



KEY CAUSES AND DRIVERS OF ENERGY PERFORMANCE GAPS IN MALAYSIAN NON-RESIDENTIAL GREEN BUILDINGS

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Abstract

The Building Energy Performance Gap (BEPG) describes the difference between predicted and actual energy consumption, a mismatch that ultimately weakens the credibility and effectiveness of green buildings. Despite various technological and regulatory efforts, many Malaysian non-residential green buildings continue to consume more energy than anticipated. This study addresses a critical research gap, namely the absence of a comprehensive framework that integrates the root causes and driving factors of BEPG specific to the Malaysian context. The root causes are categorised as design-related, construction or commissioning-related, and operational-related. To examine these relationships, 21 hypotheses were tested through a survey of 278 Malaysian energy management and green building experts. The findings reveal that operational-related causes are the most prevalent, with the highest Relative Importance Index (RII), and exert the greatest influence on the energy performance gap. Key contributing factors include organisational, leadership, and behavioural aspects. The novelty of this study lies in its integrative approach to identifying and categorising BEPG root causes, as well as its contextual focus on Malaysia. The findings not only highlight high-priority intervention areas but also offer practical strategies for stakeholders to improve energy performance outcomes. The study contributes actionable insights for improving energy efficiency practices and supporting the long-term success of green building initiatives in Malaysia.

Keywords: Energy performance gap; Energy efficiency; Office building; Sustainability; Green Buildings; Malaysia.

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INTRODUCTION

The Building Energy Performance Gap (BEPG) refers to the discrepancy between predicted and actual energy use in buildings, or between designed and actual energy performance. Addressing this gap requires an understanding of its magnitude, patterns, and underlying causes to formulate effective interventions (Li et al., 2023; Shi et al., 2019). The discrepancy between simulated building energy performance and actual measured outcomes significantly hampers progress towards achieving sustainability goals (Igugu et al., 2025). Contributing factors include building type, location, ownership, occupancy rate, and usage patterns (Liang & Qiu, 2019; Zheng et al., 2024). Broadly, BEPG causes can be categorised into design, construction, and operational issues (Wilde & Jones, 2013; Zou et al., 2018; Zheng et al., 2024). Many existing buildings were not originally designed for energy efficiency (Ramli et al., 2023), and some fail to perform as intended due to design and technological shortcomings during early development stages (Zheng et al., 2024). In certain cases, actual energy consumption can be up to 2.5 times higher than anticipated, significantly undermining energy-saving goals. Bridging this gap requires identifying the factors that prevent buildings from achieving optimal performance. These factors span the building lifecycle stages of design, construction, and operation, each stage contributing to the emergence or mitigation of BEPG (Li et al., 2023; Zheng et al., 2024). Non-residential buildings are affected by a combination of socio-technical factors, including technological, organisational, and behavioural factors (Liang & Qiu, 2019; Zheng et al., 2024). Other influential elements include leadership (Li et al., 2023; Staddon et al., 2016; Zou et al., 2018), knowledge and skills (Shrubsole et al., 2019; Ramli et al., 2023), access to information (Li et al., 2017; Mineeva, 2016; Zheng et al., 2024), and external influences (Cattaneo, 2018; Shi et al., 2019). These have been categorised into seven key driving factors: organisational leadership, technological attributes, behavioural patterns, skills and knowledge, informational resources, and external influences, each shaping how green buildings perform in practice (Zheng et al., 2024).

However, current research has not yet comprehensively categorised, managed, or addressed the root causes of BEPG (Zou et al., 2018; Zheng et al., 2024), highlighting the need for deeper investigation into the complex relationships between BEPG causes and their drivers (Li et al., 2023; Shi et al., 2019). In response, this paper offers new empirical insights into these causes and influencing factors while emphasising the importance of strategies that reduce the energy performance gap effectively in Malaysian non-residential green buildings.

