

ASSESSMENT OF AIR CONDITIONING ENERGY CONSUMPTION IN A SMALL-SCALE HOTEL

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ABSTRACT

Energy consumption in the hospitality sector has become a critical concern due to increasing operational costs and environmental impacts. This study presents 3,000-square-foot small-scale hotel using a case study approach. Primary data were collected over a seven-day period, including outdoor temperature, indoor temperature, occupancy levels, and AC load. Thermodynamic analysis and energy calculations were carried out to estimate the cooling load and energy consumption. In addition, linear regression analysis was performed to examine the relationships between the key variables. The results indicated a moderate correlation between outdoor temperature and AC load ($R^2 = 0.684$), whereas a very strong correlation was found between occupancy and energy consumption ($R^2 = 0.977$).

The findings suggest that occupancy has a greater influence on energy consumption than environmental conditions in small-scale hotel operations. The study further demonstrates that optimizing operational factors, such as occupancy-based control, thermostat settings, and regular maintenance practices, can substantially reduce energy consumption. Overall, this research provides practical insights into improving energy efficiency and contributes to the development of sustainable energy management strategies for small hospitality establishments.

Keywords: Air-conditioning; energy consumption; cooling load analysis; energy efficiency; HVAC performance; occupancy impact; outdoor temperature; small-scale hotels; sustainable energy management.

INTRODUCTION

The rapid growth of the hospitality sector has led to a significant increase in energy consumption, particularly in small-scale hotels, where operational efficiency is often constrained by limited resources (Sharma & Gupta, 2020). Among the various energy-consuming

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systems, air-conditioning (AC) systems account for substantial proportion of total electricity consumption because of their continuous operation and high power demand, particularly in regions with warm climates (Kumar *et al.*, 2019). In developing countries such as India, the increasing demand for thermal comfort in hospitality establishments has further intensified energy consumption, making it essential to evaluate and optimize the performance of AC systems (Patel & Singh, 2021). Small-scale hotels, typically occupying an area of approximately 3,000 square feet, often lack advanced energy management systems and rely on conventional cooling technologies, resulting in inefficient energy utilization (Verma, 2018). Furthermore, factors such as building design, occupancy patterns, insulation quality, thermostat settings, and maintenance practices significantly influence the energy consumption of air-conditioning systems (Reddy & Rao, 2022). Understanding the influence of these factors is essential for identifying opportunities to reduce energy consumption without compromising guest comfort.

This study focuses on assessing the energy consumption of air conditioning systems in a 3000 sq. ft. small-scale hotel setup. By analyzing usage patterns, load distribution, and operational efficiency, the research aims to provide insights into energy-saving strategies and sustainable practices applicable to similar hospitality establishments (Joshi & Mehta, 2020). The findings are expected to contribute to improved energy management, cost reduction, and environmental sustainability in the small-scale hotel industry.

Literature Review

The study of energy consumption in hotel buildings has received considerable attention due to rising energy costs and increasing environmental concerns. Research indicates that air-conditioning (AC) systems are among the largest contributors to energy consumption in hospitality facilities, often accounting for approximately 40–60% of total electricity consumption (Priyadarsini *et al.*, 2009). This high energy demand is particularly evident in warm and humid climates, where cooling loads remain consistently high throughout the year (Saidur *et al.*, 2010). Consequently, improving the efficiency of air-conditioning systems has become a key component of energy management strategies in the hospitality sector.

Several studies have examined the factors influencing air-conditioning energy consumption in small- and medium-sized buildings. Building envelope characteristics, including insulation quality, window glazing, and building orientation, significantly influence cooling loads (Omer, 2008). Poor insulation and excessive solar heat gain increase dependence on mechanical cooling systems, thereby resulting in higher energy consumption (Santamouris *et al.*, 2011). In addition, occupancy patterns and user behaviour play a crucial role, as variations in guest occupancy directly influence cooling demand (Bohdanowicz & Martinac, 2007).

Technological advancements have also been investigated as effective measures for reducing energy consumption. The adoption of energy-efficient heating, ventilation, and air-conditioning (HVAC) systems, such as inverter-based air conditioners and Variable Refrigerant Flow (VRF) systems, has demonstrated considerable potential for reducing energy consumption compared with conventional cooling systems (Chua *et al.*, 2013). Furthermore, the integration of smart control technologies, including occupancy sensors and programmable thermostats, has been

shown to optimize AC operation and minimize unnecessary energy consumption (Wang *et al.*, 2012).

