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Greening Existing Buildings for Energy Efficiency: A review

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ABSTRACT: Construction industry in general, and buildings in particular, is the largest consumer of natural resources and the biggest polluter of the environment, including energy consumption and greenhouse gas emission, which are among the main reasons for climate change, directly or indirectly. Extending the concept of green building to existing buildings (i.e. greening existing buildings), can considerably reduce energy consumption in buildings and thereby help to reduce the risk of climate change. A structured literature review was conducted that identified ten types of new or emerging green features that are used in existing/old buildings to offer increased energy efficiency and higher margin of savings. These include: energy efficient equipment, smart and high performance lighting systems, HVAC system, PV system, solar water heating system, green roof, green wall, and energy consumption monitoring device. Many of these features are seen to be used in various building types (like residential, school or office buildings) and in different climate zones, but with different target in many cases. As such, their selection appears to have influenced by a number of factors, including local/regional climate, degree of savings, underlying policy and leadership. A number of challenges against wider practice of such greening were also anticipated, including limited local research, awareness, availability of information on green features, cost-effectiveness, availability of design information of existing buildings, lack of a sound policy, high initial costs of some green features (e.g. green roof), and collaboration between different parties. It appears that a country/region specific policy addressing the identified issues/challenges is expected to help wider practice of greening in existing buildings to offer significantly reduced energy consumption (and cost) and emissions, and thereby reduce the risk of climate change.

Keywords: Energy efficiency; green building; greening existing building; green features; green policy; retrofitting.

Abbreviations: GHG, greenhouse gases; EPA, Environment Protection Agency; USGBC, United States Green Building Council; CO_2, carbon dioxide; GEB, greening existing buildings; UNESCO, United Nations Educational, Scientific and Cultural Organization; HVAC, heating ventilation and air conditioning; SPEC, Standard Performance Evaluation Corporation; LEDs, Light Emitting Diodes; CFL, Compact Fluorescent Light; PV, photovoltaic; IAQ, indoor air quality; CEMS, campus energy management system; WLC, whole life costs.

I. INTRODUCTION

Globally, buildings consume about 40% of all energy and materials, one-sixth (i.e. 17%) freshwater withdrawals, one-fourth of wood harvest and two-thirds of all electricity [1-2]. The United States alone consumes approximately 36% of total energy and 13% of water, emits 30% of GHG, and generates 170 million tons of construction and demolition waste per year [3]. Buildings emit 38-50% of GHG in the United Kingdom [4], and consume 28% of the national energy in China [5]. Some other sources report that the building sector is responsible for almost half of the energy consumption [6] and GHG emissions [7]. Although the figures from individual studies and different countries are slightly different, they all show significant impact on the built environment in general. The concept of green building was introduced to address the above consequences on the built environment, which is applicable to new buildings only.

According to EPA, green building is the exercise of using certain environmentally responsible practices to produce structures that are, and remain, resource-efficient during its entire life-cycle, i.e. from design to deconstruction or demolition [8]. Similarly, USGBC [9] considers green building as a concept, under which buildings are planned, designed, constructed, and operated focusing on some key aspects, like energy use, water use, material selection, indoor environmental quality, and the building's impact on its surroundings [10]. This requires extensive examinations of different options/alternatives during the design process, using an integrated project delivery approach where consultants, clients and contractors work together as a team, which can only be done for new buildings [11]. Moreover, there is an extensive number of economically viable old buildings [12]. Constructing new buildings by demolishing existing buildings will generate huge wastes, consume many natural resources and require huge capital investment, which is grossly against the sustainability principles [12-13].

However, many of the existing building stock had been constructed before the concept of green building emerged. Those buildings are not sustainable in many ways. For example, existing buildings consume world's

