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AESTHETIC EFFECTS AND ENERGY GENERATION POTENTIALS OF ROOF MOUNTED PHOTOVOLTAIC (PV) PANELS ON A HOSTEL BUILDING: A CORRELATION STUDY

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Abstract

The placement of photovoltaic panels on roof may affect the aesthetic quality of the building. The study sought to establish any correlation between energy generation potentials of PV panels on roof and aesthetic quality of a building. The experimental research design is a study by simulation of a hostel building elevation in Modibbo Adama University of Technology, Yola. Twelve simulated elevations with different arrangement and area coverage of roof solar photovoltaic panels were produced, and ranked in order of aesthetic appeals by 140 respondents in four groups. Frequencies and Spearman's Rank Order correlation coefficient were employed to analyze data. Results indicated that the aesthetic appeals of the elevations varied, but not consistently with coverage area of PV panels on roof: the elevation with PV of 21% roof coverage (7th in coverage area) was rated most aesthetically appealing; that with PV of 6% roof coverage (the lowest) rated least appealing. Aesthetic effect was not appreciably correlated with PV panels' coverage on roof. It was concluded by recommending that PV panels be arranged on roof, guided by the aesthetic principles of composition, in order to optimize (and not maximize) energy generation.

Key Words: *Aesthetic effect, Photovoltaic panels, Building roof, Energy generation, correlation*

Introduction

The meaning, theory and import of aesthetics have been subjects of discourse among architectural researchers and authors. Aesthetics has been defined as the study or theory of beauty and the psychological responses to it (Healthy Spaces and Places, HSP, 2009). Earlier, Philipp (2001) had described it as that having an appreciation of the sense of beauty in accordance with the principles of good taste. The aesthetic response, according to Philipp (op cit), involves emotions that include being 'uplifted', 'moved', 'exhilarated', and 'entranced'; 'aesthetic' thus implying the presence of qualities that are pleasing to the senses.

Morgan (1960) and Cho (2011) enunciated that beauty (*venustas*) or aesthetics is one of the essential qualities of Architecture, along with firmness (*firmitas*) and utility (*utilitas*). While

Arjum (2012) described aesthetics as what people see and admire, Pazooki (2011) viewed it from architectural perspective as the appreciation of shapes and structures of the environment. According to Arjum (2012), aesthetic expression is a product of coherent, controlled and formal composition of the various architectural elements, which also fulfils the functional and structural requirements of the building. In an architectural design, line, shape, colour and texture are combined to make formal compositions, creating pattern, rhythm, symmetry, balance, contrast, proportion/scale, theme, and unity (Vinchu *et al.,* 2017; Arjun, 2012; Lorenz, Andres and Frank, 2017; Pazooki, 2011). A design exhibits coherence and unity in variety when various elements are tied together in a logical and systematic manner that adds interest to the design (The Center for the Study of Art and Architecture, CSAA, 2002). The perception of unity in designs is believed to align with the Gestalt principles of Closure, Aesthetic Consistency, Good Continuation, Proximity and Similarity, as espoused in Lidwell *et al.* (2003). The CSAA (2002) further elucidated that rhythmic patterns create dynamism and liveliness, and add visual excitement to a form. Balance is achieved symmetrically or asymmetrically in buildings when a sense of equal, visual weight on either side of a centre line drawn through the facade is maintained. Contrast, used to add visual variety to designs, exists when two adjacent parts are different from each other. Proportion is the relationship between two things of different sizes, and the same as scale with reference to buildings. Lidwell *et al.* (2003) reported the preference for aesthetic forms conforming to a ratio within the elements of the form approximating the golden proportion (or golden ratio $\doteq 0.618$).

Authors (Philipp, 2001; HSP, 2009) espoused the impact of the aesthetic quality of the built environment on the overall experience and use of the area. Philipp (2001) posits that aesthetic appreciation gives personal pleasure, encourage social interaction in public places, and stimulate personal creative endeavour, all of which in turn benefit health. He further submits that the environment with high aesthetic quality provides pleasurable places to be for contemplation, personal reflection, enjoyment, relaxation and replenishing the soul. The attractiveness of an urban environment has been associated with the overall experience and use of the area. According to HSP (2009), the relationship between people, their spatial setting and increased physical activity can be achieved by creating attractive and welcoming streets with buildings that frame public spaces and form a distinct street frontage creating a pleasant pedestrian edge and human scale.

