https://doi.org/10.52968/15601264
ISSN: 2805-3346

RESEARCH ARTICLE

Adaptive Energy Behaviours of Thermal Comfort under Grid Instability among Shopping Malls in Ghana

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Received: 10 January 2026

Revised: 7 February 2026

Accepted: 9 April 2026

Published: 5 June 2026

Cite article as: Appau, W. M. (2026). Adaptive Energy Behaviours of Thermal Comfort under Grid Instability among Shopping Malls in Ghana. *African Journal of Housing and Sustainable Development, 7*(2), pp. 71-81.

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ABSTRACT

Frequent grid instability in Ghanaian cities poses a substantial challenge to energy efficiency in commercial buildings, mostly shopping malls. Whereas technical remedies such as smart devices, energy-saving systems and backup generators have been widely adopted by consumers and examined in the literature, there is a critical gap in research on tenant or occupant perceptions and behaviours during grid instability. This study closes this gap by assessing the influence of thermal comfort, trust in technology and awareness of energy systems on tenant satisfaction and adaptive energy behaviour in shopping malls in Ghana. Grounded in the Unified Theory of Acceptance and Use of Technology, the study adopted a quantitative approach in surveying 202 tenants across four major shopping malls in Accra and Kumasi. Multiple linear regression and Binary Logistic regression models showed that thermal comfort is the strongest predictor of tenant satisfaction, whereas awareness is the strongest predictor of adaptive behaviour. Trust in adaptive technologies also recorded a positive effect on both outcomes. In particular, frequent grid instability reduced the likelihood of adaptive responses, indicating signs of resilience fatigue among tenants. Also, demographic variables such as age and education further shaped user engagement, while income had a marginal effect on adaptive behaviours. The study recommends a user-responsive energy approach such as energy awareness campaigns and transparent backup systems for shopping malls in Ghana.

Keywords: indoor environmental quality, shopping mall, sustainability, energy efficiency, thermal comfort

1.0 Introduction

The impact of climate change volatility on urban energy demand makes it necessary to achieve energy efficiency and build performance, as buildings contribute to nearly 40% of global energy use and greenhouse gas emissions (IEA, 2020). Despite commercial investors' demand for building technologies that enhance energy efficiency, such as smart lighting and smart HVAC systems, they are frequently constrained by grid instability, especially in developing countries. In commercial buildings, operational resilience and energy efficiency have become relevant, especially for shopping malls serving large numbers of occupants. Yet, in instances of grid instability, the efficiency of shopping mall systems is severely hampered by occupant satisfaction, highlighting the neglect of adaptive energy behaviour in sustainable building studies.

In Africa, rapid urbanization, energy supply deficit and infrastructure challenges continue to affect

commercial real estate investments (Berahab, 2022). To be sure, grid instability, especially in sub-Saharan Africa countries such as Ghana and Nigeria, affects business operations in commercial facilities. In Ghana, unreliable power supply, especially in upscale urban neighbourhoods, forces shopping malls to consider other renewable energy systems (Owusu et al., 2022). This leads to additional costs for investors despite not promising long-term sustainability (Nyirenda et al., 2025; Ochedi & Taki, 2022). In this context, occupants' adaptive energy behaviours become critical for sustainable operation and mitigating the impact of grid instability in commercial buildings.

Although policies have been designed for promoting energy efficiency, there has been limited implementation among most commercial buildings in Ghana. Studies have confirmed that more than 70% to 85% of installed inverter air conditioners are actually inefficient in residential and public buildings in Ghana (Afonaa-Mensah et al., 2024). Moreover, most air conditioners frequently receive low energy-efficiency ratings (Opoku et al., 2019). These challenges are the result of limited technical knowledge, cost challenges and occupants' problematic perceptions, contributing to the huge gap between policy goals and practical outcomes. According to Appau et al. (2026), energy consumption patterns in shopping malls are influenced by shoppers' satisfactions and occupant decisions. Studies have established the need for integrating adaptive behaviours in shopping malls. For instance, Zhao et al. (2025) highlighted the need to balance between user comfort and trust in spatial and thermal efficiency in public space. Ohene et al. (2024) noted that perception, social dynamics and adaptive behaviours are critical in the Ghanaian context. These studies confirm the limited empirical evidence on adaptive energy behaviours in commercial buildings during grid instability in sub-Saharan Africa, especially Ghana. Accordingly, it is important to address the following research questions: How do adaptive behaviours among shoppers, tenants and facility managers influence their comfort levels in malls during grid instability? How do these comfort levels affect satisfaction among shopping malls in Ghana? Based on this, this study examines the impact of adaptive thermal comfort on users of shopping malls in Ghana.

