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Smart, but Not Spontaneous? Exploring the satisfaction Gap and drivers in Smart Lighting in Student Housing in Ghana

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Abstract

Smart lighting is emerging in student housing across Africa. This study assesses the drivers and satisfaction of smart lighting in university housing in Southern Ghana. The study used an embedded research method, including a survey of 334 student residents and interviews with 10 housing managers across five purpose-built student housing facilities at five selected public universities in Southern Ghana. The Relative Importance Index and thematic analysis were used as data analytical techniques. The findings reveal that accommodation needs primarily drove the adoption of smart lighting in student housing. The satisfaction levels of smart lighting were limited to lighting controls in lavatories, bedrooms, study areas, the kitchen, and common areas. However, dissatisfaction with lighting was associated with adjusting to the minimum light intensity and controlling artificial lighting. Technically, the limited influence of facilities management factors on smart lighting adoption poses a significant risk to energy sustainability if left unaddressed. Interviews reveal that students' lack of knowledge impacts their satisfaction with and usage of smart lighting systems. At a minimum, student housing managers and students would need education on smart lighting.

Keywords: Energy sustainability, smart lighting, sustainable design, student housing, Technology Acceptance Model

1. Introduction

In recent years, the widespread adoption of smart lighting in buildings has been hindered by several factors. Firstly, people do not have strong control over overall light quality; modest energy-saving returns complicate the justification for high initial investments, and user-responsive functionalities are limited (Füchtenhans et al., 2023). Despite these challenges, smart lighting continues to emerge as a promising multidisciplinary field, advancing not only energy conservation but also photobiological health, environmental psychology, and facilities management. In this context, smart lighting is widely regarded as a key element of sustainable building performance rather than purely a technological enhancement. Worldwide, smart lights can save up to 60 per cent of energy compared with conventional lighting systems in buildings (Papinutto et al., 2022). These systems increase productivity and improve light quality while offering dynamic adaptability. Despite this, technical importance, user satisfaction, perceived usability, and behavioural engagement remain underexplored, as the scholarly focus is still skewed disproportionately toward energy metrics, automation protocols, and return-on-investment calculations; these user-related contexts ultimately determine system performance in practice.

Smart building technologies address both surging energy costs and sustainability imperatives. They gained importance in Africa as economies grew. African Universities South of the Sahara consume much energy, and student residences are a key part of this demand (Appau et al., 2024). This has led institutions to implement green building policies to

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reduce carbon footprints and energy costs by integrating smart lighting technologies. Based on that, student housing has become a deliberate testing ground for smart lighting implementation in higher education across Africa. African nations are retrofitting student housing or designing smart student housing. These countries include South Africa, Egypt, Nigeria, and Ghana, and the features are occupancy-based controls, daylight-linked dimming, and remote monitoring systems (Gentile et al., 2022). In Ghana, interest in smart lighting arose from dissatisfaction with the legacy lighting infrastructure in student housing, as energy efficiency declined and utility costs rose (Appau et al., 2023).

Notwithstanding these developments, questions remain about how users experience and interact with lighting systems, particularly regarding satisfaction and effective use.

Although smart lighting is emerging in West Africa, particularly in university housing, empirical research has rarely examined user satisfaction and the factors that drive adoption. Most existing literature focuses on technical performance rather than user satisfaction and outcomes. How these findings hold in regions facing distinct economic constraints, energy policies, and environmental conditions remains unclear. At the same time, studies such as those by Soheilian et al. (2021) and Kwong (2020) suggest that user-controlled smart lighting systems positively influence indoor visual comfort and occupant well-being. Dong and Zhang (2021) link daylight exposure in student dormitories to improved mood, sleep quality, and cognitive performance. This work further supports the view that lighting is not merely a utility but a determinant of well-being. Recent studies also emphasise that emotional responses are significantly shaped by spatial ambience, thermal comfort, and lighting colour (Wei et al., 2023). However, these studies are mainly concentrated outside sub-Saharan Africa, underscoring the need for context-sensitive evaluations that account for regional and sociocultural variations, particularly in rapidly growing education hubs such as Ghana.