LITERATURE REVIEW

Green Buildings and Energy Demand in Malaysia

Energy is a critical resource in Malaysia's built environment, with national energy demand reaching 4.11 exajoules in 2020. The highest energy-consuming sectors were industry (40%), transport (38%), commercial and residential (13%), non-energy use (8%), and agriculture (1%) (Suruhanjaya, 2020). More than 80% of national electricity use occurred in the industrial, residential, and commercial sectors, underscoring buildings as major contributors to greenhouse gas emissions. It was largely proven that the economic growth and energy consumption are linked to the emission of carbon dioxides, which negatively degrade the environment (Ahmat et al., 2025). The projection of Malaysian population is expected to surge to 40 million by 2050, with anticipated urbanisation increase from 75 % in 2020 to 85 % by 2040, Malaysia is poised for heightened energy demands in every sector (Fernandez et al., 2025).

In Peninsula Malaysia, energy demand is projected to rise from 19,480 MW in 2024 to 20,049 MW by 2030 (Yiau, 2024), driven by economic growth, industrialisation, and the expansion of data centres.

Malaysia has introduced several initiatives to promote sustainable construction and energy efficiency. There is an increasing effort from the government in the energy sector, particularly in energy security, sustainability, efficiency, and affordability (Ahmad et al., 2024). The Green Building Index (GBI), established in 2009, assesses buildings across six areas, including energy efficiency, indoor environmental quality, and water conservation (GBI, 2009). The national agendas and strategic plans, including:

- a) National Green Technology Policy (NGTP, 2009): *Aims to position green technology as a driver of economic growth and sustainable development.*
- b) Renewable Energy Act (2011): *Seeks to increase electricity generation from renewable energy sources.*
- c) National Energy Efficient Action Plan (NEEAP, 2016-2025): *Targets reduced electricity demand growth through efficiency measures.*
- d) Green Technology Master Plan (GTMP, 2017-2030): *Outlines strategies to support sustainable growth in the energy sector.*
- e) National Energy Policy (DTN, 2022-2040): *Defines energy transition as a structural shift towards a more sustainable energy system.*

While Malaysia has made notable progress in promoting green technology, energy efficiency, and green building development, both green and conventional buildings frequently fall short of achieving expected reductions in energy use and greenhouse gas emissions (Cross et al., 2017). Green buildings continue to face challenges that hinder their widespread adoption and effective

performance (Zakaria et al, 2024). For example, Zaid & Kiani (2016) observed that buildings certified under the GBI exhibited a higher Building Energy Index (BEI) at 111 kWh/m²/year compared to non-certified buildings, which recorded 69 kWh/m²/year. Despite a rising number of GBI applications, fewer than 18% of buildings achieve final certification through the Completion & Verification Assessment (CVA), largely due to poor operational performance (Coleman & Robinson, 2018; Liang & Qiu, 2019; Zaid & Kiani, 2016).

Building Energy Performance Gap Factors

Many buildings, including those equipped with advanced energy efficiency technologies, have been reported to fall short of their projected energy savings targets (Zou et al., 2018). Actual energy consumption can exceed intended levels by as much as 2.5 times, significantly undermining efforts to achieve energy efficiency goals. Maintaining optimal energy performance is crucial to upholding the credibility of green building certifications (Shaardan et al., 2024). The causes of BEPG are commonly categorised into three broad groups: design-related, construction or commissioning-related, and operation-related causes, which are also defined by Zheng et al. (2024).

In the global context, researchers have identified seven key driving factors that influence BEPG mitigation efforts: organisational structure, leadership, technological systems, behavioural practices, knowledge and skills, access to information, and external conditions.

(i) Organisational

Organisational or institutional factors contribute significantly to the energy performance gap in non-residential buildings (Liang & Qiu, 2019). Organisational drivers encompass governance structures, accountability systems, and internal policies that determine energy management responsibilities (Liang & Qiu, 2019; Lane et al., 2024). Strong organisational commitment forms the backbone of continuous energy performance improvement, as weak coordination will fragment the landlord–tenant roles.