2. Literature Review

2.1 Unified Theory of Acceptance and Use of Technology

The study adopted the Unified Theory of Acceptance and Use of Technology (UTAUT2). This model was propounded by Viswanath Venkatesh (2012) as an extension of the Unified Theory of Acceptance and Use of Technology (UTAUT). The theory is premised on seven (7) core principles: performance expectancy, effort expectancy, hedonic motivation, price value, habit, social influence, and ease of use. These elements are moderated by individual-level characteristics such as experience, gender and age. It has been applied in energy-efficient technologies discipline, especially for the assessment of smart homes. For example, Tak et al. (2023) applied the UTAUT2 framework to examine the smart-home HVAC adoption. They found that habit, performance expectancy and effort expectancy strongly influenced occupant adaptation, while trust moderated transparency and privacy. Using the same framework, Gajdzik et al. (2024) found that environmental motivation, perceived usefulness and ease of use strongly influenced the propensity to adapt to energy-saving behaviour. Liu et al. (2023) identified performance expectancy, social influence and ease of conditions as critical in carbon labelling in shopping malls in China, whereas effort expectancy had little effect on adoption behaviour. Clearly, therefore, empirical studies validate UTAUT2's ability to capture technology acceptance in sustainability and energy contexts.

2.2 Empirical Review

2.2.1 Resilient Energy Efficiency under Grid Instability

Resilient energy efficiency in buildings has been attracting global attention as people and businesses become increasingly concerned about climate change. Energy efficiency, especially in shopping malls, entails maintaining operational and occupant resilience during disruptions. Various smart tools have been used to integrate resilience in buildings. For instance, Automated Demand Response (ADR) systems are widely known to balance electricity supply and demand in real-time situations. For example, Satpathy et al. (2025) found that ADR significantly reduces peak load, blackout risk and

grid pressure. Beyond ADR, Senthil Kumar et al. (2024) designed a Diagonally Masked Fusion Network (DMFN) combined with Alpha-Guided Dwarf Mongoose (AGDM) Optimization to for reducing peak load and grid pressure. Kumaresan and Jeyaraj (2025) designed the Reward Shaping Deep Reinforcement Learning (RSDRL), which achieved about 19.2% energy savings and a satisfaction index of 0.93. Similarly, Dai et al. (2024) designed a supply-based feedback control system, which contributed 30.8% reduction in energy demand during peak periods. Also, Ma et al. (2024) reported that ventilation systems could regulate latent cooling loads at 30-40% HVAC demand flexibility in humid climates.

In the context of energy storage, Islam et al. (2024) observed that ESSs mitigate the intermittency of renewable energy sources, enhance user flexibility and support grid stability. Zheng et al. (2023) corroborated this finding while noting that systems can reduce annual energy costs by more than 15%. In another study, Liao et al. (2024) adopted Game Theory and found that peer-to-peer energy trading within microgrids improves autonomy, equity and efficiency. Sepúlveda-Mora and Hegedus (2022) combined PV, wind and batteries for commercial buildings and found an effective power continuity during outages lasting up to three days. Similarly, Noviati et al. (2024) used AI-enabled smart grids and found that they enhanced energy efficiency by 11.76% and reduced operational costs by 20%. Despite these advances, most empirical models prioritise technical considerations, without incorporating occupant trust, comfort and behavioural intent, which are critical indicators of the UTAUT2 model.

