

Article

Green Behaviors and Green Buildings: A Post-Occupancy Evaluation of Public Housing Estates in Hong Kong

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Abstract: A green building is believed to promote green behaviors from energy-saving to waste recycling. Green building certifications have attracted wide interest, and some were made mandatory for publicly funded developments in cities such as Hong Kong. Policymakers debate whether the city's expanding public housing stock should be exempted from the green certification mandate for reasons of cost, while evidence of behavioral benefits in green residential buildings is thin, or non-existent for public housing estates. This paper describes a post-occupancy evaluation study on self-reported green behaviors in Hong Kong's public housing estates. The study subjects are 400 occupants from two pairs of public rental housing estates with or without green certifications. A natural experiment was conducted, in which surveyed occupants were allocated to certified and uncertified estates via a random lottery, without significant differences in socioeconomic characteristics and propensity to green behaviors a priori. The results show that green-certified housing estates partially induced energy-saving behaviors, but not water saving or waste recycling, nor does it enhance satisfaction or green awareness. A certification alone is insufficient to induce behavioral changes, rather, efforts should be invested in conveying the green message, public education, and appropriate fiscal incentives.

Keywords: post-occupancy evaluation; green behavior; occupant satisfaction; public housing; green building certification; Hong Kong



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1. Introduction

Green building certification (GBC) systems, alternatively known as 'green building assessment', have attracted broad interest from investors, home buyers, builders, and governments over the last three decades. The aim of a GBC is to provide an objective assessment of a building's sustainable and environmental performance over its life cycle [1], with the goal of assisting design decisions, influencing the market, and ultimately, transforming behaviors and awareness. To receive a certificate, building owners need to demonstrate considerable efforts made to preserve the environment, from the use of construction materials to innovative design; other conditions require the buildings to perform up to pre-specified criteria, such as increased indoor environmental quality and reduced energy and water usage [2]. Credits are awarded based on meeting or exceeding each criteria category and weighted based on the importance and global trends of each. A certification is then conferred, depending on the overall credits received, as 'Platinum', 'Gold', 'Silver', or 'Bronze' to demonstrate various achievement levels.

Hundreds of GBC have been developed worldwide. Notable examples include the Leadership Energy and Environmental Design (LEED) [3], the Building Research Establishment Environmental Assessment Method (BREEAM) [4], the Green Building Evaluation Label (3-Star) [5], and the Building Environmental Assessment Method (BEAM) system

adopted in Hong Kong [6], which was first introduced as HK-BEAM (1996–2009) and then as BEAM Plus (2010–the present). In Hong Kong, GBC is hailed as a means to achieve sustainability in the construction industry, and it often tops the government’s policy agenda. For instance, all public buildings built or renovated after 2009 are required to obtain an HK-BEAM Gold rating or above. As of December 2020, the city operated 1616 BEAM-certified green buildings, accounting for 3.9% of the city’s total building stock [7].

Research literature is divided over the behavioral benefits of green buildings. Proponents claim that a certified green building induces green behaviors, citing evidence of waste reduction, energy, and water savings [8,9]. Skeptical voices argue that such benefits have not been consistently observed and are difficult to quantify [10–12]. A common weakness of existing studies is the self-selection bias on the ground that occupants of green buildings are more likely to be pro-environment, and their behaviors are driven by their propensity *a priori*, rather than induced by the green building itself [13–15]. Additionally, the majority of green building studies focus on commercial buildings, rarely on residential buildings, and almost non-existent on public housing estates.

Polymakers debate whether public housing estates should be exempted from the green certification mandate. The Hong Kong Housing Authority (HKHA), the city’s dominant developer of public housing, is concerned about the additional cost of green certifications [11] which contradicted its budgetary frugality in financing low-income housing. HKHA’s resistance to the green certification mandate earned exemptions for its public housing projects until 2015. There is a need to evaluate the effectiveness of green certification programs in Hong Kong’s public housing estates. The evidence obtained can enhance our understanding of the behavioral benefits of green building certifications in large public renting housing estates. It can also inform policy in prioritizing resources in achieving environmental and sustainable goals.

This paper describes a post-occupancy evaluation (POE) of user behaviors and satisfaction in Hong Kong’s public housing estate. The aim is to test whether obtaining a green building certification, currently mandatory on all public buildings in Hong Kong, has positive effects on environmental awareness, behaviors, and satisfaction; if yes, whether such effect is independent or in interaction with occupants’ socioeconomic characteristics. A natural experiment was conducted on four public rental housing estates built during a similar period in accordance with similar technical standards. The difference between the experiment and control group is the attainment of a green building certification, which is expected to communicate the “green message” to occupants, raise environmental awareness, and drive behavioral changes. Field studies were conducted in four public housing estates, divided into the experiment group (certified) and the control group (uncertified). Green awareness, behaviors, and occupant satisfaction were captured by a questionnaire-based survey conducted among 400 households.

2. Literature Review

The study of a green building’s impact on its occupant’s behavior and attitude is a relatively new field. Pertinent literature can be categorized into three areas: green awareness, green behavior, and green satisfaction, in accordance with the Theory of Planned Behaviors (TPB) outlined by [16,17]. A conceptual framework of TPB of the channels through which a green building communicates messages to the occupant is shown in Figure 1.

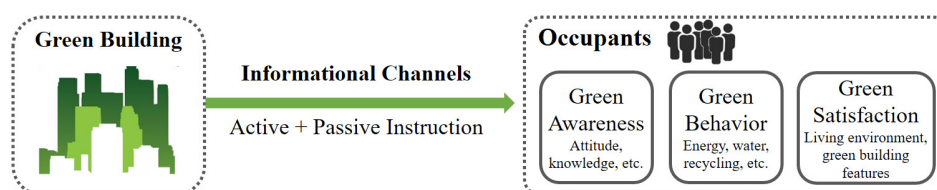


Figure 1. A conceptual framework on informational channels through which green buildings impact occupants.

2.1. Green Awareness

The impact of a green building on occupant's green awareness, in relation to environmental sensitivity, identity, or attitude, has been studied extensively with different results. In a POE study conducted in an office environment, Deuble and de Dear [18] found that occupants possessing a green attitude are more likely to accept green building features and tolerate less-than-ideal conditions, such as natural ventilation. Awareness of the green building features, concluded by Mokrzecka and Nowak [19] in a dormitory-based study, is critical for residents to adopt pro-environmental behaviors in green buildings. Rashid et al. [20] found no direct impact of a LEED-certified green building on occupant's environmental awareness, although some indirect effects can be found, which are conveyed through satisfaction with individual workspaces and the building. Similarly, McCunn and Gifford [21] found that green building features in an office setting tend to discourage a green attitude; the negative correlation is attributed to the faded novelty of green building features and dissatisfaction with the building design. A related concept is green knowledge, or knowledge about green buildings, which was found to correlate positively with green attitudes and behaviors [22]. Alternatively, Cole [23] developed a concept of "green building literacy", consisting of knowledge, skills, affect, and behavior.

