A Quantitative Investigation on Awareness of Renewable Energy Building Technology in the United Arab Emirates

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Abstract: Sustainability in architecture engages a wide range of considerations in the light of the significant negative impact of buildings on the environment. One aspect of research in this parlance engages the technological and the social dimensions of building innovation, which promote the use of renewable technology as a mitigation strategy. The challenge, however, is that the end-users or building clients do not always have sufficient awareness and information regarding these technologies to guide their decision to accept it. Consequently, the diffusion of said innovations is slow, and the environmental or building problems they were invented to solve persist at the expense of both humanity and the environment. This study, therefore, focuses on a quantitative investigation to ascertain the level of awareness and interest of residents in the United Arab Emirates (UAE) on Building Integrated Photovoltaics (BIPV) as an example of renewable energy-based building technology. In this study, 289 residents participated, following the distribution of a questionnaire to demographically distinct individuals. This distinction was used in the analysis to highlight different groups such as, gender, generations, and occupational background of the respondents. The findings of the study show, firstly, that there is a high level of awareness of BIPV in the sample. The study also shows that comparing awareness with each of these demographic variables produced a second layer of findings. For example, the statistical analysis showed that there is no significant difference between the level of awareness and any of the demographic characteristics of the study participants. However, there is a significant statistical difference ($p = 0.000$) between awareness and interest in BIPV. In concluding this study, recommendations for further research that elaborates other statistical variables and tests, as well as a follow-up qualitative investigation are planned and outlined for future studies. The findings of this investigation may be of benefit to researchers, policy makers, as well as energy companies and marketing agencies within and outside the region.

Keywords: building integrated photovoltaics; awareness; United Arab Emirates; questionnaire; demographics; sustainability; renewable energy

1. Introduction

The significance and potential of renewable energy in the Gulf Cooperation Countries (GCC) has recently aggregated much research with considerable interest in solar energy and innovations [1,2]. This body of literature has connected and integrated other topics such as energy policy [3], economic diversity and revenue [4], and architecture [5]. In recent times, significant investment and research that is focused on renewable energy aims at developing and applying the potential benefits of innovations, building energy efficiency policies and programs. One such study, for example, reported that the impact of reducing building energy consumption and peak demand in the GCC region has a multiplier effect, which doubles energy productivity [6]. Such investigations are vital when the average building energy consumption in the region is compared to the global average. Globally, buildings consume about 40% of total energy produced, however, as a case study of the GCC, buildings in the United Arab Emirates (UAE) consume about 70% of the electricity...
produced in the country, with almost 70% used for cooling [7,8]. Furthermore, reflecting on per capita energy consumption, the weighted average for GCC countries is seven times higher than the global average [5].

In the GCC, studies have investigated measures to address this trend relating to the actual energy demand and consumption scenario. One review has outlined critical projects, and plans, as well as challenges in this regard, highlighting large utility-scale projects and ambitious clean energy targets [9]. From an exemplary perspective, the current energy strategy for both the UAE and the Kingdom of Saudi Arabia aim for about 50% of clean energy by 2050 [10,11]. Considering the focus on building architecture, the fundamental concept of passive strategies towards reduced energy demand has also been investigated [12,13]. In addition, several sustainable building initiatives have been developed and applied, and enforced by rating systems. In specific terms, one study analyzed the Dubai Green Building Rating System (GBRS) in this regard. The study found that the cooling load savings, which are possible due to GBRS compliance, are up to 20%, and upgrading this with PassivHaus (PH) standards, can raise savings up to 43%. The study also found out that the addition of photovoltaic systems is able to facilitate a reduction of electricity grid dependence by as high as 73% [14].

Nevertheless, it has been argued that a lack of knowledge by building occupants can cause up to 60% increase in energy consumption, even in the case of high-performing buildings [15], and this can also influence their decision to adopt a new technology [16]. Thus, the complex interaction of users with energy technologies requires attention in order to guide both early-stage design decisions and planning, as well as building operation. This paper, therefore, argues that a puritan focus, which only addresses the technological dimension of innovative renewable building energy technologies, is only one side of the effort required for change in the GCC and beyond. The study elaborates and focuses on Building Integrated Photovoltaics (BIPV) as an example of these innovations in relation to the current discourse. Several studies suggest that there are multiple factors that have a high influence on technological diffusion and these need to be investigated. To summarize current literature, a lack of awareness and knowledge among skilled or unskilled labor, such as architects and developers, or electrical component installers for example, has a negative effect on the client’s understanding of the technology [17]. Consequently, their decision or willingness to buy into BIPV is critically influenced [18–20]. Other authors affirm that widespread resident awareness can drive BIPV innovation diffusion when it is promoted and advertised within the public domain [21].

Thus, the aim of this study is to investigate the degree of awareness of Building Integrated Photovoltaics (BIPV) among UAE residents as a means of promoting the increased diffusion of renewable energy in the building sector. BIPV serves as an example of renewable energy technology, and also, a building component in the current discussion linking energy technologies and people. The focus and scope of this paper is specifically to assess the level of stakeholder awareness and interest in BIPV in relation to demographics, as key components that may impact selection preferences or priorities in the design process.

Based on the foregoing, this study is divided into the Background (Section 2), which overviews BIPV research in the GCC as well as research on BIPV stakeholder perceptions and considerations. This is followed by a description of the research method and structure of the survey design (Section 3). The results and discussion that follow are respectively presented in Sections 4 and 5, in line with the study findings, the UAE context, and related practical aspects of BIPV technology. Section 6 summarizes the study and the main conclusions in line with the research objectives and findings.

