energy management systems, including smart meters, thermostats, and energy-efficient lighting systems in four different upazilas of the Khulna district. The building's energy consumption was monitored before and after the installation of IoT systems to assess the difference in energy usage and efficiency. The office was divided into different zones, with IoT devices installed in each zone to capture energy data based on room occupancy, lighting usage, and temperature settings. These zones, as shown in Figure 4, represented different office activities and energy usage patterns to ensure a comprehensive analysis.

The data were collected in conjunction with external variables such as energy prices and weather parameters. Energy prices were obtained from local utility providers to observe how the integration of IoT can optimize energy consumption based on dynamic pricing models. Weather data, such as temperature, humidity, and solar radiation, were collected through nearby weather stations to assess the influence of external environmental factors on energy consumption. By linking the building data with weather information, the study aimed to explore the potential of IoT systems to optimize energy use according to real-time weather conditions. In addition to experimental data, observations were conducted to understand end-user behavior and its impact on energy consumption. User interactions with IoT devices, such as smart thermostats and lighting systems, were observed and recorded to analyze how user behavior influenced energy usage patterns.

The study observed how users adjusted the devices in response to changing weather conditions, office occupancy, or other factors. Interviews were also conducted with the employees of BREB

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(Bangladesh Rural Electrician Board) to get the demand estimation information. These observational data were crucial for understanding the behavioral dimension of energy efficiency, which is an integral part of IoT's potential for reducing energy consumption. In this research, graphical data presentations were used to visually represent the findings. Various charts, graphs, and visualizations were employed to depict energy consumption patterns, the impact of IoT technologies on energy efficiency, and the relationships between variables such as energy prices, weather conditions, and user behavior. These graphical presentations helped to simplify complex data and provided a clear, visual comparison of energy usage before and after the implementation of IoT systems.

Figure 3: Installation of IoT systems in office room

Figure 4: Map of Khulna District and its' upazilas

4. Result and discussion

From Table 1, it can be found that July is the month that consumes the most power by ACs, and October is the lowest power consumption month. The maximum power saving took place in July, which saved 100 kWh for 25-degree settings and 75.6 kWh for 24-degree settings. Whereas the lowest saving took place in October for both 24—and 25-degree settings. So, it is concluded that significant power savings can be ensured if we keep the AC's temperature at 25 degrees.

Table 1: Experiment Data during March-October/2019

Month	No of Days	Consumption on set Temperature(kWh)			Savings(kWh)	
		20°	24°	25°	24°	25°
March	20	231.73	166.9	153.9	64.83	77.83
April	20	301.88	230.64	215.54	71.24	86.34
May	20	296.80	223.96	215.41	72.84	81.39
June	20	308.41	235.9	222.25	72.51	86.16

July	20	311.72	235.76	211.72	75.96	100
August	20	299.25	243.7	215.05	55.55	84.2
Sept	20	244.22	186.73	163.34	57.49	80.88
Oct	20	230.2	173.63	165.5	56.57	64.7

4.1 Preferred set temperatures by users

Various AC users in different offices have been observed between March-October in 2019. The offices include banks, universities, mobile phone operators, etc. They are mainly manager, professors, or marketing area/zonal managers. The following diagram shows the average set temperature for each month in 2019. The figure also shows that in July and August, users normally set lower temperatures, while in March and October, users set a bit higher temperature for their comfort, as shown in Figure 5.