Energy audits and case studies conducted in small-scale hotels have highlighted the importance of regular maintenance and system optimization. Inefficient operation resulting from clogged air filters, refrigerant leakage, or outdated equipment can substantially increase energy consumption (Reddy, 2013). Previous studies have also demonstrated that implementing simple measures, such as optimizing thermostat set points and carrying out periodic maintenance, can result in significant energy savings (Dascalaki & Balaras, 2004).

In developing countries, financial and technical constraints often limit the adoption of advanced energy-efficient technologies in small-scale hotels (Mensah, 2006). Nevertheless, existing research suggests that even low-cost interventions, such as improving natural ventilation, installing shading devices, and enhancing staff awareness of energy conservation practices, can significantly improve energy efficiency (Chan *et al.*, 2009). Therefore, a comprehensive understanding of both technological and behavioural factors is essential for reducing air-conditioning energy consumption and promoting sustainable energy management in small-scale hospitality establishments.

Research Gap and Problem Identification

Despite extensive research on energy consumption in the hospitality sector, several gaps remain, particularly concerning small-scale hotels. Most existing studies focus on large or luxury hotels with advanced energy management systems, leaving smaller establishments underrepresented in empirical research (Bohdanowicz & Martinac, 2007). Small-scale hotels, especially those operating within limited areas such as 3000 sq. ft., often have different operational characteristics, resource constraints, and energy usage patterns that are not adequately captured in broader studies (Mensah, 2006). This lack of targeted research limits the applicability of existing energy efficiency strategies to smaller facilities.

Furthermore, while previous studies have examined the overall energy consumption of hotel buildings, there is limited focus on the detailed assessment of air conditioning systems as a standalone component in small-scale settings (Priyadarsini *et al.*, 2009). Given that air conditioning accounts for a major portion of energy use, a more granular analysis is required to understand load distribution, system performance, and inefficiencies specific to such compact infrastructures (Saidur *et al.*, 2010). Additionally, the influence of local climatic conditions, occupancy variability, and building design on AC energy consumption in small hotels remains insufficiently explored (Omer, 2008).

Another significant gap lies in the limited availability of real-world case studies that combine technical analysis with practical, cost-effective solutions. Many studies propose advanced technologies such as smart HVAC systems and automation; however, their implementation is often not feasible for small hotel owners due to financial and technical constraints (Chua *et al.*, 2013). There is a need for research that emphasizes affordable and scalable interventions tailored to small-scale operations (Chan *et al.*, 2009).

METHODOLOGY

This study adopts a quantitative case study approach to assess air conditioning energy consumption in a 3000 sq. ft. small-scale hotel. The methodology involves data collection, analysis, and modeling of key variables influencing AC performance.

Primary data were collected through direct observation and monitoring of the hotel's air conditioning system over a period of seven days. Measurements were recorded daily, including outdoor temperature, indoor temperature, occupancy levels, AC load (kW), and daily operating hours. Energy consumption was calculated using standard energy relations (Kreith & Goswami, 2008).

The cooling load and energy consumption were analyzed using basic thermodynamic and heat transfer principles. Mathematical models such as heat transfer equations and energy consumption formulas were applied to estimate system performance (Cengel & Ghajar, 2015). The collected data were then organized into tables and graphical representations to identify trends and relationships.

Finally, the results were interpreted to identify inefficiencies and propose practical energy-saving measures suitable for small-scale hotel operations.

Mathematical Modelling

Mathematical modeling of air conditioning energy consumption is essential for quantifying cooling loads and evaluating system performance in small-scale hotel environments. One of the fundamental approaches involves estimating the cooling load based on heat gains from various sources, including building envelope, occupants, lighting, and equipment (ASHRAE, 2017). The total cooling load Q_{total} can be expressed as the sum of sensible and latent heat loads:

$$Q_{\text{total}} = Q_{\text{sensible}} + Q_{\text{latent}}$$

The sensible heat load is primarily influenced by external heat transfer through walls, roofs, and windows, as well as internal heat gains. It can be calculated using the heat transfer equation:

$$Q = U \times A \times \Delta T$$

where U is the overall heat transfer coefficient, A is the surface area, and ΔT is the temperature difference between indoor and outdoor environments (Cengel & Ghajar, 2015). This equation is widely used to estimate heat gain through the building envelope.

