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# COMPARATIVE ANALYSIS OF BUILDING ENERGY PERFORMANCE IN MALAYSIA: A MULTIPLE LINEAR REGRESSION STUDY ON GREEN VS. CONVENTIONAL BUILDINGS

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## ABSTRACT

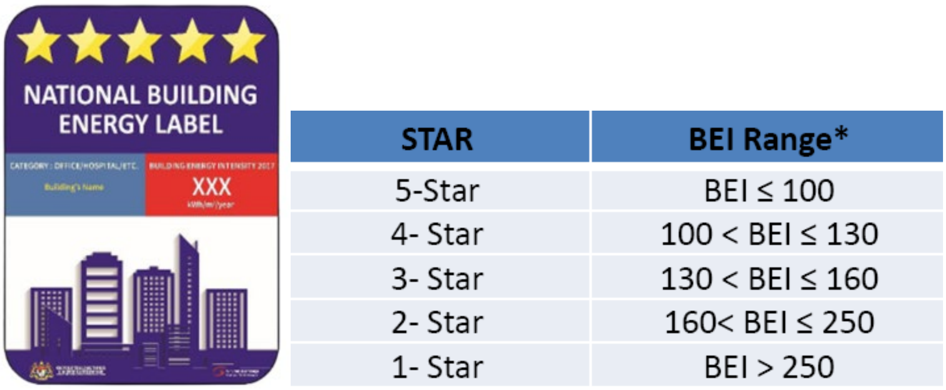
This study presents a detailed comparison of energy consumption between green and conventional commercial buildings by analyzing actual energy usage against benchmarks derived using Multiple Linear Regression (MLR) and Building Energy Intensity (BEI). MLR, selected for its statistical robustness and ease of implementation, incorporates variables such as Cooling Degree Days (CDD), temperature, humidity, rainfall intensity, wind speed, and number of working days as independent factors. The study evaluates energy consumption across 20 office buildings in Klang Valley, Malaysia, from 2019 to 2023. The findings indicate that both green and conventional buildings generally consumed less energy than their benchmarks. In terms of the difference between actual energy consumption and the benchmarks; green buildings recorded a narrower gap (26.49%) than conventional buildings (34.99%). However, green buildings consistently achieved superior energy efficiency, with BEI values ranging from 110 to 150, compared to 170 to 220 for conventional buildings. A notable reduction in energy usage occurred from 2020 to 2021 due to COVID-19-related remote work environment, though BEI slightly increased in 2023 with the normalization of operations. Energy label ratings further highlighted green buildings' superior performance, with 42% achieving a 4-star rating, while 80% of conventional buildings received only 2-star ratings. The results emphasize the importance of green building practices, demonstrating their long-term benefits in reducing energy consumption and achieving higher energy efficiency for sustainable living. This study offers valuable insights for policymakers, developers, and stakeholders, underscoring the need for sustained efforts in energy saving and innovation to enhance building energy performance.

Keywords: building energy intensity; green building; conventional building; sustainable; energy saving.

## 1.0 INTRODUCTION

Sustainability in buildings involve multiple dimensions, including environmental, economic, social, ecological, and technological aspects. Experts often describe sustainable buildings as green structures that outperform conventional ones in reducing greenhouse gas (GHG) emissions and have the potential to meet the Net-Zero Carbon Buildings Commitment [1]. The European Environment Agency (EEA) defines building energy efficiency as the amount of energy used or expected to meet various needs, such as heating, cooling, ventilation, and lighting. This energy usage is measured through numerical indicators that consider factors such as insulation, design, orientation, and self-energy generation, among others. Globally, buildings consume about 40% of total energy, with this number expected to rise to 50% by 2030. In Malaysia, buildings account for 48% of electricity consumption, contributing to 25% of GHG emissions [2]. In 2018, Malaysia's primary energy consumption reached 3.79 quadrillion British Thermal Units (BTU), growing annually by 4.58% [3].

The Building Energy Intensity (BEI) measures energy efficiency by dividing a building's annual energy consumption by its total floor area, expressed in kWh/m²/year, with a lower BEI indicating a more efficient building. The Malaysian Standard (MS) 1525 recommends a BEI of 200 kWh/m²/year. However, office buildings in Malaysia typically have a BEI of 200-250 kWh/m², which is three times higher than similar buildings in ASEAN countries [2].



| STAR | BEI Range* |
|---|---|
| 5-Star | BEI ≤ 100 |
| 4- Star | 100 < BEI ≤ 130 |
| 3- Star | 130 < BEI ≤ 160 |
| 2- Star | 160< BEI ≤ 250 |
| 1- Star | BEI > 250 |

**Figure 1.1:** BEI Range for Office Building. Adapted from Malaysian Energy Commission, 2019

Figure 1.1 shows the star ratings established by the National Building Energy Label; whereby buildings involve are rated from one (1) to five (5) star, based on their BEI value. Challenges in building energy performance mainly involve the need to address increasing energy demand, environmental concerns, inefficiencies in existing buildings, rising costs, and public awareness. In Malaysia, green building rating systems such as the Green Building Index (GBI) and Green-Certified-Tool for Real Estate (GreenRE) have been developed since 2009 to optimize building performance and reduce environmental impact [4]. Improving energy efficiency in buildings not only reduces carbon emissions but also offers additional benefits, such as reducing vulnerability to energy price fluctuations, contributing to economic recovery, and improving indoor conditions [5].

## 1.1 Studies on Buildings Energy Performance in Malaysia

In Malaysia, the energy performance of buildings has emerged as a critical focus in the nation's pursuit of sustainable development and environmental responsibility. With rapid urbanization and economic growth, there has been a heightened awareness of the significant role that buildings play in energy consumption and carbon emissions. There has been studies on the consumption of energy and Building Energy Intensity (BEI) in Malaysia for the past years, as detailed in Table 1.1.

**Table 1.1.** Previous Studies on Buildings Energy Consumption and BEI in Malaysia

| Subject | Methods | Description | Author / Year |
|---|---|---|---|
| Effectiveness of Energy-Saving Strategies and Energy Consumption Levels in a Multi-Building Complex in Malaysia | Literature review and energy audit was done to determine the energy consumption, then BEI was calculated. | Six numbers of office blocks were involved (Building A, B, C, D, E, F). The BEI were in the range of 78 to 183. | [7] |
| Energy Star based benchmarking model for Malaysian Government hospitals - A qualitative and quantitative approach to assess energy performances | Regression analysis | 84 Malaysian government hospitals were involved. Final output demonstrated a good fit for all hospital datasets, considerations such as new classification on energy score and air-conditioned area (ACA) usage were examined for comparing hospital rankings. | [8] |
| Quantifying Energy Savings for Retrofit Centralized HVAC Systems at Selangor State Secretary Complex | Linear Regression (LR) and MLR | Investigation of Sultan Salahuddin Abdul Aziz Shah (SSAAS) buildings post-upgrade of the water cooling package unit (WCPU), examining factors like number of working days (NWD), CDD, and occupancy using single and multiple linear regression analyses. | [12] |
| Evaluation of Energy Usage and Potential Energy Savings in an Institutional Building in Malaysia | Energy audit (EA) and potential energy conservation opportunities (ECOs) were identified and analysed. | The Research & Development (R&D) Building, University Malaya (BEI: 54). | [10] |
| Energy Efficiency Initiatives in Two Commercial Buildings in Malaysia | Energy audit was performed. For energy prediction; Autoregressive integrated moving average (ARIMA), Artificial Neural Network and LR were used. | Two office blocks (Skywarth and Skymage Building). The BEI were 155 and 171 respectively. | [11] |
| A Review on Building Energy Index (BEI) in Different Green Government Buildings (GGBs) in Malaysia | Comparison of Energy Efficient Technologies (EET) and Energy Conservation Opportunities (ECO) | The study of five GGBs in Malaysia; Green Energy Office (GEO) Building (BEI:30), Low Energy Office (LEO) Building (BEI: 100), Pusat Pertubuhan Arkitek Malaysia (BEI: 53), Diamond Building Malaysian Energy Commission (BEI: 85) and Menara Kerja Raya (BEI: 91). | [9] |
| BEI Examination of a Government Office Building at a Malaysian Public University | Preliminary and energy audits were done to obtain the details and energy data. | An office block in University Utara Malaysia (Chancellery Building) (BEI: 202) | [14] |

## 1.2 Research Gap

Recent advancements in research on energy usage performance in Malaysian office buildings have been fueled by increasing awareness of sustainability and the need to address energy consumption across various sectors. Despite this progress, significant research gaps remain. Comprehensive studies focusing on the actual energy consumption patterns of multiple green and conventional office buildings in Malaysia are scarce, particularly with regard to influential parameters [1]. Existing research often relies on localized studies or single-building analyses, primarily based on predicted energy values derived from design and materials. A deeper understanding of real-world energy usage variations across office building types is essential to evaluate the effectiveness of energy efficiency measures and develop targeted strategies for optimizing energy performance. [15] Dahlan et al. utilized regression analysis for energy benchmarking, analyzing data from 84 government hospitals in Malaysia. However, the study was limited by its focus on technical and equipment variables, excluding environmental factors that can significantly impact energy consumption. Hence this study will venture into the possible environmental factors that affect energy usage in buildings. A study on comparison of actual and predicted EUI in government offices in Shenzhen, China was done in 2018 [16], providing valuable insights. However, similar studies are needed in tropical climates like Malaysia to enhance the analysis and inform context-specific measures. Additionally, examining a broader range of building types is crucial to capture diverse trends and support the development of effective energy policies.

## 1.3 Research Questions

a) How does the energy performance of certified green buildings compared to that of conventional buildings when analysed using MLR model benchmark?
b) Which statistical method can be used to evaluate the benchmark of energy level in buildings?
c) How does the BEI of certified green buildings compared to that of conventional buildings considering the net floor area (NFA)?

## 1.4 Objectives

a) To analyse the energy performance in certified green buildings and a conventional buildings by using Multiple Linear Regression model benchmark.
b) To analyse the Building Energy Intensity (BEI) of certified green buildings and conventional buildings using the net floor area (NFA).

# 2.0 METHODOLOGY

## 2.1 Building Samples

This study examines two types of commercial buildings: (i) certified green buildings and (ii) conventional buildings, with 10 samples in each category. These buildings are government offices, which operates on Monday to Friday from 7.30 a.m to 6 p.m. These office buildings are located in the Klang Valley, specifically in Kuala Lumpur, Selangor, and Putrajaya. This region is a major urban hub, renowned for its economic and cultural significance, and serves as the primary location for most federal government offices and agencies. For the green buildings, this study does not specifically refer to any particular certification rating tool or level of certification; as there are a lot of certifications that can be adapted in order for a building to be considered as green building. There are also no specific restriction on the buildings' certification period, buildings' age or maintenance details imposed in this study. The samples in this study also vary in terms of buildings size and occupancy. Due to confidentiality purposes, the actual names and addresses of the buildings are not disclosed and are instead referred to as Building A, B, C, and so forth.

## 2.2 Scope and Limitations

The independent variables data in this study are Cooling Degree Days (CDD), temperature, humidity, rainfall intensity and wind speed; and the data are referred to the Subang/Sultan Abdul Aziz Shah Airport weather station (WMSA) and Kuala Lumpur International Airport station (WMKK). Another independent variable is number of working days; taken specifically for Klang Valley for the specific year, not considering the weekends and public holidays as the buildings consist of government offices that operate on weekdays. These variables are chosen for this study as they have the impacts on Heating, Ventilation and Air Conditioning (HVAC) system; which is a major contributor to building's energy usage and plays a crucial role in the energy system [18]. Based on a study utilising machine learning method to predict impactful factors to energy use, temperature and wind speed are among the top ten variables ranked by both the random forest and decision tree models besides total floor area, number of extensions, number of habitable rooms, number of heated rooms, floor type, wall type, roof type, and pressure [19]. This study utilizes actual energy consumption data from these buildings for five recent years, from January 2019 to December 2023. The actual energy consumption data is sourced from Sustainable Energy Development Authority (SEDA) Malaysia.