(ii) Leadership

Strategic leadership is crucial for sustaining long-term energy efficiency and balancing social, environmental, and economic objectives. While facilities managers oversee broad operational functions beyond energy management (Myeda et al., 2014; Liang & Qiu, 2019), appointing dedicated energy managers is vital to maintain focus on performance goals (Staddon et al., 2016). Leadership thus shapes both the underlying causes and solutions to energy performance gaps throughout the building lifecycle.

(iii) Technological

Technological shortcomings remain a key contributor to the energy performance gap. Technological drivers concern system design, specification, commissioning, and compatibility between modelling assumptions and real-world operation (Zheng et al., 2024; Tanaka et al., 2022). The energy gap often arises when actual equipment efficiency, control strategies, or occupancy conditions differ from those simulated.

(iv) Behavioural

Occupant behaviour significantly affects building performance during the operational stage (Zou et al., 2018). Multiple factors influence behaviour, impacting both comfort and satisfaction. Behavioural change remains complex, influenced by contextual and informational variables (Liang & Qiu, 2019). Behavioural interventions are vital for closing the performance gap in the operational phase.

(v) Skill and knowledge

Skill and knowledge drivers relate to the technical competencies of professionals throughout the building lifecycle, from designers and contractors to FM personnel (Lane et al., 2024; Hair et al., 2017). Insufficient expertise in simulation, commissioning, or energy management can lead to inaccurate design assumptions and inefficient operation. Growing environmental concerns underscore the importance of facilities management (FM) involvement from the design stage (Jawdeh, 2013). However, FM is often overlooked during design, resulting in costly post-construction modifications (Zou et al., 2018). Addressing knowledge gaps among stakeholders across a building's lifecycle is critical to narrowing the energy performance gap.

(vi) Informational

Information is crucial for effective energy management, yet challenges persist across the building lifecycle. The lack of reliable data hinders continuous calibration of models and performance tracking (Zou et al., 2018; Gupta & Gregg, 2016). Ensuring reliable data and developing interpretive competencies are essential for precise energy forecasting (Wilde, 2014). The "human-in-the-loop" concept has emerged as a solution, integrating occupant data via pre- and post-occupancy evaluations with digital modelling tools (Zou et al., 2018). Integrating post-occupancy evaluation (POE) data and real-time monitoring enhances feedback between operational outcomes and future designs.

(vii) External

External drivers encompass climatic conditions, market incentives, energy tariffs, and regulatory enforcement that influence building energy use (Zheng et al., 2024). Weather-related uncertainty can lead to annual performance deviations of up to around 6–7 % (Van Dronkelaar, 2016; Wang et al., 2012). Although these factors are largely beyond organisational control, they shape energy priorities and investment decisions. Yet, energy-related policies, including subsidies and tax incentives, may reduce investment risk and promote efficiency (Cattaneo, 2018). Therefore, inclusive and accessible measures are essential to realising broad societal benefits.

RESEARCH METHODOLOGY

A survey was conducted across three Malaysian states using cluster sampling to collect responses from professionals involved in green building initiatives. Of the 795 individuals invited via email, 278 responded, yielding a response rate of 33.9%. According to Tan et al. (2005), a minimum of 20 respondents per subgroup is required to justify cluster analysis. Therefore, the sample size of 278 provides sufficient statistical power (Dalmaijer et al., 2020). Cluster sampling was appropriate as the target population was geographically concentrated, enabling the efficient grouping of relevant respondents and enhancing data collection effectiveness. The research population included 105 active Green Building Index (GBI) facilitators and 1,302 Registered Electrical Energy Managers (REEM) within the Klang Valley area of Malaysia. Respondents were categorised into three groups: Group A – experts not involved in the green building industry (89 respondents), Group B – experts in the green building industry but not GBI facilitators (130 respondents), and Group C – experts actively involved as GBI facilitators (59 respondents). All groups met the minimum requirement of 20 respondents per subgroup, ensuring statistical adequacy. The survey comprised three sections: demographics (Section A); root causes of the energy performance gap (EPG), categorised into design-related, construction/installation and commissioning-related, and operation-related causes (Section B); and driving factors to bridge the EPG, encompassing organisational, leadership, technological, behavioural, skill and knowledge, informational, and external factors (Section C). A five-point Likert scale was used to rate items. The measured constructs in the survey were extracted from the literature review. The data were analysed using SPSS and PLS-SEM to explore relationships among latent variables.