2. Background

2.1. What Is BIPV?

BIPV is an innovative multifunctional building technology that is designed to serve more than one purpose in the building envelope [22–24]. As an integrated application of PV technology, BIPV produces clean renewable energy but also serves other tasks such
as weather protection, shading, and aesthetics explained below. Three identified classes of such added functionality or benefits include design, economic and environmental advantages [25]. From a design point of view, benefits relating to architectural integration include the provision of view and daylighting, aesthetics, shading, and noise protection [23,26]. Economic benefits relating to financial advantages of BIPV application include savings due to on-site energy generation and the removal of costs associated with long distance energy distribution, infrastructure, and maintenance [27,28]. The reduction of carbon emissions and the social cost associated with it, are also reported as part of the environmental benefits of BIPV including the use of clean renewable energy [29,30]. Figure 1 shows various applications of solar panels integrated in building structures with emphasis on BIPV structures, highlighting the design contribution to the building envelope.

In general, there are two broad perspectives that fundamentally underscore the importance of BIPV; these relate to the “energy dimension”, and the “building dimension” [31]. From an energy viewpoint, BIPV harnesses solar energy, which provides in an hour, more energy than the total global energy demand for one year [32–34]. This potentially makes BIPV a very effective sustainable energy source. Unlike utility-scale PV plants, BIPV provides energy at the point of use, removing the need for the long distance transmission of electricity with its associated transmission and distribution (T&D) costs as well as conversion/line losses [28,35,36].

To articulate the building dimension, as far back as 1998, it was argued that building impact on the environment is determined by its design, construction, use, and location [37]. These considerations could not be truer today, two decades later, as the building industry is deemed responsible for atmospheric emissions (40%), raw materials use (30%), solid waste (25%), water use (25%), water effluents (20%), land use (12%), and other emissions (13%) [38]. As a building material, BIPV can now replace conventional building components such as roofing, walls, glazing, cladding, and fenestrations; and other structures like shading devices, parapets, and balconies [22,23,26,39–41]. Figure 2 shows the Copenhagen International School, Denmark, designed by C.F. Moller Architects and built in 2017. The building has 12,000 bluish BIPV panels that cover the façade and are individually inclined at an angle to create a “sequin-effect” and produce a distinct architectural character. Estimated to produce 200 MWh per year, the solar cells cover an area of over 6000 square meters [42].
2.2. BIPV Research in the GCC

In recent times, research on BIPV grown in the UAE and the GCC. Examples include studies related to energy simulations and generation potentials [43–45] and thermal management [45], as well as design and building integration [46–49]. In greater details, these studies have expanded the literature on BIPV and related technologies within the region. One study investigated the performance of a 86.4 kW BIPV roof in the desert town of Awali in Bahrain [43]. The authors report that when installed in the south-west orientation at 25 degrees tilt angle, the system generated 26.0% and 34.2% less than the projected values by the manufacturer and PVWatts, respectively. However, the study reported a 6% increase in the yield of solar electricity when cleaned bi-monthly, and a potential CO2 emission reduction of about 9 tons. Another research studied the overall impact of rooftop photovoltaic (PV) systems in a 100 km² area in the city of Al-Khobar in Saudi Arabia covering 33,000 residential units [48]. The simulation results show an average specific annual yield of 1391 kWh/kWp, a performance ratio of 70%, a cooling load reduction of 2%, and a 19% offset of the electricity demand when 25% of the building roof is utilized. From another perspective, it was reported that up to 10% of the total energy consumption from a school building construction in the Emirates of Abu Dhabi sourced from BIPV [46].

Considering the impact of PV technologies, assessment of the performance of different roof mounted PV systems in Abu Dhabi was carried out [50], and it was found that poly-Si types have a higher annual yield than the mono-Si types. The performance degradation of PV modules installed in Dubai for more than two years was also investigated [51]. The results suggest that mono-Si PV modules have the lowest degradation rate of 0.07%/year, compared to CIGS (3.9%/year) and Poly-Si (2.9%/year). An experimental study on six (6) different types of photovoltaic (PV) modules in the Dubai climate over a two-year period has also been carried out [44]. The findings show that both the highest yield and loss, due to temperature, are linked with bifacial monocristalline modules while poly-Si modules generally showed higher yield due to a combination of temperature effect and soiling effect on the samples. Focusing on innovative hybrid systems, a study of a novel exhaust air heat recovery system with a hybrid photovoltaic/thermal (PV/T) system with a thermal wheel (TW) system for residential applications was investigated [52]. The technological commonality of these studies from a holistic point of view suggests high interest in the understanding of concepts such as system performance, energy generation, and optimization strategies in the study context under review.

2.3. BIPV Adoption and User Perceptions

Although the literature on BIPV from a technological point of view is growing, there is less literature on the social dimension of stakeholder perception, particularly in the UAE. This significance of this often overlooked aspect is evident in the low global adoption rate
of BIPV as less than 1% of the total solar PV supply to the global energy mix as at 2016 was from BIPV [53,54]. From a global perspective, the topic of BIPV user perceptions has been recently investigated by several authors mentioned below. The summary of the motivation for such investigations is occasioned by the generally low international adoption rates, which are related in broad terms to the cost, technological, and knowledge aspects [55,56].