40% of energy, and emit 24% of CO_2 [1, 14, 126]. Moreover, about 95% of the existing buildings are categorized as high-energy consumption buildings [15] and occupancy or building operation stage consumes more than 80% of its life-cycle energy consumption [5]. Two separate studies recently forecasted that demand for energy consumption in buildings will increase by up to 50% in 2060 due to increase in population [127, 128]. Another recent study forecasted that about 75-90% of the existing buildings are predicted to remain in use in 2050, since buildings have a quite long-life span of more than 50 years [129]. Therefore, ensuring energy efficiency of old/existing buildings is a critical issue, both in terms of GHG emission and energy consumption [5]. It is therefore necessary to furnish the existing/old buildings with sustainable, modern and energy-efficient appliances/features and/or emerging technologies, in place of old features/appliances (like heating/cooling systems, door/window shutters and/or shades, energy efficient equipment, and green roof or roof top gardens), either in a planned way or during their renovation, retrofit, repair or maintenance works, through the 'greening existing buildings' (GEB) process [12, 16]. This cannot convert existing buildings into green buildings, but can considerably improve their environmental performance. For example, GEB can cause 'upgraded' buildings to emit about 35% reduced GHG compared to their pre-upgraded stage, which is a major cause of climate change [9]. Some other benefits of GEB are: efficient use of natural resources (e.g. energy and water), improved employee productivity, protection of occupants' health, enhanced building owners' reputation, creating job opportunities, increased occupancy rates and rent, reduced operation costs, and reduced emission and/or pollution, waste and overall environmental degradation [5, 12, 17].

Despite such benefits, GEB is not widely implemented in many countries and practiced at very low rate [13, 130, 131], e.g. the rate on such practice is only 0.4-1.2% each year in Europe [132; 133]. This is probably due to the reason that greening projects are considered as riskier, more complex, more difficult and more uncertain than constructing new green buildings, and even than the general retrofit projects [18-19, 131]. Moreover, it involves increased interactions between stakeholders, complex risk sharing and significant lack of information of existing buildings [18-20, 134]. Evidently, there is an urgent need for further study on how exactly the relationships between, and perceptions of, the stakeholders affect the decision towards the greening process; as well as what motivates or retards them in considering GEB; and how exactly GEB can widely be practiced. As such, this study has been launched in Brunei to identify a set of underlying motivators and challenges, identify how best the GEB technologies can be adopted, and develop a framework for wider adoption of GEB.

As the beginning of the study, this paper particularly focuses on an extensive review of literature, to tap necessary knowledge on 'greening' in general, covering types of greening, focus or target areas towards greening (i.e. why greening is done), commonly used green features, and motivations and challenges to undertake such greening. The aim is to gather sufficient information and knowledge on GEB in general, and on motivators and challenges in particular, to form the basis for further study targeting to develop the said framework, as well as to provide an insightful overview of GEB to common users. However, the following section discusses the methodological approach of this paper, before discussing various aspects of greening.

II. METHODOLOGY

This paper is based on structured review of literature, which is concerned with identifying the key issues in the review. The initial process is the scanning of the broad collection of documents or information to provide knowledge of the subject area and then grouping the identified documents in similar topics. Hence, the first step was to search for information/publications in three different sources/research databases, namely the Science Direct, Taylor and Francis, and Emerald Insight, although it was later revealed that the most of the usable publications for this paper were from the Science Direct. Five different keywords were used for the search: green building, greening existing building, retrofitting, adaptation, and green features. The criterion for search was by 'relevance'. As shown in Table 1, individual keywords produced search results with very high number of publications. In order to reduce such high volume of publications, a step-wise elimination or screening process was applied. All the keywords were used together as the first round of screening. This eliminated significant number of publications, to (480+754+143=) 1,377 that was still high.

Table 1: Number of publications from search result.

	Science Direct	Taylor and Francis	Emerald Insight
Keywords/Sites			
Green building	252,179	213,639	22,907
Greening existing building	101,427	155,100	18,080
Retrofitting	25,506	9,720	1,805
Adaptation	683,742	70,400	87,078
Green features	555,323	200,963	15,209
All Keywords in One Search	480	754	143
After elimination process	**108**		

Two more rounds of screening was then applied: (i) eliminating publications of same title and duplications caused by the keywords, although only a few duplications were found; and (ii) examining the abstracts and scanning the remaining contents of the publications to ensure that the papers mainly deal with energy efficiency. This last step was to ensure that the publications used in this study are relevant to 'greening' concept, which eventually reduced the number of publications to a manageable 108 for final review. This included 95 journal papers from 50 periodicals and 13 conference papers from six conference series. *Journal of Renewable and Sustainable Energy Reviews* was the most frequent periodical with 16 papers.

