

Data-Driven Benchmarking of Building Energy Performance Using Electricity and Gas Consumption Data

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ABSTRACT

Buildings are a major contributor to global energy demand, making improved building energy performance an important component of energy management and decarbonisation strategies. This paper assesses the energy performance of a portfolio of ten buildings using historical electricity and gas consumption data. Annual energy consumption and Energy Use Intensity (EUI), expressed in kWh/m²/year, were calculated to compare energy intensity across buildings of different floor areas. The results showed substantial variation in EUI, ranging from 78.01 to 476.45 kWh/m²/year, with a mean of 191.35 kWh/m²/year and a median of 136.24 kWh/m²/year. Buildings A and B recorded the highest EUI values at 476.45 and 410.53 kWh/m²/year, respectively, while Buildings H, I, and J recorded the lowest values. Electricity and gas consumption showed a strong positive correlation $r = 0.98$. The findings indicate that consumption-based benchmarking can provide a practical screening approach for identifying buildings that warrant further investigation. However, EUI should be interpreted as an indicator of energy intensity rather than a direct measure of energy efficiency because building function, occupancy, operating schedules, and weather conditions were not fully incorporated. The study provides a basis for prioritising further energy audits and operational assessments, with future research recommended to incorporate weather normalisation, occupancy characteristics, building-function classification, and end-use energy data.

Keywords: Building energy performance; Energy consumption; Building benchmarking; Data analytics; Decarbonisation.

INTRODUCTION

Buildings are major consumers of energy and are consequently an important focus of efforts to reduce operational energy demand and associated greenhouse-gas emissions. Improving the energy performance of existing buildings can contribute to reductions in operating costs and environmental impacts while supporting wider organisational and decarbonisation objectives [1]. Consequently, reliable assessment of building energy consumption is an important component of contemporary energy-management practice [2]. The increasing deployment of digital meters, smart-metering systems, and building-management technologies has resulted in the availability of increasingly large quantities of building energy-consumption data [3]. These data provide opportunities to assess building performance using consumption-based analytical approaches [4]. Historical energy records can be used to identify consumption patterns, compare performance between buildings, and screen for potentially unusual levels of energy use. In comparison with approaches based exclusively on periodic energy audits, consumption-based analysis can provide a relatively accessible means of undertaking portfolio-level screening and identifying buildings that warrant more detailed investigation [5]. One of the most used indicators for comparing building energy performance is Energy Use Intensity (EUI) [6]. EUI normalises annual energy consumption by floor area and is generally expressed in kWh/m²/year. This normalisation allows buildings of different sizes to be compared using a common indicator. However, EUI represents energy intensity rather than a complete measure of energy efficiency. Differences in building function, occupancy, operating hours, equipment, and environmental conditions can all influence energy consumption. Consequently, EUI-based benchmarking is most appropriately considered a screening and comparative assessment technique rather than a standalone diagnostic method [7]. Previous research has

demonstrated the value of data-driven approaches for building energy assessment, prediction, and management. Consumption data can be used to establish performance benchmarks, identify unusual patterns, and support energy-management decisions [8]. Nevertheless, organisations may not fully exploit the information available from their energy-consumption records, with decisions sometimes being based primarily on aggregate utility expenditure rather than normalised energy-performance indicators [9]. Against this background, the present study applies a consumption-based benchmarking approach to a portfolio of ten buildings. Electricity and gas consumption records are analysed to quantify total annual energy consumption and EUI, compare energy intensity between buildings, examine the relationship between electricity and gas consumption, and identify buildings that warrant further investigation [10]. The study therefore focuses on the practical use of routinely available consumption data as an initial screening tool for building energy management [11]. The specific objectives of this study are to quantify the annual electricity, gas, and total energy consumption across the building portfolio and to calculate the Energy Use Intensity (EUI) of each building using floor-area-normalised energy consumption [12]. This study aims to assess building energy performance across a portfolio of ten buildings using electricity and gas consumption data. Specifically, it calculates annual electricity, gas and total energy consumption; determines floor-area-normalised EUI; compares energy intensity across buildings; examines the relationship between electricity and gas consumption; and identifies buildings requiring further investigation [13].