Although smart energy technologies are increasingly adopted in Ghanaian universities, an evident knowledge gap persists due to the limited user-oriented focus of existing studies. Smart lighting studies often assume a technologically literate population capable of interacting with complex systems. Nevertheless, findings from Appau et al. (2023) indicate that many Ghanaian student housing residents and facility managers are unaware of system features, such as automated dimming and daylight sensors. The smart lighting market is expected to grow at nearly 8 per cent globally by 2025 (Zissis, 2021). Hitherto, this projected growth has not been empirically assessed in terms of user satisfaction, behavioural engagement, or perceived usefulness in Ghanaian student housing. Even in more data-rich environments, such as Nigeria, residents may be dissatisfied with artificial lighting that is often poorly maintained, contributing to suboptimal residential experiences for students (Dennis et al., 2024). Nduka et al.'s (2021) research highlights health risks beyond those posed by inadequate indoor environmental quality, including sick building syndrome. These concerns raise questions about the expected benefits of smart lighting when user knowledge, training, and system adaptability are insufficient.

Against this background, this study addresses the limited understanding of user satisfaction and the drivers of smart lighting systems in Ghanaian student housing.

Having provided this background, the present study aims to assess residents' satisfaction levels and the drivers of smart lighting adoption in Ghanaian student housing. Student housing is a particularly suitable context due to its high occupancy levels, intensive energy use, and diverse user behaviours, making it an ideal context for examining the performance of smart lighting technologies.

Dormitory environments integrate institutional regulations, occupant behaviour, and spatial design, enabling examination of smart lighting under varying social and physical conditions. This contributes to knowledge by addressing an identified gap in the literature concerning user-centred evaluations of smart lighting in student housing within developing contexts.

First, it provides valuable feedback to facility managers and housing administrators on the features and configurations of smart lighting, ensuring alignment with user needs and preferences. This can guide procurement, retrofitting, and maintenance strategies that prove both cost-effective and user-friendly. Second, the study provides empirical grounding for sustainability efforts aimed at reducing the energy cost burden on universities and investors by identifying satisfaction levels and key drivers of adoption. These findings contribute to broader scholarly discussions on interior environments. In evaluating smart technologies, user-centric metrics are foregrounded. The study thereby addresses the increasing demand for research that balances technical performance with human experience, especially in areas that global scholarship has typically underrepresented.

2. Literature Review

2.1. Technology Acceptance Model

Davis (1989) developed the Technology Acceptance Model (TAM) as an extension of Ajzen's Theory of Reasoned Action. The model suggests that users' acceptance of technology is primarily influenced by two factors: perceived usefulness and perceived ease of use. Davis also emphasised that external variables, such as social influence, can significantly impact an individual's acceptance and adoption of new technology, within the context of bright lighting. The Technology Acceptance Model provides a suitable theoretical lens for understanding how students perceive lighting technologies and their perceived influence on satisfaction and usage behaviour. Recent advancements in applying the Technology Acceptance Model to smart buildings and energy technologies underscore its significance for understanding adoption decisions in residential and institutional contexts. Studies show that when users perceive smart systems as beneficial and easy to operate, adoption rates increase, even in shared living environments such as student housing. Although Technology Acceptance Model studies often assume a standard level of technological literacy among users, this assumption may not hold in all contexts, particularly in developing countries (Chen et al., 2017; Gerhardsson & Laike, 2021). This limitation highlights the need to contextualise TAM when examining smart lighting adoption in student housing.

2.2. Smart lighting systems adoption drivers in buildings

Smart lighting systems, as a subset of smart building technologies, integrate automation, sensing, and control mechanisms to optimise energy consumption and enhance operational efficiency. Studies have constantly identified energy efficiency and cost reduction as primary drivers of smart lighting adoption. For instance, Füchtenhans et al. (2023) and Kumar et al. (2021) report energy savings of up to 30.9 per cent, positioning smart lighting as a key strategy within sustainable building design frameworks.

Beyond energy considerations, managerial and organisational drivers also influence adoption decisions. Gøthesen et al. (2023) highlight perceived value and peer influence as factors shaping adoption, while Saleem et al. and Tekler et al. emphasise the role of real-time monitoring, automation, and personalised controls. In institutional contexts such as universities, facilities management priorities, maintenance budgeting, and security considerations also shape decision-making. However, these studies are conducted in commercial or general residential buildings, limiting their direct applicability to student housing environments, where shared spaces, high occupancy rates, and regulated usage patterns introduce additional complexity.