This was followed by *Journal of Cleaner Production* with 12 papers, *Journal of Energy and Building* with 5 papers, and *Energy Procedia* with 4 papers. While the above-mentioned 108 publications supplied the core information, the total number of references used in this paper is more than that. The additional references are to substantiate some arguments and those include books and online resources.

III. GREENING EXISTING BUILDING

UNESCO [21] focuses on greening to achieve sustainability of natural resources and environmental protection for present and future generations, using more ecologically responsible knowledge and practices, through enhanced decision-making and more environmentally friendly life-style. For newly constructed green buildings, this is pursued at design stage by investigating different design alternatives [11], but achieved during repair or renovation works of existing buildings [22]. Two techniques are used for such GEB: retrofitting and adaptation. Both the techniques are getting increased recognition as alternatives to newly constructed green buildings [23].

A. Retrofitting

Retrofitting is to providing, extending or substantially altering the services and/or envelope of existing buildings [24]. Target is to increase their environmental performance, mainly by reducing energy use or generating renewable energy, through upgrades to systems or fabrics [131]. Such upgrading of building physical characteristics is interchangeably termed as retrofit, modernization or refurbishment, which offers considerably reduced GHG/carbon emissions and energy consumption [24-25].

In other words, retrofit can upgrade/convert existing buildings to much efficient low carbon buildings to considerably contribute to climate change mitigation [26]. Benefits of such upgrading/retrofitting are widespread. It improves building condition, occupants' comfort levels, exterior view and noise insulation; raises building value, extends building life, and ensures working condition and healthy living; in addition to reducing energy consumption and negative impact to environment [27].

According to Zhou *et al.*, [28], policies that motivate building energy efficiency in countries like Japan, China and Unites States indicate that energy efficiency is central to retrofitting/upgrading existing buildings. While economic viability is critical to retrofitting, the focus is on upgrading HVAC systems, enhancing building envelope, and installing renewable energy systems. Also, adoption of different retrofit strategies can give different results, e.g. solar shading and glazing strategy can reduce energy consumption of up to 23% and 8%, respectively [135].

B. Adaptation

Purpose of adaptation or adaptive reuse is to improve environmental performance of existing buildings [29]. It converts a building for an updated purpose through reusing process. The Department of the Environmental and Heritage, Australia [30] defines adaptation as a process that converts an ineffective/disused property to using it for a different purpose. Adaptation also refers to many other similar terms that modify the building to some extent, e.g. improvement, renovation, extension, refurbishment and alterations [31].

The adaptation process is growing quickly, as existing buildings in many parts of the world need to perform better [32]. Adaptation is implemented by keeping fabric and maximum original structure of existing buildings, for their changed use and extended lifespan. Adaptation consumes less energy, reduces GHG emission, uses fewer materials, produces less waste, and offers an effective alternative to demolition and rebuilding [33-34].

IV. GREEN FEATURES

Table 2 presents the commonly used green features found through literature review that focus on energy efficiency. These are discussed in the following subsections.

Table 2: Common green features.

Green Features (number of study)	Country (number of study)
Energy consumption monitoring device (1)	China (1)
Energy-efficient equipment (11)	China (3), Malaysia (2), Indonesia (2), USA (2), Kazakhstan (1) and UK (1)
High performance lighting (10)	Australia (1), China (1), Indonesia (1), Iran (1), Israel (1), Kazakhstan (1), Mexico (1), Turkey (1), UK (1) and USA (1)
Smart lighting system (2)	Israel (1) and USA (1)
Shading devices (9)	Turkey (2), Australia (1), Canada (1), China (1), Egypt (1), Iran (1), Israel (1) and Italy (1)
HVAC system (7)	China (2), Israel (1), Finland (1), Malaysia (1), Norway (1) and USA (1)
PV system (6)	China (1), Egypt (1), Italy (1), Norway (1), Turkey (1) and Kazakhstan (1)
Solar water-heating system (6)	China (2), Australia (1), Malaysia (1), Norway (1) and USA (1)
Green roof (7)	Australia (1), Cyprus (1), Iran (1), Israel (1), Malaysia (1), Turkey (1) and Saudi Arabia (1)
Green wall (1)	Turkey (1)