Researchers (Colleen, 2006; Wassef, 2014) indicate that roofs serve as a major platform and best position for mounting photovoltaic (PV) panels to generate renewable energy for use in buildings. The Nigerian Energy Support Program, NESP (2014) has also noted that renewable energy from PV panels could satisfy between 18 to 100% of annual electricity demand by buildings in Nigeria. Therefore, there is a tendency to mount PV panels on roofs at appropriate tilt angle and orientation in order to maximize energy generation (Wassef, 2014). This has implication not only on the structural integrity, but also on the aesthetic quality of the roof and the building. Bonomo (2016) had argued that the public acceptance of solar technology in construction, including PV panels on roofs can only be won by convincing visual appeals. The PV panel unit size and proportion, the number, composition and placement of units on roof, and the color contrast between panels and roof are some of the factors that may alter the aesthetic quality of the roof and building. The proportional relationship of the PV coverage with windows, doors and other elements of the building also affect aesthetics (Yannis, 2015; Probst and Roecker, 2012; Arjun 2012). In addition, a study (Shukla *et al.*, 2015) shows that the visual appearance of a solar panels is dependent in part by its arrangement pattern, colour, and framing. However, a contrary position (Heinstein *et al.*, 2013) suggests that total coverage of PV panels on roof is more aesthetically sound and more energy generating than partial coverage.

Oyedepo *et al.* (2015) revealed that 68% of energy consumption in student hostels is on lighting and cooling by air circulation equipment (fans). A preliminary survey in the study area also identified computers, in addition to the lighting and cooling equipment as appliances consuming energy in student hostels. In academic environments where studies occur day and night, and uninterrupted power supply from the national grid cannot be guaranteed, renewable energy generation from PV panels mounted on hostel building roofs becomes attractive option. However, studies (Deloitte, 2016; Faiers, 2006) have suggested that the visual appearance is important, and a limiting factor to the adoption of solar power. Deloitte (2016) reported that 17% of respondents were not interested in installing solar panels because they found the panels were not attractive. The issue, therefore, is not whether to generate energy from roof-mounted PV panels, the question is, what is the aesthetic effect of composition, placement, and coverage of PV panels on roof? The main objective of this study is to establish any correlation between energy generation potentials from roof and aesthetics of the building.

Methodology

The experimental research design is a study by simulation of a hostel building elevation in Modibbo Adama University of Technology, Yola. The hostel is the most visible and closest to the Department of Architecture among others in the University, and the simulated elevation is opposite the nearest main road. Twelve elevations, labelled G, H, K, L, M, N, P, Q, R, S, T and U with different arrangement and area coverage of roof solar photovoltaic panels were produced on one page of an A4-size paper (as shown in Figure 1). The arrangement of the panels on the roof in each case was guided by known aesthetic principles of balance and symmetry in relation to the other building elements. Contrast, another principle of aesthetics, informed the choice of colour of the panels. An instruction was placed before the elevations for respondents to kindly rank them in order of aesthetic appeal by indicating positions as 1 or 1st (most appealing), 2 or 2nd (second most appealing)………12 or 12th (least appealing). Copies of this instrument were produced and administered to four groups of respondents including Architecture lecturers and practitioners (ALP), Master of Technology in Architecture students (MTAS), Bachelor of Technology in Architecture students (BTA4 and BTA5) in 400-level and 500-

level classes. Soft copies were also posted to 'whatsapp chat fora' of architecture professionals to which one of the authors belongs. Forty-nine respondents of the BTA4, 51 of the BTA5 and 23 of the MTAS found in their respective classes, participated and returned their responses. Of the respondents in the ALP group, 17 returned responses in hard copies while 8 returned soft copies.