Some researchers have studied adoption BIPV in Switzerland [57] and their findings reveal that while different types of technologies do not influence adoption, and the concept of community solar as a BIPV application has a positive impact on the residents’ Willingness to Buy (WTB). Another study focused on strategies used by adopters of residential solar systems in Finland [58]. The study suggests that the motivating factors are trustworthy information and advice from experts, as well as personal interest in environmental and energy matters. In Singapore, various perspectives of BIPV were studied from a policy point of view [59]. The authors surmise that support, investigation, and promotion of BIPV are crucial to increase adoption. The public perception of residential solar in the hot climate of Bahrain has also been investigated [19]. The study focused on Bahraini citizens and found that although many of the participants were interested in the technology, issues such as installation complexity and high capital cost are key limiting factors. Another study on the status of BIPV in the hot climate of Iran investigated the contextual adoption factors [60]. Results of the study suggest that income level, building type, as well as environmental consciousness and knowledge of renewable systems are significant adoption determinants.

BIPV Awareness and Other Adoption Factors

Literature suggests that there are many barriers and drivers that act as factors that influence BIPV adoption. Recently, a qualitative investigation on BIPV diffusion in the UAE identified over 50 factors that influenced stakeholders’ decision to adopt BIPV [61]. The findings from the series of interviews carried out suggested that knowledge and awareness were the most frequently mentioned factors to impact the residents’ decision to adopt BIPV. Building on this previous research, the current study reviewed literature on BIPV adoption studies in other contexts and found out that a simple general environmental awareness positively impacts and encourages residents to adopt innovative building energy technologies [60,62,63].

Specifically reviewing literature on BIPV awareness, its impact has been reported to have a major impact on the adoption of BIPV or other related innovative renewable energy technologies [17,19,21,61]. One study conducted in Switzerland has concluded that awareness is a fundamental issue and a problem that is considered by potential BIPV investors and clients [64]. The lack of sufficient studies in the UAE and GCC region on this topic requires attention, which the current study seeks to explore quantitatively among UAE residents.

Furthermore, some studies infer that resident demographics and interest in BIPV are also considered potential variables, which may or may not impact the level of adoption [19,55,65,66]. It is possible that further investigation may define a connection between BIPV awareness and these factors as suggested in related literature within the region [61]. To establish a further level of novelty, the current study highlights the division of human society into “generations”, which has been significantly used in related literature [67–69]. This grouped classification provides a stratification of society that connects with technological development and architecture [69], and was applied to investigate the interest in understanding factors that may influence BIPV development [70]. This classification provides insight into how stakeholders respond to technological innovations and has been identified in literature as [69]:

- Generation X (1965–1979)
- Generation Y (Born in the 1980s)
- Generation Z (Born after 2000)

There is clearly an overwhelming support in literature to support the critical role that awareness plays in the decision to adopt renewable technologies by stakeholders in the
building industry. Firstly, widespread low levels of awareness and a lack of knowledge was reported among architects, real estate owners, and developers, leading to customer confusion and high project or transaction expenses [64]. Secondly, awareness and information was reported to play a critical role in the residents’ decision or willingness to buy into BIPV [18,19]. Thirdly, BIPV awareness becomes a driver of adoption when widespread promotion is achieved within the public domain [21]. Other studies report that novel façade designs such as BIPV will not significantly diffuse or be accepted due to the simple obstacle of awareness or inexperience, courting both the non-technical and technical stakeholders in this scenario [20]. Finally, the fact that awareness and access to information about various BIPV design considerations such as aesthetics, cost, environmental benefits, policies, and more have been reported as a need, affirms the importance of investigating this aspect further [61].

The underlying assertion made from referred literature is that awareness of BIPV covers multiple aspects. Significant areas that are related to the architectural aspect and design priority of BIPV should thus, also be prioritized due to the fact that they impact client preference, appeal, and decision making [20]. Based on the foregoing, the research design that follows in Section 3 highlights the investigative focus of the current study, the variables that are studied, and the analysis approach.

3. Materials and Methods

This study aims to investigate the level of BIPV awareness and determine if it influences the decision to adopt it by focusing on stakeholders who are residents in the study context. In general, investigations related to the understanding of preferences, human satisfaction, and public perception have been carried out using various methods; sometimes starting from a background with theoretical models [71], other times in line with relevant behavioral theories [72]. In line with similar studies within the region [19,60], and in part, related to seminal work on the diffusion of innovations by Everett Rogers (1993–2004) [16], the research design for this investigation was developed. This study is the first step in a projected series of investigations with broader considerations, statistical focus, demographics, and methodological exploration. The quantitative approach was selected in this instance, due to its ability to reach a wide range of participants across the study area, as well as provide numerical data for further statistical analysis. Additionally, Section 5.3 outlines multiple research pathways as extensions of the current study, highlighting potential areas of interest and practical importance.

The development of the questionnaire used for this study was prepared based on an extensive literature review of international surveys on BIPV referenced in literature, which covered 10 different investigations over a ten-year timespan, from 11 countries and with over 1000 respondents [25]. The questions asked covered multiple aspects of BIPV design and considerations, which were elaborated in Section 2. These were participant demographics, awareness, and interest in BIPV; participants were also asked to select their preferred location and design priority if they were considering a BIPV installation. BIPV alternatives deduced from other practical applications and products available were used to generate the options relating to the building location, such as roof, façade, windows, or others. For the client’s top priority, beauty, cost or performance options were given. To facilitate participant understanding, images were used in the survey to communicate the various types of BIPV that exist using both market-ready products and built projects. Table 1 below, shows a summary of these aspects in line with referenced literature, which were used for the current investigation. The table lists each of these aspects as a variable and the assessment parameters under each level. The questionnaire used for the survey is provided in the Supplementary Materials to this paper.