2.2.2 Occupant Perceptions, Comfort and Adaptive Behaviours

Occupant perceptions of comfort and adaptive behaviours are critical in measuring sustainable building operations. According to He et al. (2025), buildings consume nearly 40% of global energy. Empirical studies show different views on the relationship between comfort, occupant perceptions and adaptive behaviours. Xue et al. (2024) assessed comfort personalized relationship with radiative heating and cooling ones in micro-textile buildings and found that users' control of heating features of their small spaces positively influenced reducing energy consumption. Yu et al. (2024) established that customer features significantly affect adaptive behaviours, particularly during severe heat-related blackouts. Lin et al. (2025) also confirmed behavioural strategies. According to their study, integrating user agency is based on their categorisation of interventions into more passive, more control-optimisation and even behavioural approaches. However, this system remains directive rather than collaborative. On their part, He et al. (2025) argued that the contrastingly aligned daylight access with circadian rhythms supports occupant well-being.

Similarly, window configuration shapes user perception of energy design, even as shading systems equally influence how users perceive it. Tootkaboni et al. (2025) showed that regional climate scenarios can inform adaptive cooling strategies, as building typology with retrofit measures significantly influences thermal comfort outcomes. Lighting and shading configurations equally affect energy loads and visual comfort, as highlighted by complementary studies (see Abedini et al., 2025; Albatayneh et al., 2025). How users interact with and perceive these systems remains largely unaddressed within their strong technical focus.

Similarly, Roumi et al. (2023) and Deng et al. (2024) established a direct relationship between indoor environmental quality (IEQ) and occupant satisfaction. According to their study, IEQ determinants such as thermal comfort, lighting and air quality improve both energy use and user experience. However, their study lacked longitudinal validation. On their part, Kim et al. (2022) and Yong et al. (2022) used Post-Occupancy evaluation to validate earlier studies. Their study found that customer experience with user feedback must be incorporated into building design and operation.

Nevertheless, integrating subjective experiences into energy modelling for design remains a persistent challenge. To be sure, occupant preferences are context-dependent and influenced by personal, cultural and environmental variables, as argued by Fakhari et al. (2021) and Roumi et al. (2024), particularly with respect to lighting and

thermal conditions. Because optimisation within one comfort domain compromises another, this complexity often necessitates multi-domain optimisation strategies. Elhami et al. (2025) attempted to address this through machine-learning-based HVAC controls that prioritise both IAQ and thermal comfort; however, even such advanced systems depend on an accurate understanding of occupant needs.

Following the review, it can be deduced that studies do not directly model or test how users perceive comfort and satisfaction, or how they feel and behave, in ways that affect the success of resilient energy plans, particularly in places such as malls. Therefore, it is necessary to evaluate users' perceived building performance during grid instability in environments with fluctuating occupancy, high energy demand and diverse user profiles.

3. Research Methodology

This study adopted a quantitative research design approach to examine the impact of occupant perceptions and adaptive behaviours in shopping malls during grid instability in Ghana. The study selected four shopping malls in Accra and Kumasi: Accra Mall, West Hills Mall, and Kumasi City Mall. From these malls the researcher made tenant selections as follows: 97 tenants from West Hills Mall, 84 tenants from Accra Mall and 54 tenants from Kumasi Mall. Among these 235 tenants, 202 participated in the survey. These malls were selected based on their high tenant capacity and diverse retail categories (fashion and jewellery, electronics, health and medical, groceries). This sampling method also ensured representation across various shop sizes and types of ownership. Data on building resilience and occupant perception were collected using a structured questionnaire. The instrument was designed to cover demographics, assess thermal comfort, measure trust in adaptive technologies, assess awareness of energy systems, elicit details of experiences with power outages, measure satisfaction, and assess behavioural intentions. Copies of the questionnaire were distributed electronically and in-person within shopping malls.

3.1 Variable Definition and Measurement

The variables of the study were defined using the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2). The study conceptualised tenant perception towards thermal comfort as a critical factor influencing energy resilience and adaptive behaviours in shopping malls during grid instability. Variables such as thermal comfort, trust and level of awareness of energy systems were conceptualised as elements of UTAUT2. Additionally, the frequency of power outages (grid instability) and demographic factors such as income, education and age were assessed to determine satisfaction levels and adaptive energy behaviours in shopping malls. These variables (thermal comfort, awareness, and trust in technology) were measured using a 5-point Likert scale ranging from 1 (very low) to 5 (very high). Power outage frequency (grid instability) and adaptive behaviour were reported as a binary outcome (Yes/No) (see Table 1). Furthermore, income and education were treated as dummy variables, while age was treated as a continuous variable.