Method of Analysis

Respondent feedback was analysed using SPSS and PLS-SEM, incorporating descriptive analysis, Relative Importance Index (RII) analysis, and PLS-SEM

modelling. RII analysis was used to rank the critical root causes of the BEPG and the key mitigation factors, based on expert perceptions. RII values were computed according to Equation (2), adapted from Fagbenle (2011):

$$\text{Relative Importance Index (RII)} = \frac{\sum W}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N} \quad (1)$$

$(0 \leq \text{RII} \leq 1)$

Where W is the weight assigned by respondents on a five-point Likert scale (1–5), A is the highest possible weight, N is the sample size, and n is the total responses for each scale. Akadiri (2011) states that RII values range from 0 to 1 and can be divided into five levels of importance: high (H) for values between 0.8 and 1.0, high–medium (H–M) for 0.6 to 0.8, medium (M) for 0.4 to 0.6, medium–low (M–L) for 0.2 to 0.4, and low (L) for 0 to 0.2.

PLS-SEM was employed to examine the relationships between exogenous constructs (root causes) and endogenous constructs (driving factors) within the structural model using Smart-PLS Version 3.2. Following Hair et al. (2014), the model was evaluated using five key criteria: collinearity, path coefficients (β), effect size (f^2), predictive relevance (Q^2), and coefficient of determination (R^2).

ANALYSIS AND DISCUSSION

Background of Respondents

Of the 278 responses received, engineers represented the largest proportion of respondents (27.3%), followed closely by executives (27%), senior managers (22.3%), directors (15.8%), and lecturers (7.6%). Within the green building sector, 47% were actively involved as green facilitators, 32% were involved but not in a facilitator role, while 21% reported no involvement. In terms of professional experience, 30.6% had 6 to 10 years of industry experience, and 33.5% had less than 5 years of experience specifically in green building. A smaller proportion of respondents (10.4% and 1.4%) reported 16 to 20 years of experience in the industry and the green building sector, respectively, indicating a wide range of professional backgrounds and levels of expertise among participants.

Relative Importance Index (RII) Analysis

(a) Root Causes to BEPG Analysis

Table 2 presents the RII values and corresponding rankings of the root causes contributing to the BEPG. Operational causes emerged as the most critical category with the highest RII value of 0.753, followed by construction and

commissioning-related causes (0.743) and design-related causes (0.729). Among operational causes, the most significant factors identified with High Level Important were lack of occupant awareness (ORC1), inadequate financial resources and incentives (ORC11), insufficient skills and knowledge (ORC14), and poor occupant interaction with building systems (ORC2). The lowest-ranked operational factor was the failure of energy-efficient equipment to meet specifications (ORC17), with an RII of 0.649. Within construction and commissioning-related causes, poor workmanship and improper techniques (CRC3) ranked highest, with an RII of 0.773. As for design-related issues, inefficient or oversized systems (DRC7) recorded the highest RII in this category and ranked twelfth overall with a score of 0.760. A comprehensive list of the RII rankings is provided in Table 2.

