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Relationship between sustainable technology and building age: evidence from Australia

John Dadzie*, Grace Ding, Goran Runeson

School of Built Environment
University of Technology Sydney, Australia

Abstract

The overall energy performance of existing buildings is an important consideration in decisions to demolish or refurbish. To refurbish means to use sustainable technologies (STs) to improve energy efficiency, health of occupants, energy cost and environmental sustainability. This paper examines the use of STs to streamline energy efficiency in existing buildings. It analyses various buildings of different ages retrofitted over the last 5 years and the various STs used to enhance energy efficiency through an in-built case study in a survey. The results show that buildings less than 15 years old have been improved with fewer façade technologies compared to those between 16-30 years old. Overall, buildings aged between 16-30 years are the most improved with STs followed by buildings less than 15 years old and those between 31-45 years, in that order. Buildings over 45 years are the least improved with STs for energy efficiency. They had received less than 10% of ST technology injection. The lighting systems, sensors, energy efficient equipment and passive strategies have been applied improve energy efficiency across all ages. However, solar technologies, HVAC systems, façade technologies and building management systems are the least adopted across all ages

Keywords: Building age; sustainable technology; energy efficiency; energy consumption; refurbish

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* Corresponding author. Tel.: +61-95148705; fax: +61-295148051.
E-mail address: John.Dadzie@student.uts.edu.au

1. Introduction

It is estimated that new buildings add about 1% to 1.5% to the building stock each year. More specifically, the Office of Climate Change, UK reported in 2007 that new buildings add at most 1% a year to the existing stock, the other 99% of buildings are already built and produce 27% of all carbon emissions. The Australia percentage variations of building stock is similar to that of the UK. Indeed the Department of Climate Change and Energy Efficiency (DCCEE) in Australia has reported that the total area of existing buildings increased from 113 million m^2 in 1992 to 138.8 million m^2 in 2010. This figure is expected to increase to 165 million m^2 by 2020. The United Nations Environmental Program (UNEP) in 2008 stated that the building stock in the world consumes approximately 40%, 25% and 40% of the energy, water and land resources respectively, and is responsible for emitting one third of the total greenhouse gases (GHG) emissions. This is because many of the existing buildings are old with poor energy savings technologies. Interestingly most of these old buildings were constructed decades ago, where there was little innovation in the construction industry. Energy efficiency retrofit of existing buildings has the potential of reducing energy demand throughout the year [1, 2]. Sustainable Technologies (STs) installed in existing buildings through renovation and refurbishment are improving energy consumption. Buildings installed with sustainable technologies and other construction procedures improve the ecological, human health and environmental life cycle [3]. Sustainable construction technologies lead to the creation of an environmentally sound and resource efficient environment, high performance buildings and a reduction of GHG emissions [4, 5].

Many authors have studied energy performance of existing buildings improved with various sustainable technologies. Quite a number discuss energy use in existing buildings through the development of methods and strategies including roof top photovoltaic (PV) retrofitting for old structures in Egypt [6], energy retrofit techniques for various building ages in Tehran [7], and energy saving potential in retrofitting of non-residential buildings in Denmark for old buildings [8]. However, existing literature indicates that energy efficiency regulations apply mostly to new buildings, which add on the average a mere 1% to the built environment yearly [9]. Also the application of sustainable technologies for energy efficiency does not cover old apartment buildings that need to be refurbished [10, 11]. There is lack of detailed studies indicating relationships between sustainable technologies and building ages. What are the technologies for improving existing buildings built before and after 1980? Are all the technologies improving all the various building ages? These are questions which need to be answered in order to address the shortfalls in energy savings of existing buildings. The aim of this paper is to investigate the relationship between ST and building age. Further to identify which class of building age is improved with STs through refurbishment for energy efficiency.

2. Definition and types of sustainable technologies

A ST is any well designed technology capable of addressing high energy demands without posing negative effects to the environment. Any technology that exceeds the benchmark of conventional systems in reducing energy can be classified as a sustainable technology [12]. There are many types of these technologies. Thus, [13] provides a range of various sustainable technologies. They include solar thermal, low energy techniques for cooling, geothermal, wind energy, photovoltaic cells and bioenergy. For each technology [13] provides the types, functions, advantages and disadvantages and concluded with their efficiency potentials needed to reduce energy demand or consumption. However, [12] improved the various types of sustainable technologies for new and existing buildings provided by [13]. They include the underfloor air distribution system, radiant cooling, displacement ventilation, chilled beams, and displacement induction unit. Others are high performing envelope, solar energy, geothermal systems, and cogeneration. Quite recently [14] improved the studies on the HVAC systems conducted by [12] and provided detailed descriptions of the functions of each component required for energy efficiency. Although these studies were extensive, key technologies such as lighting and lighting control systems were not addressed by [12-14]. Lighting is an important electrical end use in every sector and building type across the world. These gaps relating to lighting and lighting control systems were filled by [15] and [16].