METHODOLOGY

Study Data and Building Portfolio

The study used historical electricity and gas consumption data for a portfolio of ten buildings managed within an organisational estate-management framework. Energy consumption data were collected from organisational energy records. Building characteristics, including floor area and available occupancy information, were collected to support normalisation and comparative analysis. The analysed portfolio comprised Buildings A–J. Floor areas ranged from 420 m² for Building C to 5,080 m² for Building B. Annual electricity and gas consumption were available for each building and were combined to obtain total annual energy consumption. The study was conducted using data from corporate buildings located in Liverpool, United Kingdom [14]. The building portfolio comprises corporate buildings with different energy-use characteristics. Energy consumption data were collected over a one-year monitoring period from April 2024 to March 2025, with electricity and gas consumption recorded monthly for each building. The dataset therefore comprised 120 building-month observations, representing 10 buildings monitored over 12 months. The monthly electricity and gas consumption data were aggregated to calculate annual consumption for each building [15]. These data were subsequently used to calculate Energy Use Intensity (EUI), compare energy performance across the building portfolio, and identify buildings requiring further investigation [16]. These data were used to quantify annual electricity, gas, and total energy consumption, calculate floor-area-normalised Energy Use Intensity (EUI), compare energy performance across the building portfolio, and identify buildings that may require further investigation [17].

Building	Floor area (m ²)	Electricity (kWh)	Gas (kWh)	Total energy (kWh)	EUI (kWh/m ² /year)
A	508	78,093	163,942	242,035	476.45
B	5,080	435,871	1,649,620	2,085,491	410.53
C	420	59,958	31,466	91,424	217.68
D	706	17,321	113,387	130,708	185.14
E	629	29,019	67,550	96,569	153.53

F	1,235	52,645	94,258	146,903	118.95
G	3,781	81,910	279,561	361,471	95.60
H	4,588	79,766	340,968	420,734	91.70
I	4,948	82,522	342,453	424,975	85.89
J	1,201	24,461	69,232	93,693	78.01

Table 1. Characteristics and annual energy consumption of the study buildings

Data Pre-Processing

Prior to analysis, the 120 building-month observations were assessed for missing, duplicate, and anomalous records. No missing or duplicate records were identified, and all observations were retained for subsequent analysis. No duplicate records were found, and therefore no observations were removed based on duplication [18]. Potential anomalous observations were assessed using two statistical criteria, the interquartile range (IQR) method and the ± 3 standard deviations criterion. Under the IQR method, observations falling below $Q1 - 1.5 \times IQR$ or above $Q3 + 1.5 \times IQR$ were considered potential anomalies. Under the standard-deviation criterion, observations falling outside three standard deviations from the mean were considered potential anomalies [19]. No observations met either criterion, or therefore no anomalous records were identified. Consequently, no records were excluded, interpolated, replaced, or otherwise modified during the data-cleaning process, and all 120 observations were retained for subsequent energy-consumption and Energy Use Intensity (EUI) analysis [20].

Energy Use Intensity

Total annual energy consumption was calculated by combining annual electricity and gas consumption for each building

$$\text{Total Energy Consumption} = \text{Electricity (kWh)} + \text{Gas (kWh)}$$

$$\text{EUI} = \frac{\text{Total Energy Consumption (kWh)}}{\text{Floor Area (m}^2\text{)}}$$

EUI was used as the primary benchmarking indicator because it provides a simple means of comparing energy intensity between buildings with different floor areas. Accordingly, a high EUI is interpreted in this study as an indicator of relatively high observed energy intensity and a reason for further investigation, rather than conclusive evidence of operational inefficiency [21].

Consumption Analysis

Electricity, gas, and total annual energy consumption were compared across the buildings. The analysis considered both absolute consumption and floor-area-normalised consumption. This distinction was important because large buildings may have high absolute energy consumption while exhibiting relatively low EUI. The relative contribution of electricity and gas to total consumption was also examined to provide an indication of the dominant energy source within each building [22].

Statistical Analysis

Descriptive statistics were calculated for EUI, including the mean, median, minimum, maximum, and standard deviation. The relationship between electricity and gas consumption was examined using a correlation coefficient. The analysis reported a correlation coefficient of $r=0.98$.

Identification of Buildings for Further Investigation

Buildings were screened according to their observed EUI and total energy consumption [23]. Buildings with comparatively high EUI were identified as candidates for further investigation. This screening approach was intended to support prioritisation of detailed energy audits and operational assessments [24]. The screening does not establish the technical cause of high consumption.

Potential contributors, such as HVAC operation, equipment performance, control strategies, occupancy, and operating schedules, therefore, require verification through building-level investigation before specific retrofit measures are recommended [25].

Data Analysis Tools

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RESULTS AND DISCUSSION

Building-Level Energy Performance

The calculated EUI values demonstrate considerable variation across the ten-building portfolio. Building A recorded the highest EUI at 476.45 kWh/m²/year, followed by Building B at 410.53 kWh/m²/year. Building C recorded an EUI of 217.68 kWh/m²/year, while Buildings D and E recorded 185.14 and 153.53 kWh/m²/year, respectively. The remaining buildings had EUI values below 120 kWh/m²/year, with Building J recording the lowest value at 78.01 kWh/m²/year.