Mean and frequency of rankings within and across the respondent groups were computed to determine overall order of aesthetic appeal of the elevations. The Spearman's rank order correlation coefficient was employed to determine any correlation between aesthetic appeal and area of coverage of solar photovoltaic panels on roof.

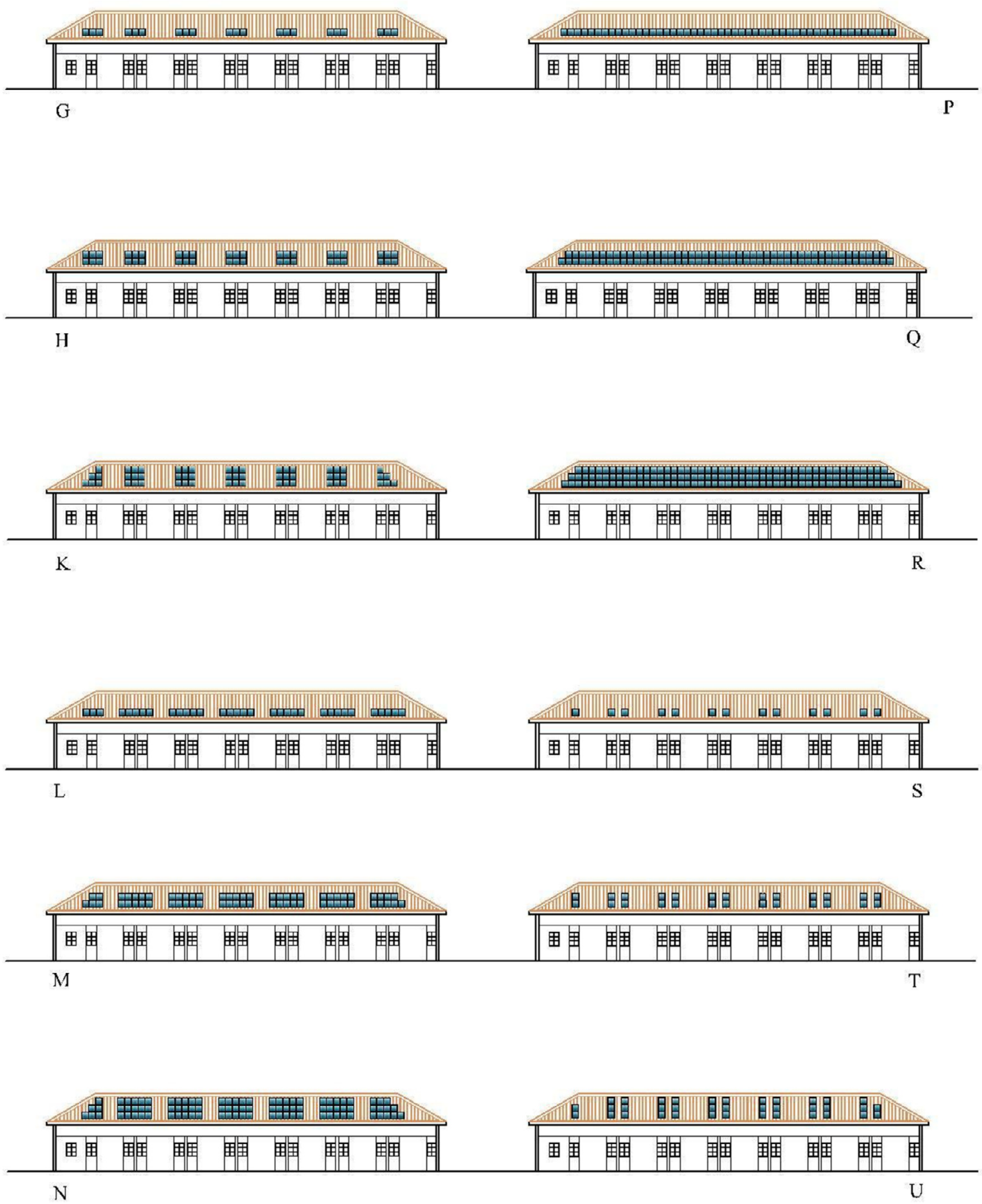

Fig. 1: The study elevations

Table 1: Study Elevations Roof and Solar Photovoltaic Panel (SPV) coverage

	G	H	K	L	M	N	P	Q	R	S	T	U
Roof area (m^2)	142	142	142	142	142	142	142	142	142	142	142	142
SPV area (m^2)	15	30	41	24	46	68	35	69	102	09	19	27
SPV number	21	42	57	33	64	94	49	96	141	13	26	37
SPV area %	11	21	29	17	32	47	25	48	71	06	13	19
SPV coverage rank	11th	7th	5th	9th	4th	3rd	6th	2nd	1st	12th	10th	8th