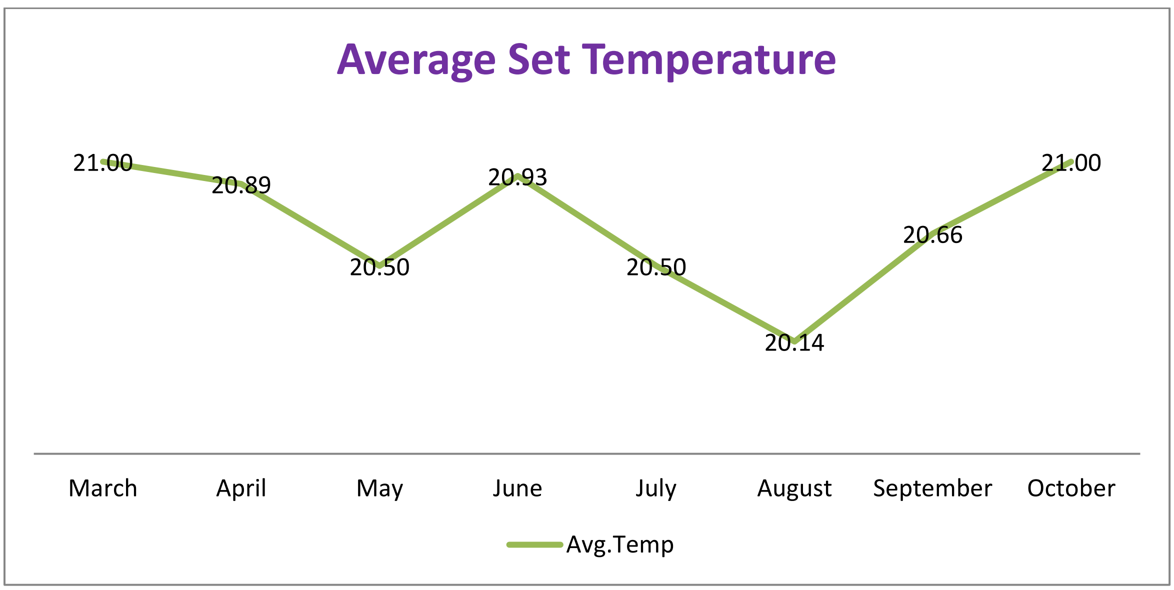

Figure 5: Avg. Set temperature

4.2 Power consumption in various modes

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The total electricity consumption in March for the baseline year 2019 was 231.73 kWh when AC's Temperature was set at 20 C. Experiments have been conducted on three modes i.e. luxury, moderate, and frugal state and it is observed that power consumption is lower if we set the temperature at 24 or 25 degrees than the three modes as shown in Figures 6 and 7.