2.2. Green Behavior

A growing number of studies consider occupant behaviors, which are stochastic in nature, matter more to building performances, user satisfaction, and wellbeing, than to the acquirement of green building certification. Advancement in green building technologies alone, argued by D'Oca et al. [24], does not guarantee a reduction in building energy consumption. Green building certification focusing on energy-saving technology installation, by itself, often stops short of delivering real energy savings [11,12]. Wasteful behaviors could double the energy consumption of a building [25]. Subsequently, researchers advocated for the right policy, pricing schemes, and incentives to induce green behaviors. Fiscal regulations, such as energy pricing schemes and income subsidies on utilities, are commonly adopted in the residential sector to induce behavioral changes toward energy efficiency [26]. However, inappropriate policies would fail to induce behavioral changes or even backfire. For example, certain energy efficiency measures were found to have increased energy consumption, an unintended consequence known as the "rebound effect" [27]. Occupants would discard the efficiency option if the green technologies were not recovered via cost savings within a short timeframe [28]. Another barrier preventing the adoption of energy-efficiency products is the "principal-agent problem", in which the purchasers of energy-efficiency products do not benefit from the energy-efficiency products themselves [29].

2.3. Green Satisfaction

While a large body of research literature concurs that a green building can enhance occupant satisfaction, some reported conflicting evidence. Kern et al. [30] resulted that occupants of certified green buildings exhibit higher satisfaction levels and consume less energy, compared with those residing in buildings without green certification. Newsham et al. [31] reported that credits awarded to acoustic performance and reduction of Volatile Organic Compound (VOC) enhance indoor environmental qualities and occupant satisfaction in certified green buildings. Similarly, Cheng et al. [32] found higher occupant satisfaction in certified green buildings, driven by the use of green materials with reduced VOC emissions, such as carbonyls, benzene, toluene, ethylbenzene, and xylenes. From the users' perspective, Andersen et al. [33] discovered that green building credits awarded to user control enable occupants to directly control the thermal conditions, ventilation rate, and lighting, which reduces energy consumption while enhancing occupant satisfaction compared with buildings with limited user control. Contrary to the above findings, Paul and Taylor [34] found insufficient evidence to prove that certified green buildings are more comfortable than conventional ones in aspects like lighting, ventilation, acoustics, and hu-

midity. Altomonte and Schiavon [35] found that occupants of certified green buildings were less satisfied with the internal specifications, such as lighting, ease of interaction, and visual comfort. Similarly, Khoshbakht et al. [36] found that occupants of certified green buildings expressed lower levels of satisfaction towards indoor environment qualities (i.e., air freshness, odors, artificial lighting, and noise level), possibly due to a green building's priority of natural ventilation and daylighting at the expense of occupant comfort during daily and seasonal operations. Thatcher and Milner [37] attributed the low satisfaction in certified green buildings to occupants' high expectations for such a building. Newsham et al. [31] found that a green building improved its image perceived by the public but not its users' perception nor their satisfaction level. Moreover, occupant wellbeing in certified green buildings showed no statistical improvement over those of uncertified buildings [38]. "Individual variability" is an element that should be taken into consideration compared to the performance parameters used in any other rating system [39].

2.4. Research Gaps

Two important gaps persist. First, post-occupancy evaluation studies are lacking on green behaviors in residential buildings. Existing studies focus mostly on commercial buildings, emphasizing the behavioral benefits of a green-feature-equipped work environment and productivity gains. From a handful of POE studies on residential buildings (e.g., [40–42]), rarely are there studies focusing on occupant behaviors in public housing estates. This is an important area because residential buildings consume 26% of the city's electricity and grow at an annual speed of 3.5% on average [43]. Therefore, it is essential to include green residential buildings in post-occupancy literature.

Second, many existing studies suffer from the self-selection bias in research design. Environment-conscious homebuyers express a stronger preference for "environmentally friendly" or "green" buildings; thus, the causality between green building certification and environmental conscious behaviors cannot be determined [13,14]. A POE study on green behaviors, awareness, and occupant satisfaction in residential buildings would need to rigorously control for the self-selection bias in order to inform causality and policy.

3. Methods

The paper aims to study the impact of occupancy in certified green housing estates on green awareness, behaviors, and satisfaction. Four housing estates were selected to represent the experiment group (certified green buildings) and the control group (uncertified green buildings). Green awareness, behaviors, and occupant satisfaction were captured by a questionnaire-based survey conducted among 400 households. Differences between the experiment and control groups were analyzed using statistical analysis.

3.1. Study Area and Sampling Strategy

We selected two pairs of public housing estates in the Kwun Tong District, Kowloon, which has a high concentration of public housing estates (Figure 2). The experiment group consists of Lam Tin Estate (E1) and Upper Ngau Tau Kok Estate (E2), selected out of a pool of 15 public housing estates successfully obtaining a certification from BEAM by December 2020. In particular, E1 and E2 received Platinum ratings in BEAM certification under the New Building Scheme 4/04. The control group consists of Choi Fook Estate (E3) and Sau Mau Ping (South) Estate (E4), selected from a pool of 14 public housing estates built around the same time by HKHA without a green building certification.

The reason why E3 and E4 did not apply for the BEAM certificate can be explained partially by the cost of doing so, both in budget and time, according to an interview with the project architect of HKHA [44]. Certification-related fees for the size of the housing estates in this study would range between HK\$ 562,500 and 735,000, including both Registration and Assessment Fee [45] at the time of construction, and the fee has nearly doubled in 2019. Time is another barrier. Obtaining a BEAM certificate takes between 4 and 11 months from

application to approval, according to the procedural document provided by HKGBC [46]. This does not include the time needed for preparing for the application.

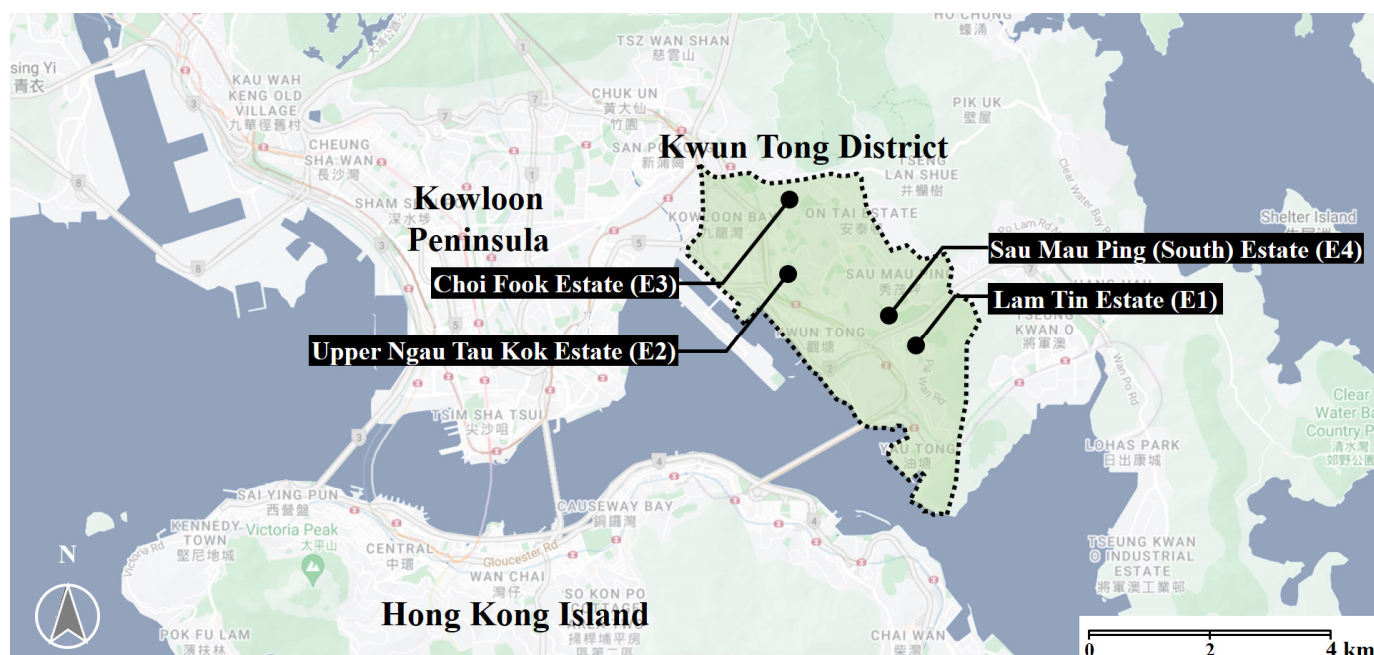


Figure 2. Location of Four Public Housing Estates in Kwun Tong District, Kowloon.