Results

The solar photovoltaic panel coverage and ranking on roof of the study elevations are revealed in Table1. Table 2 shows the frequencies of ranking of the elevations by the 400-level Bachelor of Technology in Architecture student respondents; those by their 500-level counterparts and the Master of Technology student respondents are shown in Table 3 and Table 4 respectively. The frequencies of ranking of the elevations by the Architecture lecturer and practitioner respondents are indicated in Figure 5. The weighted mean of the aesthetic ranking of the elevations by each of the respondent groups on one hand, and by all the respondents on the other hand are indicated in Table 6. The Spearman's rank order correlation coefficient of the relationship between roof solar photovoltaic panel coverage and Aesthetic rankings by the respondents are captured in Table 7.

The surface area of the roof plane of building under study is $142m^2$, while the solar photovoltaic panels (SPV) occupy areas ranging from six percent ($9m^2$) to 71 percent ($102m^2$) of the roof. The elevations with these SPV panel coverage fringes are labelled S and R, and ranked 12th and 1st in coverage respectively. Close to the fringes are G ($15m^2$ or 11%) and T ($19m^2$ or 13%) ranked 11th and 10th in low SPV panel coverage, and Q ($69m^2$ or 48%) and N ($68m^2$ or 47%) in high coverage (Table 1).

The modal frequency of ranking of the elevations as the most appealing (1st) varies among the respondent groups as 10 for G (by BTA4), 17 for H (by BTA5), seven for R (by MTAS) and seven for K (by ALP). The modal frequency of ranking of the elevations as the least appealing (12th) also varies among the respondent groups as 18 for R (by BTA4), 18 for S (by BTA5), seven for R (by MTAS) and nine for R and S (by ALP). The elevations were ranked as most appealing, second most appealing or third most appealing (1st, 2nd or 3rd) with modal frequency varying among the respondent groups as 19 for H (by BTA4), 25 for H (by BTA5), 10 for G (by MTAS) and 11 for K (by ALP) (Tables 2, 3 4 and 5).

The weighted mean of the aesthetic appeal ranking of the elevations also varies among the respondents ranging from 4.45 for H to 7.51 for U (as ranked by BTA4), 4.06 for H to 8.37 for S (by BTA5), 4.78 for H to 7.78 for P (by MTAS) and 4.36 for K to 8.28 for S (by ALP). The grand weighted mean of ranking of the aesthetic appeal of the elevations by all the respondents varies from 4.40 for H to 7.67 for S (Table 6). The weights of difference between the mean ranking of the most appealing and the least appealing elevations by the respondent groups BTA4, BTA5, MTAS and ALP are 3.06, 4.31, 3.00 and 3.92 respectively. For all respondents the weight of difference between the grand mean ranking of the most appealing and the least appealing elevations is 3.27.

There is a negative correlation coefficient of 0.08 (which is considered negligible) between solar photovoltaic panel coverage and the aesthetic appeal of the roof as ranked by BTA4. A moderate positive correlation coefficient of 0.44 was found between solar photovoltaic panel coverage and the aesthetic appeal of the roof as ranked by BTA5. There is also a negative correlation coefficient of 0.39 (considered low) from the ranking by MTAS, and a low correlation coefficient of 0.22 from the ranking by APL respondents. In the aggregate, a negligible correlation coefficient of 0.06 was found between solar photovoltaic panel coverage and the aesthetic appeal of the roof.