Various tools can be employed to perform regression analysis, offering a range of functionalities and capabilities. This study utilized Microsoft Excel tool, which provides a straightforward platform for regression analysis, particularly for basic and advanced models, using its built-in data analysis toolpack. Software such as 'R' and 'Python' are popular due to their flexibility, open-source nature, and extensive support for different regression techniques. 'SPSS' and 'SAS' are also widely used in academic and professional settings, offering user-friendly interfaces for conducting linear, logistic, and multiple regression analyses with built-in statistical tests. Each of these tools provides the necessary features to estimate coefficients, generate R-squared values, and assess the overall model performance.

MLR is chosen for this study as it is a highly effective method in statistical analysis, utilizing robust adjustments to standard errors. This allows for more accurate, unbiased, and efficient estimation of regression coefficients [20]. Moreover, MLR is easy to implement and can be performed using various statistical software tools. However, there are also weaknesses pertaining to MLR model, as indicated by [21] which concluded that Random Forest (RF) has better performance than MLR in utilization of climate change analysis and building's envelope. Among the factors are overfitting, limited applicability for complex relationship and high dependency on sample size.

## 2.3 Preprocessing Data

Data preprocessing is to ensure that data is clean, consistent and suitable for the intended analysis. After data collection, they are checked for missing, irrelevant or improperly formatted in order to prepare for the upcoming analysis. The available raw data involved in this study represented by five (5) years of annual data on energy consumption.

The next stage included the application of MLR using Microsoft Excel software to generate the regression's summary output. The coefficients values for each independent variable is used to formulate the MLR model equation to compute the benchmarks of every building sample. The summary output also includes regression statistics that detailed the values of multiple R, R-square, adjusted R-square, standard error and observations. Apart from that, Analysis of Variance (ANOVA) is also presented in the summary output; which is an essential tool to determine the overall effectiveness of the model and the significance of independent variables in explaining the variability of the dependent variable. It provides a statistical basis for evaluating model fit and ensures the regression results are meaningful and reliable.

## 2.4 Parameter Optimization and Constraint Criteria

In regression analysis, P-value and $R^2$ are key criteria used to evaluate the model's effectiveness and the significance of its predictors. The P-value tests the null hypothesis that a predictor's coefficient is equal to zero, or no effect. Typically, a p-value less than 0.05 indicates that the predictor is statistically significant and contributes meaningfully to explaining the variability in the dependent variable. The $R^2$ value; which measures the proportion of variance in the dependent variable explained by the independent variables must also be considered. A high $R^2$ indicates a good fit of the model, but an excessively high $R^2$ may signal overfitting, especially of it is accompanied by insignificant p-values. Balancing statistically significant p-values and a meaningful $R^2$ is essential for building an effective regression model that avoids overfitting while accurately capturing the relationships in the data.

**Table 2.1.** Parameter optimization for regression analysis

| Statistical indication | Description | Validity |
|---|---|---|
| Coefficient of determination, $R^2$ | A measure of the extent to which variations in the dependent variable Y from its mean value are explained by the regression model. | >0.75 |
| Significance, P-value | A low p-value suggests a significant relationship between the dependent and independent variables. Specifically, a p-value below 0.05 indicates with 95% confidence that the regression line's slope is not zero, confirming a meaningful linear association between the variables. | <0.05 |
| Lack of fit, F-test | The F-test in regression analysis evaluates the hypothesis that all model coefficients are equal to zero. Additionally, it is used in statistical analysis to compare models fitted to the same dataset and factors, helping identify the model that provides the best fit. | >2.5 |

## 2.5 Evaluation of Energy Benchmark Using MLR

Evaluating energy benchmarks using the MLR model involves comprehensive statistical techniques to analyze various factors influencing energy consumption over a five-year period from 2019 to 2023. MLR enables the simultaneous examination of multiple independent variables, providing a more robust understanding of their relationships with energy consumption patterns. For this study, historical data on building designs, energy consumption and the six independent variables are collected. Once the data is collected, the MLR is applied to identify the equations and coefficients of determination ($R^2$) for each independent variable. These coefficients indicate the strength and direction of each factor's influence on energy consumption. The resulting MLR equation reveals the weighted contribution of each variable to the overall energy consumption pattern, serving as a valuable tool for assessing energy benchmarks. This quantitative framework helps evaluate the effectiveness of energy management strategies and pinpoint areas for improvement.

The MLR models were formulated based on the most comprehensive equation available [22]:

$$Y_i = b_0 + b_1 X_1 + \ldots + b_i X_i + \ldots + b_k X_k + e, \quad i = 1, 2, 3, \ldots, k \tag{1}$$

Where

$Y_i$ represents the dependent variable (output);
$X_i$'s represent the independent variable (input);
$b_0$ is the intercept of the relationship
$b$'s are the i-th regression coefficient that determines the used weight
by the equation on the i-th explanatory variable to provide the estimate output;
$e$ is the error related to the i-th observation.

## 2.6 Evaluation of Building Energy Intensity (BEI)

Evaluating BEI involves the assessment of the energy efficiency and consumption patterns within buildings. This process begins with the collection of relevant data, including historical energy usage for the period of 2019 – 2023 and building's total occupied area. These data points serve as the foundation for quantitative analysis and benchmarking, aiming to quantify the energy intensity of a building or group of buildings.

BEI serves as a key performance indicator for assessing energy efficiency and identifying opportunities for improvement. Comparing BEI values across different buildings or industry standards, stakeholders can gain insights into relative energy performance and prioritize resource allocation for energy management initiatives. BEI is represented by the equation:

$$BEI\ (kWh/m^2/year) = \frac{Total\ Energy\ Consumption\ a\ Year\ (kWh/year)}{Total\ Occupied\ or\ Net\ Floor\ Area\ (m^2)} \tag{2}$$

# 3.0 RESULTS

## 3.1 Regression Summary Output

The summary output of an MLR analysis provides a key statistical metrics to evaluate the model's performance and the relationships between the dependent variable and multiple independent variables. Key components of the summary include the coefficient of determination ($R^2$) and adjusted $R^2$ values, which indicate the proportion of variance in the dependent variable explained by the model. Additionally, the output includes coefficients for each independent variable, along with their standard errors, t-values, and p-values, which help to determine the strength and significance of each predictor's impact. Excel tool further provides an Analysis of Variance (ANOVA) table, showing the overall significance of the regression model through the F-statistic and its p-value, which tests whether the model fits the data better than a simple average model. This comprehensive output allows users to assess both individual predictors and the overall model effectiveness.

### 3.1.1 Final Multiple Regression Analysis Summary

Table 3.1 and 3.2 show the final multiple regression summary based on the summary output of each analysis done on the building samples. Referring to the parameter optimization, the $R^2$, P-value and F are indicated for green buildings and conventional buildings.

**Table 3.1**. Final multiple regression analysis for green buildings

| Summary | |
|---|---|
| Number of observations in the analysis<br>(Independent variables ) | 6 nos:<br>i. CDD<br>ii. Average temperature<br>iii. Average relative humidity<br>iv. Rainfall<br>v. Wind speed<br>vi. Working days |
| Dependent Variables | Energy Usage (kWh) |
| Samples | 10 buildings (Building A – Building J) |
| **$R^2$ value** | **0.70** |
| **Significance (P-value)** | **>0.05** |
| **Lack of fit, F test** | **2.11** |

**Table 3.2.** Final multiple regression analysis for conventional buildings

| Summary | |
|---|---|
| Number of observations in the analysis<br>(Independent variables ) | 6 nos:<br>i. CDD<br>ii. Average temperature<br>iii. Average relative humidity<br>iv. Rainfall<br>v. Wind speed<br>vi. Working days |
| Dependent Variables | Energy Usage (kWh) |
| Samples | 10 buildings (Building A – Building J) |
| **$R^2$ value** | **0.72** |
| **Significance (P-value)** | **>0.05** |
| **Lack of fit, F test** | **2.85** |

### 3.1.2 Coefficients Parameter

Table 3.3 and 3.4 indicate the $R^2$ values and the coefficients for each independent variable for every building sample involved in this study.

**Table 3.3.** Coefficients parameter for green buildings

| **Parameter** | **Buildings** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** |
| *R square ($R^2$)* | 0.71 | 0.71 | 0.69 | 0.61 | 0.52 | 0.66 | 0.78 | 0.77 | 0.82 | 0.68 |
| *Coefficients* | | | | | | | | | | |
| Intercept | 4,378,931.23 | 1,309,454.96 | 5,690,518.57 | 14,620,474.62 | 2,954,759.00 | 156,918.50 | 898,107.48 | 1,003,756.80 | 6,256,882.78 | 2,251,458.00 |
| CDD °C (WMSA) | 4,882.27 | 1,451.65 | 7,600.76 | 13,050.53 | 2,823.01 | 2,397.80 | 1,682.79 | 1,856.48 | 11,785.38 | 3,340.23 |
| Average Temperature, °C | -148,337.66 | -44,265.71 | -210,952.68 | -470,176.29 | -86,162.75 | -6,248.78 | -33,679.33 | -40,651.52 | -224,092.62 | -86,143.01 |
| Average Relative Humidity | -6,779.06 | -2,031.01 | -4,003.34 | -21,633.09 | -7,514.63 | 989.53 | -141.57 | 3,654.84 | -4,672.82 | 1,934.30 |
| Rainfall, mm | 136.42 | 41.62 | 225.78 | 617.82 | 161.82 | 141.89 | 48.69 | 69.77 | 748.72 | 92.64 |
| Wind Speed, km/h | 1,061.69 | 658.48 | 7,169.38 | 54,636.02 | 16,147.92 | -5,963.33 | -2,556.73 | 13,427.01 | 20,426.04 | 7,336.74 |
| Working Days | 1,968.63 | 462.45 | 28,175.27 | -26,619.75 | 1,921.54 | -2,625.53 | -791.30 | -8,644.12 | 8,861.31 | -4,586.77 |

**Table 3.4.** Coefficients parameter for conventional buildings

| **Parameter** | **Buildings** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** |
| *R square ($R^2$)* | 0.60 | 0.71 | 0.90 | 0.72 | 0.54 | 0.57 | 0.74 | 0.86 | 0.82 | 0.71 |
| *Coefficients* | | | | | | | | | | |
| Intercept | 3,650,128.97 | 6,654,388.19 | 1,373,398.79 | 4,287,354.90 | 1,993,214.65 | -1,061,894.70 | 995,289.51 | 3,625,820.88 | 3,588,408.41 | 1,750,982.68 |
| CDD °C (WMSA) | 3,636.24 | 7,419.28 | 2,608.30 | 6,953.77 | 3,751.01 | 1,165.25 | 1,555.87 | 5,192.49 | 6,759.08 | 1,952.25 |
| Average Temperature, °C | -120,376.34 | -225,419.48 | -56,890.88 | -174,170.61 | -80,079.79 | 16,773.36 | -35,494.04 | -140,356.71 | -128,520.20 | -59,315.09 |
| Average Relative Humidity | -6,756.01 | -10,301.72 | 1,446.04 | 4,423.11 | 3,069.15 | 7,745.98 | -831.51 | 4,680.60 | -2,679.92 | -2,710.71 |
| Rainfall, mm | 113.81 | 207.31 | 36.64 | 138.25 | 127.06 | -67.20 | -40.84 | -92.02 | 429.40 | 54.55 |
| Wind Speed, km/h | 728.27 | 1,613.39 | -3,835.24 | 15,756.03 | 5,401.79 | -11,508.17 | 2,125.98 | 4,605.69 | 11,714.61 | 424.53 |
| Working Days | 3,726.06 | 2,991.60 | -1,745.79 | -12,329.50 | -6,551.19 | 15,011.20 | 3,107.71 | -15,955.90 | 5,082.08 | 787.19 |

## 3.2 Coefficient of Determination ($R^2$) of Buildings

Table 3.5 and 3.6 display the $R^2$ values for each independent variable in every building sample. The $R^2$ values then converted into an average figure that represent each independent variable for both types of buildings considered in this study.