Table 2: High and high-medium importance ranking of root causes to BEPG

Rank	Codes	Codes	Mean RII	Level
1	ORC1	Lack of occupant awareness	0.829	H
2	ORC11	Insufficient funds and incentives	0.809	H
3	ORC14	Lack of skills and knowledge	0.807	H
4	ORC2	Poor occupants' interactions	0.801	H
5	ORC19	Lack of documentation	0.789	H-M
6	ORC12	Decision-makers are less attentive	0.788	H-M
7	ORC15	Lack of sub-metering	0.785	H-M
8	ORC16	Lack of fine-tuning	0.785	H-M
9	CRC3	Poor workmanship and improper techniques	0.773	H-M
10	ORC5	Lack of top management support	0.772	H-M
11	ORC4	Lack of information	0.768	H-M
12	DRC2	Incorporation of inefficient or oversized systems	0.760	H-M
13	DRC7	Change orders during the design stage	0.756	H-M
14	ORC13	Bypassing of the energy control system	0.756	H-M
15	CRC2	Contractors occasionally engage in dishonest practices	0.756	H-M
16	CRC1	Contractors with limited experience	0.754	H-M
17	DRC5	Lack of attention to buildability and maintainability	0.750	H-M
18	ORC3	Negative interactions and influences among occupants	0.746	H-M
19	DRC4	Lack of attention to end users' needs and convenience	0.745	H-M
20	ORC7	Poor communication between management and occupants	0.744	H-M
21	CRC5	Failure to uncover hidden problems	0.741	H-M
22	CRC7	Change orders during the construction stage	0.736	H-M
23	DRC6	Lack of communication between the designer and the owner	0.734	H-M
24	ORC6	Lack of authority for FM	0.729	H-M
25	CRC6	Lack of information on design details	0.728	H-M
26	ORC10	Excessive use of additional appliances	0.722	H-M

27	CRC4	Full performance testing is not conducted	0.714	H-M
28	DRC1	Overestimation of the actual performance technology	0.705	H-M
29	DRC3	Inappropriate parameters used in modelling	0.695	H-M
30	DRC8	Regulatory compliance does not account for all building energy uses	0.686	H-M
31	ORC8	Increase the level of occupancy	0.685	H-M
32	ORC9	Extension of operating hours	0.683	H-M
33	ORC18	Suppliers fail to meet the specifications for replacements	0.657	H-M
34	ORC17	Energy-efficiency equipment does not meet specifications	0.649	H-M

(b) Driving Factors to Bridge BEPG

The RII analysis of the driving factors confirms the significance of all seven categories in addressing the BEPG. Ranked by RII values, the most influential factors were organisational (0.849), leadership (0.847), behavioural (0.817), external (0.816), informational (0.815), technological (0.812), and knowledge and skill (0.803). The top four factors highlight the critical role of organisational commitment, particularly the involvement of top management (ODF2), a culture of energy efficiency (ODF8), a compulsory comprehensive energy management plan (ODF3), and a clear, concise energy policy, particularly during the operational phase. Effective energy management practices and active engagement from key stakeholders, especially top management and building occupants, are essential to overcoming organisational challenges that contribute to the BEPG.

Table 3: High and high-medium importance ranking of driving factors to BEPG

Rank	Codes	Constructs	Mean RII	Level
1	ODF2	Top management commitment to continuous improvement	0.829	H
2	ODF8	Energy efficiency and energy conservation become the culture in an organisation	0.809	H
3	ODF3	A compulsory comprehensive energy management plan	0.807	H
4	ODF4	Energy policy should be short and comprehensive	0.801	H
5	LDF4	Energy managers should have the capabilities to produce complete and comprehensive evaluations	0.789	H
6	ODF7	Clear and defined roles of the energy management committee	0.788	H
7	TDF3	Well-scheduled and informed maintenance of equipment and building sub-systems	0.785	H
8	TDF4	Establishment of operational criteria and a checklist for energy efficiency	0.785	H
9	ODF5	Energy policy should be reviewed, and recommendations should be made accordingly	0.773	H
10	LDF3	Employment of an on-site energy manager	0.772	H