The questionnaire was prepared in both English and Arabic using Google Forms, and was sent to prospective participants to choose which version they preferred to ensure fuller understanding. To gather as much data as possible across various people groups and Emirates, a convenience sample was used based on a snowballing-peer effect approach,
where one participant can direct the researchers to others; allowing the researcher to engage as many participants as possible. The study was deployed electronically from July to November 2019 by sending out weblinks using WhatsApp, and a total of 289 individuals participated in the survey. Although the sample does not statistically represent the entire UAE population, it serves as a first step towards the provision of public perception as a guide for future investigations. All participant responses were transferred from the Google Forms auto-generated Excel file and then analyzed using SPSS.

For this initial study, the data collected was analyzed using the Pearson’s Chi-square test to identify trends or patterns that may or may not exist in the data, which can be applied in future research [73]. The assumptions and analysis steps taken are similar to other recent studies [74–76]. The Pearson’s Chi-square test for independence was conducted and used to identify if any statistical differences exist between the studied variables using the following formula:

$$\chi^2 = \sum \frac{(o_i - E_i)^2}{E_i}.$$ 

where:

- $\chi^2$ = chi square;
- $o_i$ = observed value; and
- $E_i$ = expected value.

Table 1. Assessment parameters: dependent and independent variables.

| Variables        | Classification | Parameters                              | References |
|------------------|----------------|-----------------------------------------|------------|
| Demographic      | Independent    | Gender, Generations, and Background     | [65,66,77] |
| BIPV Location    | Dependent      | Roof, Wall, Window, and Others          | [19,20,60,65] |
| Design priority  | Dependent      | Aesthetics/Beauty, Performance Cost      | [20,65,78,79] |
| Awareness        | Dependent      | Yes or No                                | [19,21,61] |
| Interest         | Dependent      | Yes or No                                | [19,55,58] |

4. Results

The data collected for this study was divided into four main aspects. Firstly, demographic information of the participants was collated to identify three specific demographic variables: these are gender, generations, and occupational background. Secondly, the awareness of BIPV in the study area was assessed in general, and in line with the study’s objective. In this section, the evaluation of the level of awareness regarding BIPV is presented as a dependent variable in comparison with the three demographic (independent) variables. Thirdly, the level of participants’ interest in BIPV was also evaluated in general terms, and then reviewed across the different demographic groups. Fourthly, the results on the participant’s preference for BIPV location is presented along with the top design priority of each study participant. Results of these last two variables—preference and priority—were also evaluated across the demographic distinctions of the study sample. The results of a secondary level of assessment to compare awareness and interest in general terms, is also presented in this section.

4.1. Demographic Composition of the Participants

Table 2 shows a summary of the demographic composition of the study participants. Regarding gender, females made up 64.4% of the sample while males made up 35.6%. For the generations, the highest percentage was Generation Z at 51.9%, next was Generation Y at 33.6%, and Generation X, at 14.5%. Generally, the younger population was more than the older generations in the study sample. Considering the nature of the topic under investigation, the occupational background of the participants showed that the Architecture and Engineering group made up 25.3% while all “Others” made up 74.7%. This
“Others” group includes participants from Law, IT and Media, Finance and Management, Medical, Science and health-related professions. In this study, this variable was included to allow for a specific focus on the Architecture and Engineering profession due to its close association with BIPV. Future studies will distinguish other professions independently. The results from the comparison of these variables with the participants’ level of awareness are presented below.

Table 2. Demographics of the study participants.

| Demographic Variables (n = 289) | Total |
|-------------------------------|-------|
| Gender                       |       |
| Female                       | 64.4% |
| Male                         | 35.6% |
| Total                        | 100%  |
| Generations                  |       |
| X                             | 14.5% |
| Y                             | 33.6% |
| Z                             | 51.9% |
| Total                        | 100%  |
| Background                   |       |
| Architecture and Engineering | 25.3% |
| Others                       | 74.7% |
| Total                        | 100%  |

4.2. BIPV Awareness

This section presents the responses of the respondents, given the option to assess their pre-knowledge of BIPV. Awareness levels investigated were simply, “Yes I have heard of it”, or “No I have not heard of it”. The results show that 92.4% of the sample are aware of BIPV, while only 7.6% indicated that they do not have any awareness about the technology. For each demographic representing the independent variables, the SPSS analysis using cross-tabulation and Chi-square tests, was conducted to identify if any statistical differences exist in the data. This section highlights these results and shows, that there was no statistical difference found between awareness and any of the demographic variables.

4.2.1. Awareness vs. Gender

The results shown in Table 3 indicate that 65.5% of participants who were aware of BIPV were female while 35.4% were male. Reviewing the female population specifically (n = 186), 94.1% indicated that they are aware of BIPV while for the male (n = 103), 89.3% indicated that they were aware of the technology. Overall, the results show that within the population with no awareness of BIPV (n = 22), 50% were female and 50% were male. Using a degree of freedom of 2, maintained through the analysis, there was, however, no statistical difference comparing the level of the awareness and gender (p = 0.143).