### 3.2.1 Green Buildings

**Table 3.5.** Parameter $R^2$ of green buildings

| **Parameter** | **Building** | | | | | | | | | | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | |
| *$R^2$* | | | | | | | | | | | |
| CDD °C (WMSA) | 0.010 | 0.010 | 0.000 | 0.087 | 0.072 | 0.465 | 0.305 | 0.017 | 0.068 | 0.000 | 0.103 |
| Average Temperature, °C | 0.005 | 0.005 | 0.020 | 0.176 | 0.024 | 0.433 | 0.186 | 0.001 | 0.018 | 0.023 | 0.089 |
| Average Relative Humidity | 0.002 | 0.002 | 0.028 | 0.144 | 0.003 | 0.208 | 0.066 | 0.056 | 0.001 | 0.089 | 0.060 |
| Rainfall, mm | 0.040 | 0.041 | 0.080 | 0.245 | 0.001 | 0.062 | 0.004 | 0.056 | 0.084 | 0.124 | 0.074 |
| Wind Speed, km/h | 0.087 | 0.091 | 0.101 | 0.000 | 0.225 | 0.131 | 0.137 | 0.063 | 0.129 | 0.032 | 0.100 |
| Working Days | 0.385 | 0.385 | 0.575 | 0.214 | 0.284 | 0.000 | 0.076 | 0.023 | 0.346 | 0.211 | 0.250 |

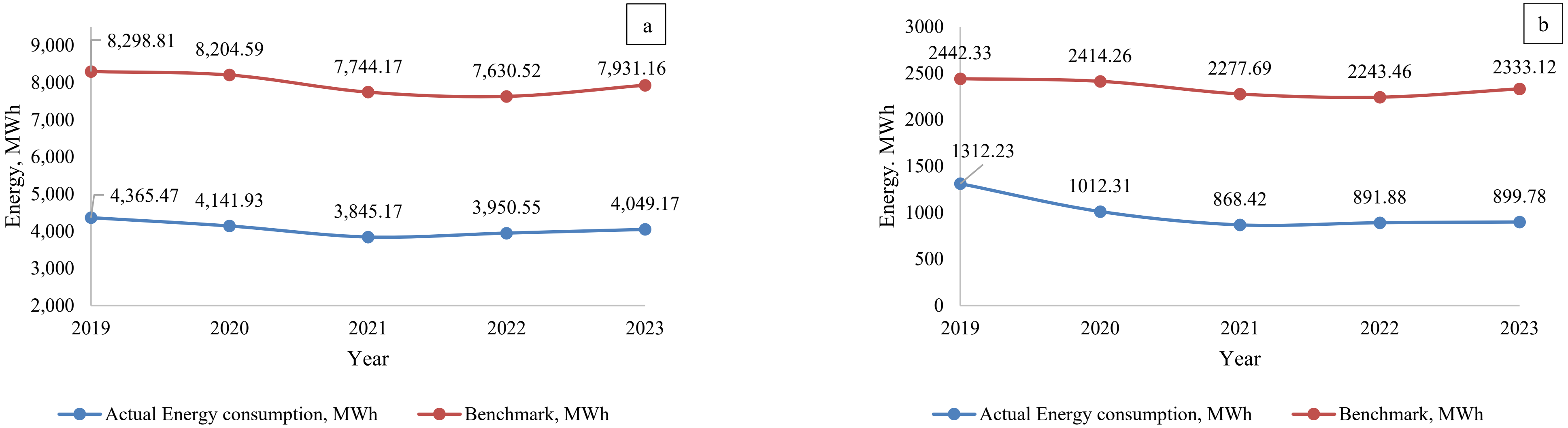
### 3.2.2 Conventional Buildings

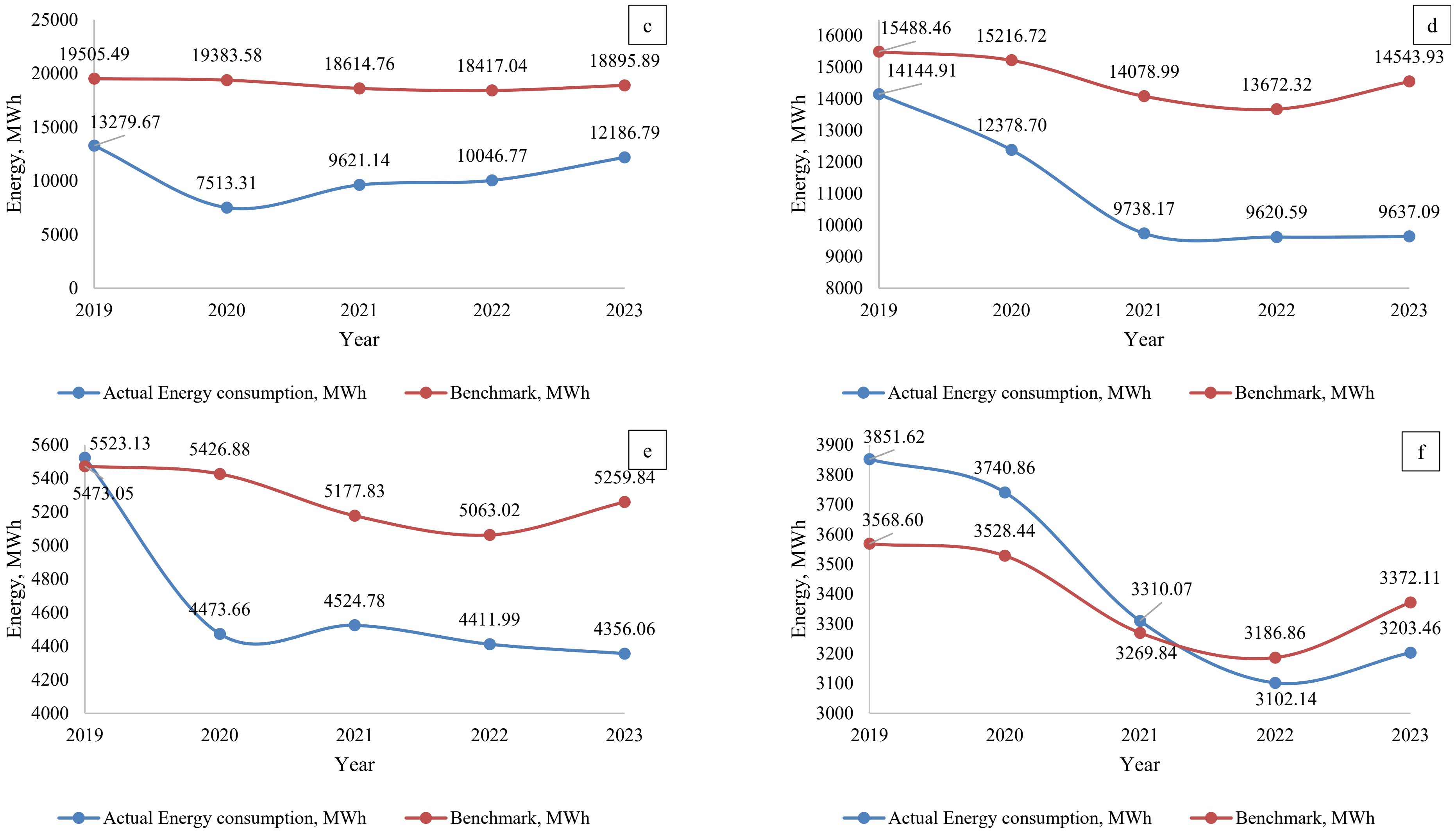
**Table 3.6.** Parameter $R^2$ of conventional buildings

| **Parameter** | **Building** | | | | | | | | | | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | |
| *$R^2$* | | | | | | | | | | | |
| CDD °C (WMSA) | 0.0033 | 0.0098 | 0.2349 | 0.0615 | 0.032 | 0.2826 | 0.5707 | 0.3165 | 0.0683 | 0.0098 | 0.159 |
| Average Temperature, °C | 0.0416 | 0.0045 | 0.1065 | 0.008 | 0.0047 | 0.1996 | 0.4423 | 0.215 | 0.0184 | 0.0045 | 0.105 |
| Average Relative Humidity | 0.0203 | 0.0017 | 0.0156 | 0.0059 | 0.0162 | 0.0768 | 0.4366 | 0.1558 | 0.0007 | 0.0017 | 0.073 |
| Rainfall, mm | 0.0811 | 0.0401 | 0.0026 | 0.0106 | 0.0496 | 0.0722 | 0.4206 | 0.3739 | 0.084 | 0.0401 | 0.117 |
| Wind Speed, km/h | 0.0349 | 0.0866 | 0.1129 | 0.1223 | 0.0344 | 0.2427 | 0.5316 | 0.1548 | 0.1291 | 0.0866 | 0.154 |
| Working Days | 0.3789 | 0.3854 | 0.0875 | 0.1334 | 0.0755 | 0.1548 | 0.0543 | 0.0521 | 0.3459 | 0.3854 | 0.205 |

## 3.3 Energy Benchmark and Actual Consumption

### 3.3.1 Green Buildings

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3102.14
3372.11
3203.46
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2022
2023
Year
Actual Energy consumption, MWh
Benchmark, MWh