The cooling load due to occupants is another important factor and can be modeled as:

$$Q_{\text{occupants}} = N \times (\text{SHG} + \text{LHG})$$

where N is the number of occupants, SHG is sensible heat gain, and LHG is latent heat gain per person (ASHRAE, 2017). Similarly, heat gains from electrical equipment and lighting can be estimated based on their power ratings and usage duration (Saidur *et al.*, 2010).

To evaluate the energy consumption of the air conditioning system, the Coefficient of Performance (COP) is commonly used. It is defined as the ratio of cooling output to electrical energy input:

$$COP = \frac{Q_{\text{cooling}}}{W_{\text{input}}}$$

A higher COP indicates a more efficient system (Dincer & Rosen, 2013). The actual energy consumption of the AC unit over a period of time can then be calculated as:

$$E=P \times t$$

where E is energy consumption (kWh), P is power input (kW), and t is operating time (hours) (Kreith & Goswami, 2008).

Additionally, for dynamic analysis, cooling load variation with time can be modeled using hourly load calculation methods, incorporating external temperature fluctuations and occupancy patterns (Omer, 2008). These mathematical models provide a structured framework for analyzing and optimizing air conditioning energy consumption in small-scale hotels, enabling the identification of inefficiencies and potential energy-saving measures.

Observation Table

Observation No.	Day	Date	Outdoor Temp (°C)	Indoor Temp (°C)	Occupancy (%)	AC Load (kW)
1	Day 1	30/03/2026	32	24	60	5.2
2	Day 2	31/03/2026	34	24	70	5.6
3	Day 3	01/04/2026	35	23	65	5.3
4	Day 4	02/04/2026	36	23	60	5.0
5	Day 5	03/04/2026	33	24	75	5.8
6	Day 6	04/04/2026	31	24	80	6.1
7	Day 7	05/04/2026	30	24	85	6.5

Cooling Load and Performance Calculations from Observed Data

The following parameters are calculated:

- i. Q: Total cooling load (kW)
- ii. SHG: Sensible Heat Gain (kW)
- iii. LHG: Latent Heat Gain (kW)
- iv. COP: Coefficient of Performance
- v. W: Power input (kW)

Assumption (standard for small hotel studies):

- i. SHG $\approx$ 70% of total load
- ii. LHG $\approx$ 30% of total load

Typical COP = 3.0 (moderate efficiency AC system)

It has been assumed that the AC operates 10 hours per day.

Obs. No.	AC Load Q (kW)	SHG (kW)	LHG (kW)	COP	Power Input W (kW)
1	5.2	3.64	1.56	3.0	1.73
2	5.6	3.92	1.68	3.0	1.87
3	5.3	3.71	1.59	3.0	1.77
4	5.0	3.50	1.50	3.0	1.67
5	5.8	4.06	1.74	3.0	1.93
6	6.1	4.27	1.83	3.0	2.03
7	6.5	4.55	1.95	3.0	2.17

For **Observation 2:**

- i. $Q = 5.6 \text{ kW}$
- ii. $SHG = 0.7 \times 5.6 = 3.92 \text{ kW}$
- iii. $LHG = 0.3 \times 5.6 = 1.68 \text{ kW}$

$$W = \frac{COP}{Q} = \frac{5.6}{3} = 1.87 \text{ kW}$$

Total Weekly Energy

$$E_{\text{total}} = 17.3 + 18.7 + 17.7 + 16.7 + 19.3 + 20.3 + 21.7 = 131.7 \text{ kWh}$$