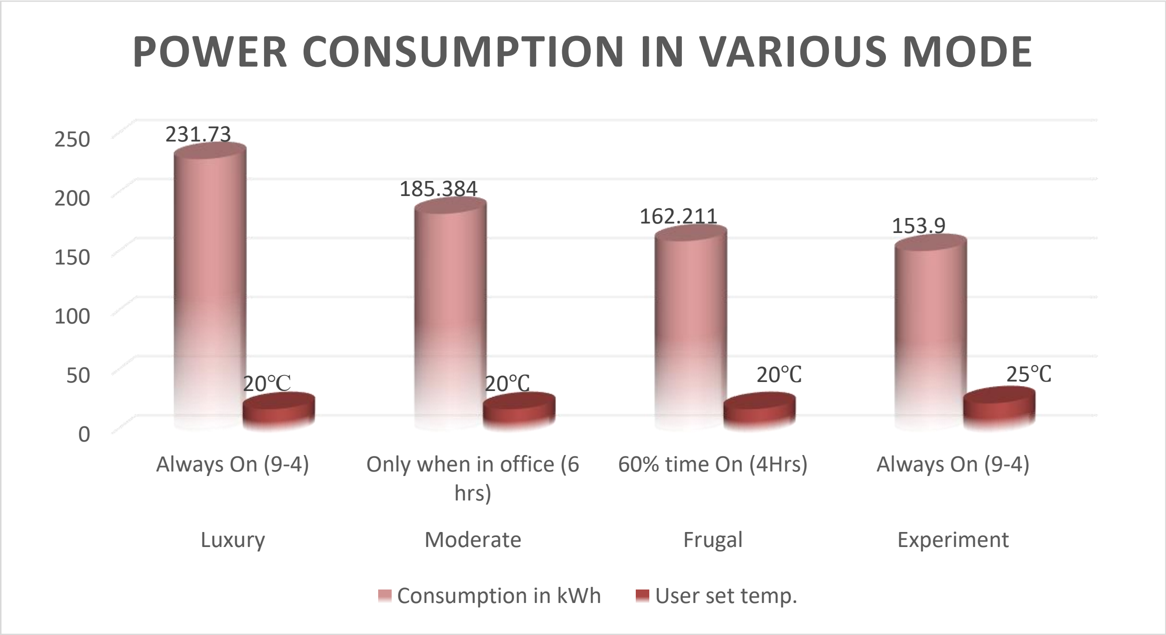

Figure 6: Power consumption in various modes

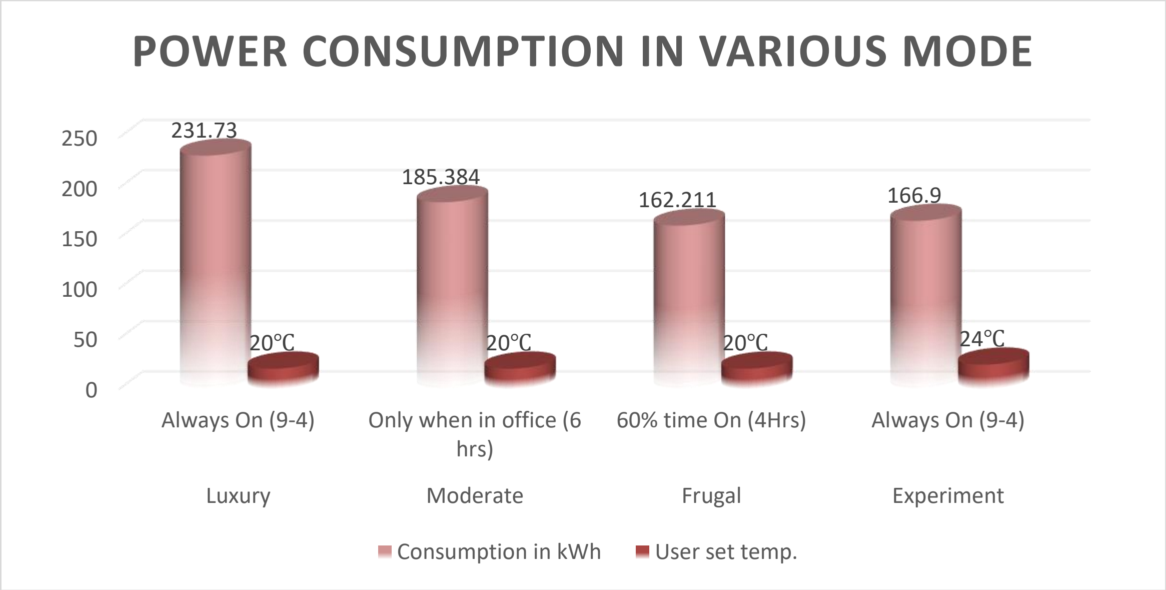

Figure 7: Power consumption in various modes

It was also found that a single AC if it is set to 25 degrees, can save like 664 kWh of energy from March to October, as shown in Figure 8. Based on the findings it can be calculated total savings in Bangladesh concerning the annual demand of AC.