3.2. A Natural Experiment

The research design in this study followed a natural experiment, in which occupancies were randomly assigned, and the behavioral differences between occupants of certified and uncertified housing estates can only be explained by the certification itself, instead of confounders. The natural experiment might be the best possible approach since manipulation in experimental ways are impractical and unethical. The research design is summarized in Figure 3.

The assignment of households to the experiment and control groups, i.e., certified and uncertified housing estates, can be regarded as “naturally occurred” without manipulation by the households or the researcher. This satisfies the concept of a natural experiment [47] since applicants of Hong Kong’s public housing have no control over what types of buildings they prefer. Eligible applicants can only indicate their preference in four approximate location categories: the urban core, new town, the new territories, and offshore islands in their application. They are assigned to a housing estate by a lottery-based computer system [48], without any control over whether their residence will be a green or non-green building. The lottery-based random allocation, therefore, eliminates the self-selection bias, i.e., the propensity of green behaviors is not expected to differ between the experiment and control groups before the start of occupancy. The observed behavioral difference between the two, if any, can therefore be attributed to occupancy in the housing estate.

Further, the four housing estates are similar in basic information, such as developer, location, age, and building layout. All were developed by the HKHA between the years 2009 and 2010 with coherent design, construction, and technological standards. They are located within 3 km from each other in the same urban district, and all are conveniently served by the Hong Kong MTR, the city’s subway system. The site and building layout of the four housing estates, which are largely similar, are depicted in Figure 4.

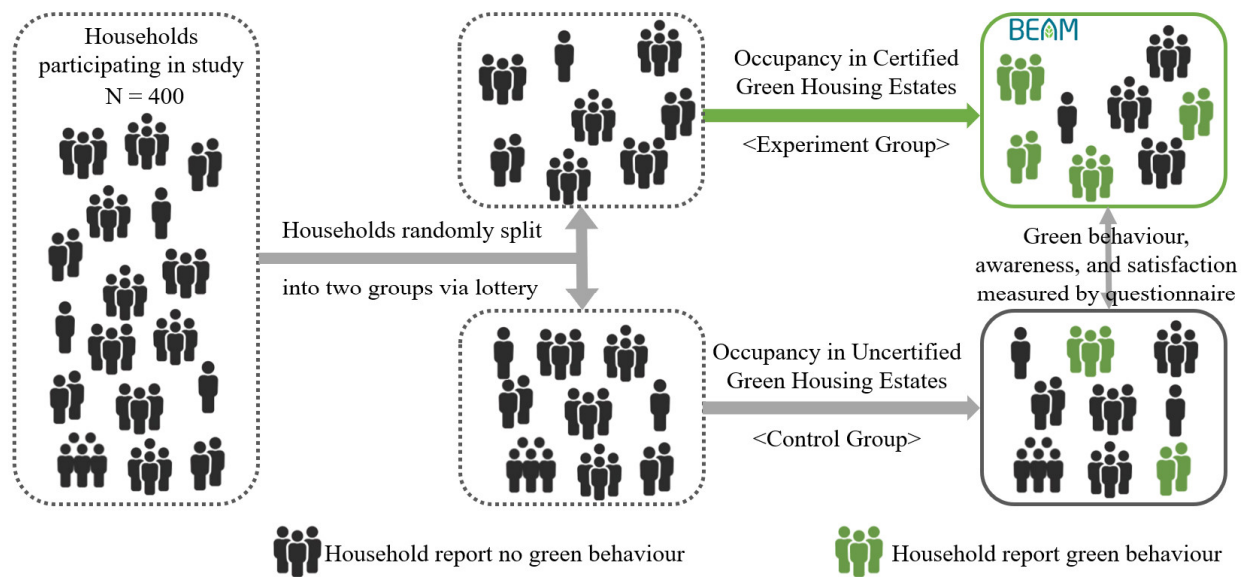


Figure 3. A conceptual framework of the natural experiment on certified green housing estates and green behaviors.

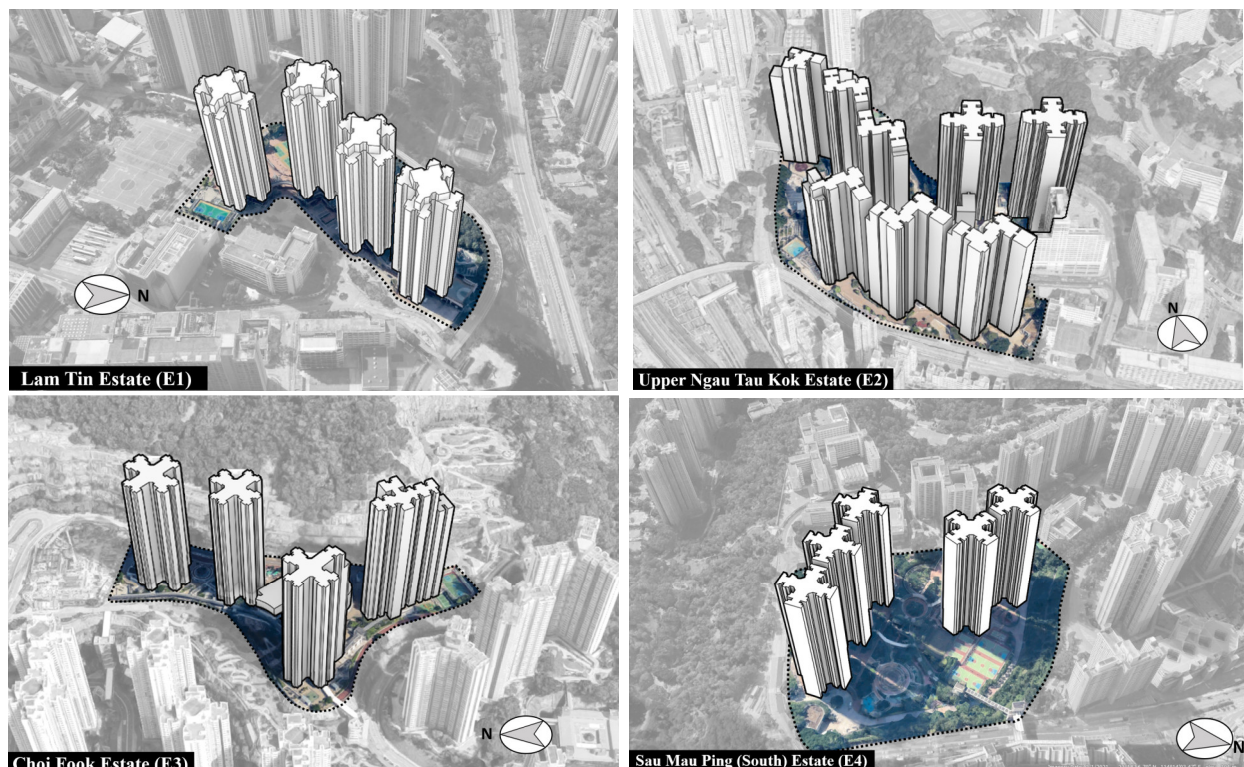


Figure 4. Birds' eye view drawings of (E1) Lam Tin Estate, (E2) Upper Ngau Tau Kok Estate, (E3) Choi Fook Estate, and (E4) Sau Mau Ping (South) Estate.