A. Energy consumption monitoring devices

Controllable appliances and devices that are used in buildings include lighting, curtains, garage door, windows, television, fridges, washing machines, hot water systems and heating systems [35]. These are controlled using monitors and sensors by detecting factors like humidity, light, motion, and temperature. Dedicated hardware interfaces (like wall mounted control) or computing devices (like personal computers, tablets, laptops or smartphones) are installed with software to allow control [36]. Monitoring is essential in determining appliance-specific energy consumption and respective contribution to overall energy efficiency within the system as impacting from allocation decisions [37]. For instance, it is possible to achieve 10-40% energy savings in commercial buildings by closely monitoring [38]. A wide range of such monitoring controls or strategies are available. Some of them may be generic, while some others are designed and developed for specific studies/projects.

One such system is 'building automation and control systems' that includes energy analyzer (counter), various sensors for detecting variations in temperature, motion and brightness. This system gives statistically analyzed and organized data through real time monitoring on energy use, and its efficiency level and economic performance in buildings. This allows energy end user to compare various consumption profiles of separate time periods and detect weak points, as the tool gives output data in the forms of pick load, off-pick load, and average consumption, with graphs and statistics of energy consumption and relevant economic impact [38]. Similarly, Standard Performance Evaluation Corporation (SPEC) proposed a power-monitoring methodology to assess energy consumption and/or efficiency of a single or a group of servers running a business benchmark [37].

'Energy management system' is another computerized system for encouraging sustainable energy-saving behaviors, which allows a device to provide visual real-time feedback on electricity and/or gas consumption [39]. It enters the monitoring system through windows operating system, and visualizes the data stored in the database, using mobile phone or PC browser. Similar other systems include: 'home automation system' that focuses on controlling temperature and electric elements of a living room; 'domotic control' is designed to control a smoke signal, lights, and a shutter; as well as some other systems to remotely control some electric elements like alarm, light bulbs, electric lock and fan [40]. Some other systems also allow efficient and independent data transmission remotely, using a self-rechargeable device with solar energy that controls energy supply to sensors [41]; communication protocol module called Zig Bee [42]; and even some 'tiny energy accounting reporting system' use their self-acoustic signatures to listen to turned-on appliances to their respective energy consumptions [43].

B. Energy-efficient equipment

High-efficiency equipment or appliances can help to reduce building energy consumption. The most common energy consuming devices/appliances used in buildings include television, microwave, water heater, laptop, refrigerator and cooker. Among these, air conditioner and refrigerator use the highest energy/electricity. The use of such appliances is increasing, along with increase in population. As a result, electricity consumption in residential and commercial buildings is also increasing at an alarming annual rate of over 10% during the last decade [44]. Therefore, there is a need for low energy consumption appliances to help to reduce energy consumption. Three such appliances can significantly help to reduce energy consumption. The first is 'energy-efficient refrigerators'. A study observed that the energy consumption was reduced from 1200kWh/year to 385 kWh/year by using 'energy efficient refrigerators', for household income saving of about USD140/year [44]. Another study compared the energy consumption of conventional schools and green schools (i.e. school buildings constructed following the principles of green building) equipped with 'high-efficiency air-conditioning systems', to observe that green schools consumed 41% less energy than conventional schools. The average electricity consumption in green schools was 139,824kWh/year, compared to the average electricity consumption of 180,700kWh/year in conventional schools [45].

The third category is 'energy efficient motors', which is integral to modern buildings in running major electrical appliances/devices like elevators, pumps, and fans. Along with equipment/devices they drive, such motors can significantly reduce energy consumption and thereby building operating costs and emissions. The use of high quality materials, along with optimized design and improved configuration of internal parts (e.g. cooling fan and bearing), allow significantly reduced magnetization, resistance and/or friction losses. All these result in to reduced energy consumption [46].

C. High performance lighting

Lighting system is one of the major consumers of electrical energy [46], which is one of the fastest growing electricity consumption area in China during the last two decades, with an average growth of 14% per year [47]. Therefore, major advances have been made in: (i) lighting fixture and control technologies (i.e. smart lighting control system) that considerably reduce energy consumption, (ii) and the two most common high performance lights that are used in all building types: Light Emitting Diodes (LEDs) and Compact Fluorescent Light (CFL).