Table 2: BTA4 elevation ranking frequencies

	G	H	K	L	M	N	P	Q	R	S	T	U
1st	10	07	08	08	01	07	03	00	09	03	04	01
2nd	10	03	03	04	05	03	02	10	04	08	03	02
3rd	05	09	04	04	03	01	03	07	04	03	02	02
4th	02	07	03	07	06	02	06	03	01	04	04	03
5th	01	08	02	07	03	01	08	02	05	02	05	03
6th	04	05	04	04	07	02	04	04	02	03	06	01
7th	03	03	05	01	05	04	04	03	00	04	01	13
8th	05	01	07	03	05	03	04	01	03	04	05	06
9th	02	02	03	08	05	03	06	03	01	01	06	06
10th	03	01	02	02	04	08	01	08	01	04	08	04
11th	04	00	03	01	04	07	07	07	01	04	05	04
12th	00	02	04	00	01	07	01	01	18	09	01	04
1st/2nd/3rd	15	19	15	16	09	11	08	08	17	14	09	05
Rank	4th	1st	4th	3rd	8th	7th	10th	10th	2nd	6th	8th	12th

Table 3: BTA5 elevation ranking frequencies

	G	H	K	L	M	N	P	Q	R	S	T	U
1^{st}	05	17	03	02	01	02	01	02	13	04	02	01
2^{nd}	09	00	05	02	04	05	01	15	04	03	07	01
3^{rd}	02	08	05	10	05	09	04	03	06	03	01	02
4^{th}	06	05	00	02	15	03	06	03	03	01	04	03
5^{th}	03	04	07	07	05	04	04	04	03	02	03	03
6^{th}	03	06	07	08	02	06	05	04	00	01	02	06
7^{th}	05	06	01	03	05	05	05	03	02	04	04	07
8^{th}	02	01	03	05	08	02	08	03	03	03	04	07
9^{th}	03	00	06	04	05	02	05	04	02	05	07	07
10^{th}	05	04	04	05	04	01	05	04	01	02	08	07
11^{th}	08	00	04	03	01	07	02	06	02	05	09	03
12^{th}	00	00	06	00	01	05	05	00	12	18	00	04
$1^{st}/2^{nd}/3^{rd}$	*16*	*25*	*13*	*14*	*10*	*16*	*06*	*20*	*23*	*10*	*10*	*05*
Rank	*4^{th}*	*1^{st}*	*7^{th}*	*6^{th}*	*8^{th}*	*4^{th}*	*11^{th}*	*3^{rd}*	*2^{nd}*	*8^{th}*	*8^{th}*	*12^{th}*

Table 4: MTAS elevation ranking frequencies

	G	H	K	L	M	N	P	Q	R	S	T	U
1st	06	03	03	02	02	00	03	01	07	01	03	01
2nd	04	04	01	02	02	01	00	05	00	02	03	03
3rd	00	02	04	03	01	03	02	00	01	02	02	01
4th	01	02	01	04	01	03	01	02	02	01	01	02
5th	01	02	03	01	04	01	00	02	01	03	01	03
6th	02	03	01	03	03	01	00	02	00	01	03	03
7th	02	04	02	01	02	02	00	00	02	02	01	03
8th	00	01	00	02	05	02	05	01	00	01	03	00
9th	02	01	03	01	01	02	03	01	00	03	02	02
10th	00	00	02	02	00	02	04	03	01	01	03	01
11th	05	00	00	01	01	03	01	05	02	00	01	03
12th	00	01	03	01	01	03	04	01	07	06	00	01
1st/2nd/3rd	*10*	*09*	*08*	*07*	*05*	*04*	*05*	*06*	*08*	*05*	*08*	*05*
Rank	*1st*	*2nd*	*3rd*	*6th*	*8th*	*12th*	*8th*	*7th*	*3rd*	*8th*	*3rd*	*8th*