3.3. Field Studies

A questionnaire-based survey was conducted to capture green awareness, behaviors, and satisfaction. The questionnaire was structured in response to three hypotheses to be tested in accordance with the research design. First, whether occupants of certified green buildings demonstrate electricity and water-saving behaviors; second, whether a certified green building is conducive to higher levels of occupant awareness of green fixtures/technologies and higher satisfaction levels of the built environment; and lastly, whether green behaviors are attributable to socio-demographic characteristics, such as

educational attainment, household income, household size, and the length of residency, etc. The above hypotheses were formulated in accordance with the research literature.

The questionnaire includes 38 questions in four categories: (1) electricity and water consumption, (2) waste recycling, (3) recognition of green fixtures and devices (GFD), and (4) overall satisfaction with the living environment. These categories cover contents featured in a recent questionnaire-based study by Sena et al. [49], each designed to test key hypotheses between green certification status and behaviors. For electricity and water consumption, questions were designed to capture the usage pattern of key electrical appliances, such as air conditioning, lighting small power devices, electric stoves, etc., and on whether energy and water-saving devices are used in the household. On waste recycling, questions were asked about the frequency, patterns, and habits related to waste recycling. On green fixtures and devices, a quiz was included in the questionnaire asking whether respondents recognize common GFDs in reference to a list suggested by Zhang et al. [50], i.e., dual-level lighting, water-saving tap and closet, solar panels, vertical greenery, etc., installed in their housing estates. If yes, to what extent do they relate to participants' daily life? The quiz included nine images of these GFDs installed in both the public common areas and domestic units. Correct identification of GFDs, according to a recent study [51], was found to correlate with occupants' attitudes and willingness for green behavior. The questionnaire also included 15 items that measure satisfaction with the living environment using a 5-point Likert scale, including eight GFD installations (items h–o), five outdoor and indoor built environmental factors (items a–e) and two social factors that are a part of the BEAM Plus assessment criteria (items f and g). Information on gender, educational attainment, household income, household size, and the length of residency were also collected from participants, which aimed to test whether behaviors are attributable to socio-demographic characteristics.

The survey was administrated face-to-face in the four housing estates between January and June 2018. The recruitment was conducted on a voluntary basis at the main entrances of each housing estate since researchers do not have access to buildings and individual households. A questionnaire participant needs to be (1) an adult person above 18, and (2) the head of his/her household in order to possess sufficient knowledge to complete the survey. One-hundred valid responses were collected from each housing estate, adding to a total of 400. The survey had a margin of error of 5%, given the population size of 42,400 in all four housing estates. The study protocol received ethical approval from the Research Grants and Contracts Office from the authors' institution (Reference No.: 11611919), the complete questionnaire is shown in S2 of the Supplementary Materials.

Field inspections were conducted in each housing estate in parallel. The aim was to verify both the "passive" and "active" instructions in accordance with the Theory of Planned Behaviors through which green building messages were communicated to occupants. For the former, we looked for a pre-defined list of green building features, such as solar panels, green roofs, and recycling facilities promoted by the Hong Kong BEAM Plus [52]. For the latter, we checked the presence of engagement platforms such as green building educational signage, brochures, and sustainable living showcase demonstrations promoted by IDCM 14 (Occupant Engagement Platform) and IDCM 17 (Design for Engagement and Education on Green Buildings) in Hong Kong BEAM Plus, both credit categories are intended to provide physical and digital platforms to engage occupants and drive behavior change [52]. Findings were marked on maps and backed up by photographic evidence.

3.4. Statistical Analysis

Statistical analyses were deployed to test two hypotheses: (1) Occupants' environmental-related behavior patterns and user satisfaction with the living environment that are related to the building's green certification status; and (2) Compared to occupants of the uncertified green estates, occupants' behavior in the certified ones are likely induced by their demographic characteristics and estate specifications.

To determine whether there are environment-related behavioral differences between the occupant groups defined by where they live, one-way ANOVA tests were conducted with five dependent variables, namely (1) electricity consumption behavior, (2) water consumption behavior, (3) waste recycling behavior, (4) recognition of GFD, and (5) satisfaction with the living environment. As shown in Table 1, these variables were quantified based on questionnaire items, with the independent variable being the living environment measured by the green certification status of the respondents' housing estate. Furthermore, to compare estate-level means, we took a two-step process by first testing whether all the means are equal, followed by a *post hoc* Tukey's Honest Significant Difference (HSD) test to determine which means are unequal and whether the variations are significantly different.

Table 1. Measurement of occupant behavior using a questionnaire.

Dependent Variable	Measurement Item	Question
Electricity consumption	Days and frequency of using A/C; office equipment; and lighting	Q8–14
Water consumption	Shower time; full-load laundry machine operation; dripping tap repair	Q17–19
Waste recycling	Frequency of using recycling bins and clothing recycling bins	Q26, Q28
Recognition of GFD	Ratio of numbers of GFD recognized to actual GFD installed in the estate	Q30
Satisfaction with the living environment	Satisfaction with various GFD, built environment, social interaction within neighborhood, accessibility to public spaces, and environmental promotion program.	Q31

Note: GFD = green fixtures and devices.

To test the second hypothesis about the effect of household socioeconomic characteristics on behaviors and satisfaction levels, a series of OLS regressions was adopted as follows. Model 1 takes the basic form $Y = \alpha + \beta X_i$, in which Y is the five dependent variables identical to those in the above ANOVA tests and X_i indicates occupants' socio-economic characteristics, including age, educational attainment, household income, and household size. In Models 2 and 3, dummy variables, such as green certification status and estate dummies, were included respectively.

4. Results and Discussion

The differences in awareness, behavior, and satisfaction between occupants of certified and uncertified green housing estates were discerned; the interactive effects between green behaviors and socio-economic characteristics were investigated using regression analysis. Policy recommendations were discussed.

4.1. Data Characteristics

The basic information on the four housing estates obtained from the census data is summarized in Table 2, including the block design, building height, orientation, and occupant information.

The personal characteristics obtained from the questionnaire respondents are provided in Table 3, in which each variable is presented categorically as explained at the end of the table. The respondents have mean ages of 41–49 and average family sizes between 2.5 and 3.3. They are moderately educated with an average educational attainment of lower and upper secondary level (middle and high school graduates). Median monthly household income ranges from 9050 to 15,850 Hong Kong dollars, which is significantly lower than the city's average of 32,700 for a three-person household in 2018. Acknowledging the limitations associated with the voluntary recruitment strategy, sample statistics (Table 3) were compared with those obtained from the Census for the same housing estate (Table 2); the results suggest a reasonably good agreement between the two in terms of median age (age band), median income, educational attainment, etc., suggesting that our samples obtained are representative of the socioeconomic characteristics of the four housing estates.