3. Sustainable technologies applied to improve buildings of varying ages

Energy consumption of some old buildings is expected to improve when upgraded with STs. Many studies have been undertaken on how to improve energy efficiency of old buildings with various technologies. The main aim of this section is to identify building ages as well as technologies applied to improve energy efficiency of existing buildings by focusing on studies undertaken internationally. These technologies vary from renewable to simple energy efficiency technologies. A study conducted in Tehran, [7] presented findings of schools built before and after 2000 using low quality construction materials. The schools had no exterior insulation but single glazing windows with metal frames. Through an initial preliminary audit of energy consumption and a study of the general conditions of the buildings, the authors reduced the scope of the technologies used to address only air tightening, window replacement, and roof insulation from a complete overhaul of the building. After the application of the technologies, the energy consumption and thermal environment of the schools were monitored for a period of time. The results show primary energy reduction of 29.87% for the revised scope and 38.29% for the original scope. However, these are not the only techniques or strategies that can be adopted for old buildings. Indeed in relation to the roof, [6] focused solely on how to renovate existing old buildings built in the 19th century with a PV roof panel on vernacular buildings. They estimated that the dwellings were built around the late 18th and early 19th centuries, because of lack of information to trace the actual age of the buildings. They employed basic materials primarily salt clay (*Karshief*), adobe, and palm tree wood to build the envelope. Results show that by combining passive strategies with affordable active renewables such as roof top solar panels results in a hybrid energy efficient retrofitting solution for deprived off-grid vernacular buildings.

The early part of the 1940s to the 1960s witnessed massive improvement in building construction. Many of these buildings were built with little injection of ST due to their unavailability and lack of knowledge concerning their effectiveness. Similarly [8] studied the upgrade of an office building originally built in 1968, which had undergone an initial energy renovation carried out in 1991. Providing details of technologies introduced during the first upgrade is likely to influence the rate of technology injection. Because their performance and the rate at which they improve energy performance of existing building will be recorded. According to the authors, the building had a relatively poor insulation level and the windows from 1991 were reaching a state where they had to be replaced after the initial upgrade. Because the envelope is just an aspect of decisions to retrofit, ventilation and the use of renewable energy technologies such as solar panels were added. This was to increase the technologies to address other sections of the building. The renovation included changing both the distribution system and the radiators in the building, an 80 kW cooling surface was added to the ventilation system and the entire ventilation system was replaced during the energy retrofitting. A single case study of one of the largest buildings in the former Faculty of Technology in Zagreb built from 1958 to 1964 was studied by [17]. The building had undergone many renovations to address roof leakages and air infiltration. The flat roof of the building was partially refurbished in the 1980s. However, lack of information on the refurbishment made it difficult to determine which parts of the roof were repaired. This agrees to similar statements shared by [8] where they could not identify key technologies introduced during an initial refurbishment of the building they studied. After initial calculations using the U-values of the external envelope, the authors settled on improving the energy efficiency of the building using thermal insulation of walls and roofs, replacement of old windows and doors and installation of a door for wind protection for the 52 years old building [17]. It was identified through the review that studies relating to STs and building age lack structure and focused on using case studies. This structure is needed to identify STs improving energy efficiency for each category of building age. Investors, industry and academia require such analysis to help in decision making as well as improvement in the energy efficiency of existing buildings.

4. Questionnaire survey and design

The paper examines the relationship between ST and building age. The study adopts a questionnaire survey to collect quantitative data about the use of sustainable technologies to improve 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 selfreported quantitative and qualitative data from a large number of respondents [18]. A questionnaire and an in-built case study were developed using a three-stage process. First, literature review was conducted to identify STs and building ages used in previous research. This contributed to the framing of relevant questions such as identifying which types of STs are improving energy efficiency and for which building age group. To ensure the validity of the questions, the questionnaire for users was piloted before being finalized. The main objective of conducting the pilot study was to discover similar or varying opinions of respondents and verify the relevance of the questions. In order to achieve this objective; a small pilot study was conducted using 12 consultants in April 2015. Suggestions were proposed during the exercise in line with most pilot studies. Before distributing the questionnaire, suggestions proposed by the consultants were used to modify some of the questions and a few new questions were added. Some proposals were made concerning other types of STs that were missing in the initial structure. Key example is the addition of Phase Change Materials (PCMs) to the list of STs. After modifying the questionnaires through the pilot survey, a final version was administered to the sample. This approach is in tandem with similar sustainability studies by [19].