2.3. User satisfaction with Smart lighting and Daylighting

User satisfaction is a critical determinant of the long-term success of smart lighting systems, yet it is often examined inconsistently across studies. Existing studies often overlap discussions of daylighting, visual comfort, and energy savings, resulting in repetitive treatment of similar concepts. Studies by Soheilian et al. (2021) and Kwong (2020) demonstrate that user-controlled lighting systems improve visual comfort and perceived well-being. Similarly, Dong and Zhang (2021) link daylight exposure in student dormitories to improved mood, sleep quality, and cognitive performance.

Satisfaction levels, however, vary across spatial contexts. Bae et al. report dissatisfaction with artificial lighting and daylighting in dormitories, with implications for both comfort and academic performance. Conversely, Dong et al. (2022) report higher satisfaction in private dormitory rooms than in common areas. Osei-Poku et al. (2020) and Orman and Wojtkowiak (2022) find generally high satisfaction with lighting conditions in student housing in Ghana and Poland, respectively, illustrating the effects of regional, architectural, and cultural factors on user perceptions. Jakubiec et al. further note spatial variation in satisfaction, with students expressing greater contentment in bedrooms than in shared kitchens or communal areas.

Beyond perceptual outcomes, physiological and emotional responses to lighting are increasingly emphasised in the literature. Wei et al. (2023) show that lighting colour significantly affects emotional responses, while studies on daylight exposure highlight its impact on circadian rhythm and overall well-being. Despite this growing body of studies, user satisfaction is often treated as a secondary outcome rather than a central evaluative criterion.

2.4. Gaps in Sub-Saharan African Student Housing Research

Although research on smart lighting is expanding globally, significant gaps persist regarding Sub-Saharan African student housing. Most studies prioritise technological optimisation or energy performance metrics, with limited attention to user satisfaction, behavioural engagement, and contextual constraints. When user satisfaction is examined, findings are often drawn from data-rich or technologically advanced contexts, raising concerns about their transferability to developing regions.

In the African context, Appau et al. (2023) reveal limited awareness of smart lighting features among student housing residents and facility managers in Ghana. Similarly, Nduka et al. (2021) link inadequate lighting conditions to health risks, including symptoms of sick building syndrome, in Nigerian student hostels. These studies suggest that assumptions of ease of use and perceived usefulness may not align with lived experiences in student housing environments where training, maintenance capacity, and user literacy are limited. What emerges is a clear research gap: few studies integrate technology acceptance theory, adoption drivers, and user satisfaction within the specific context of Sub-Saharan African student housing. The intersection of high occupancy rates, energy cost pressures, and limited user knowledge remains underexplored. This gap underscores the need for empirical, user-centred investigations that examine not only why smart lighting is adopted, but also how it is experienced and utilised by students and housing managers in developing contexts, and how lighting influences well-being and academic engagement in student accommodations.

3. Research Methodology

The study employed embedded mixed-methods research. Thus, qualitative data were used to explain the quantitative findings. This method was used to assess students' satisfaction with smart lighting in student housing. The study adopted an embedded mixed-methods research design, where quantitative data collection preceded qualitative inquiry, and qualitative findings were used to explain and contextualise the quantitative results. This approach enabled a comprehensive understanding of students' satisfaction with smart lighting systems and the factors driving their adoption in student housing. The mixed-methods design is appropriate for examining both measurable satisfaction levels and underlying behavioural and managerial explanations. The questionnaire used in the quantitative phase was developed based on an extensive review of the literature on smart lighting, indoor environmental quality, and technology acceptance. The measurement indicators for smart lighting satisfaction (see Table 1) and adoption drivers (see Table 2) were adapted from validated constructs used in prior studies, including Appau et al. (2023), Bae et al. (2021), and Soheilian et al. (2021), to ensure content relevance. To establish content validity, the draft questionnaire was reviewed by two academics with expertise in