4.2.2. Awareness vs. Generations

Reviewing the level of awareness across the various generations, the overall percentages for those who indicated they are aware of BIPV shows that Generation Z was the highest, at 52.4%, while Generation Y was 33% and Generation X was lowest at 14.6%. Examining the 150 participants from Generation Z, the results show that 93.3% indicated that they have awareness about BIPV. Table 3 shows that although the Generation Z made up the highest percentage of those who indicated that they are aware of BIPV, this group also had the highest overall lack of awareness percentage which was 45.5% of the total, but only 6.7% of this group. The table further shows, however, the Chi-square results which indicate that there was no statistical difference comparing the level of awareness and the generation groups (p = 0.746).
Table 3. Awareness versus Demographics of the study participants.

| Demographic Variables | Awareness (Yes; n = 267) | Awareness (No; n = 22) | p-Value (Awareness/Demographics) |
|-----------------------|---------------------------|------------------------|-------------------------------|
| Gender                |                           |                        |                               |
| Female                | 65.5%                     | 50.0%                  | 0.143                         |
| Male                  | 34.5%                     | 50.0%                  |                               |
| Total                 | 100%                      | 100%                   |                               |
| Generations           |                           |                        |                               |
| X                     | 14.6%                     | 13.6%                  | 0.746                         |
| Y                     | 33%                       | 40.9%                  |                               |
| Z                     | 52.4%                     | 45.5%                  |                               |
| Total                 | 100%                      | 100%                   |                               |
| Background            |                           |                        |                               |
| Architecture and Engineering | 24.7% | 31.8%                  | 0.461                         |
| Others                | 75.3%                     | 68.2%                  |                               |
| Total                 | 100%                      | 100%                   |                               |

4.2.3. Awareness vs. Background

The Architecture and Engineering group made up 24.7% of those who indicated that they are aware of BIPV, and the “Others” group made up 75.3%. For each group, 90.4% and 93.1%, respectively, made up those who have awareness of BIPV. Interestingly, for those who lack awareness of BIPV, the percentages were 31.8% and 68.2% respectively. This comparatively suggests more people in the Architecture and Engineering group lack BIPV awareness, and this is discussed further in Section 5. As shown in Table 2, there was, however, also no statistical difference comparing the level of the awareness between the participants’ background (p = 0.461).

4.3. Interest in BIPV

Similar to Section 4.2, this section presents the responses of the respondents, given the option to assess their interest in BIPV. Investigated options were simply, “I like it”, and “I do not like it/I do not know if I like it”. These two options align with two stakeholder characteristics, “interested” and “disinterested/uncertain”. The results show that 88.9% of the sample are interested in BIPV, only 11.1% indicated that they are not interested or do not know whether they are interested or not. A further statistical analysis comparing these interest levels with each demographic representing the independent variables was conducted to identify any statistical differences in the data. This section highlights the results and shows that there was no statistical difference found between interest and any of the demographic variables, except gender. The results of the Chi-square test for interest versus demographics are shown in Table 4.

4.3.1. Interest vs. Gender

The results show that 67.3% of participants who had interest in BIPV were female, while 32.7% were male. Reviewing the female population specifically (n = 186), 93% indicated that they are interested in BIPV while for the male (n = 103), 81.6% indicated that they are interested in the technology. Overall, the results show that that for those uninterested or uncertain, females made up 40.6% and males, 59.4%. Using a degree of freedom of 2, maintained through the analysis, the results showed that there is a strong statistical difference between interest in BIPV and gender (p = 0.003), and indicates that female respondents have a greater tendency to be interested in BIPV than male participants.
Table 4. Interest vs. Demographics of study participants.

| Demographic Variables | Interest (I Like It; \(n = 257\)) | Interest (I Don’t Like It/I Don’t Know; \(n = 32\)) | \(p\)-Value (Interest/Demographics) |
|-----------------------|-----------------------------------|-----------------------------------------------|----------------------------------|
| Gender                |                                   |                                               |                                  |
| Female                | 67.3%                            | 50.0%                                         | 0.003                            |
| Male                  | 32.7%                            | 50.0%                                         |                                  |
| Total                 | 100%                             | 100%                                          |                                  |
| Generations           |                                   |                                               |                                  |
| X                     | 14.8%                            | 12.5%                                         | 0.666                            |
| Y                     | 32.7%                            | 40.6%                                         |                                  |
| Z                     | 52.5%                            | 46.9%                                         |                                  |
| Total                 | 100%                             | 100%                                          |                                  |
| Background            |                                   |                                               |                                  |
| Architecture and Engineering | 25.3%                       | 25.0                                          | 0.971                            |
| Others                | 74.7%                            | 75.0%                                         |                                  |
| Total                 | 100%                             | 100%                                          |                                  |

4.3.2. Interest vs. Generations

Reviewing the level of interest across the generations, the percentages for those who indicated they are interested in BIPV shows that the Generation Z was highest, at 52.5%, Generation Y at 32.7%, and Generation X was lowest, at 14.8%. Focusing on the group (Generation Z) that made up the largest percentage of those who are interested in BIPV, showed that 90% of the group was interested. For those uninterested or uncertain, the percentages were 12.5%, 40.6%, and 46.9% for Generation X, Y, and Z, respectively. Table 4 shows the details of these percentage differences. The Chi-square results, however, indicate that there was no statistical difference comparing the level of interest between the generation groups \((p = 0.666)\).

4.3.3. Interest vs. Background

The Architecture and Engineering group made up 25.3% of those who indicated that they are interested in BIPV while the “Others” group made up 74.7%. For these two groups, 89% of the each, individually, were interested in BIPV. For those who lack interest or uncertain of BIPV, the percentages were 25% and 75%, respectively. The Chi-square test results indicate that there was no statistical difference comparing the level of interest and the participant’s background \((p = 0.971)\). All other comparative values are shown in Table 4 below.