The study used multiple linear and logistic regression models to assess the impact of power outages on building performance across shopping malls in Accra. The multiple linear regression model estimates the relationship between the dependent variable (occupants' satisfaction) and the independent variables, e.g., thermal comfort, trust, awareness level, age, income, and education. The model is represented as follows:

$$Y = \beta_0 + \beta_1(Thermal\ Comfort) + \beta_2(Trust\ in\ Technology\ ) + \beta_3(Frequency\ of\ Power\ Outages) + \beta_4(Level\ of\ awareness) + \beta_5(Income\ Levels) + \beta_6(Age) + \beta_7(Education) + \varepsilon \quad \text{eq. (1)}$$

In the MRL model, Y represents tenants' satisfaction, β_0 is the intercepts and $\beta_1 - \beta_7$ represents the predictors of the model. This represents how a one-unit increase in thermal comfort affects satisfaction, with ε indicating the error term.

Furthermore, the study uses the binary logistic regression model to predict the likelihood of tenants engaging in energy-saving behaviours under periods of grid instability. In this model, the dependent variable is defined as the probability of engaging in adaptive behaviours (1 = Yes, 0 = No). The independent variables were identified as thermal comfort, trust in technology, age, frequency of power outages, awareness, education, and income. The model is represented thus:

$$Log\left(\frac{p}{1-p}\right) = \alpha_0 + \beta_1(Thermal\ Comfort) + \beta_2(Trust\ in\ Technology\ ) + \beta_3(Frequency\ of\ Power\ Outages) + \beta_4(Level\ of\ awareness) + \beta_5(Income\ Levels) + \beta_6(Age) + \beta_7(Education) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. (2)}$$

The left side of the model shows the log-odds of thermal behaviours of tenants, with $\beta_1 - \beta_7$ representing the one-unit change of the predictors' influence on the log-odds of thermal behaviours.

3.3 Model Validity, Testing and Analysis

The model evaluations underwent several tests. First, the MLR model was tested for linearity, independence of errors and homoscedasticity. Moreover, Variance Inflation Factors (VIF) and Durbin-Watson statistics were used to determine the autocorrelation. With respect to the logistic regression, the Hosmer-Lemeshow goodness-of-fit test was conducted to evaluate the binary model for logistic regression. AIC and BIC, along with pseudo-R-squared statistics such as McFadden's R^2, aimed to evaluate the multinomial logistic regression model. The data were analysed using STATA.

4. Research Findings

4.1 Model testing

Table 1 describes the model's evaluation and fit summary. The regression model examined the predictors of tenant's satisfaction in shopping malls during grid instability in Ghana. Table 1 reports a strong positive correlation with satisfaction levels (R-value = 0.766). The study also found 62.1% of the variance in satisfaction (R-squared = 0.621). This implies that thermal comfort, trust in technology, outage frequency, awareness, age, income and predictors (0.612) confirm the model's robustness. Likewise, the 1.32 standard error indicates that the level of satisfaction departs from predicted scores at a moderate level. Also, the ANOVA results (F-value of 177.38, p-value of 0.000) show that the regression model is highly significant. This confirms that the combined effect of the predictors reliably predicts satisfaction. Perceptual factors such as comfort, trust and awareness, along with demographic factors, crucially shape building performance during energy stress.

Table 1: *Model Summary of Predictors Influencing Occupant Satisfaction in Ghanaian Shopping Malls*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.766	0.621	0.612	1.32

Source: Field data, 2025

Table 2: *ANOVA Results for Regression Model Predicting Satisfaction of Mall Occupants*

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1865.13	7	264.03	177.38	0.000**
Residual	1136.43	293	3.92		
Total	2982.55	299			

