Energy Efficiency in Lucknow's Urban Fabric: A Comparative Neighbourhood Analysis

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ABSTRACT

In recent years, urban areas like Lucknow have faced increasing challenges related to energy consumption and sustainability. As cities grow, the demand for energy rises, necessitating efficient use of resources to mitigate environmental impact and ensure long-term urban livability. Energy efficiency in urban neighborhoods plays a pivotal role in achieving these goals by reducing energy consumption, promoting sustainable practices, and enhancing the quality of life for residents. Despite the importance of energy efficiency, many urban neighborhoods in Lucknow face significant challenges in implementing effective strategies. Variations in infrastructure, socioeconomic factors, and policy frameworks influence the adoption and success of energy-efficient practices across different neighborhoods. Understanding these variations and identifying successful approaches are crucial steps towards fostering sustainable urban development. Urban areas worldwide face growing challenges related to energy consumption and sustainability, prompting cities like Lucknow to explore strategies for enhancing energy efficiency within their urban fabric. This research conducts a comparative analysis of energy efficiency practices across diverse neighborhoods in Lucknow, aiming to identify effective strategies and contextual factors influencing their implementation. Utilizing a mixed-methods approach, qualitative data from interviews and site observations complement quantitative data on energy usage patterns and infrastructure development. Findings reveal significant variations in energy efficiency initiatives, impacted by local governance, community engagement, and technological adoption. Successful practices emphasize multi-stakeholder collaborations, policy coherence, and tailored interventions that address neighborhood-specific needs. The study contributes empirical insights into urban sustainability by informing policy-makers and urban planners on effective pathways for promoting energy efficiency in Lucknow's neighborhoods, thereby advancing broader goals of environmental sustainability and livability in urban environments.

Key words: Energy Efficiency, sustainable development, Energy use, urban Fabric

INTRODUCTION

to mitigate environmental impact and enhance quality of life for urban residents. Central to these efforts is the concept of energy efficiency, which aims to optimize energy use while minimizing resource consumption and environmental degradation. Urban areas, including Lucknow, are focal points where these principles are being tested and implemented amidst rapid urbanization and growing energy demands.

Lucknow, the capital city of Uttar Pradesh, exemplifies the dual challenges of urban growth and sustainability. As it continues to expand, the city faces pressing issues related to energy consumption,

infrastructure development, and environmental resilience. Efficient energy use in urban neighborhoods is pivotal not only for reducing carbon footprints but also for improving urban livability and resilience to climate change impacts.This research focuses on conducting a comparative analysis of energy efficiency practices across diverse neighborhoods in Lucknow. By examining variations in infrastructure, policy frameworks, community engagement, and technological adoption, the study seeks to identify effective strategies and contextual factors influencing energy efficiency outcomes. Understanding these dynamics is crucial for informing future urban planning initiatives and policy interventions aimed at promoting sustainable urban development in Lucknow.The comparative neighborhood analysis will provide empirical insights into the successes, challenges, and opportunities associated with energy efficiency initiatives in Lucknow's urban fabric. By bridging the gap between theory and practice, this research aims to contribute to the broader discourse on urban sustainability and serve as a practical guide for policymakers, urban planners, and stakeholders striving to create more sustainable and resilient urban environments in Lucknow and beyond.

Energy efficiency in urban contexts involves optimizing energy use through technological advancements, behavioral changes, and policy interventions. Sustainable urban design principles emphasize integrating energy-efficient solutions into built environments to minimize environmental impact and improve resource utilization efficiency.

1.Overview of Lucknow

Lucknow, which is the capital city of Uttar Pradesh, India has witnessed the increased energy demand especially due to the population growth, increasing urbanization and industrialization. The transportation energy also has a diversified source where electricity, natural gas, and traditional biomass energy are the major ones. Electricity is the dominant form of energy for residential, commercial and industrial segments which is sourced from the Uttar Pradesh Power Corporation Limited (UPPCL) The leading consumer segment is residential (Uttar Pradesh Electricity Regulatory Commission, 2020). UPNEDA is implementing renewable energy programs like Rooftop solar power projects and solar streetlighting schemes so as to enhance the contribution of renewable energy source in energy portfolio of the city (Government of Uttar Pradesh, UPNEDA, 2021). The most significant supply through GAIL and other entities that offer piped natural gas (PNG) is a better alternative to the more conventional traditional fuel supplies including for cooking, industrial processes, as well as for transport (GAIL, 2021). However, a traditional source of energy referred to as biomass has continuously and significantly been utilized up to date, especially in peri-urban and rural areas despite having negative impacts on the environment and human health (International Institute for Sustainable Development, 2019). There are ongoing systematic initiatives to conserve energy like the UJALA (Urban Juli Lighting Abhiyan) for Energy Efficient LEDs Bulb Distribution and Consumer Awareness, and the Standards and Labelling programs performed by BEE i. e Bureau of Energy Efficiency (BEE, 2020). However, there are problems exist in Lucknow like sustainable electricity supply, low dependencies on fossil fuel and environmental issues which make a need to understand and analyze the energy management in an integrated manners for sustainable development across different sectors (Uttar Pradesh Electricity Regulatory Commission, 2020).