11	LDF1	Good relationship between stakeholders (e.g. Management team and building occupants)	0.768	H
12	BDF4	Create the feel of ownership among building occupants for energy management	0.760	H
13	ODF1	Active involvement of top management in energy management	0.756	H
14	EDF1	The government should produce a more comprehensive policy or a guiding principle	0.756	H
15	KDF2	Good competency level of the energy manager	0.756	H
16	BDF2	Promote energy management practices and awareness among building occupants	0.754	H
17	IDF3	Energy conservation opportunities to prioritise based on its resources, budget and profitability	0.750	H
18	LDF2	The energy manager should be positioned high enough in the organisational structure.	0.746	H
19	IDF1	Continuously promoting the energy target for the upcoming years	0.745	H
20	IDF2	Conduct pre-occupancy data collection and post-occupancy data collection	0.744	H
21	BDF3	Action plans should be grouped into design, construction and commissioning and operation	0.741	H
22	TDF2	Clearly defined and documented purchasing, supply or delivery of energy services and products needs to be energy efficient	0.736	H
23	TDF5	More seminars/workshops for building practitioners	0.734	H
24	EDF3	To have an open discussion between industry, government and academia	0.729	H
25	EDF2	Energy reduction has been reduced and continuously improved every year	0.728	H
26	KDF1	Detailed information about the different initiatives in different stages	0.722	H
27	KDF4	Full understanding of the climate and energy system by both the designer and end user.	0.714	H
28	KDF5	Assignment of a sustainability champion who is a willing and knowledgeable person	0.705	H
29	BDF5	Giving rewards/recognition to occupants creates more involvement in energy saving	0.695	H
30	BDF1	Get more feedback from building occupants on how they can help more in energy saving	0.686	H
31	KDF3	Technical training for the Energy Management Committee at least once a year	0.685	H
32	KDF6	Different forms of education training should be conducted	0.683	H
33	TDF1	Simplicity in building equipment technology for an energy management system	0.657	H
34	TDF6	An energy committee should be formed; the members should be rotated once a year	0.649	H
35	ODF6	Energy audit every year	0.829	H-M

Because RII only measures importance but not causal direction, the next section uses PLS-SEM to test whether the highly ranked causes significantly affect the driving factors.

Partial Least Squares Structural Equation Modelling (PLS-SEM) Analysis Structural Model

The PLS-SEM analysis includes both measurement and structural model evaluation, that essential for hypothesis testing and to ensure the validity and reliability of the constructs measured. The measurement models were assessed for construct validity, encompassing both convergent and discriminant validity. All exogenous and endogenous constructs demonstrated strong correlations within their respective measurement models, and in total, there were 21 relationships to be assessed as illustrated in Figure 1. The structural model was assessed based on five criteria present in the validated path model. Table 5 summarises the findings of the structural model analysis.

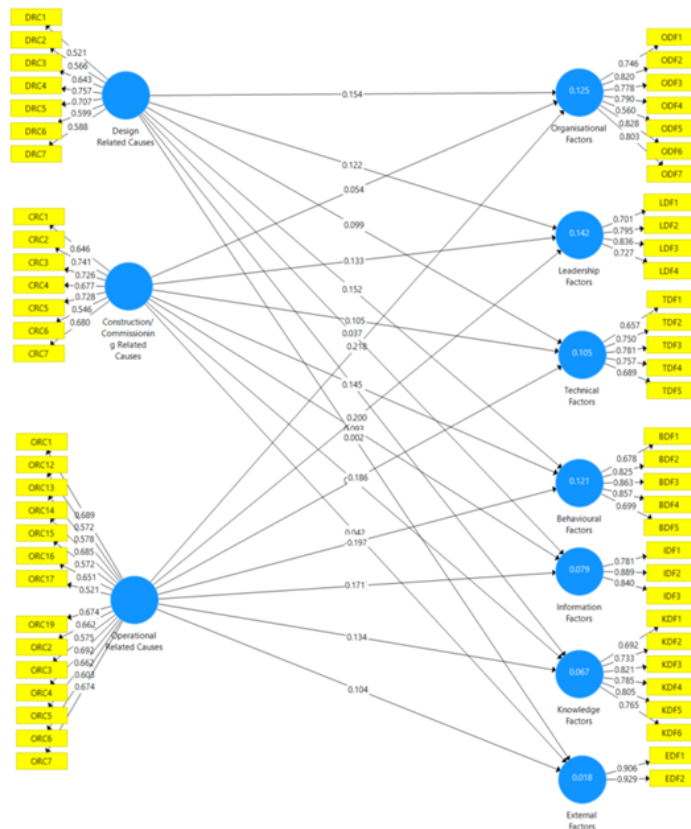


Figure 1:
Validated
PLS-SEM
Structural
Model

Step 1: Collinearity Assessment

In this study, all constructs exhibited VIF values below 5 as indicated in Table 4, confirming the absence of collinearity issues. This result demonstrates acceptable quality and robustness in the examined correlations.