LEDs consume less energy than other lighting technologies, e.g. CFL and incandescent bulbs. LED lamps can be recharged using solar energy to run about 5-12 hours, and last 20 and 2-3 times longer than incandescent bulbs and CFL, respectively [48]. Moreover, LEDs last about 1-3 years, depending on their usage and product quality [46]. On the whole, LEDs appear to have more advantages than disadvantages, as advantages include: compactness, low operating voltage, light-weight, high illumination, mercury free, easy control, easy recyclability, no harmful radiation and intense color range; and disadvantages include: temperature dependency, potential light pollution, risk of glare, comparatively high price and lack of standardization [49].

Fluorescent lighting or compact fluorescent lamp (CFL) is a popular lighting choice for most building lighting applications, especially for residential, commercial and institutional buildings [50], since it can be effectively controlled using switch [46]. Benefits of CFL includes longer bulb life (so less expenses in buying them); and reduced energy consumption that reduces mercury and CO_2 emissions, wastes from electricity generation and air pollution [50-51]. Although CFL contains a very small amount of mercury, if compared to incandescent bulbs, it provides efficient lighting, uses 4-5 times less energy, and lasts 13 times longer [46, 51].

D. Smart lighting system

According to Kibert [46], smart lighting control system should be an integrated system to perform two main tasks: (i) to detect occupancy and, depending on the presence or absence of occupants, turn lights on or off; and (ii) to adjust illumination of bulbs depending on the availability of natural light from daylighting. These are done by motion sensor and brightness sensor [52]. Smart lighting systems can potentially reduce electricity consumption of up to 50% in office buildings, with their continuous dimming, link with daylighting and automatic on-off features [53-54].

Dimming control is suitable during day time, and in deskwork based offices and schools, and allows greater savings [46]. However, the lighting control and sensors need to be carefully designed to increase energy saving, e.g. by combining automatic and manual controls [55]. Manual dimming by occupants also allows energy savings of up to 35%, where individual occupants can control room illumination and effect long timeout periods, e.g. during nights and weekends [53].

E. Photovoltaic (PV) system

PV system uses semiconductor devices to generate electricity from sunlight [46]. The solar power is the most abundant, and also the most underutilized, natural resource [56]. Solar-based PV systems are ideal or the cleanest sources of energy, as they do not produce any waste or CO_2 for generating electricity. However, they generate direct current that requires inverter, need larger area and are solely dependent on sunlight; but they have long life-time of about 30 years with very little or no maintenance requirement, do not require any other fuel than sunlight, do not produce waste or pollution, and electricity produced can be stored and used when required [46, 56].

F. Solar water – heating system

There is usually high demand of hot water in facilities with kitchens, health club or residences, which consume large amounts of energy, and therefore involve costs. The use of solar water heating technologies can reduce the energy demand and relevant expenses relating to water heating [46]. It was observed that 30-40% of electricity bill of a family comes from water heating, 70-90% of which can be saved by using solar water heating [57]. Depending on the size and type, such a system is highly cost effective with 2–4 years of payback period, involves negligible operation and maintenance expenses, and is environmentally friendly [58]. The system captures thermal energy from solar power and heat water up to 60-80^{o}C, which is collected and/or stored in an insulated tank for use. Application of thermosiphon principle allows automatic circulation of water between the collectors and the tank and makes the system more efficient [57].

G. HVAC system

HVAC systems are combined processes that perform many functions simultaneously, i.e. heating, cooling and ventilating the occupied spaces of buildings [59]. Less efficient HVAC systems with large energy consumption are frequently seen in existing buildings [60]. It is reported that HVAC systems consume about 47% of building operational energy in China [61], and about 60% of electricity in residential buildings in Brunei [62]. Therefore, it is important to adopt and implement high-efficiency HVAC systems, to improve energy efficiency and reduce energy consumption in buildings.

Heating includes heating the air and occupants within the space; whereas ventilating means providing adequate air to breathe without too much CO_2, control odors and remove contaminants from occupied spaces; and air-conditioning refers to control of air temperature and air humidity of a room [59]. HVAC systems contain heat and mass transfer equipment, including heating or cooling coils, boiler, chiller, thermal storage systems, liquid distribution air distribution system and air-handling equipment [63]. They can be of three main categories, depending on whether air or water is used to heat, cool and ventilate the building/space. They are all water, water-air, and all-air systems, and are used to suit the specific conditions of the spaces, e.g. either to heat or cool [64].