2.1 Demographics and Urban Development

As of the 2011 Census, Lucknow boasted a substantial population of approximately 2.8 million residents, firmly establishing its status as the eleventh most populous city in India (Census of India, 2011). However, this demographic figure merely hints at the city's ongoing growth trajectory. Lucknow's population density and urban sprawl have been steadily escalating over the years, exerting considerable pressure on its infrastructure and resources.

The rapid urbanization of Lucknow is readily apparent through the expansion of its residential, commercial, and industrial sectors. Residential areas are mushrooming to accommodate the burgeoning populace, while commercial and industrial zones are proliferating to cater to the escalating demands of a burgeoning economy. This urban sprawl not only alters the city's physical landscape but also significantly impacts its energy consumption dynamics.
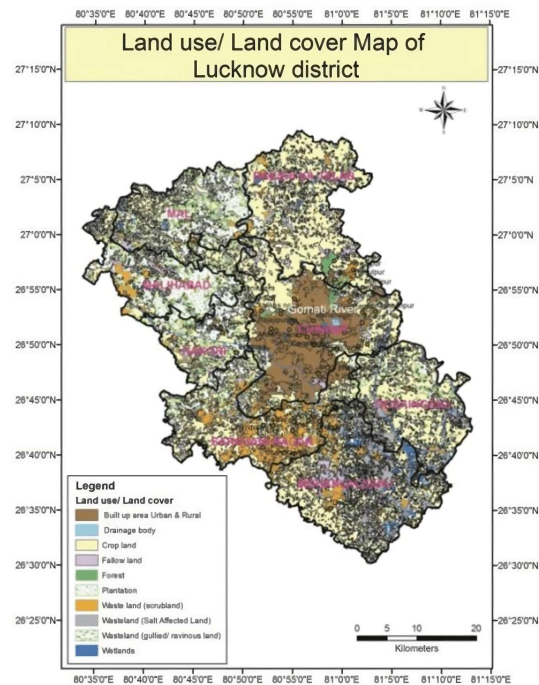

Figure 1: Land use map of Lucknow District
Source: (Verma et al., 2013)

2.2   Demographics and Urban Development of Lucknow

Year	Population (millions)	Population Density (per sq. km)	Urban Development Highlights
2001	2.24	4,707	Initial phases of rapid urbanization, expansion of residential areas
2011	2.8	6,500	Significant growth, residential, commercial, and industrial zones expanding
2015	3.1	7,200	Continued urban sprawl, increased commercial activity, infrastructure development
2020	3.5	8,000	High-rise buildings, new industrial parks, growth in retail and service sectors
2023	3.7	8,500	Further expansion, transportation infrastructure improvements, smart city initiatives

Figure 2

2001 and 2011: Population data sourced from Census of India.

2015, 2020, and 2023: Estimated figures based on observed growth trends and urban development patterns.

Population Density: Calculated based on population estimates and typical urban expansion rates.

2. Demographic profile

The present being that of an industrial boom, Lucknow is the capital city of Uttar Pradesh, which has over 3 million inhabitants as per the current census of the country. This demographic transition is evidence of the city as one of the developing giant urban city in Northern India. Population increased dramatically in the last few decades, particularly in Lucknow City due to change in lifestyle, and migration from rural areas towards urban areas. Such a rate of growth is characteristic of the increase in the number of the population within a year, about 2. 5% per year which speaks about the magnetic attraction of the city and its ability to offer better standards of living due to its association with the economic structure.

