

Leveraging on Sustainable Building Designs: Exploring the Drivers and Satisfaction of Smart Lighting in Student Housing in Ghana

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Abstract

Smart lighting continues to emerge in student housing in Africa. This study assesses the drivers and satisfaction of smart lighting in university housing in Southern Ghana. The study surveyed 334 student residents and interviewed 10 housing managers across five purpose-built student housing facilities at five selected public universities in Southern Ghana. Relative Importance Index and thematic analysis were data analytical techniques used. The findings reveal that accommodation needs primarily drove 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 adjustment to minimum light intensity and control of artificial lighting. Technically, the limited influence of facilities management factors in adopting smart lighting 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 best, 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 times, the widespread adoption of smart lighting in buildings has been hindered by a lack of robust total light quality control, average energy-saving returns that impact initial investment costs, and inadequate functionalities (Füchtenhans et al., 2023). Despite these obstacles, it is a multidisciplinary research area that has the potential to advance critical studies related to photobiology and human health, as well as commercial and residential buildings. Evidence within the built environment indicates that buildings with integrated energy-saving lighting control systems typically demonstrate savings of about 60% compared to traditional lighting control (Papinutto et al., 2022). Smart lighting can enhance productivity, spur growth, and improve light quality. As a consequence, most studies in this emerging field are currently focused on understanding maximum energy savings and efficiency, with limited focus on satisfaction from end-users' perspectives.

Over the past decade, challenges of high energy consumption and increases in energy costs have pushed most of the developing world to adopt sustainability practices related to smart buildings and technology. Within the sub-Saharan African countries, universities consume much energy. According to Appau et al. (2024), student housing is a unit that consumes high energy within the African university system. Despite

this, most universities have developed sustainability policies that include not only environmental sustainability but also the implementation of smart lighting in both on-campus and off-campus facilities. In the context of student housing, innovative lighting with wireless control sensors and daylight-dependent dimming has already been evident in some student housing in South Africa, Egypt, Nigeria, and Ghana (Gentile et al., 2022). Within the Ghanaian context, the genesis of smart lighting adoption in student housing was due to empirical evidence of dissatisfaction with lighting services and increased energy consumption and efficiency (Appau et al., 2023).

Additionally, the limited adoption of smart lighting is due to a lack of understanding of smart energy solutions (Appau et al., 2023). Research has shown that the use of smart lighting in residential buildings is expected to increase by nearly 8% in 2025 (Zissis et al., 2020). Despite this, scholars have yet to examine the satisfaction, usability, and acceptance levels of smart lighting systems. According to some student housing studies (Appau et al., 2024; Soheilian et al., 2021; Kwong, 2020), indoor visual comfort and general student well-being are achieved when smart lighting systems are combined with some level of personal control. Even though several smart lighting systems are emerging in the student housing market, the satisfaction in use and drivers have not been explored, especially in West Africa. Therefore, this study aimed to assess the

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satisfaction levels of smart lighting and its drivers in the Ghanaian student housing market. The study is relevant in three ways. First, it provides feedback to facilities managers on the choices of smart lighting demand. Second, it ensures energy efficiency and reduces the energy cost burden on student housing investors. Finally, it contributes to sustainable indoor environmental quality and the well-being of students.

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 ease of use and perceived usefulness. Davis also highlighted that external variables, such as social influence, can play a significant role in shaping an individual's acceptance and usage of new technology. These foundational ideas are crucial for understanding how students may perceive and adopt smart lighting in student housing, as they provide insights into the factors that could influence their attitudes and behaviours toward this technology.