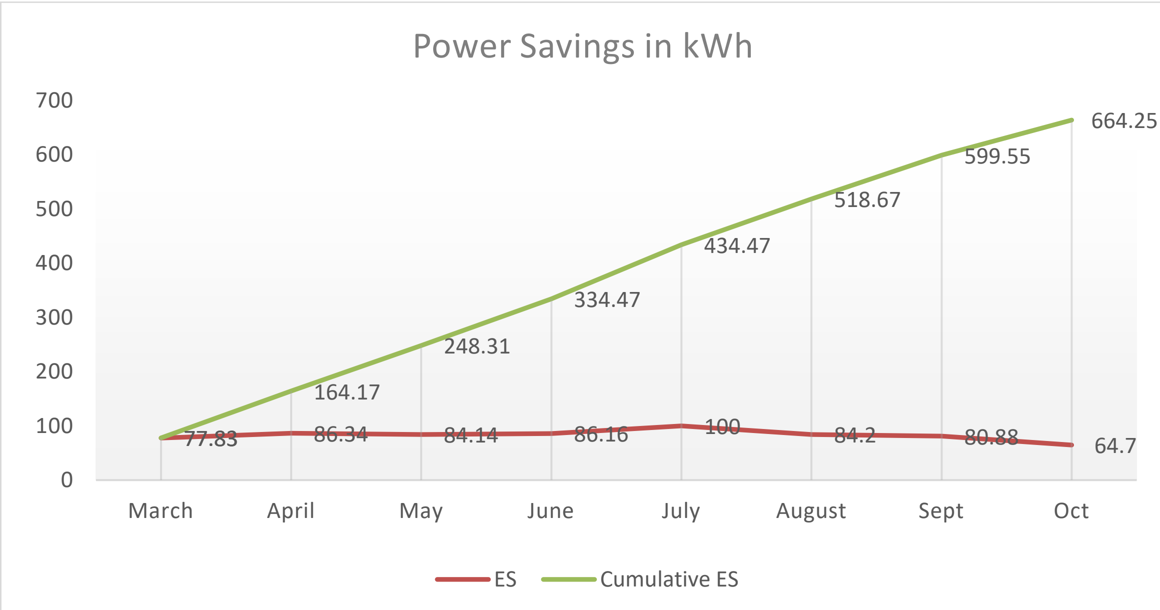

Figure 8: Power Savings when AC is set to 25 degrees from March-October/19 by Single AC

4.3 Impact of IoT for a certain percentage of annual demand for AC

Table 2 shows four selected upazilas in Khulna district and their power consumption in both peak and off-peak demand. It also shows the total number of subscribers and electricity demand in each Upazilla. The data have been collected through interaction with a field-level employee of Bangladesh Rural Electrical Board.

Table 2: Daily electricity demand in selected upazilas of Khulna district

Upazila	Peak Demand (MW)	Off-peak demand (MW)	Avg. Demand (MW)	No of Subscribers
Paikgacha	9	6	7.5	55000
Rupsha	10	5	7.5	35000
Koyra	9	4	6.5	30000
Terokhada	7	4	5.5	32000

Source: Interview with a field-level employee of Bangladesh Rural Electrical Board (BREB)

From Table 3 in 2018, AC demand in Bangladesh was 202000 units (approximately) as per the Japan Refrigeration and Air Conditioning Industry Association (JRAIA). If we consider only 70% of AC demand then in March saved energy can be used for 55 more upazilas of Bangladesh. The result is significant as it helps to supply electricity in some new areas that are not under electricity coverage as shown in Table 4.

Table 3: National AC demand among countries from 2013 to 2018

(1) Overall AC demand

(in thousands)

	2013	2014	2015	2016	2017	2018	y/y
World total	104,367	103,790	99,355	102,312	110,972	110,971	100
Japan	9,817	9,336	8,899	9,146	9,744	10,521	108
Overseas	94,550	94,454	90,456	93,166	101,229	100,450	99
China	43,308	42,477	39,222	40,587	45,945	44,633	97
Asian countries	13,672	14,540	15,146	16,411	17,604	17,817	101
India	3,633	3,862	4,063	4,507	5,394	5,241	97
Indonesia	2,246	2,287	2,202	2,300	2,337	2,339	100
Vietnam	998	1,229	1,607	1,984	1,943	2,037	105
Thailand	1,163	1,315	1,388	1,561	1,536	1,493	97
Taiwan	952	1,014	1,014	1,005	1,090	1,097	101
Malaysia	902	898	878	936	970	1,002	103
Philippines	664	687	717	800	867	955	110
Pakistan	613	672	675	720	774	824	106
South Korea	1,236	1,236	1,253	1,252	1,263	1,263	100
Hong Kong incl. Macao	539	538	531	530	585	604	103
Myanmar	123	180	181	206	224	226	101
Bangladesh	156	170	183	185	188	202	108
Cambodia	81	85	90	110	119	130	109
Singapore	163	162	158	157	143	142	100
Sri Lanka	80	81	84	88	101	108	107
Laos			0			84	-
Others	123	123	123	71	73	69	96

Source: Japan Refrigeration and Air Conditioning Industry Association (JRAIA)