Table 2. Basic Information and green features in four public housing estates.

Description	E1	E2	E3	E4
Green building certification attainment	BEAM Platinum	BEAM Platinum	NA	NA
Completion year	2009	2009	2010	2009
Population (count)	8000	15,800	8800	10,300
Median Household Income (HK\$/month)	12,250	12,000	11,780	12,000
Median Age (yr.)	38.5	51.9	40.0	41.3
Educational Attainment (% at secondary level or above)	70.4%	59.8%	70.8%	72.1%
No. of buildings	4	9	4	5
No. of flat units	3000	6600	3400	4000
Size of flat unit (m ²)	17.97–38.05	16.30–48.80	21.20–43.60	17.05–39.15
Altitude elevation (m)	97	20	103	115
Highest occupancy floor	39	36	36	39
Building layout	Cruciform with each hallway facing cardinal directions	Partial units facing both west and east	Partial units facing both west and east	Cruciform with each hallway facing cardinal directions
Green coverage (%)	10	50	20	75
Distance to main road (Nearest to Farthest) (m)	8–120	13–75	12–86	15–145
Sources of noises	Road, Schools, Expressway, Mall	Road, Wet Market	Road, Construction site	Road, School

Source: compiled by the authors.

Table 3. Descriptive statistics of questionnaire respondents.

Estate	Variables (Score)	Min	Max	Mean	Std. Deviation
E1	Age ¹	1	10	5.13	0.502
	Education Level ²	1	5	2.58	1.288
	Household Income ³	1	6	3.67	1.393
	Household Size ⁴	1	5	3.34	1.224
	Age	1	10	6.29	2.808
	Education Level	1	5	2.33	1.334
	Household Income	1	5	2.31	1.295
	Household Size	1	5	2.80	1.203
E3	Age	1	10	5.08	2.936
	Education Level	1	5	2.58	1.165
	Household Income	1	6	3.51	1.508
	Household Size	1	5	2.55	0.903
	Age	1	10	4.86	2.913
	Education Level	1	5	2.71	1.250
	Household Income	1	6	3.51	1.453
	Household Size	1	5	3.30	1.068

Note: ¹ Ten levels of age groups: 1 = 18–24; 2 = 25–29; 3 = 30–34; 4 = 35–39; 5 = 40–44; 6 = 45–49; 7 = 50–54; 8 = 55–59; 9 = 60–64; 10 = over 64. ² Five levels of educational attainments: 1 = Primary and below; 2 = Lower secondary; 3 = Upper secondary; 4 = Post-secondary non-degree; 5 = Post-secondary degree or above. ³ Six levels of household income (in HK\$): 1 = less than \$5000; 2 = \$5000–9999; 3 = \$10,000–14,999; 4 = \$15,000–19,999; 5 = \$20,000–24,999; 6 = more than \$24,999. ⁴ Five levels of household size: 1 = one person; 2 = two people; 3 = three people; 4 = four people; 5 = five and more people.

4.2. Green Awareness

The study found no significant differences in green awareness measured between certified and uncertified green housing estates, either by attitude towards environmental protection or green building features. Self-reported green awareness and the variety of informational channels for green promotion are summarized in Figure 5. The ANOVA and

Tukey test results are shown in Table 4. Responses to Q36 “How much do you care about the environment protection in daily life?” vary by housing estate, with minor differences between the experiment and the control group. Similarly, responses to Q37 “How much do you care about the green building features in daily life?” do not appear to differ significantly between the two groups, while E4 has the lowest scores. This finding is consistent with previous studies that occupancy in a green building does not necessarily promote a green attitude or the awareness of green buildings and the environment at large [19–21], and Hong Kong’s green public housing estates are no exceptions.

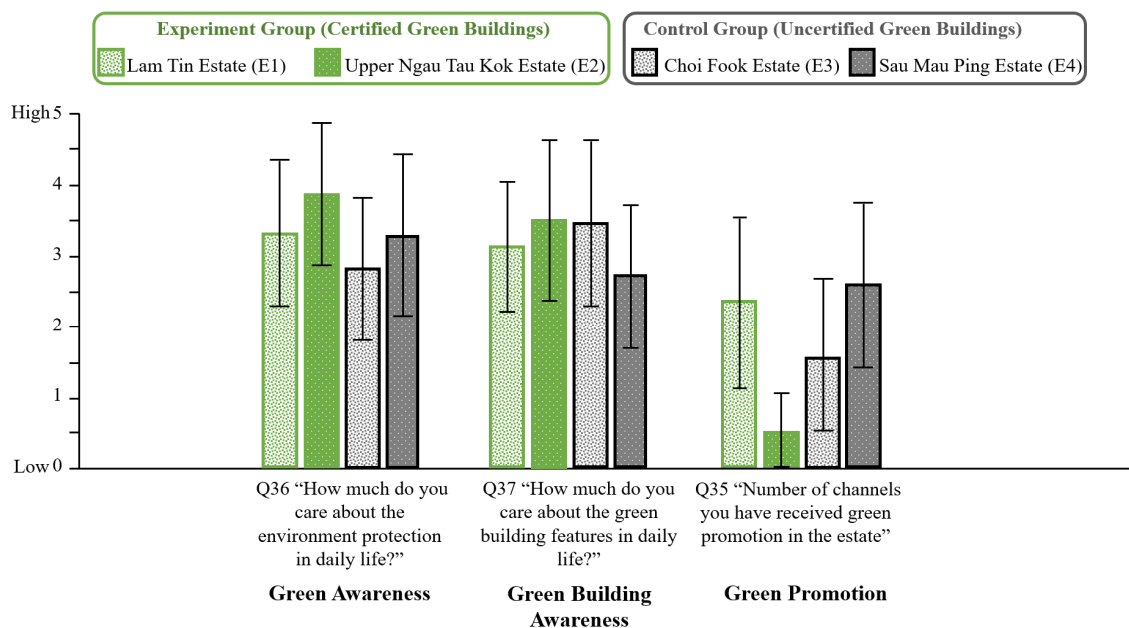


Figure 5. Mean scores by categories of green awareness and informational green promotion in the four housing estates.

Table 4. ANOVA results of relationships of occupants’ green attitude and green promotion channels.

Housing Estate	F/Sig.	Mean	SD	Tukey's HSD Comparison (Sig.)		
				E1	E2	E3
Green Promotion Channels (Q35)						
E1	72.464/0.000	2.31	1.16			
E2		0.50	0.86	1.810 *		
E3		1.62	1.02	0.690 *	−1.120 *	
E4		2.58	1.27	−0.270	−2.080 *	−0.960 *
Green Awareness (Q36)						
E1	11.733/0.000	3.30	0.95			
E2		3.93	0.87	−0.633 *		
E3		2.83	0.89	0.470 *	1.103 *	
E4		3.28	1.02	0.020	0.653 *	−0.450 *
Green Building Awareness (Q37)						
E1	10.331/0.000	3.11	0.87			
E2		3.49	1.22	−0.380 *		
E3		2.71	1.08	0.400 *	0.780 *	
E4		2.90	0.96	0.210	0.590 *	−0.190

* $p < 0.05$

The lack of attitudinal differences in awareness between the certified and uncertified green buildings can perhaps be explained by the lack of variety through which green promotions were conducted. In responding to Q35, E2 occupants reported the lowest score, suggesting that the diversity of green information receivable to most E2 occupants is quite limited. Consider that E2 features a higher percentage of elderly residents, who might not be as easily reachable via unconventional informational channels, such as digital platforms, online workshops, promotional carnivals, etc. This finding pointed to a potential limitation in the current Hong Kong BEAM, which awards credits to digital platforms as a major channel for occupant engagement [52]. Such channels, as it is observed in E2, should be diversified in order to better serve an increasingly aging population. Through field inspections, the authors found no educational signage, brochures, nor sustainable living showcase demonstrations in E1 and E2, suggesting a missed opportunity in conveying green building messages to occupants through “active instruction”.