2.2. *Smart lighting systems: integration, benefits, and drivers in buildings*

Smart buildings incorporate smart lighting systems. The concept of smart buildings, from a vision in the 1980s to prototypes and basic implementations by the early 2000s, was driven by advancements in technology. Smart lighting utilises sensing and automation technologies to reduce the need for manual control by occupants, enhance indoor environmental conditions and safety, and regulate energy consumption patterns in buildings. While scholars have examined various factors influencing the adoption of smart lighting, these studies often focus on different contexts, such as market-driven factors and facilities management. For instance, Fächtenhans et al. (2023) argue that the perceived benefits of smart lighting, including reduced energy consumption and cost savings, contribute to improving the environmental footprint of buildings. Gøthesen et al. (2023) support this view but emphasise the role of social influence and perceived price value in the adoption of smart lighting. Kumar et al. (2021), through simulation studies, found that integrating smart lighting can reduce energy consumption by 30.9%.

On the other hand, Saleem et al. (2023) argue that the adoption of smart lighting is influenced by users' knowledge of its ability to leverage real-time monitoring and advanced algorithms, offering several advantages over traditional systems. Tekler et al. (2022) highlight the potential of plug load automation, influenced by user preferences, non-intrusive indoor localisation systems, and personalised interfaces, in

driving smart lighting demand. While many studies focus on perceived benefits and user knowledge, Putrada et al. (2022) stress that user safety, comfort, and lighting utilisation security also play a significant role in smart lighting adoption, citing factors such as high lighting ratios and power reduction rates. Despite the growing body of literature on smart lighting, there is still debate about its implementation across different types of buildings.

While there is evidence of significant penetration of smart lighting in buildings, scholars have pointed out that user preferences vary widely across different building systems (Al Dakheel et al., 2020; Hassanain et al., 2022). Empirical studies highlight varying satisfaction levels with smart lighting in student housing. For example, Bae et al. (2021) found dissatisfaction with lighting and daylighting in dormitories, which could impact classrooms. Dong et al. (2022) reported high satisfaction with the lighting environment in rooms but dissatisfaction with lighting performance levels in university dormitories. Conversely, Osei-Poku et al. (2020) found high satisfaction with natural lighting in rooms in two types of on-campus accommodation at Takoradi Technical University. Orman et al. (2022) also found high satisfaction with lighting conditions in bedrooms and reported normal productivity among students at Poznan University, Poland. Jakubiec et al. (2019) found 80% satisfaction with daylighting in bedrooms compared to kitchens, driven by spatial values of annual sensor mean illuminance. On the other hand, Song et al. (2021) found low satisfaction with lighting quality in campus public spaces. Vosoughkhosravi et al. (2022) found high satisfaction with comfort in non-LEED-certified buildings but higher energy consumption in LEED-certified buildings. While these studies suggest varying levels of satisfaction with lighting conditions, they also highlight the potential of smart lighting to improve the work environment in university campuses. For instance, Hassanain et al. (2022) found that the amount of natural lighting through low-E windows was satisfactory, and the adoption of smart lighting could enhance the work environment. Al Dakheel et al. (2020) also support this, adding that integrating smart lighting with innovative shading systems leads to increased user satisfaction and greater energy savings. However, despite these findings, there is a clear gap in the literature regarding the satisfaction and drivers of smart lighting adoption, particularly in developing regions. While much of the existing research focuses on developed countries, limited attention has been given to the specific context of developing nations, especially in Africa. This study aims to fill this gap by exploring the perspective of student housing in Ghana, where smart lighting adoption and user satisfaction are underexplored.

3. Research Methodology

The study used the embedded mixed research methods. Thus, qualitative data were used to explain the quantitative findings. This method was used to understand students' satisfaction with the use of smart lighting in student housing. The study used two stages to sample 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 ϵ , and 95% confidence level:

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

A sample of 334 was determined and used. Secondly, the study sampled two student housing managers, each from one of the five selected student housing facilities. The purpose of selecting these respondents is first to understand the satisfaction levels from the student perspective and, second, to understand the rationale of student satisfaction from the student housing manager's perspective. To ascertain the satisfaction levels, students were asked to describe their satisfaction with smart lighting based on illumination levels in bedrooms, kitchens, study areas, common areas, and lavatories (see Table 1). Again, the drivers of smart student housing were ascertained from the student housing investors' perspectives (see Table 2). Face-to-face questionnaires and semi-structured interview guides were the data collection instruments used for students and student housing managers.