Table 1: Measurement of smart lighting systems satisfaction

Construct	Indicators	Mode of measurement
SLM1	End-users' control for indoor lighting (bedroom)	1=very dissatisfied, 5=very satisfied
SLM2	End-users' control for indoor lighting (study area)	1=very dissatisfied, 5=very satisfied
SLM3	End-users' control for indoor lighting (kitchen)	1=very dissatisfied, 5=very satisfied
SLM4	End-users' control for indoor lighting (lavatories)	1=very dissatisfied, 5=very satisfied
SLM5	End-users' control for indoor lighting (common areas)	1=very dissatisfied, 5=very satisfied
SLM6	End-users' artificial lighting power based on daylight levels	1=very dissatisfied, 5=very satisfied
SLM7	End-users' adjustment to minimum light intensity	1=very dissatisfied, 5=very satisfied
SML8	End-users' adjustment to control of natural lighting.	1=very dissatisfied, 5=very satisfied
SLM9	End-users' satisfaction with outdoor lighting illumination	1=very dissatisfied, 5=very satisfied

Source: authors' construct, 2024

Table 2: Drivers of the smart lighting adaptation

Variables	Indicators	Construct	Mode of measurement
Facilities management aspect	Student housing managers perceived the benefit of using smart lighting	ADD3	1=very low high influence, 5=very high influence
	Security and safety control	FMD1	1=very low high influence, 5=very high influence
	High energy cost	FMD2	1=very low high influence, 5=very high influence
	Maintenance budgeting	FMD3	1=very low high influence, 5=very high influence
	Availability of the smart lighting control manual	FMD4	1=very low high influence, 5=very high influence
Market-driven factors	Emergence of smart lighting in the student housing market	MDF1	1=very low high influence, 5=very high influence
	Student housing marketing appeal	MDF2	1=very low high influence, 5=very high influence
Accommodati on demand-driven factors	High occupancy	ADD1	1=very low high influence, 5=very high influence
	User knowledge of the smart lighting control device	ADD2	1=very low high influence, 5=very high influence

construction management and sustainable building systems, and by one facilities management practitioner with experience in student housing operations. Their feedback informed minor revisions to improve the clarity and relevance of the indicators. A pilot survey was subsequently conducted with 20 student housing residents who were not included in the final sample. The pilot test confirmed the clarity of questions and the average completion time.

Internal consistency reliability of the questionnaire items was assessed using Cronbach's alpha. Both the satisfaction scale and the adoption driver scale had alpha coefficients above the recommended threshold of 0.70, indicating acceptable reliability. These validation procedures ensured that the questionnaire items were both reliable and suitable for measuring the study constructs.

3.1. *Sampling Technique and Sample Size*

The study employed a two-stage sampling process to select respondents. First, the study conveniently sampled 5 out of 9 purpose-built on-campus university student housing in southern Ghana. The purpose was limited to a lack of accessibility to the remaining 4. Further, using the Yamane (1967) formula for sample size determination, a sample frame (N) of 2544, 50% of the population proportion, 5% margin of error Ɛ, and 95% confidence level:

$$n = \frac{N}{1 + N(e^2)}$$

$$n = \frac{2544}{\{1 + 2544(0.05^2)\}}$$

A sample of 331 was determined and used. Secondly, ten student housing managers were purposively selected for qualitative interviews, with two per selected housing facility. This dual perspective enabled triangulation between student experiences and managerial decision-making rationales. Qualitative data were collected through semi-structured interviews and analysed using a systematic thematic analysis procedure. Interview recordings were transcribed verbatim, after which open coding was conducted to identify recurring themes related to smart lighting use, satisfaction, and operational challenges. Codes with similar meanings were then grouped into broader categories, which informed the development of key themes. The coding process followed an iterative approach involving repeated reading of transcripts to refine and consolidate themes. Two researchers independently coded a subset of the transcripts; the coding outcomes were then compared, and discrepancies were discussed until consensus was reached, thereby strengthening interpretive reliability. This process enhanced the credibility and dependability of the qualitative findings. Data saturation was achieved when no new themes emerged from subsequent interviews. Final themes were reported using anonymised identifiers (e.g., SHM1, SHM2) to ensure confidentiality and clarity in data presentation.

3.2. *Ethical consideration*

Ethical approval for the study was obtained from the research committee of the study area and the Dean of Students' Office. These include: University of Cape coast (DHR/TDS/100/V.5/63), Kwame Nkrumah University of Science and Technology (KNUST/RO/GEN), University of Education, Winneba (R.252/RFU/80), University of Energy and Renewable Natural Resource (74 SF.1). All participants were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any stage without penalty. Written informed consent was obtained from all respondents before administering questionnaires and conducting interviews. No personal identifiers were collected, and interview data were securely stored and accessed only by the research team.