Table 4: Impact of IoT in 25°C for 70%, ACs Demand

Month	No of Days	Energy Savings for 25c	Total savings for 70% AC Demand	Mega Watt	**New Electricity Connection in Upazilas by saved energy**
March	20	77.83	**11005162**	11005	55
April	20	86.34	**10464408**	10464	52
May	20	84.14	**10197768**	10198	51
June	20	86.16	**10442592**	10443	52
July	20	100	**12120000**	12120	60
August	20	84.2	**10205040**	10205	51
Sept	20	80.88	**9802656**	9803	49
Oct	20	64.7	**7841640**	7842	39

The following figures (Figures 9, 10, and 11) depict three scenarios where 80%,70%, and 60% AC demand have been calculated, and the impact of IoT on those ACs is shown. For example, in the case of 80% Acs, demand and use of IoT in those ACs can help to cover 52 numbers of more upazilas in March, while in July, the maximum number of upazilas, like 61 equivalent upazilas, electricity consumption can be saved.

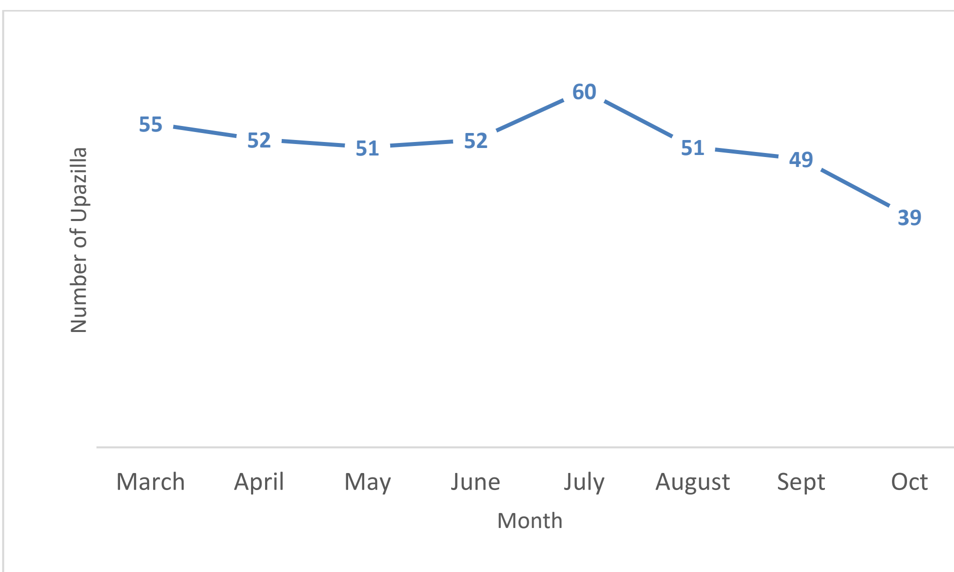

Figure 9: Impact of IoT in 25°C for 70%, AC Demand

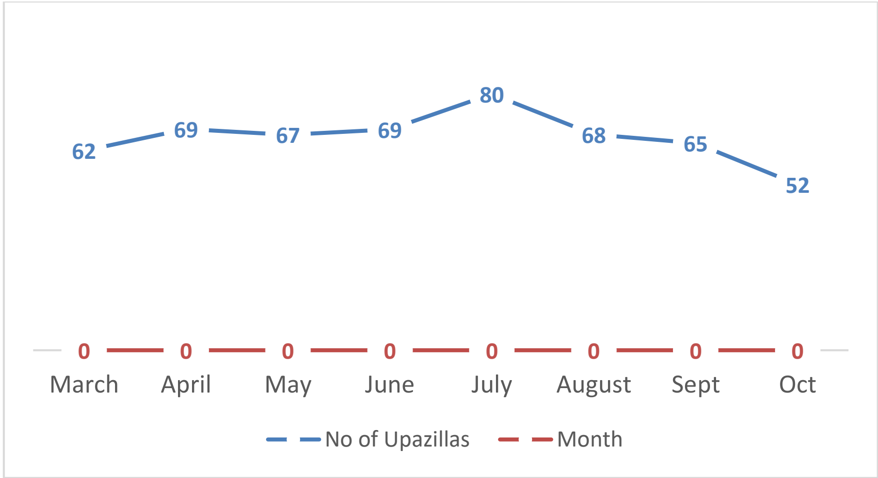

Figure 10: Impact of IoT in 25°C for 80%, ACs Demand

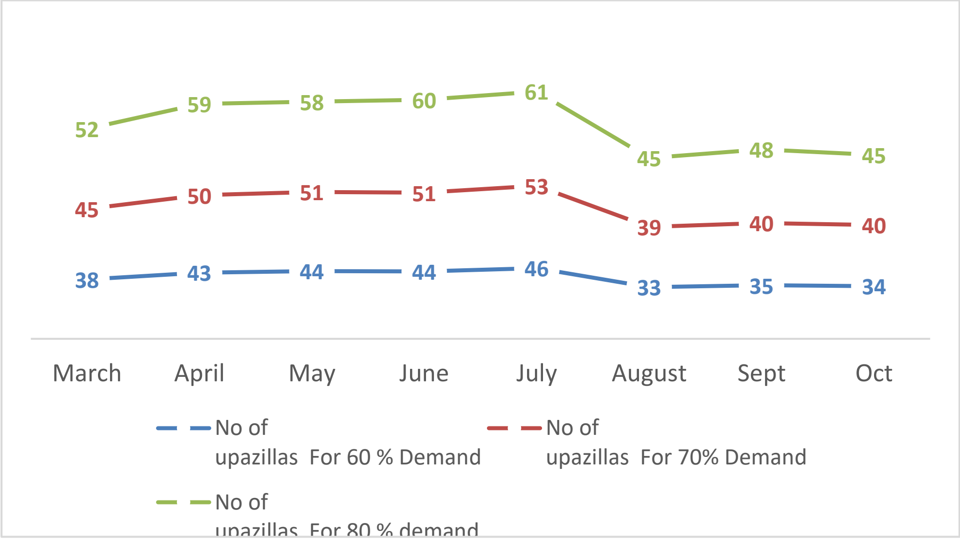

Figure 11: Impact of IoT for 24°C in 80%, 70% & 60% ACs Demand