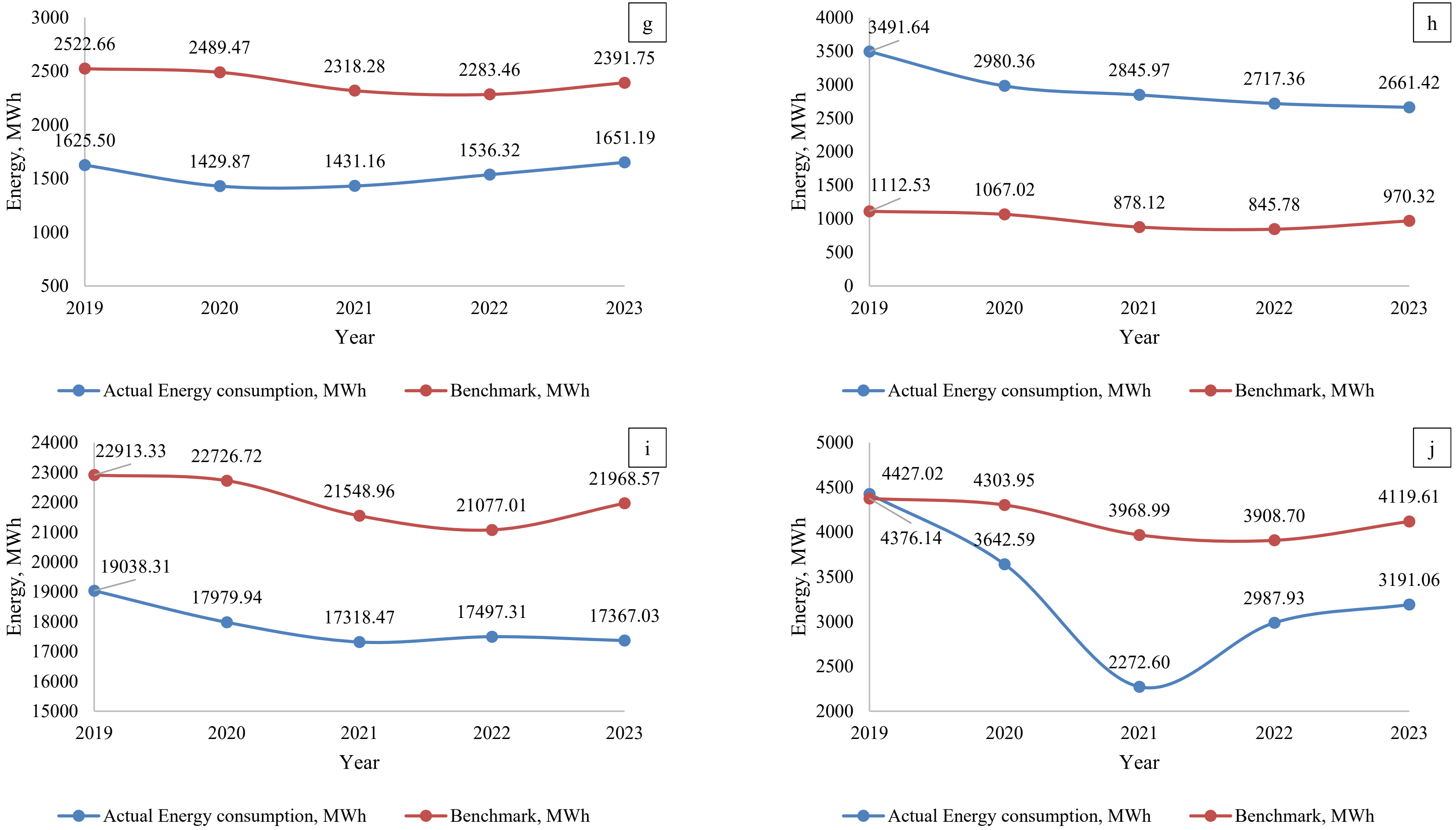
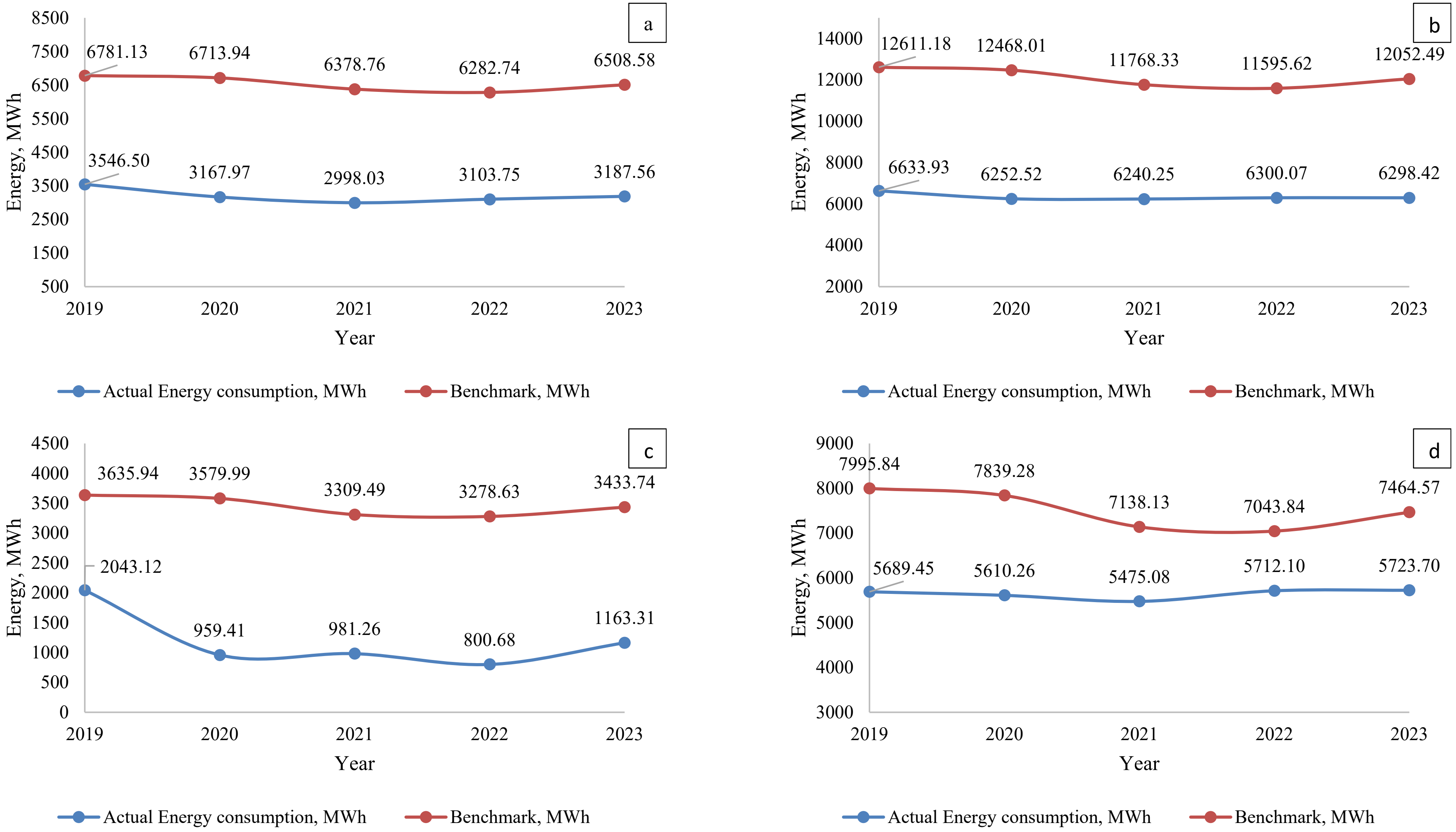
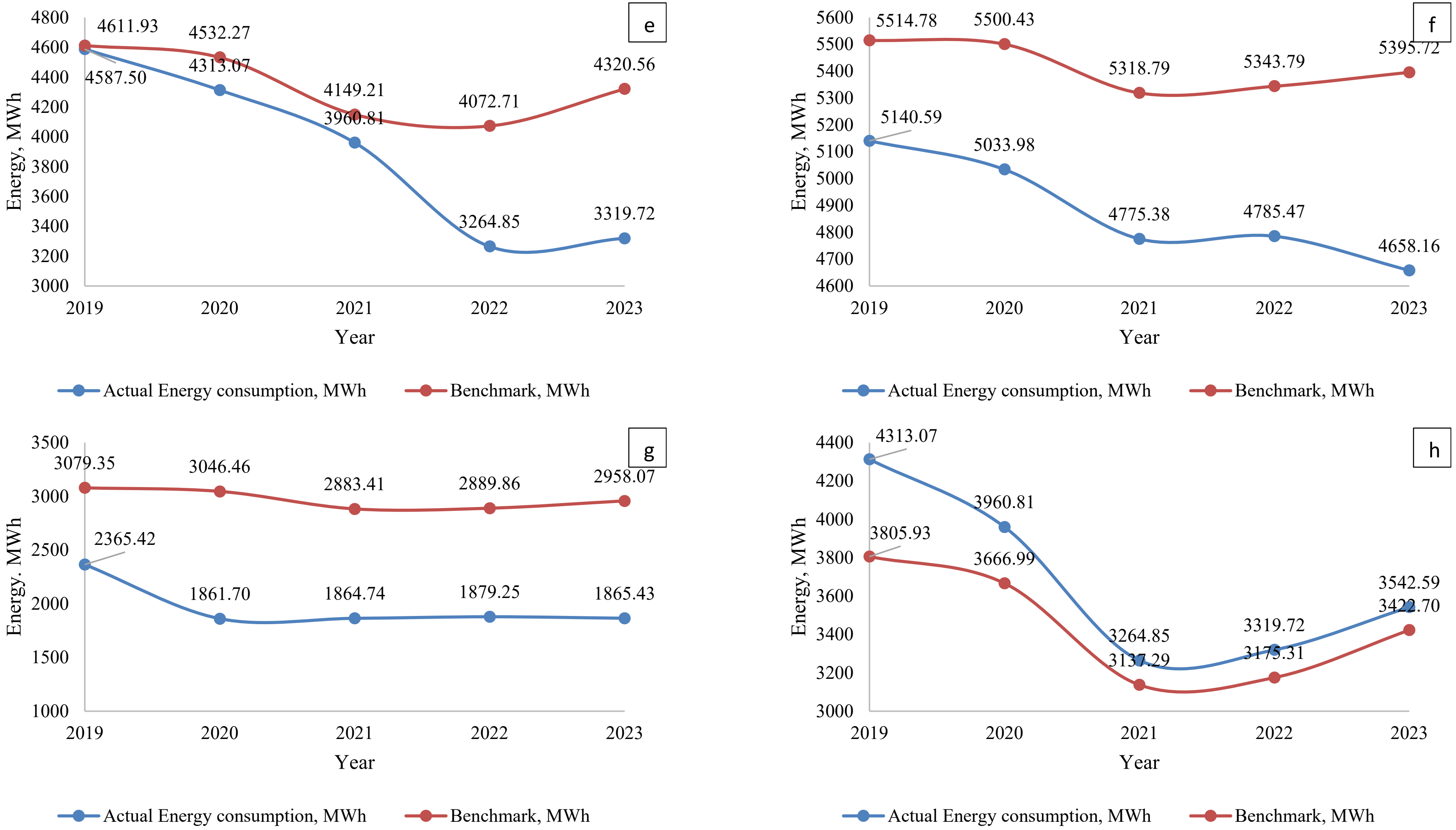


**Figure 3.1.** Comparison of eergy benchmark and actual energy consumption for green building in (a) Green building A, (b) Green building B, (c) Green building C, (d) Green building D, (e) Green building E, (f) Green building F, (g) Green building G, (h) Green building H, (i) Green building I, and (j) Green building J

### 3.3.2 Conventional Buildings




e
Energy, MWh
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
4611.93
4587.50
4532.27
4313.07
4149.21
3960.81
4072.71
3264.85
4320.56
3319.72
2019
2020
2021
2022
2023
Year
Actual Energy consumption, MWh
Benchmark, MWh
f
Energy, MWh
5600
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
5514.78
5500.43
5318.79
5343.79
5395.72
5140.59
5033.98
4775.38
4785.47
4658.16
2019
2020
2021
2022
2023
Year
Actual Energy consumption, MWh
Benchmark, MWh
g
Energy. MWh
3500
3000
2500
2000
1500
1000
3079.35
3046.46
2883.41
2889.86
2958.07
2365.42
1861.70
1864.74
1879.25
1865.43
2019
2020
2021
2022
2023
Year
Actual Energy consumption, MWh
Benchmark, MWh
h
Energy, MWh
4400
4200
4000
3800
3600
3400
3200
3000
4313.07
3960.81
3805.93
3666.99
3264.85
3137.29
3319.72
3175.31
3542.59
3422.70
2019
2020
2021
2022
2023
Year
Actual Energy consumption, MWh
Benchmark, MWh