The difference between the highest and lowest observed EUI was substantial, with Building A having an EUI approximately six times that of Building J. This variation indicates that energy intensity differs considerably across the portfolio and demonstrates the usefulness of EUI as an initial screening indicator. However, these differences should not be interpreted as evidence that one building is intrinsically more energy-efficient than another without accounting for building function, occupancy, operating hours, and other relevant variables.

Annual Electricity, Gas, and Total Energy Consumption

Table 1 shows substantial differences in absolute energy consumption between buildings. Building B had the highest total annual energy consumption at 2,085,491 kWh. Building A had a substantially smaller total consumption of 242,035 kWh but recorded the highest EUI because of its relatively small floor area. This comparison illustrates the importance of distinguishing between absolute consumption and normalised energy intensity.

Building B consumed considerably more total energy than Building A, but Building A exhibited the higher energy consumption per unit of floor area. The results therefore demonstrate why portfolio-level energy assessment should consider both total consumption and floor-area-normalised indicators rather than relying on a single measure.

Descriptive Statistics

The mean EUI across the ten buildings was 191.35 kWh/m²/year, while the median was 136.24 kWh/m²/year. The maximum EUI was 476.45 kWh/m²/year, and the minimum was 78.01 kWh/m²/year. The standard

deviation was 134.09 kWh/m²/year.

Descriptive Statistics of Building Eui

Statistic	EUI (kWh/m ² /year)
Mean	191.35
Median	136.24
Maximum	476.45
Minimum	78.01
Standard deviation	134.09

Table 2 EUI statistics

The mean being higher than the median indicates that the distribution is influenced by buildings with relatively high EUI, particularly Buildings A and B. The substantial standard deviation relative to the mean further demonstrates heterogeneity in observed energy intensity across the portfolio. Because the dataset contains only ten buildings, these descriptive statistics should be interpreted as characteristics of the study portfolio rather than as representative estimates of a wider building population.

EUI Benchmarking

The EUI comparison identifies Buildings A and B as the two buildings with the highest observed energy intensity. Buildings C, D, and E form an intermediate group, while Buildings F–J have comparatively lower EUI values. The results suggest that Buildings A and B should be considered priorities for further investigation. Such investigation could examine operational schedules, HVAC performance, control settings, equipment condition, occupancy, and other factors that may contribute to their elevated energy intensity. Importantly, the EUI results alone cannot establish the underlying causes of the observed differences. Detailed audits and additional building-level data would therefore be required before attributing the elevated EUI to specific technologies or operational practices.

Building Energy Benchmarking

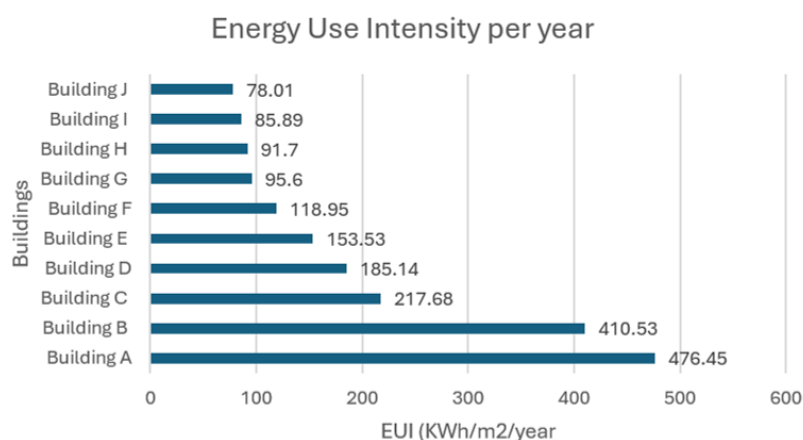


Figure 1 presents the Energy Use Intensity (EUI) values for the analysed buildings. Buildings A and B exhibited significantly higher EUI values than the remainder of the portfolio, indicating greater energy demand per unit floor area. Buildings C, D and E demonstrated moderate energy intensity. The results reveal substantial variation in energy performance and suggest that Buildings A and B should be prioritised for

detailed energy audits and efficiency improvement measures. Their elevated EUI values suggest that these buildings should be prioritised for detailed energy audits and operational reviews. Conversely, Buildings H, I, and J demonstrate comparatively lower energy intensity and may provide examples of good operational practice within the portfolio.