Table 5: ALP elevation ranking frequencies

	G	H	K	L	M	N	P	Q	R	S	T	U
1st	02	05	07	00	01	01	00	02	06	01	00	00
2nd	01	03	05	00	02	02	01	05	03	01	00	02
3rd	03	02	01	04	07	02	05	02	00	00	00	00
4th	02	04	02	02	02	03	03	00	01	00	02	03
5th	03	01	01	04	04	02	00	01	01	03	05	00
6th	01	02	03	01	02	00	02	03	01	02	05	02
7th	03	06	01	04	01	00	02	00	01	03	01	03
8th	01	01	01	03	03	03	01	01	00	04	02	05
9th	04	00	00	02	03	06	02	02	00	00	03	03
10th	01	00	02	03	00	02	07	03	02	01	00	04
11th	03	01	01	00	00	04	02	06	00	01	07	00
12th	01	01	01	00	00	00	00	00	09	09	00	03
1st/2nd 3rd	*06*	*08*	*11*	*04*	*08*	*05*	*06*	*09*	*09*	*02*	*00*	*02*
Rank	*6th*	*4th*	*1st*	*9th*	*4th*	*8th*	*6th*	*2nd*	*2nd*	*10th*	*12th*	*10th*

Table 6: Elevations ranking weighted means

	G	H	K	L	M	N	P	Q	R	S	T	U
BT4	4.80	4.45	6.00	5.10	6.41	7.45	6.31	6.23	6.76	6.82	6.92	7.51
BT5	5.92	4.06	6.78	6.06	6.14	6.33	7.16	5 57	5.84	8.37	7.14	7.67
MT1	5.26	4.78	6.04	5.61	5.96	7.44	7.78	6.74	6.78	7.26	5.74	6.30
ALP	6.48	4.64	4.36	6.48	5.00	7.00	6.80	6.52	7.04	8.28	7.60	7.68
GRD	*5.54*	*4.40*	*6.00*	*5.74*	*6.01*	*7.00*	*6.92*	*6.07*	*6.50*	*7.67*	*6.93*	*7.40*
Rank	*2nd*	*1st*	*4th*	*3rd*	*5th*	*10th*	*8th*	*6th*	*7th*	*12th*	*9th*	*11th*

Table 7: Correlation of Roof SPV coverage and Aesthetics

	BT4	BT5	MT1	ALP	GRND
SROCC*	-0.08	+0.44	-0.39	+0.22	+0.06
Remark	*Negligible*	*Moderate*	*Low*	*Low*	*Negligible*

*****Spearman's Rank Order Correlation Coefficient

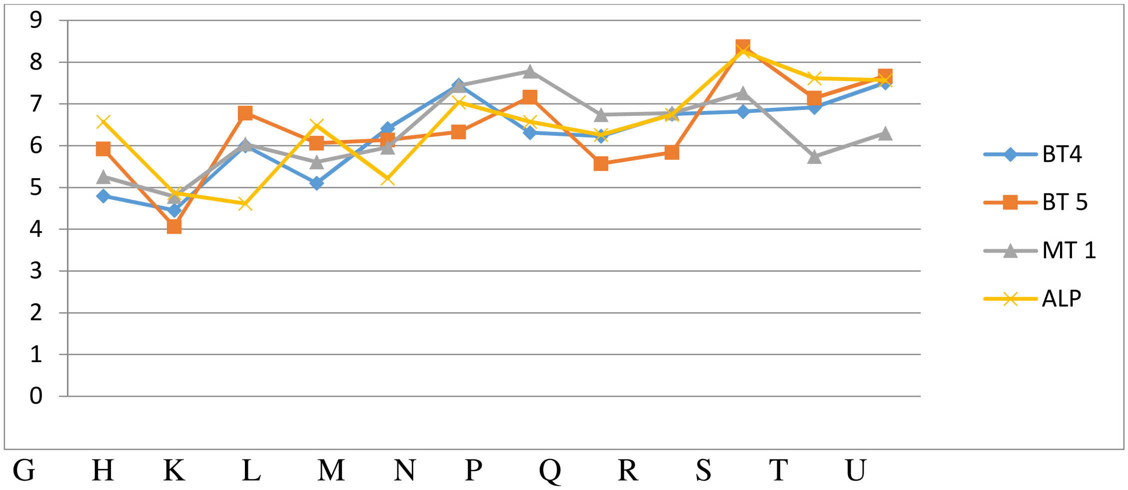

Figure 2: Variation of aesthetic ranking among respondent groups

Discussion

The data from this study seem to suggest that there is no relationship or correlation between solar photovoltaic panel coverage on roof and aesthetic appeal of the building. If at all there is any such relationship or correlation it is moderate at most, and not in any way appreciable or substantial. The weights of difference (3.06, 4.31, 3.00, 3.92 or 3.27) between the mean ranking of the most and least appealing elevations by all the respondent groups appear low. If this is a measure of the gap in aesthetic appeals among the 12 elevations with a possible gap of 11, then it may be considered narrow.