Monthly Load Estimation

Assuming similar weekly patterns over a month:

$$E_{\text{monthly}} = 131.7 \times 4 = 526.8 \text{ kWh}$$

Final Result

Total Monthly AC Energy Consumption $\approx 527 \text{ kWh}$

This represents the overall cooling load demand for the hotel

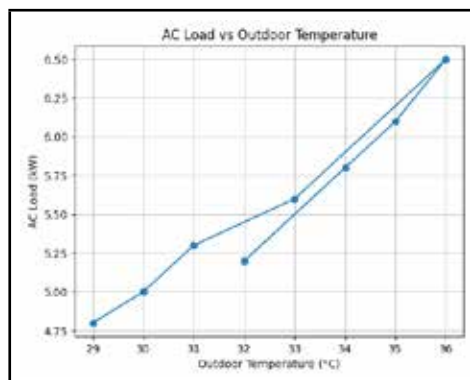


Fig. 1: AC Load vs Outdoor Temperature

AC load increases with rising outdoor temperature, indicating a direct relationship due to higher cooling demand.

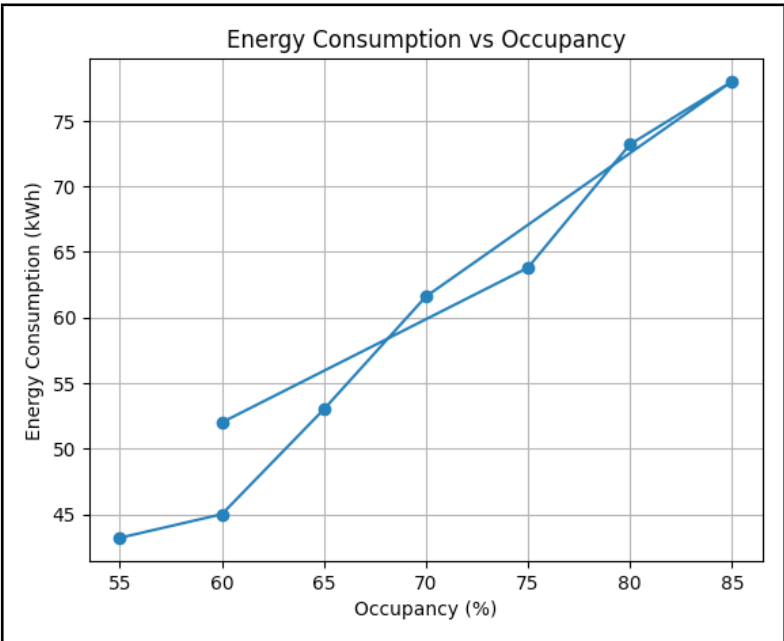


Fig. 2 :Energy Consumption vs Occupancy

Energy consumption shows a strong positive correlation with occupancy, as more guests increase cooling usage and operational hours.

Slight variations suggest influence of secondary factors such as indoor setpoint and system efficiency.

DISCUSSION

The analysis of air conditioning energy consumption in a 3000 sq. ft. small-scale hotel reveals a strong relationship between environmental and operational variables and overall energy use. The results indicate that AC load increases proportionally with outdoor temperature, confirming that higher ambient conditions impose greater cooling demands on HVAC systems. This finding aligns with previous studies that emphasize the sensitivity of cooling loads to climatic conditions, particularly in warm regions (Saidur *et al.*, 2010; Omer, 2008).

Similarly, the study demonstrates a strong positive correlation between occupancy levels and energy consumption. As occupancy increases, the demand for cooling rises due to higher internal heat gains from occupants, appliances, and extended operational hours. This observation is consistent with earlier research highlighting occupancy as a critical determinant of building energy performance (Bohdanowicz & Martinac, 2007). The results also suggest that behavioral factors, such as thermostat settings and usage patterns, may further influence consumption levels.

The regression is based on only seven paired observations ($n = 7$, $df = 5$), With low data points, the “very strong correlation” result for occupancy vs. energy consumption is thus a limited case.

From a practical perspective, the findings highlight the importance of implementing energy-efficient strategies in small-scale hotels. Measures such as optimizing thermostat settings, improving insulation, and adopting energy-efficient AC systems can significantly reduce energy consumption without compromising comfort. Despite financial constraints, even low-cost interventions can yield substantial energy savings (Chan *et al.*, 2009).

CONCLUSION

This study assessed air conditioning energy consumption in a small-scale hotel environment and identified key factors influencing energy usage. The results confirm that outdoor temperature and occupancy levels are primary drivers of AC load and energy consumption. As temperature and occupancy increase, the energy demand of the air conditioning system rises significantly, leading to higher operational costs.