4. Data analysis

The data analysis involved two stages. First, the study analysed the mean values of the indicators in Table 1 to ascertain satisfaction levels. Second, the study used the Relative Importance Index (RII) to derive the drivers of smart student housing. Here, ranks were assigned to the average levels of influence of adopting smart lighting in student housing. Where;

$$RII = \frac{\sum w}{A * N} = \frac{1n_1 + 2n_2 + 3n_n + 4n_4 + 5n_5}{5 * N}$$

$where\ (0 \leq RII \leq 1)$

Weight was assigned to each respondent, ranging from 1n (Very low influence), 2n (low influence), 3n (moderate influence), 4n (high influence), and 5n (very strong influence). A and N, on the other hand, show the highest weights and the largest numbers of respondents. Furthermore, the results were ranked in order of increasing importance. Moreover, the interviews were thematically analysed. Here, recorded data were transcribed into words and grouped into themes based on similar responses. Codes were assigned to student housing managers to ensure the ethical presentation of data. Finally, data saturation was achieved by gathering similar perspectives on the challenges of smart lighting usage from different student housing managers.

5. Findings

5.1. *Descriptive results*

The descriptive statistics in the study indicate a high response rate of 99.1%, with 331 of 334 student housing occupants participating. Males constituted a slight majority (53.8%) of respondents, and females 46.2%. Most participants were undergraduates (82.5%), while only 17.5% were postgraduates. This suggests that the studied group was skewed toward lower academic ranks (See Table 3).

The age distribution shows that most respondents were between 18 and 26 years old, with the 24-26 age group having the highest number (85). Afterwards, the numbers dropped to 21, 23 (79) and 18, 20 (73). Respondents aged 32 or older were very few, with only two participants aged 39 or older.

All age groups were represented in all five student housing facilities. Older students tend to live in Housing 2 and 3, with the majority of occupants being in the 24-26 age group. Older students were, by comparison, somewhat fewer in Housing 43 and Housing Preferences of the resident population, as well as in usage habits, implying that smart lighting strategies should prioritise the preferences of younger undergraduates, who dominate this area. Their impact on design decisions may be minimal given the relatively small number of older students. However, the age and academic-level distributions provide valuable context for understanding user satisfaction and adaptation to smart lighting systems in student housing environments.

5.2. Satisfaction with smart lighting adaptation

Table 4 presents the satisfaction of smart lighting systems in student housing. Table 4 reports five satisfactory levels of smart lighting system usage in Ghana. These include mean scores higher than the average mean scores (end-users' control for indoor lighting (bedroom), end-users' control for indoor lighting (study area), End-users' control for indoor lighting (kitchen), End-users' control for indoor lighting (lavatories), end-users' control for indoor lighting (common areas). On the flip side, student housing users expressed high dissatisfaction with end-

Table 3: Descriptive results

Age	**18-20**	**21-23**	**24-26**	**27-29**	**30-32**	**33-35**	**36-38**	**39+**
student housing 1	12	11	10	9	5	1	1	0
student housing 2	17	15	22	10	9	5	2	1
student housing 3	10	21	18	11	7	2	3	0
student housing 4	20	13	17	7	6	0	1	0
student housing 5	14	19	18	8	4	1	0	1
TOTAL	73	79	85	45	31	9	7	2
Gender								
Male	178	53.8						
Female	153	46.2						
TOTAL	331	100						
Levels in Class								
Undergraduate	273	82.5						
Postgraduate	58	17.5						
TOTAL	331	100						

Source: field data, 2024

Table 4: Satisfaction with smart lighting in student housing

Construct	**Indicators**	**Mean**	**Standard Deviation**
SML1	End-users' control for indoor lighting (bedroom)	3.6	0.8
SLM2	End-users' control for indoor lighting (study area)	3.6	1
SLM3	End-users' control for indoor lighting (kitchen)	3.5	1
SLM4	End-users' control for indoor lighting (lavatories)	3.7	0.7
SLM5	End-users' control for indoor lighting (common areas)	3.5	1.1
SLM6	Artificial lighting power based on daylight levels	2.8	1.2
SLM7	Adjustment to minimum light intensity	2.7	1.2
SLM8	Control of natural lighting	2.9	1.3
SML9	Satisfaction with outdoor lighting illumination	2.6	1.4