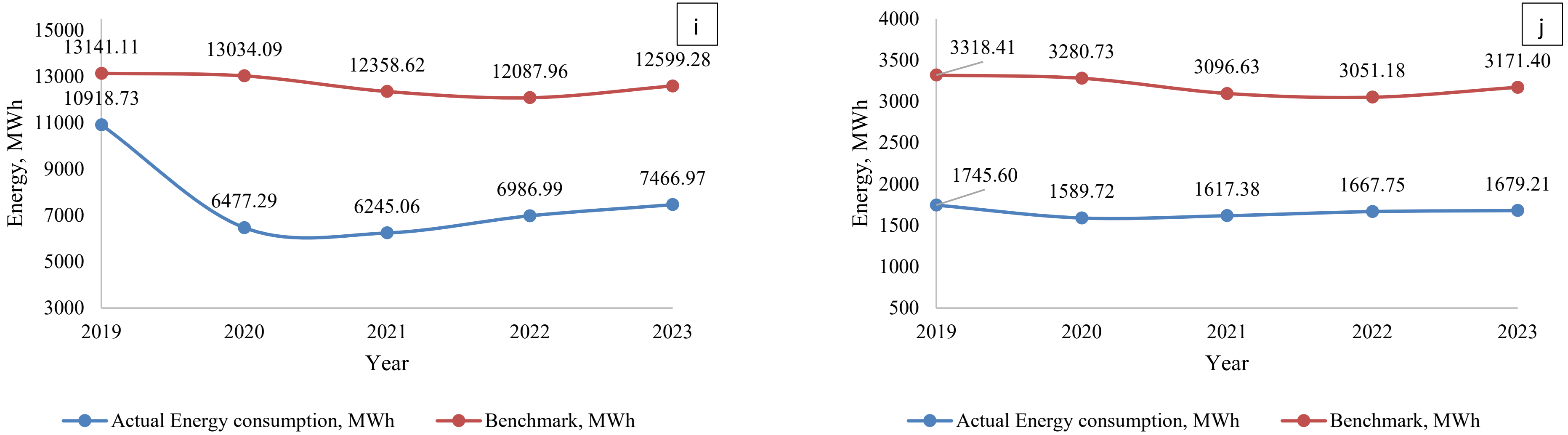


**Figure 3.2.** Comparison of eergy benchmark and actual energy consumption for conventional building in (a) Conventional building A, (b) Conventional building B, (c) Conventional building C, (d) Conventional building D, (e) Conventional building E, (f) Conventional building F, (g) Conventional building G, (h) Conventional building H, (i) Conventional building I, and (j) Conventional building J

## 3.4 Building Energy Intensity (BEI) of Buildings

### 3.4.1 Green Buildings

Figure 3.3 and 3.4 display the annual average BEI value of green buildings and conventional buildings. BEI of green buildings are in the range of 110 to 150 whereby the values are higher in conventional buildings; from 170 to 220.

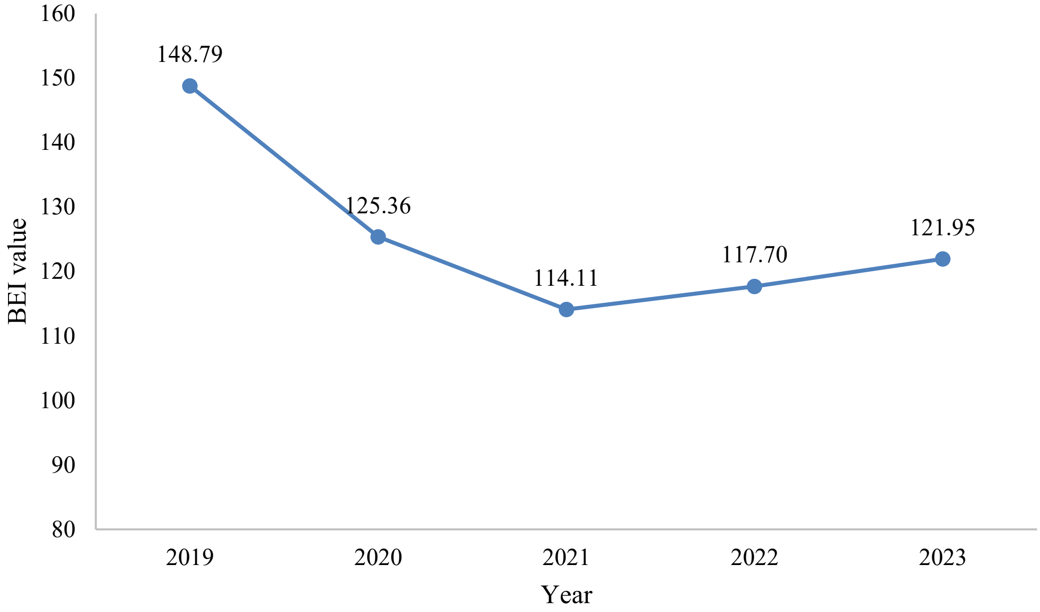


**Figure 3.3.** Annual average BEI value for green buildings

### 3.4.2 Conventional Buildings

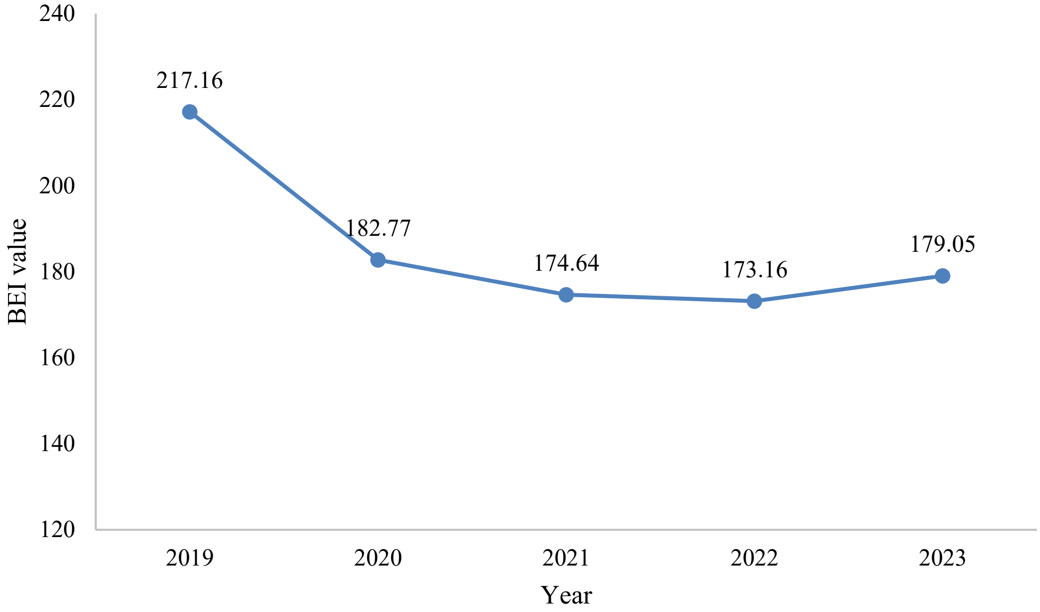


**Figure 3.4.** Annual average BEI value for conventional buildings

# 4.0 DISCUSSION

## 4.1 Regression Summary Output Analysis

The summary output of a MLR analysis provides a comprehensive overview of the model's performance and the relationships between the dependent variable and multiple independent variables. Key components of the summary include the coefficient of determination ($R^2$) and adjusted $R^2$ values, which indicate the proportion of variance in the dependent variable explained by the model, and the F-statistic, which tests the overall significance of the regression model.

For green buildings, there are 10 buildings being studied (Building A until Building J). Based on the analysis, it was found that the $R^2$ value recorded was 0.70, which can be interpreted as 70% of the variance in the response variable can be explained by the explanatory variables and there is a strong positive correlation between the variables. As for conventional buildings, the $R^2$ value is slightly higher; 0.72. This also indicates that the independent variables respond better to the dependent variable as compared to the green buildings.

### 4.1.2 Significance Testing / P-Value

Significance testing or p-value helps to determine the significance of the results in relation to the null hypothesis. Based on the analysis of both types of buildings in this study, the p-value is defined as $P > .05$; which also indicates that they are statistically insignificant and the null hypothesis is not rejected. This may be caused by the limited sample sizes for the statistical analysis, leading to higher p-values for both building types.

### 4.1.3 Lack of Fit, F-Test

The F-test is used in regression analysis to test the hypothesis that all model parameters are zero. A general rule of thumb is that if $F > 2.5$; then the null hypothesis can be rejected. In this study, for the green buildings type, the $F=2.11$ whereby for conventional buildings, the $F=2.85$.

### 4.1.4 Coefficient of Determination, $R^2$ of Independent Variables

R-squared ($R^2$) is a key statistical measure in MLR that quantifies the proportion of variance in the dependent variable that is explained by the independent variables. It provides an indication of how well the independent variables in the model account for the variability of the outcome. The $R^2$ provides more valuable and accurate insights compared to the symmetric mean absolute percentage error (SMAPE), and it avoids the interpretability challenges associated with mean square error (MSE), rooted MSE (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). Hence using R-squared as the standard metric for evaluating regression analyses across various scientific fields is recommended [23].

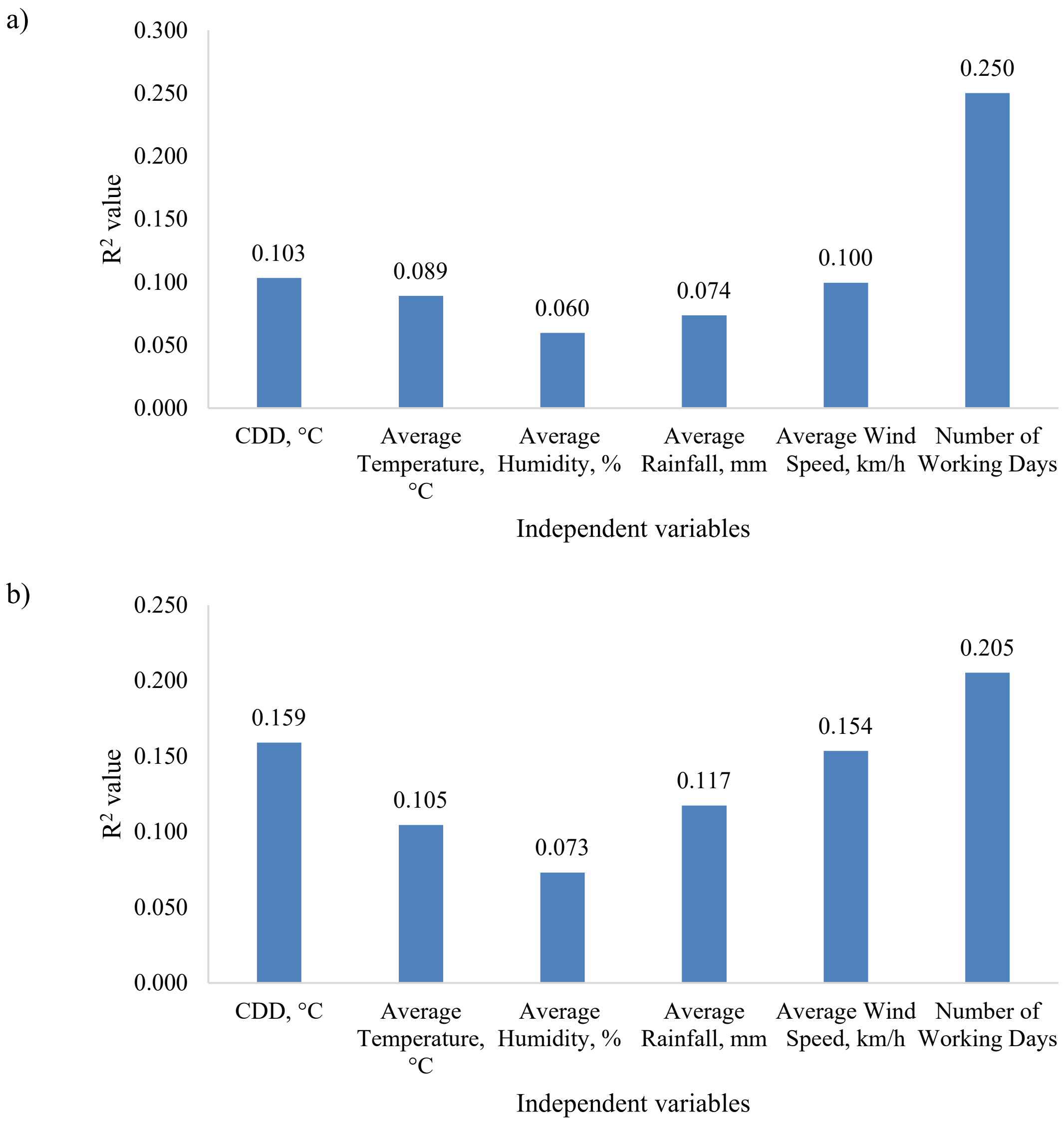


**Figure 4.1.** Value of $R^2$ for each independent variable in (a) Green buildings and (b) Conventional buildings

Figure 4.1(a) (b) indicates the $R^2$ value of each independent variable, in green and conventional buildings. As $R^2$ specifies the goodness of fit of a model particularly in regression analysis, it evaluates how accurately the regression line represents the observed data. The factor that influence most on energy usage in both types of buildings is the number of working days, followed CDD and average wind speed. Then, for green buildings; temperature, rainfall and humidity do affect energy usage in that order. For conventional buildings, rainfall play a more impactful role than temperature, followed by humidity.