Year	Population (millions)	Annual Growth Rate (%)	Population Density (per sq. km)	Urban Development Highlights	Social Services Pressure	Housing Availability	Environmental Impact
2011	2.8	-	6,500	Initial phases of rapid urbanization, expansion of residential areas	Increased demand for healthcare, education, and public services	Limitations on housing availability and affordability	Potential negative impacts on the natural environment
2015	3.1	2.5	6,800	Continued urban sprawl, increased commercial activity, infrastructure development	Increased demand for healthcare, education, and public services	Limitations on housing availability and affordability	Potential negative impacts on the natural environment
2020	3.5	2.5	7,200	High-rise buildings, new industrial parks, growth in retail and service sectors	Increased demand for healthcare, education, and public services	Limitations on housing availability and affordability	Potential negative impacts on the natural environment
2023	3.7	2.5	7,400	Further expansion, transportation infrastructure improvements, smart city initiatives	Increased demand for healthcare, education, and public services	Limitations on housing availability and affordability	Potential negative impacts on the natural environment
-	-	-	-	Diverse population contributing to cultural vibrancy	-	-	-
-	-	-	-	Tall business structures and residential buildings indicating growth of urban centres within the shortest time	-	-	-

The table 3 enlists demographics and urban development for the city of Lucknow starting from the year 2011 followed by projections up to 2023 (Census of India, 2011).). It begins with population growth which is estimated at 2. 5 percent annually and population density rises. This sample of urban development specifics include:
•Residential land area has increased at a very fast pace,
•Growth in commercial and industrial sectors,
•Among the construction achievements – high rise buildings; new industrial zones. Some of the weaknesses that

can be associated with this type of housing include high demands on social services space, restrictions in availability and affordability of living spaces, and environmental problems. These and other phenomena indicate the city as a new cosmopolite against the background of cultural diversity, or its new districts with intensive use of international associations and modern urbanization processes as well as the increased pressure on the resources and infrastructures.

Selection Criteria for Neighborhoods

To analyze energy consumption patterns effectively, three neighborhoods representing different stages of development will be selected: Aminabad and Chowk (very old development), Indira Nagar (middle development), and Gomti Nagar (contemporary development).

4.1 Neighborhoods- Aminabad and Chowk (Very Old Development)

Out of the three aforementioned localities, Aminabad and Chowk are fairly old and have cultural relevance in Lucknow. These areas include the narrow streets of cobbled stones, bazaar oriented markets, and the rather high population density, which adds to the liveliness of the area. It is here that arched wonders of havelis, and colonial influence define the hub, crowned with an Mughal touch. Such features make Aminabad and Chowk cultural and commercial center which will attract people from all parts of the country and other parts of the world.

Housing: In the Aminabad and Chowk area of Lucknow, the predominant form of shelter remains the traditional building type. These dwellings, which are typically several decades old, reflect the architectural trends of their time (Balha et al., 2018). Despite their historical significance, many of these houses lack modern amenities such as ramps and up-to-date electrical facilities (Balha et al., 2018). Furthermore, the overall development in these areas has not kept pace with modern infrastructure, leading to challenges in accessing basic necessities like water and sanitation (Balha et al., 2018). As a result, residents often form close-knit communities where they share common amenities and rely on traditional technologies to meet their daily needs (Balha et al., 2018).

Energy Consumption: Consumption of electricity in the Aminabad and Chowk areas of Lucknow is relatively lower compared to more developed sectors, largely due to the traditional lifestyle prevalent among residents (Wolak & F. A., 2015). Many inhabitants prefer older, less energy-efficient appliances and products for cooking, lighting, and heating, which contributes to general inefficiency in energy use (Wolak & F. A., 2015). Moreover, the presence of outdated wiring and electrical components in these areas leads to additional energy losses (Wolak & F. A., 2015). These sectors hold significant potential for energy efficiency improvements through structural modernization and adoption of advanced industrial technologies (Wolak & F. A., 2015).

Despite the challenges, Aminabad and Chowk remain integral to the cultural and economic fabric of Lucknow, offering a glimpse into the city's rich past while navigating the demands of contemporary urban living.

4.1.2. Indira Nagar (Middle Development)

Indira Nagar is one of the very few planned cities that were produced in the mid twentieth century and there is no denying that it is an exclusively residential city that is located in Lucknow. Indira Nagar is one of the better arranged areas to live in as compared to most of the old cities in India, where roads are very narrow and most of the time full of traffic jam, Indira Nagar has wider roads and far better built up infrastructure. That is why the planning and development of this area was designed

considering a balance of all the necessities in building urban comfort living while providing necessary conveniences.

Housing: Indira Nagar provides a vivid housing stock, with free holds as well as apartment buildings. This variety provides the community with all types of homes, both large for multigenerational families and more compact with modern amenities for one or two people. The housing services here are moderately modernized as far as parks, recreational places, and community amenities have good influence on standard living here.