The questionnaire was divided into three main parts. Part I related to general information of respondents. They include 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. The maximum value of past projects was 60 million dollars with the least, 20 million dollars. Part II focused on sustainable technologies adopted to improve energy efficiency of existing buildings. Sustainable technologies were categorised into five major groups: lighting, HVAC, automation, façade and building management systems. Retrofitted buildings over a period of 5 years were investigated. Part III focused on recently refurbished buildings, as an in-built case study in the survey design. Here respondents were asked to provide details of the project in relation to the building type, age, number of floors below and above ground level. In the in-built case study the respondents were asked to list all sustainable technologies adopted to improve that single building. The challenges encountered during the introduction of the technologies were also identified. Also requested were a brief description of the external walls and the roof of the building to show whether they were flat, pitched or green roof. This section was aimed at identifying key features of the building envelope the respondents had improved. This approach is similar to previous studies undertaken by [20]. The respondents were not restricted to any category of technology, however they were asked to list technologies they used to improve energy efficiency.

Architects, project managers, facility managers, building services engineers and quantity surveyors who formed the core of respondents were randomly selected from professionals registered with various professional bodies in Australia because of their extensive experience in renovations with sustainable technologies. These professionals work with different clients concerning various types of buildings: residential, commercial, office, retail facilities and historical buildings. They were selected as the target group to complete the questionnaires. The potential respondents were contacted through personalised contact, referrals and professional associations. Thereafter invitation letters were sent to the professionals who had the required training and experience through their professionals associations. Their email addresses were obtained from three sources-the official company websites of the respondents, referrals and professional bodies. Those recommended by other professionals were given the option to reject the invitation where they did not meet the expected working experience. The survey covered a period of 4 months, from June to September 2015. The first week was used to confirm respondents who had agreed to participate through an open invitation letter. The 2nd week was used to distribute the questionnaires through a link generated using the SurveyMonkey portal. 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 2nd month of the survey, the focused shifted to identifying more respondents through the professional bodies of the respondents. Their names, job titles and email addresses were identified. Thereafter the survey was sent to as many as possible. Initial response was good because there were regular reminders sent to all every two weeks as applied to those obtained through their company websites. The closing months 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 month of the distribution by 10-15%. The data obtained was analysed using SPSS.

5. Analysis of results

In all 350 sets of questionnaires were distributed, 86 responses were received of which 81 were complete and used for further analysis. For the in-built case studies, a total of 45 case studies were analysed. 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 or certificates. Age of respondents supports their experience and ability to take decisions with less supervision. To be able to take critical decisions with less supervision comes with experience which relates closely to age. Close to 88% of the respondents were above 30 years and more than 50% were above 50 years. This agrees and reflects earlier suggestion in terms of the years of experience of the respondents. According to the results 34% indicated that in the past 10 years, a total value close to $20 million was spent on improving energy efficiency through renovation, 26% stated that, between $21-40 million had been invested on energy efficiency improvements, 14% indicated that between $41-60 million had been pumped into energy efficiency improvements, and 26% with a total of value of renovation works of over $61million.

Relationship between sustainable technology (ST) and building age

The analysis focused on the relationship between ST and building age. In terms of the building age, it captured those below 15 years to those over 45 years old. It also covered a number of STs as shown in Table 1.

Table 1: Relationship between sustainable technology and building age

	Building Age				
Sustainable Technologies	Under 15 years	16-30 years	31-45 years	Above 45 years	**Total**
High energy efficient lighting systems	Y	Y	Y	Y	**22%**
Lighting control systems	Y	Y	Y	Y	
Double glazing	Y	Y	Y	Y	**21%**
Double skin façade		Y	Y		
Low-E glazing		Y	Y	Y	
Low-E façade		Y	Y		
Insulation(floor, wall and roof)	Y	Y	Y	Y	
High efficient and energy saving equipment(chillers,pumps,air economisers, heat recovery systems, boilers)	Y	Y	Y	Y	**17%**
Night purge			Y		
Chilled beams	Y	Y			
Underfloor air distribution systems	Y	Y			
Cooling tower	Y	Y			
Energy Efficient Fans		Y	Y	Y	
Solar PV	Y	Y	Y		**8%**
Solar hot water system	Y	Y	Y		
Solar thermal		Y		Y	
Wind turbine					
BM	Y	Y	Y		**13%**
Smart meter	Y	Y	Y		
Movement sensors	Y	Y			
Passive strategies	Y	Y	Y	Y	**18%**
Destination designed lift		Y			**1%**
Total	**27%**	**46%**	**18%**	**9%**	**100%**