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
Accommodation 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

4. Data analysis

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

$$RII = \frac{\sum w}{A * N} = \frac{1n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5}{5 * N}$$

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

Weight was given to each respondent, ranging from 1n as Very low influence, 2n as low influence, 3n as moderate influence, 4n as high influence, and 5n as very high influence. A and N, on the other hand, show the highest weight and the overall number of respondents. Further, the results were ranked in ascending order of 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 ethical data presentations. Finally, data saturation was achieved through gathering similar perspectives related to the challenges of smart. lighting usage from different student housing managers.

5. Findings

5.1. Descriptive results

Table 3 shows the descriptive results of the study. Out of the 334 student housing samples, 331 participated in the survey, which represents 99.1%. This indicates a high participation rate. The study also found a higher participation rate among male students (53.8%) than females (46.2%), with most of them being undergraduate students (82.5%).

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 using smart lighting systems in Ghana. These include, mean scores higher than the

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

S/No	Factor category	Factor	Impact on productivity
1	Project-Level Factors	Design & Planning	High
2	Project-Level Factors	Material Management	High
3	Project-Level Factors	Technology & Equipment	Medium
4	Project-Level Factors	Workforce	High
5	Management-Level Factors	Supervision & Leadership	High
6	Management-Level Factors	Organisational Factors	Medium
7	Management-Level Factors	Incentives & Motivation	High
8	External Factors	Economic Conditions	Medium
9	External Factors	Political & Regulatory Factors	Medium
10	External Factors	Environmental Factors	Medium

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 related to end-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 illumination). These are critical areas of concern that student housing managers must address to ensure inclusive, sustainable use of lighting in student housing. However, interviews with student housing managers highlighted the lack of knowledge as a critical challenge for students in using smart lighting. According to student housing managers:

here. For me, it is a good idea provided it will serve the purpose of the students [*sic*] (SHM8).

5.3. Drivers of smart lighting adaptation in student housing

Table 5 identifies the critical drivers of smart lighting adaptation in student housing in Ghana. Student housing managers support the view that Accommodation demand-driven factors, Facilities management aspects, and Market-driven factors primarily drive smart lighting adaptation. The Relative Importance Index (RII) analysis shows that accommodation-driven indicators largely influence the adaptation of smart lighting, with the two highest ranks (1 and 3). Thus, Student housing managers perceived the benefit of using smart lighting (1st) and High occupancy rate (3rd). Also, among the facilities management factors, high energy costs influenced student housing managers to adopt smart lighting in

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)

[...] 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 are visible when the lights are on. This increases the energy cost to us [*sic*] (SHM8).

[...] We have energy-saving lighting systems in place. However, most students, especially at levels 100 and 200, do not know when to use daylighting and save energy. Maybe, we may need to get a lighting system which automatically goes off when they open their windows [*sic*] (SHM3).

Another group of student housing managers expressed that:

[...] 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 because they think that it serves as a marketing strategy to increase student numbers in the hostel [*sic*] (SHM8).

[...] I think because some student housing managers have started using some, my boss also introduced some

student housing compared to security and safety control, student housing maintenance budgeting, and the availability of smart lighting control manuals.

Furthermore, the study observed that market-driven factors had a limited influence on smart lighting adaptation. Generally, the study can deduce that Student housing managers' perceived benefits of using smart lighting, high energy cost, high occupancy rate, security and safety control, and user knowledge of smart lighting control devices are the 5-top critical factors that influence smart lighting adaptation in student housing in Ghana. According to student housing managers, the benefits associated with the longevity of smart lighting and its ability to reduce student housing operational costs were reasons for its perceived benefit. Regarding the aspects of high energy cost, student housing managers believe that the adaptation of smart lighting was not meant to control user access but to reduce energy consumption and ensure high savings. Aside from this, student housing managers associated high lighting usage with the exterior part of their buildings, which works throughout the night. These have a significant impact on student housing managers' decisions to adopt smart lighting.