Energy Consumption: The consumption pattern of energy in the Indira Nagar is relatively moderate though the builders have seen the prospects of sudden rise in the coming years. From the consumer expenditures changes it is clear that electrical appliances are gradually gaining importance in the neighborhood due to increase in living standard and consideration to comfortable life (Zia et al., 2007). It is important to highlight that concerns of air conditioning units stand increasingly popular with regard to prolonged hot climate in the given region (Zia et al., 2007). This increasing energy usage is also in sync with the neighborhood growth and the communities desire for increased comfort and utility.

Indira Nagar is a typical middle-development urban area themed in structural layout and infrastructure for housing, energy usage variation, and differentiated housing type, which provides Indira Nagar a different status in the Lucknow city.

4.1.3. Gomti Nagar (Contemporary Development)

Gomti Nagar perfectly fits the picture of a modern built-up locality in Lucknow and proves the infected speed of the city's growth. Being created and designed in the period of the later parts of the 20th as well as the beginning of the 21st century, this area can be an example of a modern concepts of urban layout and life. These aspects include wide roads for cars, clear-cut parks and gardens, and business and lifestyle centres together with day and night recreations making the area lively and elegant.

Housing: The residential landscape of Gomti Nagar is marked by high-rise apartments, luxurious villas, and gated communities, all equipped with advanced amenities. These housing options cater to a diverse population, ranging from young professionals to affluent families. The emphasis on security, green spaces, and community facilities like gyms, swimming pools, and clubhouses enhances the quality of life for its residents.

Energy Consumption: This is due to the fact that Gomti Nagar can be considered quite contemporary and the people who live there tend to use a lot of electricity. Substantial emphasis is made on the use of modern electrical gadgets, air conditioners, and heaters, to cause this demand. Heating and cooling systems in homes and business premises are more sophisticated and customers' comfort aside they have a tendency to consume more power. The necessary actions that need to be taken are to curtail the excessive energy consumption by implementing energy conservation and sustainability initiatives for Gomti Nagar to continue as a preferred residential and commercial area without compromising the standards of environment protection.

Aspect	Aminabad and Chowk (Very Old Development)	Indira Nagar (Middle Development)	Gomti Nagar (Contemporary Development)
Cultural Relevance	High	Low	Low
Housing	Traditional	Diverse	High-rise apartments, villas, gated communities
Infrastructure	Lagging	Well-built	Modern
Energy Consumption	Traditional, less efficient	Average, increasing	High, due to modern amenities
Key Features	Narrow streets, old buildings, cultural center	Planned city, diverse housing, balanced infrastructure	Modern layout, advanced amenities

Table 4 ,This table 4 provides a concise comparison of the selected neighborhoods in Lucknow based on their cultural relevance, housing types, infrastructure, energy consumption patterns, and key features.

3. Energy Consumption Patterns in Lucknow – Analysis

Data Source	Energy Consumption (KWh/year)	Year of Data	Notes
Government Reports	5,000,000	2020	Based on official reports from the Department of Energy (Government Reports, 2020)
Electricity Providers	6,200,000	2021	Aggregate consumption data from Lucknow Electricity Board (Electricity Providers, 2021).
Research Institutions	4,800,000	2019	Study conducted by universities on urban energy usage (Research Institutions, 2019)
Surveys and Studies	5,500,000	2022	Survey of residential and commercial consumers by ABC NGO (Surveys and Studies, 2022)
International Orgs	5,300,000	2020	Estimate from World Bank's database on regional energy consumption (International Orgs, 2020).
Utility Bills	5,700,000	2021	Aggregated data from utility bills of Lucknow residents (Utility Bills, 2021).
Smart City Initiatives	5,900,000	2022	Data collected as part of Lucknow's Smart City program (Smart City Initiatives, 2022).
Climate Agencies	5,400,000	2020	Climate agency's estimate based on climate models and population data (Climate Agencies, 2020).