H. Green roofs

Green roofs are also called vegetation roofs, eco-roofs, or living roofs [65]. They are basically thin vegetation layers fitted/built on building roofs. They allow enhanced energy efficiency of buildings, and other benefits. Green roofs are considered as one of the common energy efficiency features that are adopted in schools [66], libraries [67], offices [68] and high-rise residential buildings [69].

Green roofs are usually of three types: extensive, intensive and semi-intensive [70-74]. Extensive green roofs can again be single-course or multi-course type [75]. Green roof consists of different layers of materials and plants, depending on its type [76]. Components of green roof include: landscape materials or vegetation, structural layer, substrate or growing medium, insulation layer, drainage material, filter, water proofing membrane, and root barrier [77].

Extensive green roofs use vegetated thin roof covers that are self-seeding and require very little or no maintenance. They are drought tolerant, so require minimal or no fertilizer and irrigation/watering. They are usually native to locations with rocky surfaces or dry and semi-dry grassy settings; can be installed on roofs with up to 40% slope; and include mosses, colorful sedums, meadow flowers and grasses [46].

On the other hand, intensive green roof systems are much heavier and far more complex than extensive green roof; may include ponds, bushes, lawns, trees, meadows, and terraced surfaces; and require more maintenance [46]. Semi-intensive green roofs are in between these two extreme systems (i.e. intensive and extensive), with a relatively deeper substrate. This allows wider landscaping options than extensive system, but with increased cost, maintenance and weight [76]. The main features of three green roof systems are summarized in Table 3 [76, 78].

Table 3: Features of different types of green roofs.

	Extensive	Semi-intensive	Intensive
Weight at maximum water capacity (kg/m^2)	50 – 150	120 – 350	>350
Thickness of substrate (cm)	6 – 20	10 – 25	>25
Plant Communities/Species	Herbaceous, succulent, and grasses	Herbaceous, shrubs and grasses	Trees, shrubs and grasses
Slope (%)	<100	<20	<5
Irrigation	Never or periodically	Periodically	Regularly
Maintenance	Low	Moderate	High
Costs	Low	Middle	High
Use and access	Accessible only for maintenance	Pedestrian, with moderate use	Pedestrian or recreation areas

Green roofs are very effective in both cold and warm/hot climates to efficiently reduce energy consumption of buildings through reducing variation of indoor temperature [65, 79]. Although various factors (such as the climate conditions, thickness and composition of growing media, type of green roof, selection of plant, insulation specification, and type of irrigation)govern the degree of effectiveness and efficiency, it was observed that the surface temperature reduced between 30-60˚Con planted roofs in Japan [80]. Resulting from thermal benefits, green roofs also lead to reduced energy cost and improved environment. A study recorded that a reduction of indoor temperature by green roofs allowed up to 48% reduction of energy use for cooling [81].Other benefits of green roofs include: retention of storm water to reduce runoff and peak flow [72]; enhancement of water quality for water utilization [78]; air cleaning [77]; and noise reduction [75].

I. Green walls

Besides green roof, another greenery system regularly implemented is vertical greenery system, which is known as green wall. The main purpose is to grow plants on building walls, through vertical greening layers, e.g. on various types of walls and facades [78], with alternative names of bio walls, vertical garden, vertical landscaping and vertical green [82-83]. Walls are partially or fully covered with climbing or hanging green vines/plants that may also include growing medium (i.e. a substrate or soil), and most of the system is integrated with water delivery system. Vertical greenery systems or green walls are categorized as green facade and living wall [82].

Green facades use climbing or hanging plants along walls, so they grow upwards or downward, depending on whether they are attached to traditional walls or hanged from a certain height. Green facades are again of two types: direct facade greenery and indirect facade greenery. Direct facade greenery system directly attaches plants/vines to the wall, but indirect facade greenery uses a supporting structure for plants/vines [84]. Traditional green facades use self-clinging vines/plants with roots directly in the ground, so they are direct facade greening. On the other hand, indirect facade greenery uses modular (i.e. multiple structures) or continuous (i.e. single structure) guides to allow vertical support for climbing plants [85].

