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Determinants of sustainable upgrade for energy efficiency – the case of existing buildings in Australia

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Abstract

The impact of existing buildings on the environment is on the rise; thus to achieve environmental sustainability requires sustainable upgrade (SU) of existing built facilities. Over the years, SU has focused on technologies with little attention given to the nature and conditions of existing buildings. The purpose of this paper is to identify existing building characteristics that impact SU. A detailed literature review on the nature and characteristics of existing buildings, as well as energy and environmental performance was undertaken. A survey questionnaire with all the determinants of existing buildings was administered to sustainability and construction professionals in Australia. The results show that size of building, age of building, U-value of wall, U-value of ceiling, area of external wall, thickness of insulation materials, occupancy, size of window opening, life span of sustainable technologies, and the type of building impact sustainable upgrade of existing buildings for energy efficiency.

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Keywords: Sustainability; sustainable upgrade; existing buildings; energy efficiency; environmental performance.

1. Introduction

Existing buildings are more than new buildings; in Australia, new buildings contribute only 2% of the building stock. Accordingly, old buildings comprise approximately 98% of the nation's total building stock [1]. In UK, the

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Office of National Statistics estimated that new buildings account for approximately 1% of the stock each year and in the United States of America (USA), the Energy Information Administration (EIA) reports that existing buildings are close to 99% of the total building stock. These cases are not different from other developed and developing countries [2]. This is a source of concern as majority of the buildings to be occupied in the next thirty years or so have been built already [3]. Unfortunately, these buildings are associated with defects [4], corrosion of steel components [5] heat losses as a result of poor insulation [6-7] highly unclassified [8], high level of air infiltration [9-10] and leakages [11] which can be attributed to design and workmanship shortfalls [12].

These defects have generated concerns about possible energy and environmental impact of existing buildings. It is often argued that as this large stock is to cater for the increase in population; a large proportion end up consuming more energy thereby negatively affecting the environment. Indeed, energy consumption of existing buildings has been highly argued, with available estimates and projections indicating that energy demand could rise by 50% in 2020. Global energy use in existing buildings is about 40% [13] of which a significant proportion might be wasted due to various faults in building design, construction and particularly in operation stages [14]. In Australia, energy consumption of existing buildings is close to 19% with 23% of carbon dioxide (CO_2) emissions. Additionally, energy consumption by standalone offices was estimated to be 26.4PJ in 1999; this increased to 33.6 PJ in 2009 and further projected to reach 38PJ by 2020. Thus there is a margin of 14% from 1999 to 2009 and over 29% comparing 1999 and 2020 projections. This pattern is similar to other types of buildings studied by [15].

Over the years, many of these existing buildings have been retrofitted using varying methods and technologies. The upgrades have focused on techniques and components such as insulation materials, HVAC retrofit, the introduction of renewable energy technologies, smart glazing, green roof systems etc. However, there is little attention given to the nature and physical conditions of the existing building stock and how that impact energy efficiency strategies. Therefore, the aim of this paper is to investigate existing building characteristics that affect energy consumption and sustainable upgrade.

2. Research methodology

The study adopts a questionnaire survey to gather quantitative data on the characteristics of existing buildings that impact SU and energy efficiency of existing buildings. The decision to use a questionnaire as a data collection instrument was influenced by the anticipated large sample size of the study population. A survey research method is considered suitable for gathering self-reported quantitative and qualitative data from a large number of respondents [16]. First, literature review was conducted to identify the nature and characteristics of existing buildings, as well as energy and environmental performance. The survey questionnaire covered working experience of respondents, projects undertaken in the past 10 years and the total value of renovations done in the past 5 years by respondents. Further, it focused on the characteristics of existing buildings that impact SU and energy efficiency of existing buildings. Architects, project managers, facility managers, building services engineers and quantity surveyors were randomly selected.

These professionals work with different clients, and buildings such as residential, educational, commercial, heritage, retail facilities and religious buildings. The potential respondents were identified through personal contacts or referrals, company websites and professional associations. Thereafter, invitation letters were sent to the professionals who had the required training and experience. Those recommended by other professionals were given the option to accept or reject the invitation to participate in the survey.