Source: Field data, 2025

4.2 Determinants of tenant satisfaction in shopping malls under grid instability in Ghana

Table 3 shows the multiple linear regression findings on the predictors of tenant satisfaction and adaptive behaviours in shopping malls during instances of grid instability in Ghana. The findings show that thermal comfort emerged as the strongest predictor (B = 0.43, p = 0.001) of thermal comfort across the shopping malls in Ghana. This implies that the improvement in thermal comfort is likely to

increase tenant's satisfaction across the shopping malls. Also, the trust in technology (B = 0.31, p = 0.000) and awareness of energy systems (B = 0.27, p = 0.001) reported strong positive effects on tenant satisfaction. This suggests that occupant satisfaction increases in relation to occupants' trust in backup systems and that tenants understand energy-saving practices in the shopping malls. Additionally, age of tenants was a statistically significant demographic factor (B = 0.04, p = 0.004). This implies that older tenants report higher satisfaction, possibly due to high tolerance for frequent power outages. Education also produced a positive, meaningful effect (B = 0.26, p = 0.014). This means that tenants with higher levels of education are likely to appreciate energy-efficiency efforts or adapt to them more effectively. Income related positively to satisfaction (B = 0.13) yet was only slightly important (p = 0.085). Notably, the frequency of power outages negatively affected satisfaction (B = -0.18, p = 0.003), as frequent blackouts significantly reduced tenant comfort and satisfaction.

Table 3: Coefficients of Multiple Linear Regression Predicting Satisfaction of Mall Occupants

Model	**Unstandardized B**	**Std. Error**	**Standardized Beta**	**t**	**Sig.**
(Constant)	2.86	0.62	—	4.11	0.000
Income	0.13	0.06	0.12	1.81	0.085
Education	0.26	0.11	0.16	2.51	0.014
Age	0.04	0.02	0.17	2.88	0.004
Thermal_Comfort	0.43	0.07	0.32	5.26	0.001
Awareness	0.27	0.09	0.23	3.52	0.001
Trust_in_Tech	0.31	0.08	0.22	3.43	0.000
Outage_Frequency	-0.18	0.07	-0.22	-3.18	0.003

Source: Field data, 2025

4.3 Predictors of Thermal Adaptive Behaviours among Shopping Malls under Grid Instability

The logistic regression model effectively predicts adaptive behaviour among tenants in shopping malls during power outages in Accra. Table 4 shows that a good model fit is indicated by a -2 Log Likelihood of 288.21. The Cox & Snell R^2 (0.334) and Nagelkerke R^2 (0.380) suggest that the predictor variables explain approximately 33-38% of the variation in adaptive behaviour. This represents a moderate level of explanatory power. In terms of classification performance, the model achieves an overall accuracy of 80.5%, indicating that it correctly predicts occupant behaviour in more than four out of five cases. Specifically, it correctly classifies 82.5% of those who engaged in adaptive behaviour and 77.8% of those who did not. This indicates that the test performs well across all outcome categories, showing a balance between adaptive and non-adaptive behaviours of tenants.

Table 4: *Model Testing 2*

-2 Log likelihood	**Cox & Snell R^2**	**Nagelkerke R^2**
288.21	0.334	0.380

Source: Field data, 2025

Table 5: Classification of the accuracy of model prediction of adaptive behaviours

Observed	**Predicted: No**	**Predicted: Yes**	**% Correct**
Yes	33	162	82.5%
No	84	25	77.8%
Overall			**80.5%**

Source: Field data, 2025

4.4 Logistic Regression Analysis of Factors Influencing Adaptive Behaviours under Grid Instability in Shopping Malls

The logistic regression analysis provides a comprehensive view of the factors influencing adaptive energy behaviour among shopping mall occupants in Ghana during power outages. In this context, adaptive behaviour includes actions such as switching off appliances when not in use, reducing energy consumption or utilising backup systems. Several predictor variables were statistically meaningful. An odds ratio of 1.36 (Exp(B)) indicated a strong positive effect on thermal comfort (B = 0.31, p = 0.007) (see Table 6). This indicates that the likelihood of adaptive behaviour does increase by 36% with each one-unit increase in perceived thermal comfort. This mirrors a major effect of warmth, ease and feeling. If tenants feel thermally comfortable, they are more likely to engage in positive behaviours when managing energy use during outages. Similarly, the reliance on generators, inverters or solar panels was a positive predictor (B = 0.37, p = 0.004; OR = 1.46). This implies that occupants who trust thermal systems across the shopping malls are 46% more likely to engage in energy-saving behaviours. This has positive effects on users' sense of control and reduce stress during power outages.