4.4. Awareness vs. Interest

In view of the results obtained when awareness and interest were separately compared with the demographic (independent) variables, both dependent variables were compared statistically. The results suggest that 92.5% of those who are “aware of BIPV” \((n = 267)\) were also interested in the technology; similarly, 55% of those who are “not aware of BIPV” \((n = 22)\) indicated a lack of interest in the technology (Figure 3). A Chi-square test to compare awareness and interest was conducted using the aforementioned statistical considerations, with a degree of freedom of 2. The results showed a significant statistical difference between awareness and interest in BIPV \((p = 0.000)\). This indicates that those who are aware have a greater tendency to be interested but those who are not aware of the technology have a greater likelihood to be uninterested or uncertain of their interest.
who are aware have a greater tendency to be interested but those who are not aware of the technology have a greater likelihood to be uninterested or uncertain of their interest.

4.5. Preference: Location on the Building

Connecting the objective of this research with practical BIPV applications, the survey participants were asked to identify which location in the building they would prefer to locate BIPV. The options given were the roof, wall, and windows. A fourth option, “Others,” was added to loosely group non-critical building aspects/areas ranging from balconies to carports. The results show that 83.6% prefer BIPV on the roof, while for the window, wall, and others, the percentage of participants were 5.4%, 4.3%, and 6.8% as show in Figure 4, indicating the frequency distribution of the participants’ responses to preferred BIPV location. This indicates an overwhelming preference for roof-integrated BIPV, which is discussed later in Section 5.

Chi-square tests were conducted to compare awareness, interest, and demographic variables with the participant responses on preferred BIPV Location. The results, revealed that none of the variables had an impact on the selected location as there was no statistical difference between each of these, compared with the top BIPV location selected by the participants of the study. Thus, regardless of the individual’s gender, generation, or background, awareness or interest, the preferred location for BIPV in this sample was on the roof.
4.6. Priority: Design Considerations

As a second criterion to evaluate design considerations, the priority requirement of each participant for a BIPV installation was also investigated. Three distinct considerations relating to performance, aesthetics/beauty, and cost were listed and the top priority selected was collated. The results show that almost 50% consider performance as the top priority, 29% selected beauty, and 21% selected cost (Figure 5). This frequency distribution of the participants’ responses \((n = 283)\) indicates that while performance ranks first, beauty and cost are ranked more closely but beauty ranks higher than cost.

![Figure 5. Top BIPV priority of the study participants.](image)

Chi-square tests were also conducted to compare awareness, interest, and demographic variables with the participant responses on top BIPV design priority. The results indicate that while there was no statistical difference between awareness and demographics, there was a statistical difference between design priority and interest \((p = 0.028)\). These findings indicate that only interest could be considered to have a direct impact on the participant’s top BIPV priority. Reviewing the cross-tabulation results, the analysis suggests that for those who are interested in BIPV, the top priority is performance. Figure 6 below shows this and suggests that for all participants who indicated that they were not interested or uncertain of BIPV, they are motivated mostly by beauty or performance. In the present study, cost was found to be the least motivating or influencing factor for both levels of interest. Comparing interested and not interested parties, the percentage of those concerned about cost was significantly higher for those not interested as the values were 22.6% to 9.7%. Moreover, comparing beauty, the comparative figures were 26.6% to 48.4% for interested and uninterested, respectively.

For all other variables, demographic and awareness, there was no statistical difference between each of these when compared with the top BIPV design priority selected by study participants. Thus, the individual’s gender, generation, or background, or awareness, do not impact the top priority choice of performance as the main BIPV design consideration.
show that over 90% of each group indicated that they were aware of BIPV, with an average provided further insight into the data. For example, for the generation variable, the results different. Moreover, in this study, the younger residents who fall into Generation Z, who significantly higher level of awareness. This indicates that age is not a determining factor generally tend to have more interest and access to online media, did not show a and does not influence the level of BIPV awareness. These results are not unexpected for 5.1. Demographic Variables in the Context of BIPV Awareness and Interest

The study findings revealed that awareness of BIPV was found to be significantly related to interest in BIPV; thus, within the sample, the greater the level of BIPV awareness, the higher the tendency for the individual to also be interested in the technology. This finding is in line with some other studies that also assert that interest is one of the strongest motivating factors for people to accept BIPV [55,80]. The findings, however, also indicate that none of the demographic variables investigated has an influence on the level of awareness. The highest comparative level of awareness was found among females (66.4%), those in Generation Z (52.4%), and participants from a non-Architecture and Engineering background (75.3%). Similarly, the highest comparative levels of interest were found among females (67.3%), Generation Z (52.5%), and participants without an Architecture and Engineering background (74.7%). Although the results indicated that there was no statistical difference between the demographic variables and awareness, but some statistical difference related to interest, a further review presents some interesting facts.

5. Discussion and Further Research

The study revealed that although gender is not statistically related to BIPV awareness, the findings show that interest in BIPV is statistically related to gender. The results show that both males and females are strongly aware of BIPV, with the percentage of awareness within each group at 89.3% and 94.1%, respectively. Moreover, though the level of interest in BIPV is high, the percentage of interest in each group was at 81.8% for male, and 93% for female. Thus, reviewing the gender demographic of this study, females are more aware and

Figure 6. Interest vs. Top Design Priority. Chi-square test was performed to test the difference between the columns. The $p$-value = 0.049.

### 5.1. Demographic Variables in the Context of BIPV Awareness and Interest

Comparing awareness with the demographic distinction of the respondents has provided further insight into the data. For example, for the generation variable, the results show that over 90% of each group indicated that they were aware of BIPV, with an average percentage calculated at 92.3%. Interestingly, the percentage of participants across all the groups of this variable, who indicated that they are aware of BIPV was not widely different. Moreover, in this study, the younger residents who fall into Generation Z, who generally tend to have more interest and access to online media, did not show a significantly higher level of awareness. This indicates that age is not a determining factor and does not influence the level of BIPV awareness. These results are not unexpected for one simple reason: with the level of information available on sustainability-related content, renewable energy and innovation, in both online and print media, residents of all ages can easily access information on BIPV. Interestingly, the group with the highest level of awareness, Generation Z (52.4%) also had the highest percentage level of interest (46.9%), confirming the initial statistical difference between awareness and interest.