4.3. Green Behavior and Satisfaction

The self-reported green behaviors and satisfaction among four housing estates are shown in Figure 6. Results of the ANOVA and the Tukey tests are shown in Table 5. Findings are discussed below by questionnaire categories:

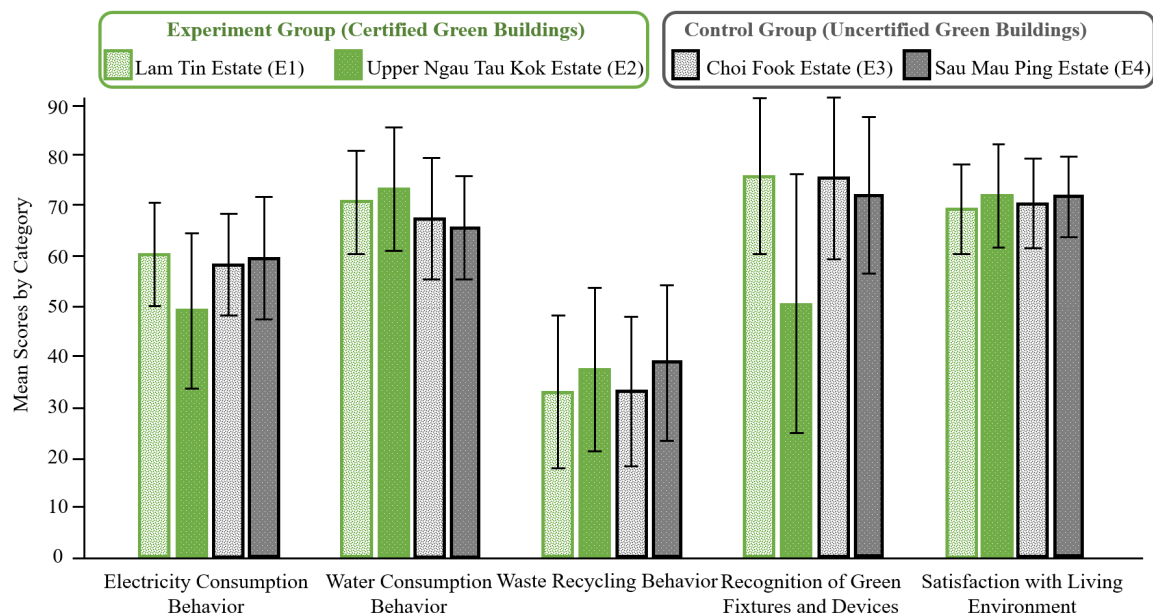


Figure 6. Mean scores by categories of green behaviors and satisfaction in the four housing estates.

Electricity Consumption Behaviors. The experiment group exhibited mixed performances in self-reported electricity consumption behaviors, with E2 scoring well below the control group level, while E1 showed no statistically significant difference from the uncertified green buildings. The housing estates certified by BEAM Plus, which assign as much as 35% weighting to efficiency in electricity use, showed no significant improvement over the uncertified housing estates. This finding echoes with those of Geng et al. [53] that green building certification status does not guarantee electricity-saving behaviors.

The above findings are also confirmed by on-site observations of building design, orientation, neighborhood amenities, and public open spaces. Despite its pre-1980s public housing design, E2’s single-loaded corridor design can facilitate natural ventilation and lighting seems to be more environmentally friendly than the other estates. A previous study on open spaces of E2 confirmed that its award-winning microclimate design creates more comfortable, attractive, and well-used public open spaces, therefore reducing the time occupants spent indoors and associated electricity consumption [54]. The other three estates adopt a trident block design with a double-loaded corridor, which on the one hand,

increases the efficiency of site usage, but on the other hand, reduces the effectiveness of natural air ventilation and lighting caused by almost-encased public areas and fixed window blinds. Additionally, E1's proximity to the expressway and schools, both being sources of environmental noise, reduces the willingness for natural ventilation, therefore encouraging the electricity consumption for air conditioning.

Table 5. ANOVA results of relationships of occupants' electricity and water consumption behavior, waste recycling behavior, recognition of green fixtures and devices, and occupant satisfaction.

Housing Estate	F/Sig.	Mean	SD	Tukey's HSD Comparison (Sig.)		
				E1	E2	E3
Electricity consumption						
E1	17.048/0.000	60.35	10.43	0.000 ***	0.000 ***	0.649
E2		49.20	15.82			
E3		57.60	9.76			
E4		59.65	12.82			
Water consumption						
E1	9.053/0.000	70.67	9.87	0.402	0.001 **	0.725
E2		73.17	12.95			
E3		67.25	11.68			
E4		65.58	10.51			
Waste recycling						
E1	2.836/0.038	34.13	14.31	0.311	0.409	0.108
E2		37.38	16.57			
E3		34.50	13.07			
E4		39.25	15.18			
Recognition of GFD						
E1	35.020/0.000	75.86	15.69	0.000 ***	0.000 ***	0.843
E2		51.33	27.90			
E3		75.71	18.33			
E4		73.38	15.86			
Satisfaction with living environment						
E1	2.958/0.032	69.29	6.47	0.051	0.331	0.476
E2		71.86	9.67			
E3		70.17	6.16			
E4		71.61	5.02			

** $p < 0.01$. *** $p < 0.001$.

Water Consumption Behaviors. Tukey's test result showed no significant advantage for certified-green housing estates in inducing water-saving behaviors over the uncertified ones. The result contradicts the conventional assumption that a certified green building induces water savings compared with an uncertified one. It is intriguing given Hong Kong's BEAM Plus allocates a sizable weight (12%) for water-use efficiency in its assessment criteria.

Waste recycling behavior. A statistically significant difference between the estates was not observed, except for in the E3–E4 pair. The provision of waste recycling facilities is a basic element required in the BEAM Plus assessment. Interestingly, the survey reveals that over 60% of E1 and E2 occupants use recycling bins less frequently than those of the uncertified estates and that E4 occupants display the best recycling behavior. We attribute this result to the location of the recycling bins. In E4, the bins for waste recycling and clothes recycling are situated inside the main entrance and they are highly visible and accessible, which has increased the awareness and frequency of waste recycling among occupants. In

contrast, the recycling bins in E1 and E3 are located outside the main entrance, visible, but less convenient. In E2, the recycling bins are placed at a hidden corner inside the main entrance, convenient, but less visible.