In green buildings, number of working days shown a big influential impact as compared to the external environmental factors, which show less variability in response to changes in CDD, temperature, humidity, wind and rainfall. Conventional buildings, on the other hand, display greater fluctuations, reflecting their lower resilience to climatic variations. This could be due to the design and technologies in green buildings such as the implementation of energy-efficient technologies [24] and sustainable design strategies in green buildings [25], which make them more adaptable to environmental variations. Hence, green buildings display a more stable response to environmental factors, which points to their superior insulation and ventilation systems that mitigate the impact of external temperature changes.

## 4.2 Actual Energy Consumption vs Benchmark

The comparison between actual energy consumption and benchmark values is crucial for evaluating a building's energy performance. Benchmarks represent standardized energy usage levels based on the factors (independent variables) in this study, serving as a reference for ideal and acceptable level.This comparison helps to identify areas for improvement, supports energy saving initiatives and aligns buildings with sustainability goals and regulatory standards.

### 4.2.1 Green Buildings

The actual energy consumption of green buildings are consistently lower than the benchmark values for majority of the buildings, except for Building F and Building H. This indicates that most of these buildings are performing better than expected in terms of energy efficiency. For building F, the actual energy consumption were higher than the benchmark for the first three years, but in 2022 the energy consumption recorded lower and showed a bigger gap against the benchmark in the following year. This positive improvement could be due to the energy management practices that promotes energy efficient behaviours among the occupants, as these buildings are already built with energy efficiency measures. Occupants behaviour plays a crucial role in energy consumption, especially in an open plan office that are usually encountered in green building concepts [26]. Habits related to temperature control, lighting usage, and appliance use can influence overall energy demand. Awareness and education about energy-efficient practices, along with the implementation of smart technologies and controls, can help modify occupant behaviour for improved energy efficiency [27].

As for building H; the actual energy consumption is constantly higher than the benchmark. This is not impossible, as there are other studies shown that analysis of data from 121 Leadership in Energy and Environmental Design (LEED)-certified buildings that during operation phase, 25% of green buildings did not meet the anticipated performance levels set during their initial designs, with some even using more energy than standard buildings [28]. Building H may faced the same situation, as the energy usage anticipated during the design phase was lower than the actual demand for building operations. Hence during the operation phase, actual energy consumption is contstantly higher.

For all buildings studied, the highest energy consumption was recorded in the first year; 2019. There is a general downward trend in energy consumption from 2019 to 2023, with the lowest being in 2020 or 2021; suggesting that green buildings are progressively becoming more efficient. All buildings recorded the least energy consumption in year 2020 or 2021; when the Movement Control Order (MCO) was in placed. During these times, most offices restricted the number of workers to be present and remote working policies were applied. Hence, energy consumption in the offices were reduced. For comparison, this is supported by a study in commercial buildings in New York City, which recorded 78 GJ/day during Pre-COVID-19 being decreased to 69 GJ/day Post-COVID-19; indicating 6.86% reduction in energy usage [31]. Hence in Malaysia, since the remote working and physical activities restriction were implemented, the energy consumption showed the same declining pattern. As for the subsequent years of 2022 and 2023, most buildings recorded increasing energy usage pattern but remained lower than the first year; 2019.

In improving energy performance of green buildings, focus can be shifted to cooling loads and lighting loads. A study by [32] has proven that in Malaysia, energy reduction in green buildings through reducing cooling loads can be achieved by integrating green roofs and green walls rather than having solar photovoltaic. Green roofs and walls hold significant potential for minimizing substantial annual cooling loads by decreasing heat transfer through a building’s wall and roof structures. As for the lighting loads, the usage of LED lighting is significantly more effective in reducing lighting loads when applied on a larger scale compared to a smaller-scale implementations. As proposed by [33]; improving underperforming green buildings can be done by using simulation model and system dynamics (SD) project management model. It can be used for any buildings despite the age, location and climate condition. It integrates SD modelling and simulation, energy performance simulation and field investigation. This framework offers a potential approach for clients to enhance actual building performance and reduce the performance gap from a project management perspective.

### 4.2.2 Conventional Buildings

Similar to green buildings, the actual energy consumption in most conventional buildings, except for Building H, were also lower than the benchmark levels. For building H, the actual energy consumption constantly surpass its benchmark level. Moreover, building H also showed noticeable fluctuation in energy consumption, with downward pattern for the first three years followed by two years of gradual inclination. Overusing the energy can occur in buildings when artificial lightings are used despite excessive daylight receive within the area, which results in over-illumination. This is due to the fact that people’s preference and visual comfort varies [34]. Analysis of energy cost based data revealed that approximately 50% of lighting energy could be saved by eliminating the use of artificial lighting during peak working hours. Another option is delamping, especially at the over-illuminated areas and use of more energy-efficient light fittings at locations where sunlight is limited.

Post-pandemic years indicated that energy consumption were increasing but majority of the buildings were still manage to keep their energy lower than the first year in 2019, except for building F. While most office operation were back to normal after the COVID-19 restrictions and causing the spike in energy consumption; there were a number of offices had started the 'new normal' by imposing the remote work system, where the employees have the option to work from home. Hence, energy usage at the office maintains low despite the lift of restrictions. Conventional buildings were built with traditional concept, where energy-efficient model were not often imposed. However, there are strategies to retrofit conventional buildings that can be adapted. Building Information Modelling (BIM) tools, such as Autodesk Revit Architecture support various data input types, including 3D designs, energy models, schedules and cost estimates [35]. These tools provide practical advanced simulation and visualization capabilities in an integrated framework, allowing engineers and contractors to efficiently monitor and manage projects. Conducting energy audits is another feasible approach, considering energy saving measurements such as the roof and exterior wall insulation, installation of window shading systems, replacement of window glazing, use of efficient lighting and daylight sensors, adjustments to cooling set points, enhancement in airtightness and implementation of regular maintenance schedules for cooling systems [36]. Then, by utilizing the Design-Builder tool, these measures can be evaluated through simulation process to asses the workability of the proposed measures. Annual energy audits can be done to provide check-and-balance to the measures done and ensure that energy reduction can be achieved.

### 4.2.3 Comparison of energy benchmark and actual consumption

Figure 4.2 and table 4.1 indicates the average green and conventional buildings' differences between the benchmark and actual energy consumption. Overall, both types of buildings shown that the actual energy consumption is constantly lower than the energy benchmarks recorded through the years.

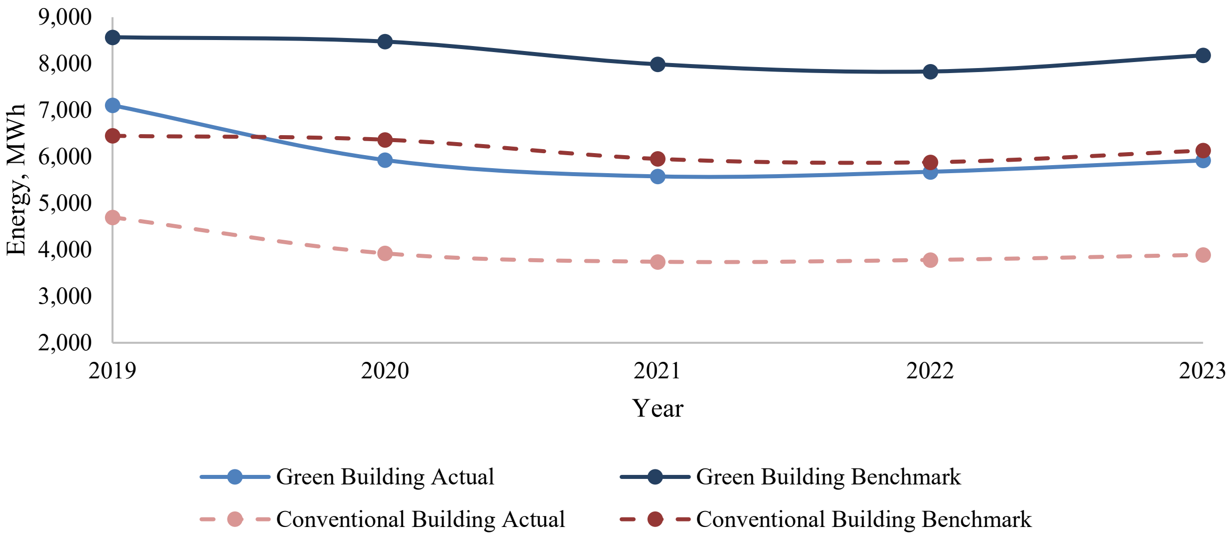


**Figure 4.2**. Comparison of actual energy and benchmark in green and conventional buildings

**Table 4.1.** Comparison of differences between actual and benchmarks in green and conventional buildings (%)

| Year | 2019 | 2020 | 2021 | 2022 | 2023 | 5-year-average |
|---|---|---|---|---|---|---|
| Green Buildings | 17.08 | 30.05 | 30.17 | 27.53 | 27.61 | 26.49 |
| Conventional Buildings | 27.15 | 38.38 | 37.15 | 35.70 | 36.56 | 34.99 |

Comparing the green buildings and conventional buildings data in Figure 4.2; the graph indicates that green buildings' energy performance is in a higher range than the conventional buildings. One of the factor that contribute to this finding is that the building samples were not restricted by size. Hence, the energy consumption data are affected by the floor area of the particular buildings. Instead, this study focus on the comparison between energy usage and benchmark of each individual building involved. Besides the size, buildings' energy performance is also influenced by the function and usage, climate condition and maintenance arrangement.

Building material and design play important roles to ensure that energy is used efficiently. For instance, the thermal conductivity for insulation materials; as it inclines gradually with temperature. Fibrous insulation material show more sensitivity to temperature, moisture and density compared to the other conventional materials [37]. The types and efficiency of appliances and equipment used within a building also significantly impact energy consumption. Modern, energy-efficient appliances, lighting systems and HVAC systems can contribute to substantial energy savings [18]. Properly designed, maintained and optimized HVAC systems can enhance energy efficiency. Regular maintenance, usage of programmable thermostats and adoption of advanced HVAS technologies can contribute to energy savings.

As referred to table 4.1; both types of buildings show positive improvement as compared to the first year data set in 2019. For green buildings, the difference increased from 2019 and reached the highest is year 2021 then reduced in 2022 and 2023; whereby for conventional buildings, the values increased and recorded the highest in 2020, before showing lower values in subsequent years. In terms of five-year-average value, conventional buildings shown better results with 34.99% difference and green buildings recorded 26.49%. This could imply that although the conventional buildings were not built with sustainable designs, energy-efficient mechanisms and equipment, but there are measures to be taken to ensure that energy saving can be performed, such as through education and awareness to the occupants, besides retrofitting the existing devices.