The study revealed that although gender is not statistically related to BIPV awareness, the findings show that interest in BIPV is statistically related to gender. The results show that both males and females are strongly aware of BIPV, with the percentage of awareness within each group at 89.3% and 94.1%, respectively. Moreover, though the level of interest in BIPV is high, the percentage of interest in each group was at 81.8% for male, and 93% for female. Thus, reviewing the gender demographic of this study, females are more aware and...
interested in BIPV than males. The ratio and total number of males to female participants in this study were random but resulted in more females than males. While this may or may not have defined these results, further research is required, probably in a controlled study with an equal number for each gender to explain these results further.

For the “background” variable, both groups had over 90% of respondents indicating that they were aware of BIPV, with the average percentage at 91.7%. However, similar to the range of the numbers for the gender variable, the range here gives added insight into this finding. The number of participants from Architecture and Engineering was 73, which was 25.3% of total participants and made up 24.7% of those who had an awareness of BIPV. However, this group had a slightly greater ratio comparing the trend from those aware to those not aware of BIPV, which was 31.8% of the total. For the Other group, the awareness percentage was 75.3%, and lack of awareness of the total was 68.2%. The implication is that although the overall percentage of those with awareness in each group was high, the Architecture and Engineering may proportionally have more individuals who do not have awareness about BIPV. This is unexpected as BIPV is principally a building and engineering component integrated into the architectural fabric of the building; thus, it relates more to participants with this background. However, the results show that for the level of interest, the ratios remained the same with no similar comparative difference in the groups between those interested and those not interested. This is because the same ratio of Architecture and Engineering participants was found for the total sample size (24.7%), interest (25.3%), and lack of interest (25%).

5.2. Client Design Preference and Priorities

The results of the analysis showed that there was no statistical difference between awareness and the design preference with a specific focus on “BIPV Location”, either on the roof, wall, or windows or anywhere else. The results also suggest that there was also no statistical difference between awareness and design priorities with a specific focus on beauty, cost, and performance. There were, however, certain broad indications from the results, which warrant a secondary review.

Firstly, regardless of the study participant’s gender, generation, background, awareness or interest, the preferred location for BIPV in this sample was on the roof where the solar panels are more concealed. This overwhelming preference in this study was unexpected considering that the UAE is generally known for its’ interest in innovation and iconic buildings. Several reasons may explain this finding. From a theoretical point of view, innovations diffuse better when there are examples that people can “observe” and “try” by themselves. This assertion was put forward in the diffusion of innovation theory and aligns with defined constructs of “observability” and “trialability” of an innovation [16].

In line with another study on this subject, it was reported that there are few examples of BIPV in the UAE and, thus, knowledge is limited [61]. Consequently, it is possible at this point, to distinguish between a general awareness of BIPV, and an in-depth, informed knowledge about the various types, design options, as well as its’ strategic and multifunctional benefits. Another reason for this inclination towards roof-integrated BIPV may be a belief that BIPV does not integrate well with the building façade. This is because some other studies assert that the limited information, misinformation, and skepticism have limited BIPV adoption [55,59,61]. Also, the current study suggests that only 30% of the participants actually consider, or are inclined to consider beauty to be the top BIPV priority or motivator.

Secondly, it is important to underscore the fact that the 88.9% of the study participants indicated that they are interested in BIPV, 50% are primarily interested in performance, and 82.6% indicated that they prefer BIPV on the roof. Moreover, since the study identified a statistical difference between interest and design priority, an inference may be made to suggest that the driving motivation for a greater percentage of the study participants is to have BIPV on the roof where it may perform better. Although one may conclude that this is a cost-driven idea, only 21% of the participants actually consider cost to be
their top BIPV design priority. It is, therefore, not unlikely that there could be another reason, probably a subconscious, technical justification for an overwhelming preference for the BIPV roof option. Specifically, this might be a belief that BIPV is primarily installed for energy generation, and the assumption that roof is the logical choice for maximum energy yield.

To review these last two assertions and assumptions further, several studies have investigated energy output from the roof and confirm that in the UAE, the optimal tilt angle could match the latitudinal location, which is about 24 degrees in the capital city of Abu Dhabi [81]. However, this idea that BIPV is primarily for energy, and the assumption that the roof always produces more energy than the façade is debatable. Firstly, to succinctly summarize existing literature, BIPV may be driven by, and, thus, installed for multiple reasons beyond maximum energy generation [61]. These include cooperate green image and prestige [82], social peer influence [17], design benefits or aesthetic appeal [22,25,26,61,83,84], tax exemption [59], benefits in line with green rating systems [85], or energy savings [23,85]. Consequently, the roof may or may not be the single best location for any of these stated reasons. Secondly, while the roof may traditionally be the inclined surface of the envelope, and easier to integrate a solar panel at the optimal tilt angle, other areas such as shading devices can also be inclined to serve as a possible location for BIPV [22,25,83].