The study also highlights the need for efficient energy management practices in small-scale hotels. Given the limited resources typically available in such establishments, adopting cost-effective and practical solutions is essential. Strategies such as regular maintenance, efficient system operation, and improved building design can help reduce energy consumption and enhance sustainability.

Overall, this research contributes to a better understanding of energy consumption patterns in small hospitality settings and provides a foundation for future studies focusing on optimization and energy-saving techniques. Further research is recommended to incorporate additional variables such as humidity, equipment efficiency, and renewable energy integration for a more comprehensive analysis.

STATISTICAL ANALYSIS USING REGRESSION METHOD

1. Introduction to Regression Analysis

Regression analysis is a statistical tool used to examine the relationship between a dependent variable and one or more independent variables. In energy studies, it helps quantify how different factors such as temperature and occupancy influence energy consumption.

In this study, simple linear regression is applied to:

Analyze the relationship between outdoor temperature and AC load

Evaluate the impact of occupancy on energy consumption

The general form of a linear regression equation is:

$$y = mx + c$$

Where

y = dependent variable

x = independent variable

m = slope of the line

c = intercept

2. Formula Used

Regression Coefficients

$$m = \frac{N\sum xy - (\sum x)(\sum y)}{N\sum x^2 - (\sum x)^2} = -0.204$$

$$c = \frac{\sum y - m\sum x}{N} = 12.361$$

Coefficient of Determination (R^2)

$$R^2 = 1 - \frac{\sum (y - y_{pred})^2}{\sum (y - \bar{y})^2}$$

where

y_{pred} = predicted value

$\bar{y}$ = mean of observed values

3. Regression Analysis 1: AC Load vs Outdoor Temperature

Data Used

Temperature (°C): 32, 34, 35, 36, 33, 31, 30

AC Load (kW): 5.2, 5.6, 5.3, 5.0, 5.8, 6.1, 6.5

Regression Equation

AC Load = $-0.204 \times \text{Temperature} + 12.361$

$R^2 = 0.684$

4. Regression Analysis 2: Energy Consumption vs Occupancy

Data Used

Occupancy (%): 60, 70, 65, 60, 75, 80, 85

Energy (kWh): 17.3, 18.7, 17.7, 16.7, 19.3, 20.3, 21.7

Regression Equation

Energy = $0.179 \times \text{Occupancy} + 6.139$

$R^2 = 0.977$

5. Results and Discussion

The regression analysis reveals two important relationships:

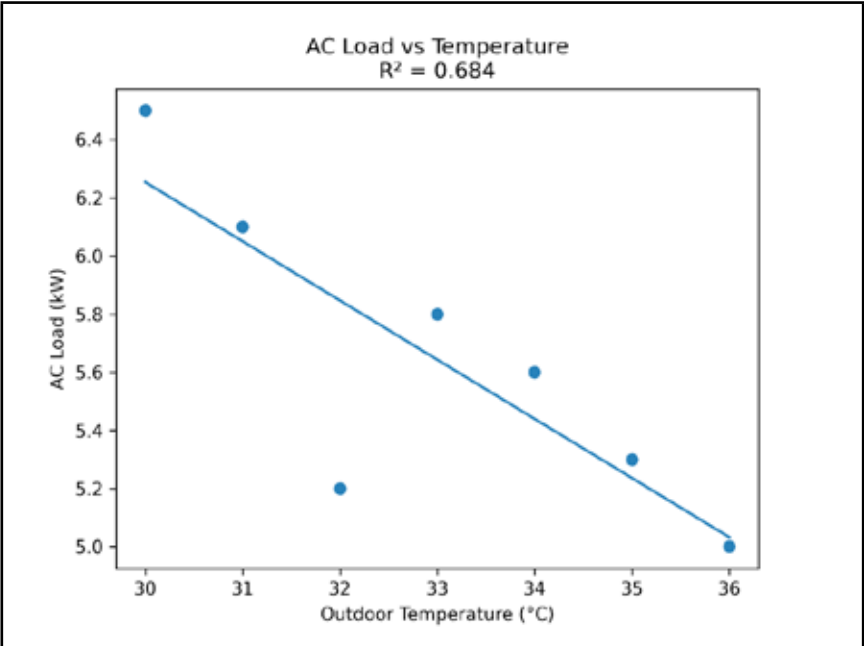


Fig. 3:Temperature vs AC Load

The R^2 value of 0.684 indicates a moderate correlation. Approximately 68.4% of variation in AC load is explained by outdoor temperature. However, the negative slope suggests that temperature alone does not fully govern cooling demand, and other factors influence system behavior.