The survey covered a period of 4 months; the first week was used to confirm respondents who had agreed to participate through an open invitation letter. The 2^{nd} week was used to distribute the questionnaires through a link generated by SurveyMonkey. After the initial two weeks of distribution, those who had not responded were sent reminders. This process helped to improve the response rate. After the 2^{nd} month of the survey, the focused shifted to identifying more respondents through the professional bodies. The names, job titles and email addresses of respondents were identified and used to distribute the survey. The initial response was encouraging as regular reminders were sent to the respondents every two weeks. The closing weeks were used to do a final distribution to reach as many respondents as possible. This helped to improve the number of responses received before the last week of the distribution by 10−15%. The data obtained was analysed using SPSS. Figure 1 shows respondents selection and survey distribution approach adopted for the study.

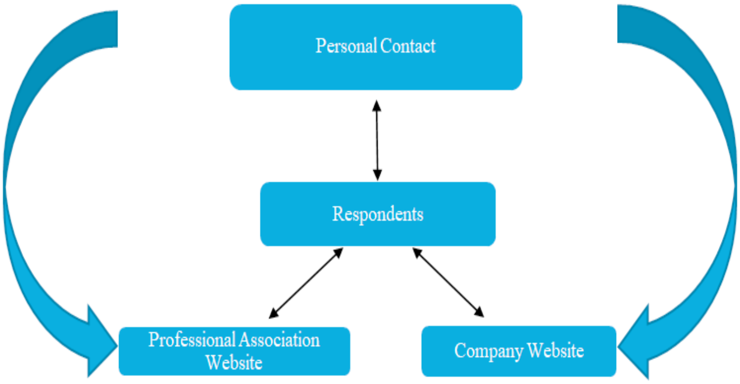

Fig. 1. Respondent selection and survey distribution.

3. Data analysis

In all 350 sets of survey questionnaires were distributed, 86 responses were received of which 81 were complete and used for further analysis. It was established that 78% of respondents were male and the remaining 22% female. Eighty percent (80%) of respondents had more than ten years of professional experience in the construction industry while 90% of respondents had more than five years of professional experience in renovations with sustainable technologies. In relation to their profession; 28% were architects, 15% project managers, 35% engineers, 11% facility managers and another 11% quantity surveyors. In all 40% had undergraduate degrees, 45% postgraduate degrees and the rest, diploma and certificates. Age of respondents supports their experience and ability to take decisions with less supervision. Close to 88% of the respondents were above 30 years and more than 50% were above 50 years. This agrees and reflects earlier suggestions in relation to the years of experience of the respondents.

The second part of the data analysis covered three main areas: reliability test, mean scores and ranking. First, in order to evaluate the reliability of the sample data, Cronbach's alpha (α) was calculated. It is a measure of internal consistency and can be regarded as a measure of reliability of sample data. It should be strong to indicate any inconsistency by testing the existence of variance in the variables [17]. After running the reliability test, a Cronbach's alpha (α) of 0.860 was achieved. Indeed, all the values for the constructs were above 0.8, meaning there is high degree of internal consistency in the sampled variables. Any Cronbach's alpha value above 0.7 is considered acceptable, an indication of minimal inconsistency in the variables [17].

According to [18] any decision to accept or reject a variable is purely a matter of hypothesis where the null and the alternative are always important in drawing conclusions. Thus, statistical t-test of the means estimated were compared with the hypothesised mean set at 3.0 at a significance level of 0.05, as proposed by [18]. This implies that thirteen (13) variables impact sustainable upgrade of existing buildings for energy efficiency. The decision was to reject H_0 and keep the thirteen (13) variables that have significance levels less than 0.05; thus the alternative H_a was accepted. The ranking shows that out of the twenty-four (24) variables, thirteen (13) were highly ranked with means above the hypothesised mean of 3 as shown in Table 1.