To investigate the relationship between age and ST, a detailed review of literature was undertaken. This was followed with data collection through survey as discussed in the previous sections. Table one shows the technologies installed in each category of building age. The 'Y" in each shaded cell represents "Yes", otherwise, "No". Similar approach was adopted by [21]. The buildings are arranged by their ages starting from those under 15 years, to those over 45 years old. In the case of the technologies, they were grouped under six main headings and sub-headings, as follows: Lighting related technologies, building envelope technologies: HVAC technologies, renewable energy technologies, building automation systems and passive strategies which natural daylighting techniques, shading, paint colours, use of eaves, cross ventilation design etc. The table only provides a list of the rate of adoption and application of each sustainable technology studied. The application of a technology for existing buildings less than 15 years old is coloured red. That is buildings built after the introduction of Green Star classifications. Buildings between the ages of 16-30 and 31-45 years are in brown yellow and finally violet for those over 45 years old. Sustainable technologies mostly installed across all the various ages were the lighting (22%), envelope (21%), passive strategies (18%) and HVAC systems (17%). In relation to ages, the most improved building were those between 16-30 years (46%) followed by those under 15 years (27%) and those between 30-45 years (18%). Those over the age of 45 years were the least improved category with less than 10% of ST injection. Existing buildings over 45 years fell short in three specific areas: the renewable energy technologies, building automation and HVAC systems.

6. Discussion of results

It is a general phenomenon that as time goes by buildings age. Technologies in buildings are rapidly advancing largely to improve energy efficiency in existing buildings. The extent of upgrade varies from simple technologies to sophisticated sustainable technologies. Upgrading aging buildings through energy retrofit had been widely accepted as the top-priority choice all over the world [22]. The analysis indicates that not all the technologies are installed in the various categories of building age. For buildings under 15 years old, few sustainable technologies were lacking. They include façade technologies, solar energy and energy efficient fans. This is because most of these buildings are already built with the injection of STs thus they often require little or no application of ST to improve energy efficiency [23]. However, not all the buildings are classified under the Green Star or the NABERS classification [24] and existing energy efficiency regulations require a minimum injection of STs. Buildings aged between 16-30 years old tend to attract investment towards energy reduction compared to the very old buildings. This implies that they had minimal level of sustainable technology when constructed. However, these buildings tend to have the structural grid and space dimension close to new buildings. Thus improving their energy efficiency with modern technologies poses a minimal challenge compared to the older buildings. In addition, buildings aged between 16-30 years old are considered economically viable hence energy efficiency actions or retrofits target this group. They are generally perceived less expensive to upgrade so as to meet Green Star rating. This allows owners of sustainable buildings to capitalise on their investment [25], meaning profit is not lost. Thereby increasing the awareness of building performance in the property market and hence the demand for high-performing buildings [26-28].

One of the reasons why old buildings are attractive is that they are irreplaceable and visually distinctive. However, they may suffer from deterioration and tend to cost more to renovate than to rebuild [29]. Common building defects include structural defects resulting in cracks; defective lighting, defective or faulty plumbing, inadequate drainage systems, faulty ventilation, cooling or heating systems, insufficient insulation or sound proofing, and inadequate fire protection. These defects make old buildings unattractive and expensive to renovate. They tend to affect the rate of technology injection into very old buildings if not for heritage reasons and other historical conditions [6]. This implies that only a few old buildings, due to commercial and other purposes are renovated with STs. It is sometimes difficult to make old buildings meet current sustainability standards [30] and often too expensive to renovate [31-32].

Apart from the cost implications, defects in old buildings lead to poor energy performance which can be improved through the use of STs. Technologies to improve energy efficiency are known for their efficiency and effectiveness but at the same time may be more expensive. They often require high initial investment cost [33]. The final cost of construction is not the only problem, the initial cost of such technologies is vital. In addition

[34] stated that usually the initial cost of renewable/sustainable energy technologies tend to be high and uncompetitive which may prohibit consumers from adopting them. Again, many clients and investors want to keep the initial cost low rather than minimizing the operating costs [35]. In some instances influence of both the firm's internal characteristics and the type of technology, features on the probability of adoption [36]. These factors hinder investment of STs in old buildings to improve energy efficiency. Indeed these results agree with earlier findings undertaken by [10, 11] where they indicated minimal use of STs to improve energy efficiency of old buildings. These discussions suggest the need for policy measures that can engage clients and investors in addressing the long term goal of sustainable construction.

7. Conclusions

It is commonly thought that the age of a building has no relationship with the type of sustainable technology adopted for energy efficiency. The main aim related to the relationship between building age and sustainable technology. This was established through extensive literature review and 45 case studies. It has been established that building age and ST are strongly related. The lighting systems, sensors, energy efficient equipment and passive strategies have been applied to improve energy efficiency across all ages. In terms of building age, the most improved were those between the ages of 16-30 years followed by those below 15 years old and those between 31-45 years old in that order. The least improved category of building age was those over 45 years old. Most of these buildings are old. They also represent the very purpose of introducing energy efficiency to improve energy savings. In addition, buildings over 45 years old fell short in terms of STs adopted to address solar energy, wind turbines, the building envelope, and the HVAC systems. They were mostly improved with the lighting and insulation systems, which are less expensive, an indication of lack willingness and investment to improve energy efficiency.

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