The study also tried to determine the amount of electricity consumed in three modes of temperature setting. Table 5 shows AC's electricity consumption for 20, 24, and 25-degree settings. If AC is set to 24-degree or 25-degree centigrade, power savings can be 20-30 %, as per the experiment result.

Table 5. IoT and Saving Scenario in %

Month	Consumption (KWh)			Savings in %	
	20°	24°	25°	24°	25°
March	231.73	166.9	153.9	27.98	33.59
April	301.88	230.64	215.54	23.6	28.6
May	296.8	223.96	215.41	24.54	27.42
June	308.41	235.9	222.25	23.51	27.94
July	311.72	235.76	211.72	24.37	32.08
August	299.25	243.7	215.05	18.56	28.14
Sept	244.22	186.73	163.34	23.54	33.12
Oct	230.2	173.63	165.5	24.57	28.11

4.4 Environmental impact assessment of CO_2 emission reduction

Greenhouse gases trap heat in the atmosphere, raise temperatures, cause sea levels to rise, and drive more extreme weather, i.e., changes in precipitation patterns and severity of the storm (Freebairn, 2012). The atmospheric concentration of main gases –carbon dioxide, methane, and nitrous oxide-that are warming the earth and triggering extreme weather events (Oertel *et al*., 2016). Levels of CO_2, a product of burning fossil fuels, reached a new record of 410.5 parts per million(ppm) in 2019 (World Meteorological Organization, 2019).