Table 4: VIF among exogenous constructs

	<i>DRC</i>	<i>CRC</i>	<i>ORC</i>	<i>ODF</i>	<i>LDF</i>	<i>TDF</i>	<i>BDF</i>	<i>IDF</i>	<i>KDF</i>	<i>EDF</i>
<i>DRC</i>		1	1.551	1.603	1.603	1.603	1.603	1.603	1.603	1.603
<i>CRC</i>	1		1.551	1.891	1.891	1.891	1.891	1.891	1.891	1.891
<i>ORC</i>	1.551	1.551		1.484	1.484	1.484	1.484	1.484	1.484	1.484

Step 2: Relevance of significant relationships assessment

After considering the path coefficients (β) and using *t-values* as well as *p-values*, from the twenty-one predetermined hypotheses, only six were supported: *ORC* → *ODF*, *ORC* → *LDF*, *ORC* → *TDF*, *ORC* → *BDF*, *ORC* → *IDF*, and *ORC* → *KDF* (Refer to Table 6). This indicates that operational issues outweigh design and construction causes in impacting the driving factors.

Step 3: Coefficient of Determination

This study uses a predictive accuracy, R^2 threshold of 0.10. As shown in Figure 1 (blue circle values in Figure 1 and refer to Table 5), the *EDF* records the lowest R^2 value of 0.01, indicating very weak explanatory power. In contrast, *LDF* shows the strongest prediction with R^2 of 0.13, followed by *ODF* (0.12) and *BDF* (0.11).

Step 4: Effect size f^2

The f^2 values for the *ORC* → *KDF* and *ORC* → *EDF* relationships are below 0.02, indicating negligible effect sizes (Refer to Table 6).

Step 5: Predictive relevance Q^2 and relative impact Q^2

All Q^2 values are above zero as determined in Table 6, but from the last criterion, Q^2 values of only three hypotheses, namely *ORC* → *ODF*, *ORC* → *LDF* and *ORC* → *IDF*, are ascertained with the relative impact of 0.02 (small impact) as in Table 6.

Table 5: The predictive accuracy (R^2) and predictive relevance (Q^2).

Code	Endogenous constructs	R^2	$Q^2 (=1-SSE/SSO)$
<i>ODF</i>	Organisational driving factors	0.12	0.07
<i>LDF</i>	Leadership driving factors	0.13	0.07
<i>BDF</i>	Behavioural driving factors	0.11	0.06
<i>TDF</i>	Technologies driving factors	0.10	0.05
<i>IDF</i>	Information driving factors	0.07	0.05
<i>KDF</i>	Knowledge driving factors	0.06	0.03
<i>EDF</i>	External driving factors	0.01	0.01