Relationship between Electricity and Gas Consumption

The analysis identified a strong positive association between electricity and gas consumption, with a reported correlation coefficient of $r=0.98$. The result indicates that, within the analysed portfolio, buildings with higher electricity consumption generally also tended to have higher gas consumption. This may reflect shared influences such as building size, occupancy, operating schedules, building function, or the intensity of equipment use. However, the available analysis does not directly measure these factors. Consequently, the observed correlation should be interpreted as an association rather than evidence that any operational variable caused higher energy consumption.

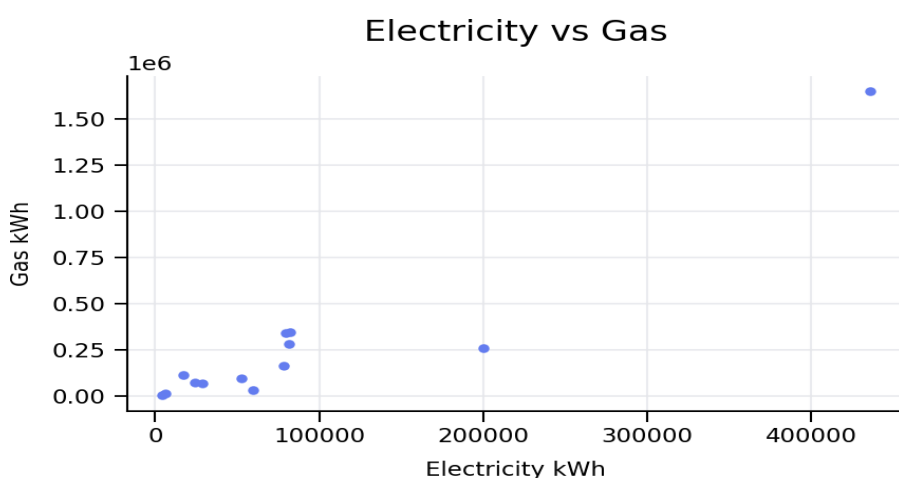


Figure 2 illustrates the relationship between electricity and gas consumption across the analysed buildings. A positive correlation is evident, suggesting that buildings with high electricity demand also tend to exhibit elevated gas consumption. Building B exhibits substantially higher electricity and gas consumption than the other buildings and therefore appears separated from the main cluster of observations.

DISCUSSION

Interpretation of the EUI Variation

The principal finding of the study is the substantial variation in observed EUI across the ten-building portfolio. The range from 78.01 to 476.45 kWh/m²/year demonstrates that buildings within the same organisational portfolio can exhibit markedly different levels of energy intensity. The difference is particularly evident for Buildings A and B, which recorded EUI values substantially above those of the other buildings. These results make the two buildings appropriate candidates for more detailed investigation. However, high EUI should be interpreted as a screening signal rather than direct evidence of poor energy efficiency. Differences in building use, occupancy, operating hours, heating requirements, equipment loads, and control strategies may all contribute to variation in energy intensity. Since these factors were not sufficiently characterised in the present dataset, the study cannot determine which factors account for the differences between individual buildings.

Absolute Consumption Versus Energy Intensity

The results also illustrate an important distinction between total energy consumption and EUI. Building B recorded the highest total annual energy consumption at more than 2.0 GWh, whereas Building A had the highest EUI despite consuming substantially less energy in absolute terms. This distinction has practical

implications for estate energy management. Buildings with high total consumption may represent important opportunities for portfolio-level energy reduction because of the scale of their energy demand, whereas buildings with high EUI may warrant investigation because their energy demand is high relative to their floor area. A robust prioritisation framework should therefore consider both indicators alongside building function and operating conditions.

Electricity and Gas Relationship

The reported correlation of $r=0.98$ suggests that electricity and gas consumption are positively associated within the analysed portfolio. This finding is consistent with the possibility that common building characteristics influence both energy sources. However, the correlation does not establish the mechanism responsible for the relationship. For example, larger buildings may naturally consume more of both electricity and gas, creating a positive association without implying that electricity consumption itself drives gas consumption. Future analysis should therefore control for building size and, where possible, building function and occupancy. A multivariable regression framework could provide a more informative assessment of the factors associated with total energy consumption or EUI.

Implications for Energy Management

The findings demonstrate the potential value of consumption-based benchmarking as a first-stage energy-management tool. Portfolio managers can use EUI and total consumption to screen buildings and identify those requiring additional investigation. For Buildings A and B, the results justify further assessment rather than immediate attribution of specific technical problems. For example, an energy audit could investigate HVAC operation, control strategies, equipment condition, operating schedules, occupancy, and building fabric. Similarly, the intermediate EUI values observed for Buildings C–E indicate that these buildings may benefit from targeted monitoring and investigation, although the available data do not provide sufficient evidence to determine the most appropriate intervention. The approach can therefore be understood as a screening framework, consumption data identify where further investigation should be concentrated, while detailed audits establish why performance differs and which interventions are technically and economically appropriate.