Aside from the two higher ranks, student housing managers reported that high occupancy rates put immense pressure on lighting usage in rooms. It was important to observe that student housing with room occupancy of 1 4 had its lights on throughout the day.

6. Discussion

The study assessed the satisfaction with smart lighting and factors that influence smart lighting adaptation in student housing in Ghana. The study reported high mean scores of end-users' control for indoor lighting in bedrooms, which is in line with Dong et al (2022); Orman et al (2022); and Osei-Poku et al. (2020), who also found high satisfaction with lighting environment in rooms, and high satisfaction with level of natural lighting in rooms of residents. However, other studies did not provide satisfaction levels of smart lighting in the kitchen, study, and common areas. Contrary findings in this study found high dissatisfaction among end-users with the artificial lighting power based on daylight levels (End-users' adjustment to minimum light intensity). This finding is similar to Bae et al (2021), who found dissatisfaction with the amount of lighting and daylighting in the dormitories. End-users' adjustment to control of artificial lighting and end-users' dissatisfaction with outdoor lighting illumination are other critical dissatisfaction determinants not commonly found in other studies. However, due to the diversity of user preferences for smart lighting across different building systems, it is important to consider these indicators in other emerging studies (Al Dakheel et al., 2020; Hassanain et al., 2022).

Considering the ranks of determinants of smart lighting adaptation, the perceived benefit of using smart lighting was recorded as highest, which supports Füchtenhans et al (2023) who found that the perceived benefit of smart lighting systems was to reduce energy consumption and savings and Gøthesen et al (2023) who found the perceived price value as critical accommodation determinant. These studies are synonymous with the reduction in operational cost and perceived longevity expectations of adopting smart student housing. The increasing perception of high energy costs in this study aligns with Kumar et al. (2021), who found that integrating smart lighting reduces energy consumption by 30.9%. An instance of a high occupancy rate in this study determines smart lighting adaptation, a feature not commonly found in other studies. However, it can serve as a determinant in housing studies that have similar features.

Notwithstanding the high student occupancy, the findings observed safety and security control as ^{the fourth} factor, which aligns with Putrada et al. (2022), where user safety and comfort through high lighting ratio, power reduction rate, and user lighting utilisation security influences smart lighting decisions. More broadly, witnessing user knowledge of smart lighting control devices as ^{the fifth} determinant showcases support

for Tekler et al (2022). However, student managers perception of user knowledge related to smart energy as "energy efficiency" and "cost saving", deviates from Tekler et al (2022) who posit user rationale based on that the potential of plug load automation, non-intrusive indoor localisation system, diverse control preferences through a personalised user interface of smart lighting, and advanced plug load identification features

7. Conclusions and recommendations

Using a mixed method, the study assessed the satisfaction and critical drivers of smart lighting in student housing in Ghana. Findings show that smart lighting in student housing was primarily driven by perceived benefit, high energy cost, high student occupancy rate, safety and security, and knowledge of using smart lighting, which aligns with the premise of the Technology Acceptance Model. These determinants are largely accommodation-driven and facilities management-related. Aside from these factors, post-occupancy evaluation of the use of smart lighting shows a higher satisfaction for the use of smart lighting in bedrooms, study areas, kitchens, and common areas than dissatisfaction for artificial lighting power based on daylight levels, adjustment to minimum light intensity, adjustment to control of natural lighting, and outdoor lighting illumination.

Considering the perceived benefit of adopting smart lighting, student housing managers must invest in high-quality smart lighting to achieve the expected benefit of energy efficiency and cost savings. Aside from that, student housing managers must invest in smart lighting that automatically goes off when students open windows for natural lighting. However, student housing users need to be educated on adjusting smart lighting to complement natural lighting and ensure energy sustainability. Managing outdoor lighting illumination levels will require an increase in smart lighting with high voltage, especially with student housing using solar panels for outdoor lighting.

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