The risk of climate change due to emissions of CO_2 from fossil fuels is considered to be the main environmental threat from the existing energy system. Other environmental problems are acidification and dispersion of metals originating from fossil fuels. Emissions vary by type of fuel /energy source and by type and efficiency of electric power plant. On Average, 2.11 pounds of CO_2/kWh for petrol (eia.gov). Another study in Malaysia found 1.21 kg/kWh (Saidur,2009).

$$CO_2 \text{ (kg/life)} = 1.21 \text{ (kg\textbackslash kWh)} * E\text{(kWh\textbackslash year)} * n\text{(year)}$$

The energy savings data analysis covers eight months from March to October, with each month consistently measured over 20 days. The data reveals significant patterns in energy conservation efforts, particularly in AC demand management. Starting in March with a 77.83% energy savings rate (equivalent to 12,577,328 kWh), the efficiency improved notably in April, reaching 86.34% (13,952,544 kWh). May and June maintained strong performance with 84.14% and 86.16%, respectively, contributing 13,597,024 kWh and 13,923,456 kWh to the total savings. July emerged as the peak performance month, achieving 100% energy savings and generating the highest monthly savings of 16,160,000 kWh. Following this peak, there was a gradual decline in efficiency, with August recording 84.2% (13,606,720 kWh), September showing 80.88% (13,070,208 kWh), and October dropping to 64.7% (10,455,520 kWh).

The cumulative energy savings demonstrated steady growth throughout the period, starting at 12,577,328 kWh in March and progressively increasing to reach a substantial total of 107,342,800 kWh by October. This pattern suggests a strong correlation between seasonal changes and energy savings efficiency, with summer months generally showing higher performance rates compared to the early spring and fall periods as shown in Table 6.

Table 6: CO_2 reduction from Energy savings for 80 % ACs demand

Month	**No of Days**	**Energy Savings for 25c**	**Cumulative Energy Savings**	**Total savings for 80% AC demand**	**Cumulative Energy Savings(kWh)**
March	20	77.83	77.83	12577328	12577328
April	20	86.34	164.17	13952544	26529872
May	20	84.14	248.31	13597024	40126896
June	20	86.16	334.47	13923456	54050352
July	20	100	434.47	16160000	70210352
August	20	84.2	518.67	13606720	83817072
Sept	20	80.88	599.55	13070208	96887280
Oct	20	64.7	664.25	10455520	107342800

In this study, the saved energy on 80 % AC demand was found to be 107342800 kWh. The total CO_2 emission reduction was 129884788 kgs or 129885 Tons approximately.

Total CO_2 Emission Reduction=107342800*1.21kgs = 129884788 kgs

Total CO_2 Reduction in Tons = 129884788/1000 = 129885 Tons

5. Conclusion

This research explores IoT's economic and environmental impact on energy management, focusing on energy efficiency and carbon emission reduction in commercial and residential buildings. IoT systems like smart meters, thermostats, and automated lighting significantly improve energy consumption. These technologies allow real-time monitoring and adjustments, ensuring energy is used only when needed. In this study, IoT devices were implemented in an office setting to track energy use, and the findings showed a marked improvement in efficiency. Smart thermostats adjusted temperatures based on weather and occupancy, while automated lighting reduced unnecessary power usage, lowering overall energy consumption. The environmental impact of IoT is equally essential. By optimizing energy use, these systems reduce dependence on fossil fuels' electricity, lowering carbon emissions. In the office setting, the efficient management of heating, cooling, and lighting systems led to a noticeable reduction in carbon emissions, as less energy was wasted.

Additionally, IoT systems can seamlessly integrate with renewable energy sources like solar or wind power, minimizing non-renewable energy use. In conclusion, the study highlights the dual benefits of IoT in economic and environmental terms. By reducing energy waste and promoting more efficient power use, IoT systems help cut costs and reduce carbon footprints. This research demonstrates that IoT technologies can transform energy management, creating more sustainable and efficient practices for residential and commercial buildings. Future research on IoT in the energy sector should explore the integration of advanced AI and machine learning algorithms to optimize energy management further. This could enable more accurate forecasting of energy needs and adaptive responses to real-time conditions. Another area for investigation is the potential for IoT to enhance the use of renewable energy, focusing on how IoT can efficiently manage energy storage and distribution. Additionally, research could assess the scalability of IoT systems across more extensive infrastructures and evaluate their long-term impact on reducing carbon emissions and energy costs in urban and rural settings.

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