Overall, the energy consumption in 2020 and 2021 showed the lowest record for all buildings and highest difference between benchmarks and actual usage; as a result of the pandemic COVID-19 that hit the world and MCO was implemented. During these times, most offices restricted the number of workers to be present and remote working hours were applied. Hence, energy consumption in the offices were reduced. Comparing the five-year-data, it is recorded that energy usage are lower than the first year figures, which indicates that energy-efficient measures are implemented and showing positive results.

## 4.3 Building Energy Intensity (BEI)

### 4.3.1 Comparison of Average BEI of Green and Conventional Buildings

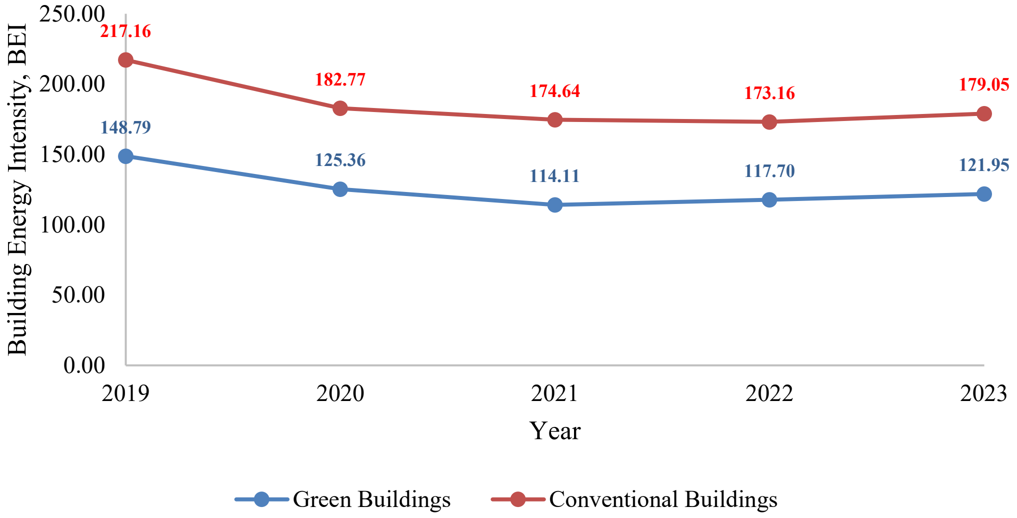


**Figure 4.3.** The comparison of a verage BEI of green and conventional buildings from 2019 until 2023

The provided data in Figure 4.3 compares the average Building Energy Intensity (BEI) for green buildings and conventional buildings from 2019 to 2023. Both green and conventional buildings show a general trend of decreasing BEI from 2019 to 2023. This suggests improvements in energy efficiency or changes in energy consumption patterns over the years. Throughout the five (5) years period, green buildings consistently have a lower BEI compared to conventional buildings. This aligns with the expectation that green buildings are designed to be more energy-efficient.

In terms of the fluctuations in BEI, green and conventional buildings experienced a noticeable decrease in BEI from 2019 to 2021, indicating significant improvements or optimizations in energy use. The main factor contributing to this downward pattern is the enforcement of Movement Control Order (MCO) that resulted in the remote working environment as a result of the global pandemic COVID-19. During this period, a lot of government office services were operated online, with very minimal physical presence. There were a few stages of MCO being in placed in 2020 and 2021, depending on the areas and cases. This is supported with a study done by [39] during the lockdown in South Korea, the average rate of change in electricity and gas energy consumption declined by 4.46% and 10.35%, respectively, compared to the previous year. Additionally, the same trend was also recorded in New York City's [31]. However, there is a slight upward trend from 2022 to 2023, which could suggest a plateau in efficiency gains or changes in usage patterns. With the office operations returning back to normal practices and the requirement of physical attendance in the office, the energy consumption were significantly impacted.

The slight increase in BEI for both building types in 2023 could be an area of concern, warranting further investigation into the causes, such as changes in building usage, external factors affecting energy consumption, or limits to current efficiency measures. However, post pandemic energy increment also occurred in other cities around the world, such as Spain, Italy, France, United Kingdom and Germany [40]. It also suggests that continuous efforts and innovations in energy management are necessary to maintain and further improve energy efficiency.

Maintaining a low BEI in commercial buildings has significant positive impacts on both the environment and operational costs. By optimizing energy efficiency, buildings can substantially reduce their carbon footprint, contributing to the global efforts to combat climate change. Lower energy consumption translates to fewer greenhouse gas emissions, helping to preserve natural resources and promote sustainable development. Additionally, focusing on improved indoor environmental quality, which can enhance the comfort and productivity of building occupants, can be achieved by having a reduced BEI. Efficient energy management ensures that heating, ventilation, and air conditioning systems operate optimally, providing consistent indoor temperatures and better air quality [42]. This can lead to improved health and well-being for employees, reducing absenteeism and boosting overall productivity.

### 4.3.2 Annual BEI values

#### 4.3.2.1 Green Buildings Analysis

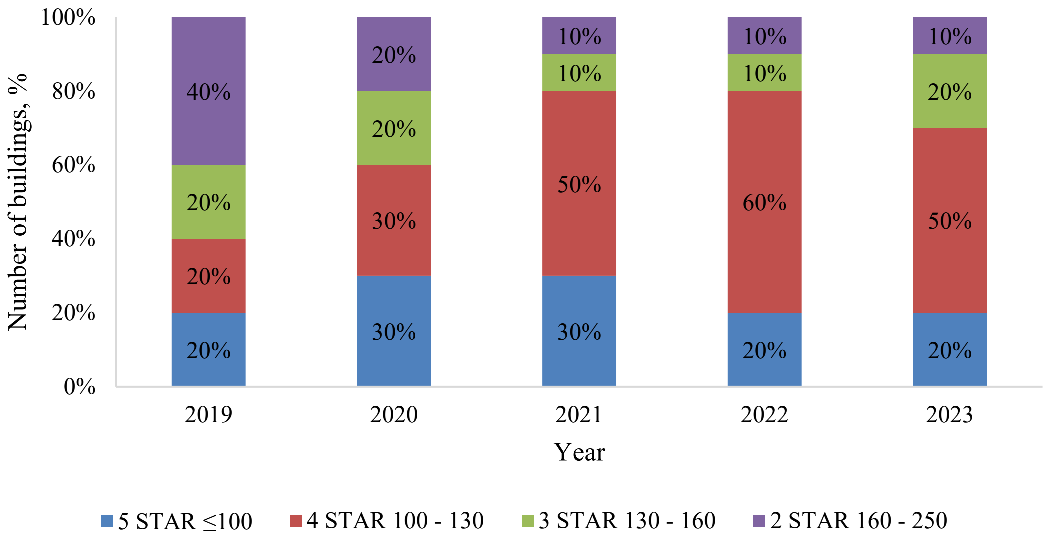


Figure 4.4: BEI of green buildings from 2019 to 2023

The chart in Figure 4.4 presents the distribution of green buildings according to their BEI from 2019 to 2023, based on the National Building Energy Label. The ratings are categorized into five star rating levels. For five star rating, the number of buildings in this category increased from 20% in 2019 to 30% in 2020 and 2021 but then decreased back to 20% in 2022 and 2023. Four star rating indicates high energy efficiency, the number of buildings in this category increased steadily from 20% in 2019 to 60% in 2022, then slightly decreased to 50% in 2023. According the system, three star rating represents moderate energy efficiency. The number of buildings remained constant at 20% from 2019 to 2023, only dropped to 10% in 2021. For two star rating which indicates lower energy efficiency, the number of buildings in this category decreased significantly from 40% in 2019 to 20% in 2020 and further down to 10% from 2021 to 2023. There are no buildings recorded to have one star rating throughout the years.

In terms of increase in high-efficiency buildings, the overall trend shows an increase in the number of green buildings with high energy efficiency (four star and five star categories) over the years. This indicates successful efforts in improving the energy performance of buildings. The fluctuations in the five star category, particularly the drop in 2022 and 2023, might indicate challenges in maintaining the highest energy efficiency standards or could be due to variations in building usage, occupancy, or external factors impacting energy consumption. The four star category saw a steady increase, suggesting a broader adoption of energy-efficient practices, but the slight decrease in 2023 may due to technical issues regarding equipment maintenance or higher adaptation to energy efficient practices is needed. The stability in the three star category indicates a steady number of buildings maintaining moderate energy efficiency or green buildings are by design default, could automatically contribute to this level of rating. The return to 20% buildings in 2023 could point to either new buildings meeting this standard or previous higher-rated buildings dropping in efficiency. The significant reduction in the number of buildings in the two star category suggests that many buildings have been upgraded or retrofitted to achieve better energy efficiency and practicing energy efficiency among the occupants, moving them into higher star categories.

The chart reflects a positive trend towards improving the energy efficiency of green buildings over the period from 2019 to 2023. The shift from lower to higher energy efficiency categories underscores the effectiveness of energy-saving measures and the growing emphasis on sustainability in building design and operation. However, the fluctuations in the highest efficiency categories highlight the need for continuous efforts and potential challenges in achieving and maintaining the highest standards of energy performance.

#### 4.3.2.2 Conventional Buildings Analysis

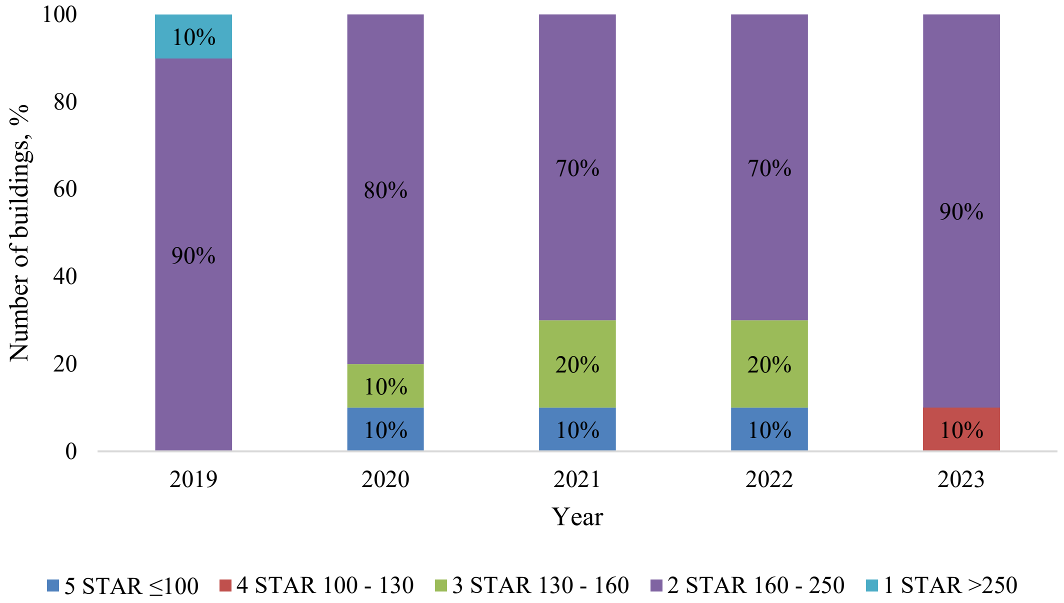


**Figure 4.5.** BEI of concentional buildings from 2019 to 2023

The chart in Figure 4.5 presents the percentage distribution of conventional buildings based on their BEI according to the National Building Energy Label star rating system from 2019 to 2023. No buildings were rated five star in 2019 and 2023, whereby from 2020 to 2022, 10% of buildings achieved this rating. There was no buildings were rated four star from 2019 to 2022 but in 2023, 10% of buildings achieved this rating. From 2020 to 2022, the percentage of buildings in three star category increased from 10% to 20% but in 2019 and 2023, there was no buildings rated the same. The majority of buildings were in two star rating category: 90% in 2019 and 2023, and 70% to 80% in the intervening years. This category implies lower energy efficiency. As for one star rating, the only year that had buildings in this category was in 2019, then there we none from 2020 to 2023.