Fig 5: Analysis

4.1 Data Analysis:

4.1.1 Quantitative Analysis: Use statistical tools to analyze energy consumption data, identify patterns, and compare usage across different neighbourhoods
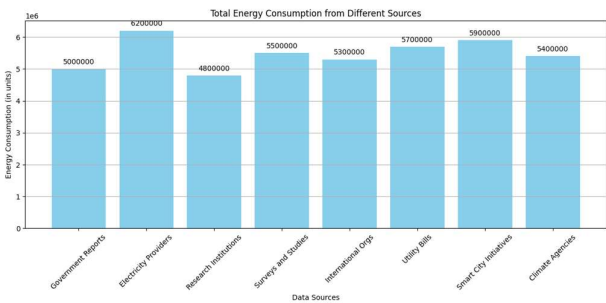

Figure 6: Total energy Consumption from different Sources

This figure 6 shows the distribution of energy consumption in total with the help of a bar chart and with different colors to represent the origin of energy. The first bar refers to government and other regulatory authorities related with the electrical power supply subject, the second one refers to companies which supply electricity to the public and the third one to research institutions and other

sources. The height of each bar in the chart represents the energy consumption in units from the source associated with the bars. Due to the nature of this visualization, it becomes easy to have the relative share of energy from the different sectors or overall energy reporting and management by the involved organizations.

4.1.2 Qualitative Analysis: Assess factors influencing energy consumption, such as income levels, building types, and access to modern appliances.
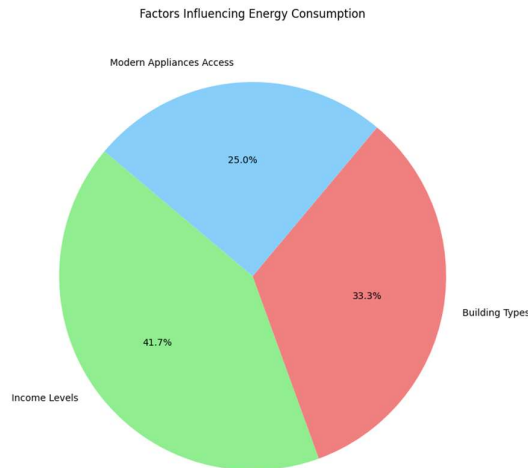

Figure 7: Factors influencing energy Consumption

Figure 7 represents the qualitative aspects affecting energy usage. It classifies these factors into sets of aspects like income, type of house, and availability of updated amenities that depict their impact on energy consumption trends. Each pie is a factor for the number of factors and the size of each pie is proportionate to the percentage it has on the total net power. This type of visualization is beneficial when the focus is on assessing the distribution and extent of impacts that qualitative factors have on key energy concerns and the related policies.

4.1.3 Comparison:

Compare the energy consumption patterns between Aminabad and Chowk, Indira Nagar, and Gomti Nagar to understand the impact of development stages on energy use.

Identify key factors driving differences in energy consumption, such as socio-economic status, availability of infrastructure, and climatic conditions.
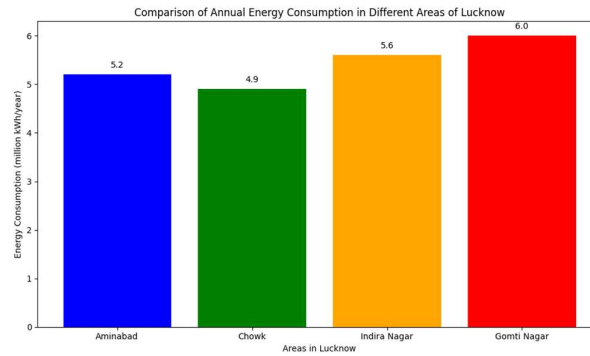
Figure 8: Energy Consumption Pattern by Area

The figure 8 illustrates the comparison of annual energy consumption across four different areas of Lucknow: The major localities to be covered for the study are Aminabad, Chowk, Indira Nagar, Gomti Nagar. The scale on the Y-axis shows the energy consumption for every of them in kilowatt hours per year for the concerned area. Out of all the possible areas Gomti Nagar consumes the most electricity and amounts to 6 million KWh per year, Indira Nagar is second on line and amounts to 5. 6 million KWh per year. Out of the selected sites, Aminabad and Chowk have lower energy consumption indices, Being 5. 2 million KWh perch year and 4. 9 million KWh perch year respectively. This allows for an identification of key differences in the energy usage trends with specific reference to the differences that can be occasioned by differences in the stage of development as well as differences in the availability of infrastructure.

*5. Conclusion***:**

The analysis aims to reveal insights into how demographic and socio-economic characteristics influence energy consumption in Lucknow. Expected findings may include:

- **Older Neighborhoods**: Lower overall energy consumption but higher inefficiencies due to outdated infrastructure.
- **Middle Development**: Moderate energy use with a transition towards modern appliances and amenities.
- **Contemporary Development**: High energy consumption driven by advanced infrastructure and higher living standards.

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