There are also two more reasons suggested in the literature why the roof may not be the best choice for BIPV. Firstly, some building clients may wish to use the roof for other functions such as a swimming pool, and secondly, there may be a challenge to locate BIPV on the roof due to space constraints for outdoor HVAC units [61,62]. In general, several researchers agree that with reference to BIPV types and products, there is a lack of awareness among both clients and consultants [53,64,72]. Additionally, therefore, the need to educate construction workers, already confirmed in literature, becomes an important consideration in the light of these findings [74], as well as the development of educational tools for specifically communicating BIPV benefits to all stakeholders [86]. Previous research also shows that UAE residents tend to have a high interest in flexibility to adapt their houses to changing trends, needs, or preferences [87]. Considering, therefore, that BIPV has a high potential for unique and flexible customization options for building facades [25], insufficient communication of these design options may well be the bane of the current findings. In line with this, Kosorić et al. recently affirmed that the knowledge-awareness-information trio is one of several key components needed in the design of a framework to promote PV/BIPV implementation in the built environment [88].

5.3. Further Research

This study has presented certain initial considerations for future investigations, which are elaborated upon in this section. Practical application of the findings, methodological approaches, and specific technological investigations based on participant responses are highlighted here for future work. The limitations from a statistical point of view as well as the sample size, and the extent to which the results can be generalized, have also been noted. In general, the results show that in the current study, BIPV awareness and interest are both high, but the facts reveal that adoption and diffusion is low in the UAE. To facilitate technological diffusion or renewable building technologies like BIPV, future research should investigate a socio-technological approach. The use of full-scale prototypes and living labs that showcase various design solutions can be used to engage residents and create a platform for innovative marketing or business strategies (social dimension). They can also be used to provide other technical and non-technical information about BIPV (technological dimension). These dimensions can be explored individually or collaboratively by research institutions and corporate organizations.

Speaking specifically on the results, extra focus is needed on the preferred location of the BIPV in the roof since it was the most preferred location by the participants as discussed in Section 5.2. Further study is required to answer the question of “why” this
result was found, and explore what current factors may be the cause, or may be needed to change the status quo. Already, a few reasons have been suggested, which relate to the level of knowledge, misconceptions, and professional experience. These variables can be explored further to generalize the real cause of the current scenario. Thus, other researchers may wish to conduct a qualitative or mixed-method investigation to probe opinions and resident bias in various locations or among different demographics. As shown in a previous study [61], this approach should be effective and can be extended to determine how future trends such as a post-pandemic world and new energy policies within a study context may be primary influencing factors.

Overall, the study found out that there is a high level of awareness of BIPV within the sample as only 7%, 22 out of 289 respondents, said they were not aware of BIPV as a building technology. However, a drive through any of the major cities in the UAE shows that there are very few examples of BIPV within the metropolis. This raises the question of “acceptability” and “diffusion” beyond the discussion of awareness and interest. Comparing awareness of the technology in relation to its acceptability as a building component, there seems to be a missing link among both residential and commercial clients in the country. Several government policies encourage the use of renewable and innovation technologies such the Abu Dhabi Solar Rooftop program, the Estidama Pearl Building Rating System, and the Dubai Green Building Rating System. Notwithstanding, the wide-scale adoption of BIPV in the UAE requires further attention as the technology seems to not be commonly used. While a previous study has initiated the discussion in this regard [61], there are other reasons beyond the scope of the current study. Other researchers may wish to, therefore, investigate the challenges faced with the implementation of these polices among specific demographics. In other regions, where such renewable energy incentives and policies have been suspended, studies that evaluate a comparison and development of adaptable incentives, in line with the UAE scenario, may also be investigated.

The study findings suggest that sustainability is a topic which a larger portion of the population is likely to be aware of. In general, this might be because the UAE government has strongly emphasized the concept of sustainability, and clean energy in the country. The current UAE 2050 Energy strategy, for example, is supported by a $700 billion investment and poised to ensure that 50% of energy comes for clean energy by 2050 UAE Government, 2020 [11]. However, the effectiveness of these policies may warrant further research and development into effective policy mechanisms and information dissemination to connect with residents because this study has shown that interest may be a stronger predictor of acceptance than awareness. Further research on strategies for motivating interest, addressing negative concerns, and facilitating the customer’s experience may well be needed in the current dispensation.

As mentioned in the discussion, the study focused on collecting data across various groups and residents of the UAE. While this provided data from different perspectives, the number of participants in various groups was not equal. Other researchers may wish to carry out a comparative study to investigate these findings. The current study has investigated BIPV as an example of innovative energy technologies for the built environment in relation to promoting environmental sustainability. Other technologies, both hardware and software-related, may also be investigated, focusing on specific professionals to investigate awareness and the flexibility of use in light of current practices in the building industry. This may require direct interactions with stakeholders whose daily practice requires the use of said technologies.

6. Conclusions

Using results from the conducted questionnaire survey of UAE residents’ awareness of BIPV as an example of renewable energy building technologies, this study has examined the degree of awareness among various demographics. The study has also highlighted the role of interest as a motivating factor; with additional focus on its relationship with awareness and demographics, in line with design preferences and priorities of building clients.
This study fits into an overall inquiry to track innovation diffusion in the GCC region and serves as the first phase of the investigation. Future work is planned to carry out a detailed study on other aspects, elaborated on in the previous section. However, the current study contributes to the current global shift towards renewable energy technology with a focus on decentralized energy technologies such as BIPV. As the topic of sustainable, renewable, and innovative energy technologies for buildings ceases to be considered as secondary or unimportant or trivial, both developed and developing nations are engaging in the goal of collective accountability. This study has engaged UAE residents in the bid to investigate their level of awareness of technology, which promotes the call to sustainability. While the study shows that the level of awareness is high, the study also suggests that there is a need to motivate interest and acceptability in residents, which can ultimately promote diffusion and the target of achieving a sustainable future.

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