The most important variable was the size of building; this was ranked 1st with a mean of 4.351. This was followed by building age, ranked 2nd with a mean of 4.208. Ranked 3rd and 4th were the U-value of wall and external wall area, with mean values of 4.127 and 4.036 respectively. The U-value of ceiling, thickness of insulation and occupancy or number of occupants were ranked 5th and 6th and 7th respectively as indicated in Table 1. The least ranked characteristics were floor structure, orientation, roof material, foundation type, number of car parking and car parking below ground level buildings. Their means and deviations are shown in Table 1. However, those found significant and maintained had p-values between 0.000 and 0.050. The p-values are summarised for all variables with building size (p=0.000), age of building (p=0.000), wall area (p=0.000), U-value of wall (p=0.000), size of opening (p= 0.000) and ceiling height (p= 0.000). Others are the thickness of insulation (p= 0.000), U-value of ceiling (p=0.000), size of window (opening) (p=0.000) and the type of building with (p=0.000), as shown in Fig. 2.

Table 1. Ranking of existing building characteristics

Code	Variables	Mean	p-value	SD	Rank
BEV1	Building size	4.351	0.000	0.664	1
BEV2	Age of building	4.208	0.000	0.726	2
BEV3	U-value of wall	4.127	0.000	0.671	3
BEV4	Area of external wall	4.036	0.000	0.654	4
BEV5	U-value of ceiling	4.001	0.000	0.564	5
BEV6	Thickness of insulation	3.968	0.000	0.613	6
BEV7	Occupancy	3.864	0.000	0.621	7
BEV8	Size of window (opening)	3.746	0.000	0.535	8
BEV9	Life span of technology	3.528	0.002	0.719	9
BEV10	Type of building	3.337	0.006	0.842	10
BEV11	Ceiling height	3.253	0.007	0.871	11
BEV12	Roof area	3.107	0.048	0.863	12
BEV13	Location of building	3.048	0.055	0.857	13
BEV14	Building shape	2.942	0.098	0.915	14
BEV15	Installed technologies	2.848	0.085	0.957	15
BEV16	Door and window positions	2.789	0.609	1.342	16
BEV17	Orientation	2.751	0.686	1.654	17
BEV18	Roof material	2.700	0.782	1.542	18
BEV19	Foundation type	2.605	0.866	1.802	19
BEV20	Number of car parks	2.563	0.862	1.865	20
BEV21	Car park below ground level	2.542	0.755	1.854	21
BEV22	Number of floors	2.431	0.864	1.822	22
BEV23	Number of maintenance	2.019	0.885	1.879	23
BEV24	Type of floor structure	2.000	1.200	1.988	24

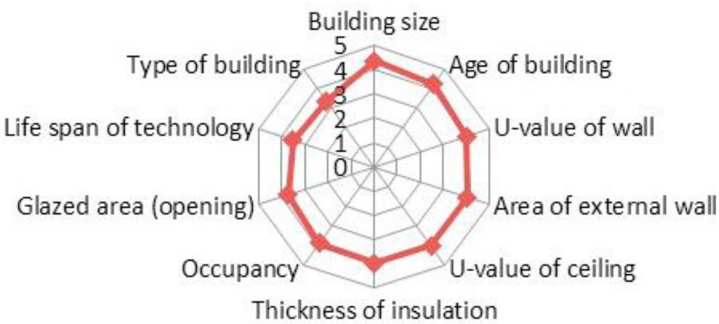

Fig. 2. Summary of highly ranked means.

4. Conclusion

This study has identified existing building characteristics that impact SU. Over the years, studies have ignored the impact of these parameters particularly, how they can impact energy efficiency of existing buildings. This study has identified these characteristics as: size of building, age of building, U-value of wall, U-value of ceiling, area of external wall, thickness of insulation materials, occupancy, size of window opening, life span of sustainable technologies, and the type of building as shown in Fig.2. The size of building as identified in this study is consistent with similar study undertaken by [19]. There is a relationship between surface area and heat transfer from the interior to the exterior environment and vice versa. The impact of insulation on energy efficiency upgrades has been widely acknowledged. Indeed, [20] explained how the level of insulation of external walls of a building impacts energy consumption. Therefore, understanding the impact of these characteristics is beneficial to energy efficiency actions and sustainable construction. Considering the fact that energy consumption in existing buildings is increasing, coupled with the reliance on technologies; the adoption and application of these parameters in SU of existing buildings can lead to environmental sustainability.

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