Source: field data, 2024

users' artificial lighting power based on daylight levels (end-users' adjustment to minimum light intensity, end-users' adjustment to control of natural lighting, and end-users' satisfaction with outdoor lighting). These are critical areas that student housing managers must address to ensure inclusive, sustainable lighting use in student housing. However, interviews with student housing managers highlighted a lack of knowledge as a critical barrier to students' use of smart lighting. According to student housing managers:

[….] It appears students are unaware of how these lights operate; maybe we need to educate them. Sometimes the need to instruct some of them to close their windows becomes apparent when the lights are on. This increases the energy cost to us [*sic*] (SHM8).

[….] "We may need a lighting system that automatically switches off when windows are opened." [*sic*] (SHM3).

[….] "Most students are unaware of how the lighting systems operate, which affects how effectively they use them." [*sic*] SHM1

[….] People should learn about smart lighting at orientation. Basic training is something that should occur during orientation. How many students switch on all of the lights in broad daylight? You will be surprised." [*sic*] SHM2

[….] We have had to remind some students about using natural lighting instead of keeping windows wide open with smart lights." [*sic*] (SHM5)

[….] Some students entirely ignore the sensors, along with becoming frustrated since they do not understand.", SHM4

[….] We only manage what is there. We think the student housing owners would need to make further enquiries before introducing these smart lighting systems in the housing, as they consider it a marketing strategy to increase student numbers in the hostel [*sic*] (SHM8).

[….] I think that because some student housing managers have started using it, my boss has also introduced it here. For me, it is a good idea provided it will serve the purpose of the students [*sic*] (SHM8).

[….] We installed the system mainly as an action to cut down on our electricity bills, not for the sake of technology.", SHM16

[….] Some landlords use smart lighting as a marketing tool instead of caring about comfort or sustainability." SHM17 states
.
[….] Energy consumption rises when many students attend. "That is why we need smart lighting. SHM18 says usage regulation involves smart lighting.

5.3. Drivers of smart lighting adaptation in student housing

Table 5 presents a detailed breakdown of the critical factors influencing the adoption of smart lighting in student housing in Ghana. The data, analysed using the Relative Importance Index (RII), are grouped into three major categories: Accommodation Demand-Driven (ADD), Facilities Management-Driven (FMD), and Market-Driven Factors (MDF). The results reveal that accommodation-driven and facilities management considerations significantly outweigh market-related influences in determining the adoption of smart lighting systems.

Table 5: Drivers of smart lighting adaptation in student housing

Indicators	1	2	3	4	5	Total (H)	Total Respondent (I)	HR (J)	I*J (K)	H/K	RANK
ADD1	1	2	0	12	15	30	10	5	50	0.6	3
ADD2	1	6	4	8	5	24	10	5	50	0.47	5
ADD3	0	2	3	16	20	41	10	5	50	0.82	1
FMD1	4	4	6	4	5	23	10	5	50	0.46	6
FMD2	1	4	9	8	10	32	10	5	50	0.64	2
FMD3	2	10	3	4	5	24	10	5	50	0.48	4
FMD4	3	8	6	0	5	22	10	5	50	0.44	7
MDF1	3	10	3	0	0	16	10	5	50	0.32	8
MDF2	2	10	6	4	0	22	10	5	50	0.44	7

Source: field data, 2024

(Note: Total weighted score for each indicator, calculated as the sum of the product of each rating scale value and its frequency, I=Total number of respondents, J=Highest weight on the Likert scale (i.e., 5), I × J (K)=Maximum possible score for each indicator, H/K: Relative Importance Index (RII), representing the relative influence of each factor.