Moreover, awareness of energy systems was the most significant predictor (B = 0.52, p < 0.001; OR = 1.63) of thermal adaptive behaviours. Table 6 shows that occupants with greater awareness will likely adapt to thermal behaviours by 63%. This indicates that the high level of awareness drives occupant's adaptation. Furthermore, frequency of power outage recorded negative and strong association with adaptive behaviour (B = -0.24, p = 0.012; OR = 0.77). This implies that the more frequent the power outages, the higher the likelihood of reduced adaptive behaviour, possibly due to helplessness, frustration and fatigue in shopping or use of space.

Despite its modest effect on adaptive behaviours, age remains a significant demographic variable (B = 0.01, p = 0.046), with older tenants being slightly more likely to engage in adaptive behaviour. Other demographic variables, e.g., Education, showed a strong prediction (B = 0.26, p = 0.021; OR = 1.26) on the adaptive behaviours of thermal systems across the shopping malls. The B = 0.26 result suggests that users with higher educational levels are associated with a 26% increase in adaptive behaviours. Also, income levels reported a positive and marginal significant effect (p = 0.067) on adaptive behaviours. This supports the possible relationship between adaptive behaviours and the socio-economic capacity of users.

Table 6: *Log predicted analysis of adaptive behaviours*

Variable	B	S.E.	Wald	df	Sig.	Exp(B)
Thermal_Comfort	0.31	0.12	7.55	1	0.007**	1.36
Trust_in_Tech	0.37	0.14	8.88	1	0.004**	1.46
Outage_Frequency	-0.24	0.08	6.46	1	0.012*	0.77
Awareness	0.52	0.13	16.73	1	0.000**	1.63
Age	0.01	0.01	4.03	1	0.046*	1.02
Income	0.22	0.12	3.17	1	0.067	1.23
Education	0.26	0.13	4.68	1	0.021*	1.26
Constant	-2.76	0.87	8.57	1	0.004	0.06

Source: Field data, 2025

5. Discussions

The study assesses the influence of thermal comfort, trust in technology and awareness of energy systems on tenant satisfaction and adaptive energy behaviour in shopping malls in Ghana. Using the Unified Theory of Acceptance and Use of Technology (UTAUT2), the study established that user perceptions, such as thermal comfort, awareness, and trust in technology, can influence tenants' thermal adaptive behaviours during grid instability in shopping malls in Ghana. The study found that thermal comfort forms a central role as a predictor of satisfaction of adaptive behaviours across the shopping malls. This aligns with the

studies by Roumi et al. (2023) and Dai et al. (2024), which concluded that tenants' comfort must be prioritised in energy design. According to the studies, thermal comfort dictates user engagement and serves as a by-product of building operations. Other scholars have noted that the evolution of thermal comfort perceptions exert psychological stress on users (Yang et al., 2023; He et al., 2025). This is uncommon to find that thermal comfort motivated tenants to take proactive measures during power outages. Existing models support this finding. For instance, existing HVAC control strategies, such as those developed by Ma et al. (2024) and Kumaresan and Jeyaraj (2025), technically optimise comfort and efficiency. However, these studies consistently neglected occupant-perceptions in the results validation.

Trust in technology is another critical finding in adaptative thermal behaviours and satisfaction in shopping malls in Ghana. This finding is supported by Tak et al. (2023) and Zhao et al. (2025), who framed trust as an enabler of behaviour during stress events, rather than performance expectancy, when determining technology adoption within energy systems. In this study, tenants with trust in backup systems are more likely to conserve energy. This forms an extension of the UTAUT2, where trust is treated as a mediating variable that directly predicts user behaviour in technology acceptance. Additionally, this study repositions trust as a requirement for effective implementation of technology systems that support thermal adaptive behaviours across shopping malls in Ghana. This finding does not support technological studies claiming that increasing efficiency and autonomy through automation and artificial intelligence shapes adaptive behaviours (Noviati et al., 2024; Sepúlveda-Mora & Hegedus, 2022).

Among the predictors, awareness of energy systems showed the most powerful behavioural predictor of satisfaction. This is in line with both Liu et al. (2023) and Lin et al. (2025) who established that awareness extends beyond passive recognition. The study affirms that tenant expectations, behavioural intent and the capacity to assess adaptive behaviours are influenced by awareness of the energy system in Ghana. Additionally, tenants are more empowered and more proactive when they understand how backup generators work or how much energy is saved by certain behaviours. Similarly, occupants also become more proactive when they understand the alternatives available during power outages. These findings reinforce the call by Ohene et al. (2024) and Ansari and Keypour (2025) for creating participatory energy design frameworks through user engagement, interface transparency and dissemination.