Green Fixtures and Devices (GFD). Overall recognition of GFDs amongst occupants of the four housing estates was found to be low. Results of ANOVA and Tukey tests demonstrate significant differences between E2 and the other estates as well as between E4 and the other estates. The low recognition of GFD by occupants of E2 is likely associated with its relatively elder population as studies have found that senior citizens are usually less observant of their living environment [55]. The high recognition of GFD by occupants of E4 can be attributed to the estate's high prevalence of landscape greenery as the occupants in the greener neighborhood exhibit better overall cognitive ability [56]. Images of roof greening and vertical greening are highly recognized by the respondents with a rate as high as 94% and 79%, respectively. The other GFD elements, such as two-level lighting systems, solar panels, and LED lighting bulkheads are only recognized by 44%, 51%, and 29% of the respondents, respectively. Domestic GFDs are also recognized by the respondents. The dual-flush water closet was recognized by 97%, the water-saving tap by 72%, and the water-saving showerhead by 77%.

The above findings were echoed with field evidence obtained on-site. We found the GFD installed in all four housing estates were similar, which can perhaps explain the lack of differentiation in GFD recognition, green building awareness, and green awareness between the experiment and control groups. A summary is provided in Table 6 below, including two-level lighting systems, LED bulkheads for lighting, solar-powered lamps, and water-saving closets, taps, and showerheads.

Table 6. The Green Fixture and Devices in according to field survey.

Description	E1	E2	E3	E4
<i>Two-level lighting system</i>	Yes	Yes	Yes	Yes
<i>Grid-connected solar panel</i>	Yes	No	No	No
<i>LED bulkhead for lighting</i>	Yes	Yes	Yes	Yes
<i>Roof greening</i>	No	No	Yes	Yes
<i>Vertical greening</i>	No	No	No	Yes
<i>Solar-powered lamp</i>	Yes	Yes	Yes	Yes
<i>Water-saving water closet</i>	Yes	Yes	Yes	Yes
<i>Water-saving tap</i>	Yes	Yes	Yes	Yes
<i>Water-saving showerhead</i>	Yes	Yes	Yes	Yes
Location of recycle bin (Inside/outside building)	Outside	Both	Outside	Inside
Availability of clothes recycle bin	No	Yes	No	Yes

Occupant satisfaction with the living environment. The ANOVA and Tukey's test results show no statistically significant difference between the estates with respect to the occupants' satisfaction. For the 15 items, 53% of the respondents are satisfied or very satisfied with the estates' landscape greenery, while the satisfaction with social interactions within the neighborhood stands at 41%. Respondents' satisfaction level is higher for domestic GFD (items n and o) than for the GFD in the public area (items h–m). Interestingly, the survey results demonstrated a higher satisfaction level among occupants in the uncertified green housing estates (E3 and E4) than those in the certified ones (E1 and E2). Except for LED bulkhead, a larger percentage of respondents are satisfied with the GFD items in E3 and E4 than in E1 and E2 by a range of 9% to 63%, with vertical greening as the smallest gap and solar-powered lamps the biggest.

4.4. Interactions with Socio-Economic Characteristics

The pooled ordinary least squares (OLS) regression results showed that green behavior, awareness, and occupant satisfaction are closely related to socio-economic factors, such as age, education level, income, and household size [57]. Table 7 summarizes the relationships between household socio-economic variables and the five dependent variables, that is, occupants' environmental behavior patterns, user perception, and satisfaction. Model 1 is the pooled regression with four independent variables. Model 2 adds a green certification dummy. Model 3 replaces the green dummy with estate dummies.

Regression analyses show that household income is negatively correlated with electricity consumption behavior, suggesting that lower-income households tend to consume more electricity. Our finding contradicts those from existing literature that household income relates positively to energy consumption behaviors [58]. We interpret that this may be caused by the tendency of over-consumption induced by government subsidies to very low-income households, such as the electricity charge subsidy scheme and concessionary tariff for the senior citizens.

Occupants of the certified green housing estates tend to consume less energy than those in uncertified buildings, and this correlation is highly significant at the 0.1% level. The household size, though not statistically significant, is adversely related to electricity consumption behaviors. Although some studies find the household size a determining factor in positively influencing electricity consumption [59], our regression suggests otherwise.

Water consumption behaviors were found to associate significantly with household size, household income, and certification status of buildings, although the sign of coefficients contradicts our expectations. Occupants of the certified-green buildings were found with higher levels of water consumption behaviors than those in the uncertified buildings. It is possible that gender might have played a role, in accordance with Sever's empirical evidence [60] that women are the primary water users in domestic consumption. The percentage of female occupants in E1 and E2 were indeed found to be higher, although not by a significant margin, than in E3 and E4. Lower-income households were found with higher levels of water consumption behaviors than higher-income households, the association remained significant after controlling for estate dummies. This is probably due to the government-provided senior living allowance eligible for water bill payments, thereby making senior households price-insensitive to water savings. Despite the same water-saving appliances being installed in four housing estates, our findings echo those of Russell and Knoeri [61], in which water-saving appliances do not guarantee water-saving behaviors.

The regression results failed to relate waste recycling behavior and user satisfaction with the certification status at a statistically significant level. Instead, respondents with higher educational attainment expressed stronger satisfaction with their public housing environment. This implies that waste recycling and satisfaction are less related to the type of buildings occupants live in; rather, it is connected to the recycling utilities that are accessible to them. Educational attainment is less related to awareness of sustainability, as reflected in Alsaati et al. [62]. The number of GFDs recognizable to the respondents is strongly related to the age and household income of the respondents before controlling for the estate dummies. This implies that younger people and households with relatively higher incomes are more aware of the GFD features. Once the certification or estate dummies were included, the socio-economic factors become much less significant or insignificant. The negative coefficient on the certification dummy suggests that occupants living at certified-green estates show a significantly lower degree of recognition of GFD. The positive coefficients on the estate dummies suggest that, compared to E2, occupants of the other estates recognize a greater number of GFD. These may be explained by E2's high percentage of older respondents and E4's high coverage of landscape greenery.

A multicollinearity test was performed for all the independent variables of the regression models listed in Table 7. The assessment result of the Variance Inflation Factor (VIF) indicates no strong correlation among the independent variables because the VIF values were all under 2. The VIF test results were included in S1 of the Supplementary Materials.

Table 7. Regression results in electricity and water consumption behaviors, recognition of GFD, and satisfaction with the living environment (No. of observations: 400).