Another group of student housing managers expressed that their motivation and operational satisfaction:

The most influential factor, ranked first, is ADD3 – student housing managers' perceived benefit of using smart lighting, with an RII value of 0.82. This underscores that managers prioritise the long-term operational advantages of smart lighting, particularly its potential to lower energy consumption, reduce utility costs, and enhance the overall efficiency of student housing operations. Following this, ADD1, with a high occupancy rate, ranks third with an RII of 0.60. This reflects the concern that higher numbers of student occupants lead to greater energy demands, making smart lighting a viable strategy for controlling excessive usage and maintaining cost efficiency. ADD2, which represents user knowledge of smart lighting control devices, ranks fifth with an RII of 0.47. Although this is moderately influential, it suggests that students' ability to use smart systems effectively is important but not a central driver of decision-making.

From a facilities management standpoint, FMD2 – high energy cost – ranks second overall with an RII of 0.64. This suggests that rising electricity costs are a significant motivator for the adoption of energy-saving technologies, such as smart lighting. Managers view smart systems as essential tools to offset the financial burden of rising utility rates. FMD3, which addresses maintenance budgeting, ranks fourth at 0.48. Although not as dominant as perceived benefits or energy costs, the desire to reduce maintenance expenditure still contributes to the adoption rationale. FMD1 – security and safety control – ranks sixth with an RII of 0.46, suggesting that safety concerns are acknowledged but are not primary drivers. FMD4 – availability of smart lighting control manuals – and MDF2 – marketing appeal of smart student housing – are tied in seventh position with an RII of 0.44. This suggests that providing users with instructions or utilising smart lighting as a marketing tool has a relatively low influence on decision-making.

The least influential factor, MDF1 – emergence of smart lighting in the student housing market – ranks eighth with an RII of 0.32. This shows that broader market trends or technological novelty are not strong motivators for adoption among student housing managers. Instead, decisions are shaped more by internal operational concerns than by external industry developments.

6. Discussion

The findings of this study contribute to the growing body of research on smart lighting adoption and satisfaction by providing context-specific empirical evidence from Ghanaian student housing. While the results broadly align with global smart lighting literature, they also reveal significant contextual deviations that extend the explanatory power of the Technology Acceptance Model (TAM) when applied to shared residential environments in developing regions. Consistent with TAM, the study confirms that perceived usefulness is the dominant determinant of smart lighting adoption, as evidenced by the high ranking of student housing managers' perceived benefits of smart lighting (ADD3). This supports Davis's (1989) assertion that perceived usefulness exerts a more substantial influence on adoption than perceived ease of use. Similar findings have been reported in smart building studies by Füchtenhans et al. (2023) and Gøthesen et al. (2023), where energy cost reduction and operational efficiency drive adoption decisions. In the Ghanaian context, perceived usefulness is primarily framed in economic and operational terms rather than technological novelty, reflecting the budgetary constraints faced by student housing operators.

However, the study extends TAM by demonstrating that perceived usefulness alone does not guarantee user satisfaction or effective system utilisation. Although smart lighting was adopted for its perceived benefits, satisfaction levels varied across lighting functions. Users reported satisfaction with lighting control in bedrooms, study areas, kitchens, and common areas, but dissatisfaction with daylight-linked dimming, minimum light-intensity adjustment, and outdoor lighting. These findings indicate a disconnect between adoption motivations (managerial-level usefulness) and user-level experiential outcomes, a relationship that the original TAM framework does not fully explain.

User knowledge emerges from the findings as a critical mediating variable between perceived usefulness and actual system satisfaction. Interview evidence indicates that many students lack awareness of how smart lighting systems interact with natural light and sensors. This mediating role of user knowledge helps explain why systems perceived as applicable by managers may still produce dissatisfaction among end users. In this sense, user knowledge mediates the relationship between perceived usefulness and actual use outcomes, thereby refining TAM's assumption that perceived usefulness directly translates into positive user behaviour.

In addition, a high occupancy rate serves as a contextual moderating variable that influences adoption decisions. The RII analysis shows that high occupancy (ADD1) strongly influences smart lighting adoption, as increased student density intensifies energy demand and operational pressures. This finding extends TAM by introducing an environmental–institutional moderator, where adoption is shaped not only by individual perceptions but also by occupancy-driven energy stress. Such a variable is absent mainly from conventional TAM applications, which focus on individual-level decision-making rather than institutional constraints.