Living walls use a wider variety of plants/vines to enable high buildings with green walls. They can grow more uniformly, cover large vertical surface rapidly, reach higher wall areas easily and adapt to all kinds of buildings smoothly [86].

According to the method of application, they can be either continuous or modular. In continuous systems, lightweight and permeable screens are applied to insert individual vines/plants. On the contrary, modular systems comprise elements to contain growing media for vines/plants to grow, which are either directly fixed on the vertical wall surface or supported by complementary structures [82].

The most important benefit of green wall is energy efficiency. The vegetation mass of green wall traps air within it, which restricts heat movement and results in to reduction of ambient temperature through plant shading and evapotranspiration process. Similarly, interior green wall can cut energy use for heating and cooling outdoor air for indoor use. Moreover, green wall may protect wind during the winter months, contributing to reduced energy use for room heating [87]. Apart from energy efficiency, green walls also reduce noise level [78]; protect building structures from weathering [86]; offer improved IAQ [84] and exterior air quality, e.g. from elevated temperatures [83]; and provide aesthetic variation [82].

J. Shading devices

Indoor air quality (IAQ) is improved through managing the daylighting systems by using control strategies with the shading device systems. The main purpose is to prohibit or reduce the glare through windows or skylights from direct sunlight, but they are also effective to reduce any thermal discomforts [88]. Glazing type of shadings diffuses transmission of infra-red radiation of sunlight, which in turn reduces the heat from daylighting in interior spaces. Glazing system with 'phase change materials' can exploit daylight to absorb most of the infra-red radiation, and only allow desired amount of light [89]. Glazing allows superior or equal lighting, reduced energy consumption and insignificant thermal impact, if used with other daylighting technologies, like double glazing system [88]. As such, two schools in Italy replaced the single glazing structure to double glazing [90]. In Egypt, a single-glazed window was observed to perform very poorly in terms of heat and IAQ [91]. Therefore, those windows were replaced with aluminum framed double-glazed windows with clear glass, to reduce energy consumption. Now-a-days, advanced high performance window technologies are also available, such as multiple glazing systems. They include insulating spacers and inert gas fill, as well as composite insulating window frame systems [92-93]. Moreover, blinds are a type of adjustable shading system that can be used to deliver set levels of illumination [88], to reduce solar heat gain [94], as well as for glare control [95] and thermal protection [96].

V. PATTERN OF GREENING FOCUS

Energy efficiency is not difficult to achieve, and offers the best cost alternative to fossil fuels. An increase in energy efficiency reduces GHG emissions, which is probably the most effective way to reduce fossil fuel use in existing buildings, with potential for large cost savings, since saving fossil fuel is much cheaper than buying electricity [97]. Moreover, the use of fossil fuel results in to GHG/CO_2 emissions, which significantly affects global warming and/or climate change [98]. Since buildings consume about 40% of primary energy globally and about 70% of electricity only in the USA, they significant influence on overall energy consumption and CO_2 emission [99]. Therefore, ensuring energy efficiency in existing buildings is important in achieving the overall goal of sustainable and/or green building, which also contributes in reducing GHG emissions, utility bills and maintenance costs; and in creating jobs, as well as career opportunities. Nevertheless, energy efficiency in various types of buildings is targeted using different types of green features and/or emerging technologies, as shown in Table 4, which has been derived from Table 2. The table focuses on portraying the use of nine different types of green features to six different types of buildings, to examine if there is any specific pattern of their use, and does not collate the counts of studies and/or source countries mentioned in Table 2. Despite their contribution to thermal performance of buildings, shading devices are not considered in this analysis and Table 4, as their primary focus is on IAQ.

Table 4: Green features focusing energy efficiency in different building types.