It is worth restating that frequent outages can significantly reduce satisfaction and adaptive behaviour. Yu et al. (2024) and de Oliveira et al. (2021) addressed the human cost of extreme outage events by incorporating health and mortality metrics into resilience frameworks. Within the context of commercial buildings, repeated power outages weaken occupants' motivation to act. This study validates those arguments, even among those who trust the systems, but disagrees with Senthil Kumar et al. (2024), who assume that optimisations benefit end users.

The study's demographic findings also contribute meaningfully to the discussion. Educational level has a positive influence on satisfaction and adaptive behaviour. Yong et al. (2022) and Liu et al. (2023) found similar correlations between educational attainment and energy literacy. These outcomes imply that education could partly affect trust. Awareness may also be mediated by education. Age was equally a meaningful predictor, perhaps showing tolerance limits or cohort variations in coping tactics. However, power outages may be more familiar to older tenants, who may respond less. Similarly, adaptive mechanisms not present among younger users may also have been cultivated later by these users. Interestingly, income showed little relevance because it remained a stand-in for energy access or efficiency (Albatayneh et al., 2025). This challenges the assumption that wealthier users are necessarily more resilient and may reflect how the relatively homogeneous energy service experience affects users across all income levels in malls.

6. Practical and Theoretical Contributions

This study contributes to sustainable real estate and energy management in commercial buildings. Theoretically, studies have identified grid systems, HVAC optimisation and energy storage systems as

key to the energy resilience approach. However, these studies assessed occupant satisfaction only to a limited degree. The introduction of determinants such as thermal comfort and trust in technology actually reinforces the UTAUT2 through user 'adaptive behaviours. These are the fundamental components ensuring technological performance.

Practically, the study found that thermal comfort is a strong predictor of tenant satisfaction and adaptive behaviour. As such, shopping mall facility managers must introduce HVAC systems that support occupants' preferences, relative to static temperature settings, especially during power instability. The findings also show that tenants' behaviour is strongly influenced by trust in backup technologies. This means that shopping operations' management must communicate when energy shortfalls are likely to occur. This can be achieved through regular display of generator performance or battery levels that strengthen energy performance and boost tenant confidence. Furthermore, the level of energy awareness and its strong impact on tenants' adaptive behaviour requires that facility managers enhance energy awareness campaigns through visual signages. Following the reported dissatisfaction over the effects of frequent power outages, shopping mall managements in Ghana should improve on outage notifications and provide rent incentives for tenants who suffer outages. Moreover, they should leverage on age and the level of education of experienced tenants as means of championing adaptive responses across shopping malls in Ghana. Lastly, the findings suggest that user satisfaction is critical in ensuring adaptive behaviours and energy consumption in conditions of unstable power supply in shopping malls. Therefore, commercial buildings in Africa should incorporate user satisfaction into energy-efficiency accounting to ensure co-design of sustainable energy management.

7. Conclusions

The study assesses the influence of thermal comfort, trust in technology and awareness of energy systems on tenant satisfaction and adaptive energy behaviour in shopping malls in Ghana. Grounded in the Unified Theory of Technology and Acceptance of Use (UTTAU2), the study positions occupants as critical partners of energy sustainability in commercial buildings. The findings show that thermal comfort, trust in adaptive technologies and energy awareness strongly influence both satisfaction and adaptive behaviour during grid instability in shopping malls in Ghana. These findings provide a key behavioural dimension that contributes to the UTTAU theory. Practically, the report recommends that shopping managements should invest in energy campaigns, energy technologies and participatory design approaches that target tenants' satisfaction.

Furthermore, there is a need to improve energy backup systems and ensure HVAC responsiveness across the shopping malls. However, this study suffers a limitation. Geographically, focusing on shopping malls in Accra and Kumasi alone prevents generalisation of the findings, even though the empirical evidence is strong. Future studies should therefore use larger samples involving other regions and extend the contextual dimension to large, medium and small shopping malls. In conclusion, this study contributes to the global discourse by advocating adaptive energy strategies as a shared responsibility in regions experiencing grid instability in the Global South.

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