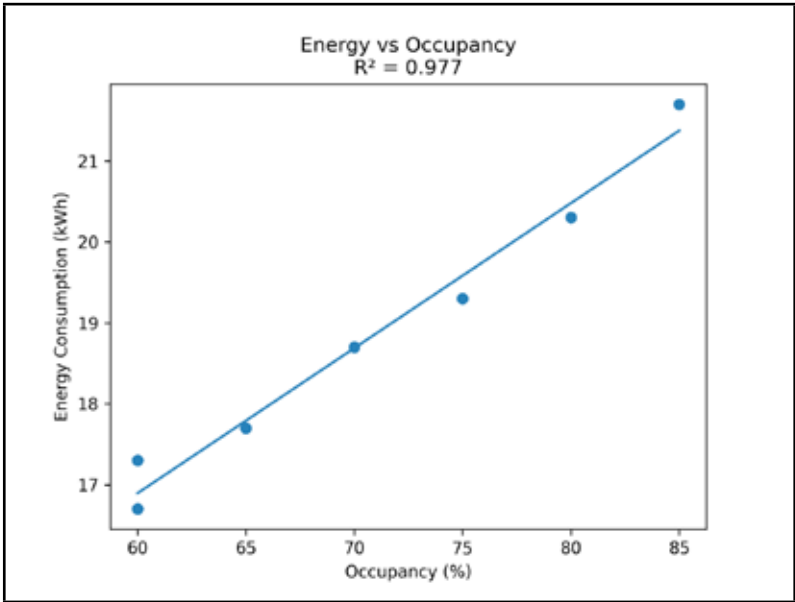


Fig. 4 : Occupancy vs Energy Consumption

The R^2 value of 0.977 indicates a very strong correlation. Nearly 97.7% of variation in energy consumption is explained by occupancy. This confirms that internal heat gains and usage patterns significantly affect AC energy consumption.

These results highlight that occupancy is the dominant factor, while temperature has a secondary influence in small-scale hotel environments.

Precautions to Reduce Power Consumption

Based on the analysis, the following measures are recommended to reduce air conditioning energy consumption:

a. Optimize Thermostat Settings

Maintaining indoor temperature between 24–26°C can significantly reduce cooling load without compromising comfort (ASHRAE, 2017).

b. Improve Building Insulation

Reducing heat gain through walls, roofs, and windows lowers the required cooling load and system workload (Omer, 2008).

c. Regular Maintenance of AC Units

Cleaning filters, checking refrigerant levels, and servicing equipment improves efficiency and reduces power input (Reddy, 2013).

d. Use Energy-Efficient Systems

Replacing conventional units with inverter or high COP systems can reduce energy consumption by 20–30% (Chua et al., 2013).

e. Install Occupancy-Based Controls

Using sensors to turn off AC in unoccupied rooms prevents unnecessary energy usage (Wang *et al.*, 2012).

f. Reduce Internal Heat Gains

Switching to LED lighting and energy-efficient appliances minimizes additional cooling load.

g. Proper Scheduling and Zoning

Operating AC only in occupied zones and during peak usage times improves efficiency.

SUMMARY OF STATISTICAL FINDINGS

The application of regression analysis provides a quantitative understanding of the factors affecting air conditioning energy consumption.

- Outdoor temperature shows a moderate impact on AC load.
- Occupancy exhibits a strong and direct influence on energy consumption.

Thus, effective energy management strategies in small-scale hotels should prioritize occupancy-based control systems and operational optimization rather than relying solely on environmental conditions.

LIMITATIONS

This was a single-site case study (one 3000 sq. ft. hotel), which limits generalizability; a short monitoring window (7 days); a constant assumed COP rather than measured performance; and a small sample size for regression analysis.

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