On the other hand the study reveals an appreciable difference in the aesthetic appeal of the elevations, and some consistency of their rankings among the respondents. For instance H and S with 21 and six percent solar PV panel coverage on roof enjoy preponderance of ranking as the most and the least appealing elevations respectively among the respondents. It is apparent that solar PV panel coverage on roof and by implication energy generation can be optimized without compromising aesthetic appeal of building. This suggests that the aesthetic condition for acceptability of PV panels on roofs as canvassed in Bonomo (2016) and Deloitte (2016) can be satisfied.

This suggests that other factors or variables are determinants of aesthetic appeal of the buildings rather than the coverage area of solar panels on roof, and may need to be considered for optimizing energy generation. These other variables or factors may be discerned by critically comparing elevations with proximate coverage area of solar panels and their aesthetic appeal rankings. The pairs of G&T, H&U, L&U, and N&Q have convergent or comparable coverage area of solar panels on roof of 11&13%, 21&19%, 17&19%, and 47&48% respectively; their aesthetic appeal rankings which are 2^{nd}&9^{th}, 1^{st}&11^{th}, 3^{rd}&11^{th}, and 10^{th}&6^{th} however seem incomparable and divergent pairs. This obviously contradicts the association of aesthetic appeal positively with PV coverage on roof as postulated in Heinstein *et al*. (2013).

Clustering of the solar panels, dimensional proportion of the clusters, and the size of cluster relative to adjacent windows appear to be some of the distinguishing variables. Clusters of size, number and proximity closer to adjacent windows seem to attract higher ranking of aesthetic appeal as apparent between G and T; each of the seven clusters of three in G seems closer and more related to adjacent windows than each of the 13 clusters of two in T. This seems to align with the position espoused in Yarris (2012), Probst and Roecker (2013) and Shuklar *et al*. (2015).

In addition, the dimensional proportion of the clusters of solar panels, and size of cluster relative to adjacent windows in H and U appears to influence their aesthetic appeal rankings. The cluster of six panels in H has height-to-width ratio of 2:3 which is closer to the 'Golden Ratio' than the ratio of 3:1 obtainable in the cluster of three panels in U. The aesthetic appeal of rectangular forms have been found to increase with closeness of their dimensional proportion to the 'Golden Ratio' which has been mathematically determined to be 0.618 (Lidwell *et al.*, 2003). The aesthetic appeal ranking of L higher than U, and of N higher than Q may be in deference to the principle of good continuation which implies that elements arranged in a straight line are perceived as a group, and are interpreted as being more related than elements not on the line(as espoused in Lidwell *et al.*, 2003). The solar panel clusters in L are not only arranged in a horizontal line which is parallel and close to that of eave, they also appear closer and more related to adjacent windows than those in U.

Conclusion

The main objective of the study was to determine the effect of photovoltaic (PV) panels mounted on a building roof on the aesthetic quality of the building. 12 elevations, with different arrangements and area coverage of roof solar PV panels, were ranked in order of aesthetic appeal by 140 respondents in four groups. Results indicated that the aesthetic appeals of the elevations varied, but not consistently with coverage area of PV panels on roof: the elevation with PV of 21% roof coverage (7th in coverage area) was rated most aesthetically appealing; that with PV of 6% roof coverage (the lowest) rated least appealing. Aesthetic effect was not appreciably correlated with PV panels' coverage on roof. It was concluded by recommending that PV panels be arranged on roof, guided by the aesthetic principles of composition, in order to optimize (and not maximize) energy generation.

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