Practical Implications

The findings have several implications for building and estate management. First, organisations can use existing utility and metering records to establish a basic energy-performance benchmark without requiring immediate deployment of complex analytical systems. Second, combining total consumption with EUI can help distinguish between buildings that consume large quantities of energy because of their size and buildings that have comparatively high energy intensity. Third, buildings identified through benchmarking can be subjected to more detailed investigation before investment decisions are made. This can help ensure that interventions are based on measured operational conditions rather than on energy consumption alone. Finally, repeated application of the benchmarking procedure could allow organisations to monitor changes in building energy performance over time. Such monitoring would be particularly valuable following the implementation of energy-efficiency measures.

Energy Saving Opportunity

Building	Priority	Recommended Action
Building A	High	HVAC optimisation
Building B	High	Equipment upgrade
Building C	Medium	Controls review

Building D	Medium	Energy audit
Building E	Medium	Energy audit

Table 3 presents the energy-saving opportunity assessment. Buildings A and B were identified as the highest-priority candidates for intervention due to their elevated EUI values. These buildings exhibit significantly greater energy demand relative to floor area and therefore offer the greatest potential for energy reduction. Recommended measures include HVAC optimisation, improved energy management controls, equipment upgrades, and enhanced operational scheduling. Buildings C, D, and E also demonstrated opportunities for performance improvement through targeted energy audits and monitoring. The screening identifies Buildings A and B as priorities for further investigation because they have the highest observed EUI. However, the available consumption data do not establish the technical causes of their elevated energy intensity or quantify achievable savings. Detailed energy audits and operational assessments are therefore required before specific energy-efficiency measures are selected.

STUDY LIMITATIONS

Several limitations should be considered when interpreting the findings. First, the analysis was based primarily on historical electricity and gas consumption and did not incorporate sufficiently detailed information about occupancy, building operation, or operating schedules. These factors can substantially affect building energy consumption. Second, the study considered a relatively small portfolio of ten buildings. The findings therefore describe the analysed portfolio and should not be generalised to buildings outside the study without additional evidence. Third, the analysis did not incorporate weather normalisation. Variations in outdoor temperature and other climatic conditions can affect heating and cooling demand and may therefore influence annual energy consumption. Fourth, the analysis was based on aggregate electricity and gas consumption rather than detailed end-use measurements. Consequently, the study cannot establish which individual systems or technologies are responsible for high energy intensity. Fifth, the analysis does not quantify achievable energy savings, retrofit costs, payback periods, or return on investment. Recommendations concerning specific interventions should therefore be considered preliminary until supported by detailed technical and economic assessment. Finally, EUI is an energy-intensity indicator and should not be treated as a complete measure of energy efficiency. Meaningful comparisons should ideally account for building function, occupancy, operating hours, climate, and other relevant variables. Future research should address these limitations by incorporating larger building portfolios, weather-normalised consumption, occupancy information, building-function classifications, end-use energy data, and more advanced statistical or machine-learning methods.

CONCLUSION

This study assessed building energy performance using historical electricity and gas consumption data from a portfolio of ten buildings. Energy Use Intensity was calculated to normalise annual energy consumption by floor area and provide a basis for comparison between buildings. The analysis identified substantial variation in observed energy intensity. EUI ranged from 78.01 to 476.45 kWh/m²/year, with a portfolio mean of 191.35 kWh/m²/year and a median of 136.24 kWh/m²/year. Buildings A and B recorded the highest EUI values, while Buildings H, I, and J recorded comparatively low values. The results demonstrate that consumption-based benchmarking can provide a practical first-stage method for screening a building portfolio and identifying facilities that warrant further investigation. The reported positive correlation between electricity and gas consumption also indicates that energy demands across the portfolio are associated, although the available data do not establish the operational or physical mechanisms responsible for this relationship. Buildings A and B should therefore be considered priorities for detailed energy-performance investigation. However, the present analysis does not provide sufficient evidence to attribute their elevated EUI to specific systems or to quantify their achievable energy savings. Detailed energy audits, operational assessments, and additional building-level data are required before specific interventions can be justified. Overall, the study demonstrates the usefulness of readily available consumption data for portfolio-level energy screening. Future

research should extend the approach through weather normalisation, occupancy adjustment, building-function classification, end-use analysis, and more rigorous statistical modelling. Such developments would improve the ability of consumption analytics to distinguish genuine performance differences from differences arising from building characteristics and operating conditions.

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