The relatively low influence of market-driven factors further reinforces the context-specific nature of smart lighting adoption in Ghanaian student housing. Unlike

Saleem et al. (2023), who found that innovation trends and technological appeal influenced adoption, this study shows that marketing appeal and market emergence play minimal roles in adoption. This suggests that external variables within TAM operate differently in resource-constrained environments, where economic survival and operational efficiency take precedence over reputational or branding considerations.

Importantly, speculative claims regarding safety, learning performance, or long-term behavioural change have been avoided in this discussion, as the study did not directly measure these outcomes. While prior studies link lighting conditions to academic performance and well-being, the present findings are limited to satisfaction levels, adoption drivers, and user knowledge gaps. Interpretations have therefore been restricted to variables empirically examined in the study, ensuring analytical rigour.

This study contributes to theory by contextualising and modestly extending TAM rather than replacing it. The findings suggest that TAM remains a useful baseline for understanding smart lighting adoption. Still, its predictive strength improves when supplemented with mediating variables (user knowledge) and moderating contextual factors (occupancy pressure and energy cost constraints). In shared residential environments such as student housing, adoption decisions are institutionally driven, while satisfaction outcomes depend heavily on user capacity to interact meaningfully with installed technologies.

7. Theoretical and practical implications

This study contributes both theoretically and empirically to the Technology Acceptance Model (TAM) by contextualising it within the context of sustainable infrastructure, specifically brilliant lighting in student housing in Ghana. This study improves the TAM, which typically centres on perceived usefulness and perceived ease of use, by introducing context-specific external factors such as occupancy rate, energy cost concerns, and facility management priorities. These drivers strongly influence technology adoption decisions, although they fall outside the original TAM framework. By managing an environment and designing infrastructure within TAM's predictive framework, the study employs a model for sustainability-oriented decisions in the built environment. For multiple stakeholders, the findings have practical implications. Firstly, university student housing administrators must educate all students to ensure they understand and use smart lighting systems properly. The study reveals that students' limited knowledge leads to inefficient use and dissatisfaction. During orientation, train individuals in a structured manner and post informational signs throughout housing facilities.

Secondly, technology building suppliers and contractors should be held fully accountable. They should integrate automated features, such as daylight sensors and adaptive dimming functions, into their lighting systems. Reported dissatisfaction includes a need to adjust lighting due to varying daylight intensities. Therefore, automation is needed to reduce dependence on manual labour.

Smart lighting integration is encouraged for university finance and energy management units. These units should incorporate smart lighting as part of their broader energy-saving strategies, thirdly. Given the emergence of high energy costs as a dominant driver, leveraging smart lighting to achieve measurable reductions in energy expenditure must be a core component of operational planning. Fourth, facilities managers and campus estate officers must consider incorporating smart lighting systems into all planning and procurement processes. They must also include them within the post-occupancy evaluation of all student housing infrastructure. These systems are designed as components of sustainable building performance. They should not be viewed simply as add-ons.

Finally, student housing design consultants and architects are responsible for ensuring uniform lighting standards across all spatial areas. Satisfaction is high in bedrooms and study areas, but relatively low in kitchens and outdoor spaces, according to the study. This spatial inconsistency suggests that design standards should ensure lighting quality and functionality across all zones.

8. Conclusions and recommendations

This study examined user satisfaction and the key drivers of smart lighting adoption in student housing in Ghana, using an embedded mixed-methods approach. The findings indicate that the adoption of smart lighting in student housing is primarily driven by perceived operational benefits, high energy costs, and high occupancy levels, whereas market-driven factors play a limited role. Regarding satisfaction, users reported positive experiences with lighting control in bedrooms, study areas, kitchens, lavatories, and common areas. Still, they expressed dissatisfaction with daylight-linked dimming, adjustment to minimum light intensity, control of natural lighting, and outdoor lighting illumination.

Given the perceived benefits of adopting smart lighting, student housing managers must invest in high-quality smart lighting to realise anticipated energy efficiency and cost savings. Additionally, student housing managers must invest in smart lighting that automatically turns off when students open windows to allow natural light. However, student housing users need to be educated on how to adjust smart lighting to complement natural lighting and promote energy efficiency. Managing outdoor lighting levels will require increased use of high-voltage smart lighting, particularly in student housing that utilises solar panels for outdoor lighting.

Future studies should include experimental evaluation of training interventions and longitudinal tracking of actual energy consumption versus perceived benefits of smart lighting in student housing.

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