	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	Electricity Consumption Behavior			Water Consumption Behavior		
Age	0.0918 (0.280)	0.0219 (0.278)	0.541 * (0.256)	0.207 (0.244)	0.0870 (0.242)	0.0556 (0.243)
Edu. Level	−1.14 (0.638)	−1.08 (0.629)	−0.609 (0.575)	0.214 (0.557)	0.153 (0.547)	0.105 (0.547)
HH size	−0.685 (0.563)	−0.464 (0.558)	−1.16 * (0.524)	1.95 ** (0.491)	1.74 ** (0.485)	2.02 ** (0.499)
HH Income	−1.00 * (0.443)	−1.29 ** (0.444)	−2.50 ** (0.4.26)	−1.57 ** (0.387)	−1.29 ** (0.386)	−1.17 ** (0.406)
Green-certified (1 = Y; 0 = N)		−4.80 ** (1.31)			4.53 ** (1.14)	
E1 dummy			15.9 ** (1.77)			−1.94 (1.68)
E3 dummy			11.9 ** (1.75)			−3.95 * (1.67)
E4 dummy			15.0 ** (1.75)			−7.13 ** (1.67)
R-squared	0.042	0.073	0.236	0.069	0.105	0.120
	Recycling behavior			Recognition of GFD		
Age	−0.347 (0.323)	−0.339 (0.326)	−0.463 (0.325)	−0.978 * (0.478)	−0.721 (0.471)	−0.213 (0.443)
Edu. Level	−0.591 (0.737)	−0.587 (0.738)	−0.763 (0.732)	0.0153 (1.09)	0.147 (1.06)	0.882 (0.995)
HH Size	−0.596 (0.649)	−0.582 (0.654)	−0.796 (0.6.67)	0.711 (0.960)	1.16 (0.944)	0.638 (0.907)
HH Income	0.791 (0.511)	0.773 (0.5.20)	1.22 * (0.543)	2.24 ** (0.756)	1.65 * (0.751)	−0.234 (0.738)
Green-certified (1 = Y; 0 = N)		−0.300 (1.54)			−9.71 ** (2.22)	
E1 dummy			−5.23 * (2.25)			24.1 ** (3.06)
E3 dummy			−5.31 * (2.23)			24.4 ** (3.03)
E4 dummy			0.0313 (2.23)			21.4 ** (3.03)
R-squared	0.010	0.010	0.039	0.046	0.090	0.216
	Satisfaction with living environment					
Age	0.181 (0.153)	0.193 (0.154)	0.133 (0.155)			
Edu. Level	0.797 * (0.349)	0.803 * (0.349)	0.717 * (0.348)			
HH Size	0.212 (0.308)	0.233 (0.310)	0.232 (0.317)			
HH Income	−0.165 (0.242)	−0.192 (0.246)	0.0277 (0.258)			
Green-certified (1 = Y; 0 = N)		−0.451 (0.729)				
E1 dummy			−2.73 * (1.07)			
E3 dummy			−1.65 (1.06)			
E4 dummy			−0.458 (1.06)			
R-squared	0.015	0.016	0.036			

Note: Values in parenthesis are Beta coefficients; * $p < 0.05$. ** $p < 0.01$.

4.5. Discussion

This study contributed new evidence to green behaviors in large public housing estates, which has not been studied previously. Findings from this paper are largely consistent with existing literature, that a certified green building does not necessarily enhance green awareness, nor does it guarantee behavioral benefits. The result does not contradict those asserting that by incentivizing green behaviors and by adopting green building technologies, significant energy savings can be achieved without obtaining the green building certification [10–12]. Different from previous literature, our study can be regarded as a natural experiment, in which the occupants were randomly allocated to certified and uncertified housing estates, therefore allowing us to control the self-selection bias.

In general, the results provided an evaluation of the three underlying hypotheses formulated in Section 3.3. First, the questionnaire responses suggest that obtaining a green building certification does not guarantee benefits in behavior and environmental performance (Figure 6), contrary to what has been hypothesized. While the intention behind Hong Kong's mandatory green building certification program in public housing is to promote green awareness, behaviors, and higher levels of occupant satisfaction, this post-occupancy evaluation suggests that the effectiveness might have fallen short of the intentions. Acquiring a green building certification can be regarded as a first step while continuing effort should be made in order to advance the carbon neutral targets set by a growing list of national and local governments.

Second, the study found no evidence that a certified green building is conducive to higher levels of occupant awareness of green fixtures and technologies; nor was there a statistically significant difference in the satisfaction of the built environment between occupants of certified and non-certified buildings, as it is demonstrated in Table 6 and Figure 6. This finding uncovers an important gap in the green building certification program currently practiced in Hong Kong and elsewhere. Currently, the checklist of BEAM Plus does not mandate the display of green labels in certified buildings; rather, it requires the label to be printed in the sales brochure, a practice that is more relevant to elevating the values of commercial real estate properties, yet it is a missed opportunity when applied to public rental housing estates, home to nearly half of Hong Kong's population. Immediate actions are to be taken in order to mandate the certification to be displayed, similar to those by LEED [3]. Furthermore, BEAM credits should also encourage public engagement and other information channels to effectively convey the green message to occupants and drive behavioral changes. Resources should also be invested in alternatives beyond green building certifications, such as environmental education geared towards green behaviors and awareness: occupant's education attainment affects the satisfaction level with the living environment. School curricula, especially K-12 science classrooms, can be used to impart factual and conceptual green knowledge, which would inspire and reinforce green behaviors at home, school, workplace, and elsewhere [23]. The channels through which green building information is communicated to occupants should be diversified and effectively tailored to serve particular age/demographic groups. It is also important to place the right subsidies.

Lastly, the evidence confirmed the hypothesis that green behaviors are attributable in part to socioeconomic characteristics such as income, age, etc. (Table 7). In particular, income was found to associate negatively with electricity consumption behavior, which can be explained by the electricity charge subsidy scheme and concessionary tariff for the senior citizens. Currently, the Social Welfare Department of the Hong Kong government operates a variety of fiscal subsidies to the very-low-income groups and senior citizens [63], including the Old Age Living Allowance, the Old Age Allowance, and the Comprehensive Social Security Assistance. Many were used by recipients to pay for the cost of electricity and water, which might have unintended consequences unfavorable to energy and water-saving behaviors. A more appropriate fiscal subsidy scheme should limit the proportion of funds payable for electricity and water bills, therefore incentivizing environmentally conscious behaviors.

The findings have timely and practical implications for the Hong Kong government, which aims at improving people's living environment by constructing more green housing properties. Public housing estates accommodate nearly half of Hong Kong's population, and higher still in cities such as Singapore. They are responsible for a sizable portion of the city's energy consumption [43]; therefore, they are an important component of the social and environmental sustainability initiatives of metropolitan governments. The findings are expected to inform policy on whether the time and investment in obtaining a Hong Kong BEAM certification, currently mandatory on all public housing estates, delivers the behavioral and awareness benefit as it was intended in the first place. A more nuanced approach to enhancing environmentally conscious behaviors is equally important, if not more than, merely mandating a green building certification for existing and new development projects.

5. Conclusions

This paper describes a post-occupancy evaluation of Hong Kong's public housing estates. The aim is to test the hypothesis that a green building certification induces green behaviors and occupant satisfaction. A natural experiment was conducted on four green public housing estates of similar backgrounds with one fundamental difference—the attainment of green building certification. A questionnaire-based survey was conducted together with ANOVA tests and OLS regression models. In general, the study found no significant impact of certified green buildings on environmental behaviors and occupant satisfaction. A green building certification can partially induce electricity-saving behaviors but does not necessarily affect behaviors towards water saving, waste recycling, or recognition of green fixtures and devices. Nor is there evidence supportive of elevated green awareness or satisfaction with the living environment in certified green housing estates. The policy implication is that green building certifications alone do not guarantee occupant green behaviors and satisfaction. BEAM Plus needs to incorporate a mandatory display of certifications, encourage public engagement, and incentivize information channels to effectively convey the green message to occupants in order to drive behavioral changes. Alternative measures such as public education, and fiscal subsidies designed to incentivize green behaviors should be considered, in addition to green certifications. The findings are relevant to the United Nations' calls for a global agenda for sustainable development [64], ensuring sustainable consumption patterns among urban inhabitants through green building technology becomes critical in dense urban settlements.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su14169862/s1>, S1: Multicollinearity Test; S2: Questionnaire.

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