The five star category saw a brief improvement from 2020 to 2022 with 10% of buildings achieving the highest rating, but this dropped to none in 2023. This fluctuation indicates challenges in maintaining the highest energy efficiency standards over time. The emergence of 10% of buildings in the four star category in 2023 suggests some progress, though modest. There was an increase in buildings rated three star from 2020 to 2022, indicating some improvements in energy efficiency. However, the absence of buildings in this category in 2023 suggests a regression or shift in the efficiency distribution. The majority of conventional buildings consistently fell into the two star category, highlighting that most buildings have not achieved high levels of energy efficiency. This category saw a slight improvement from 2019 to 2022 but returned to 90% in 2023. The elimination of buildings from the one star category after 2019 indicates progress in improving the worst-performing buildings. This suggests successful efforts to raise the minimum standards of energy efficiency.

The chart reveals that while there have been some improvements in energy efficiency among conventional buildings, significant challenges remain. The brief presence of buildings in the highest efficiency categories indicates potential, but the dominance of the two star category underscores the need for more aggressive and sustained efforts to enhance energy performance. The elimination of one star ratings is a positive sign, but the regression in higher efficiency categories in 2023 suggests that maintaining and advancing energy efficiency requires continuous focus and innovation.

### 4.3.3 BEI According to National Building Energy Label

#### 4.3.3.1 Green Buildings Analysis

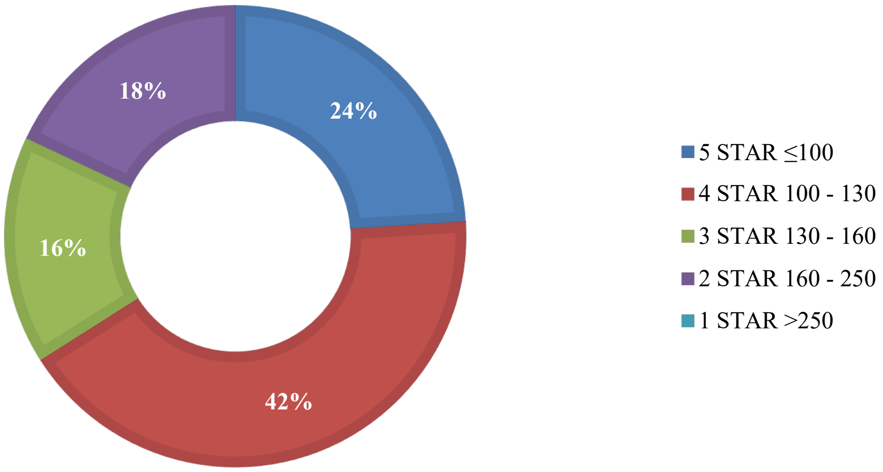


**Figure 4.6:** National Building Energy Label rating based on BEI of green buildings

The chart in Figure 4.6 illustrates the distribution of green buildings by their BEI ratings according to the National Building Energy Label established by Malaysian Energy Commission in 2019. The ratings are categorized into five star levels, indicating different ranges of energy efficiency, represented by BEI values.

The majority of green buildings are rated four (42%) star or five star (24%), demonstrating high energy efficiency. This highlights the effectiveness of green building practices in achieving significant energy savings. Then, there are buildings with moderate to lower energy efficiency, spread across the three star (16%) and two star (18%) categories. This suggests that while many green buildings achieve high efficiency, a significant portion still operates with moderate or lower efficiency. The absence of buildings in the one start category (>250 BEI) is a positive indication that green building standards effectively prevent extremely poor energy performance.

As for the focus areas for improvement, the presence of buildings in the two star and three star categories indicates areas where further progresses are needed. Targeted efforts to enhance the energy performance of these buildings could help elevate their ratings and contribute to overall energy savings. The chart effectively demonstrates the energy performance of green buildings based on BEI ratings. The significant number of buildings in the four star and five star categories underscores the success of green building practices in achieving high energy efficiency. However, the existence of buildings in the two star and three star categories suggests that there is still room for improvement. By focusing on enhancing the energy efficiency of these buildings, further advancements in sustainability and energy savings can be achieved.

#### 4.3.3.2 Conventional Buildings Analysis

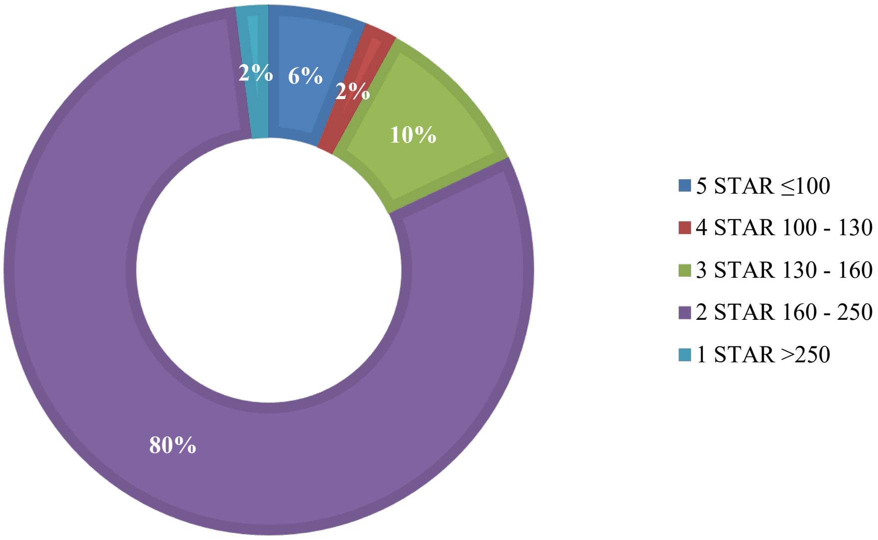


**Figure 4.7.** National Building Energy Label rating based on BEI of conventional buildings

The graph in Figure 4.7 illustrates the distribution of conventional buildings by their BEI ratings according to the National Building Energy Label. The ratings are categorized into five star levels, reflecting different ranges of energy efficiency.

In terms of the scarcity of high-efficiency buildings, only a small fraction of conventional buildings achieve high energy efficiency, with 6% in the five star category and 2% in the four star category. This suggests that achieving high energy performance is challenging for conventional buildings, possibly due to construction design and methods, less efficient technologies, or lower prioritization of energy efficiency. There are 10% of buildings in the three star category, showing moderate energy efficiency. These buildings represent a middle ground where some energy-saving measures might have been implemented, but further improvements are needed. The majority of conventional buildings (80%) are in the two star category (160 - 250 BEI), indicating that most conventional buildings have relatively low energy efficiency. This highlights a significant area for potential improvement in energy management and efficiency practices. The presence of 2% buildings in the one star category (>250 BEI) indicates that there are still conventional buildings with very poor energy performance. These buildings are likely significant energy consumers and could benefit greatly from retrofitting or upgrading to more energy-efficient systems.

The graph reveals that conventional buildings, on average, have lower energy efficiency compared to green buildings, with a large proportion falling into the two star category. The limited number of high-efficiency buildings (five star and four star) underscores the challenges faced by conventional buildings in achieving better energy performance. There is a clear need for targeted efforts to improve energy efficiency in conventional buildings, especially those in the two star and one star categories. Implementing energy-saving measures, retrofitting, and adopting newer technologies could help elevate the energy performance of these buildings, contributing to overall energy savings and sustainability goals.

### 4.4 Challenges of Imposing Green Building in Malaysia

Implementing green buildings in Malaysia has a few challenges; such as the high upfront cost with extended payback period, as highlighted by [43]. The sustainable material, certification procedures and processes involve can cause the cost to incur. Besides that, limited awareness of green building practices, insufficient financial resources and inadequate support from end-users are holding the step towards inculcating green building practices in Malaysia. Hence, despite many programs and incentives to promote green buildings, the development normally focus in the urban areas and big cities.

There are a few measure to curb this issue in Malaysia, for example by standardization, financial assistance, awareness and environmental [44]. BIM can be adapted to assist the implementation of green building by incorporating sustainable practices in building management in terms of standardization and economic related strategies. The Construction Industry Development Board (CIDB) Malaysia has consistently conducting programs through seminars and discussions to spread the awareness among the industry players to inculcate the sustainability concept into construction. There are also a lot of sustainable rating tools developed locally since 2009 to promote and educate about green building implementation in Malaysia, such as Green Building Index (GBI), Penarafan Hijau Jabatan Kerja Raya (pHJKR), Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST), Green Real Estate (GreenRE) and Green Performance Assessment System (GreenPASS).

## 5.0 CONCLUSION

a) Actual energy consumption in majority of green and conventional buildings were consistently lower than benchmark values over the studied years, with green buildings demonstrating closer alignment to the benchmarks. Overall, conventional buildings showed an average of 34.99% gap difference whereby green buildings recorded 26.49%. However, there are a few buildings that indicated contrary patterns, due to possible justifications which are not within the scope of this study, such as the behavior of building occupants, maintenance conduct, buildings' age and materials. The decreased in energy consumption pattern from 2020 to 2021 aligns with the impacts of remote work and limited physical presence in the workplace during the COVID-19 pandemic.

b) Green buildings consistently achieved a lower BEI than conventional buildings, highlighting superior energy efficiency. For the duration of five years, BEI of green buildings were in the range of 110 to 150; whereby for conventional buildings, the BEI recorded were between 170 and 220. A slight increase in BEI for both types was observed in 2023, likely due to post-COVID operational normalization such as office-based operations. As National Building Energy Label is concerned; green buildings shown a majority of 4-star ratings (42%), 5-star (24%), 2-star (18%) and 1-star (16%). As for conventional buildings, 80% of the buildings were rated 2-star, 10% with 3-star, 6% with 5-star, and 2% each for 4-star and 1-star.

The results shown a clear disparity in energy performance between green and conventional buildings, with green buildings consistently outperforming conventional ones in terms of BEI and energy label ratings. Both types of buildings have shown improvements over the years, but the increase in BEI in 2023 for both suggests that maintaining and enhancing energy efficiency requires ongoing attention and innovation, involving all stakeholders. The data highlights the importance of adopting green building practices and the need for continuous efforts to improve energy efficiency across all building types.

## 6.0 RECOMMENDATION

There are certain limitations applied within this study; pertains to the comparative analysis of energy efficiency measures across different geographic regions and climatic conditions. Understanding the impact of design choices, construction materials, and operational practices on energy consumption in varying climates is essential for informing targeted strategies to improve overall building sustainability. Furthermore, this study only take into account the five recent years, without fully exploring the long-term implications of sustainable building practices. Studies tracking the energy performance of green and conventional buildings over extended periods are needed to assess the durability and resilience of green building technologies and design principle through times. For future studies, assessment of different types of buildings can be done; varying in occupancy, weather and climate conditions or operational schedules such as healthcare facilities, residential areas and multi operational buildings. Opting for different independent variables can also be done; involving occupancy patterns and behaviours or geographical factors and utilizing different statistical analysis.

In order to add more weightage to the studies, financial worthiness of investments made in green buildings can be assessed, by comparing the energy saving and investments made to the buildings. This can assist the related stakeholders such as developers to make sound decisions to opt for sustainable buildings instead of traditional ones. As green buildings are proved to be more energy-saving than conventionals through the finding of this study, designers should focus more on having more sustainable building concepts that optimize natural daylight than relying on artificial lightings, opting to use LED lights and using insulation materials with low thermal conductivity.

Building owners and facilities management team are urged to conduct energy audits in their premises to ensure that the energy consumption are under control. Specific target and goals on short and long term basis can be made so that on-going measures on energy saving can be done not only focusing on the equipments but most importantly on educating the building occupants. End-users are the main contributor to energy usage within buildings and the right attitude can make a big difference for the future of energy-efficient users.

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