Table 6: Structural model path coefficients and hypothesis testing

Hypothesis	β -value	T-values	P-values	95% CILL	95% CIUL	Support	f^2	q^2
DRC -> ODF	0.16	1.84	0.07	0.02	0.30	Not supported	0.02	0.01
DRC -> LDF	0.13	1.61	0.11	0.01	0.25	Not supported	0.01	0.00
DRC -> TDF	0.11	1.29	0.20	-0.01	0.24	Not supported	0.01	0.00
DRC -> BDF	0.15	1.90	0.06	0.03	0.29	Not supported	0.02	0.01
DRC -> IDF	0.04	0.50	0.62	-0.08	0.17	Not supported	0.00	-0.01
DRC -> KDF	0.15	1.68	0.09	0.02	0.29	Not supported	0.01	0.01
DRC -> EDF	0.01	0.02	0.98	-0.15	0.16	Not supported	0.00	0.00
CRC -> ODF	0.06	0.68	0.50	-0.08	0.18	Not supported	0.00	0.00
CRC -> LDF	0.14	1.68	0.09	0.00	0.26	Not supported	0.01	0.00
CRC -> TDF	0.11	1.31	0.19	-0.03	0.24	Not supported	0.01	0.00
CRC -> BDF	0.10	1.14	0.25	-0.06	0.25	Not supported	0.01	0.00
CRC -> IDF	0.09	1.08	0.28	-0.05	0.24	Not supported	0.00	0.00
CRC -> KDF	0.04	0.38	0.71	-0.12	0.19	Not supported	0.00	0.00
CRC -> EDF	0.04	0.46	0.64	-0.12	0.19	Not supported	0.00	0.00
ORC -> ODF	0.23	3.21	0.00	0.13	0.34	Supported	0.04	0.02
ORC -> LDF	0.21	3.02	0.00	0.10	0.32	Supported	0.03	0.02
ORC -> TDF	0.20	2.87	0.00	0.09	0.30	Supported	0.02	0.01
ORC -> BDF	0.21	2.72	0.01	0.08	0.33	Supported	0.03	0.02
ORC -> IDF	0.18	2.29	0.02	0.06	0.30	Supported	0.02	0.01
ORC -> KDF	0.14	1.99	0.05	0.04	0.25	Supported	0.01	0.01
ORC -> EDF	0.11	1.27	0.21	-0.03	0.25	Not supported	0.01	0.01

DRC = Design related causes; CRC = Construction/commissioning related causes; ORC = Operational related causes; ODF = Organisational driving factors; LDF = Leadership driving factors; Technologies driving factors = TDF; BDF = Behavioural driving factors; Information driving factors = IDF; KDF = Knowledge driving factors; EDF = External driving factors
The five key criteria by Hair et al. (2014) as follows:

Step 1: The variance inflation factor (VIF) according to Hair, Hult, & Ringle (2017); Henseler et al. (2009), the value should be greater than 1 but lower than 5 indicate no presence of collinearity issue.

Step 2: The path coefficients (β) according to Hair et al. (2014); Kline (1998) can determine three levels of effect: 0.10-0.20 (small effect), 0.30-0.40 (medium effect) and more than 0.50 (large effect).

Step 3: The R^2 values of endogenous according to Cohen & Cohen (1983); Falk & Miller (1992); Roldán & Sánchez-Franco (2014) the construct predictive accuracy should be at least 0.10.

Step 4: The effect sizes F according to Cohen (1980) are 0.35 (large), 0.15 (medium), 0.02 (small)

Step 5: The predictive relevance Q^2 according to Henseler (2009) are 0.35 (large), 0.15 (medium), 0.02 (small)

Structural model revealed that operational-related causes demonstrate the strongest and most consistent influence across the driving factors, especially organisational (ODF), leadership (LDF) and behavioural factors (BDF) after considering the last two steps f^2 & Q^2 , confirming that BEPG issues predominantly arise during the operational phase.

CONCLUSION

Multiple factors contribute to the BEPG, encompassing both technological and non-technological (managerial) measures. This study identifies the primary causes of the BEPG and explores the relationship among factors that influence its mitigation. Operational-related causes recorded the highest RII values, marking them as the foremost contributors to the BEPG, followed by construction/commissioning and design-related causes. The analysis reveals a strong association between operational-related causes and three key driving factors—organisational (ODF), leadership (LDF), and behavioural (BDF)—all of which are human-centred issues that shape real energy outcomes more strongly than technical considerations alone. The structural model further validates these patterns, although overall R^2 values remain modest due to the complex socio-technical nature of BEPG. This study contributes to the BEPG discourse by providing empirical evidence from a developing country and highlighting the need for stronger operational governance, better commissioning, and improved facility management. The findings show that achieving intended energy

performance requires organisational commitment, leadership support, behavioural engagement, and data-driven operations. Although the study's scope is limited, it points to future research on longitudinal post-occupancy evaluation, cross-country comparisons, and socio-technical interactions to further address energy performance gaps in green buildings.

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