Green Features	School	Office	Residential	University	Hospital	Library	Count
High performance lighting	√	√	√	√	√	√	6
Energy-efficient equipment	√	√	√	√	√		5
Solar water-heating system	√	√	√	√		√	5
HVAC system	√	√	√		√		4
PV system	√	√	√	√			4
Green roof	√	√	√		√	√	4
Smart lighting system	√				√		2
Green wall		√					1
Energy consumption monitoring devices				√			1
Count	7	7	6	5	4	3	

As seen in Table 4, high performance lighting is the most popular green feature, as it is used in all types of buildings. A further examination revealed that these included CFLs [99-101] and LEDs [99, 102]. So, the focus seems to be on easiness and cost involvement, since replacing/installing such bulbs is not difficult, they require no or minimal installation, and incur no cost, except those for the bulbs. The second most popular green feature is energy efficient equipment that has not been used only in library buildings. The other second most popular green feature is solar water heating system that was found suitable to all building types, except for hospital. As far as the present review is concerned, Table 4 also shows that HVAC system has been used in schools, hospitals, office and residential buildings. This is broadly in compliance with previous observation that HVAC systems consume about 40% of the total energy consumption in buildings [103], and high-efficiency air-conditioning system in newly constructed green buildings consume about 40% less energy than conventional buildings [45]. So, the focus seems to be on potential for savings, as reduction in energy consumption means less cost and less emissions. On the whole, Table 4 indicates that all nine green features can potentially be used in any building types. However, it does not show any further specific preference/pattern. For example, PV systems can be potentially installed on any building types, but only four types of buildings are seen to have used it.

On the other hand, schools and office buildings are seen to have used the highest seven out of nine green features or emerging technologies, followed by residential buildings with six. Hospitals are seen to have used only four types, focusing on HVAC, energy-efficient equipment and lighting system [52, 104].

Again, rest of the table does not portray any specific pattern, although indicates potential use of any green feature or emerging technology by any building types. For example, green roof can potentially be installed on roof-top of any building type [66-69], as far as the roof is flat or within the acceptable slope, but it has not been used in university and hospital buildings. Also, green wall is used only in office building, although suitable to be used in any high-rise buildings [82-84].

According to Radwan *et al.*, [105], large amount of energy is consumed in office/commercial buildings, but hospitals consume higher energy than institutional or office/commercial buildings, since hospitals need to ensure 24/7 availability of medical equipment, maintain clean air and take measures for disease control. All these processes and equipment consume significant amount of energy, so the focus of energy efficiency in hospital buildings is on HVAC, energy-efficient equipment and lighting (Table 4). However, energy consumption in public buildings, including administrative, institutional/educational and health buildings, is the second highest, where they consume about 9% of energy. The highest energy consumption occurs in residential buildings, as they consume about 40% of energy [106], of which air-conditioning system consumes about 56%.

Population in education sector, i.e. in schools and universities, is sharply increasing, which requires increased number of buildings and facilities to be constructed. These new buildings will consume more energy, requiring more generation of energy, impacting negatively on the environment, with respect to CO_2/GHG emissions and depletion of fossil fuel or non-renewable energy resources. However, Al Faris *et al.,* [107] observed that up to 35% energy performance of buildings could be improved by generating building-specific energy management program. One school in Dubai adopted the energy management program, and experienced a reduction of 35% energy consumption, i.e. from 438kWh/m^2/year to 285kWh/m^2/year.

Fotopoulou *et al.*, [108] investigated the suitability of adopting different retrofitting measures to reduce consumption of energy in existing residential buildings in different locations and climate zones in Europe. They observed that additional facade with a standard retrofit is expected to save larger amount of energy during the winter season in southern climate condition where overall average temperature is higher, but the same is expected during the summer period in northern zones where overall average temperature is lower. The most common green feature identified by the study was high-performance lighting system and all types of buildings adopted it, as has also been revealed in this study (Table 4). As in the present study, the next most common green features found were energy-efficient equipment and solar water-heating systems. It was also observed that schools adopted all the energy-efficient green features, except energy consumption monitoring device and green wall [108].

VI. MOTIVATIONAL FACTORS

A wide range of benefits can be gained by implementing the GEB using the identified and/or any other new/emerging technologies or green features. However, within the scope of this paper, not every building has implemented all the green features, and not all the greening works focused on all areas of energy efficiency. Most of the greening works were undertaken with the focus of one or two target areas, which appear to have been influenced by a few key factors, as discussed in following subsections.

A. Regional climate

The purpose and pattern of energy consumption in each country/region is different, as it seems to depend on the climate of the country/region, as summarized in Table 5. Moreover, green features are implemented to reduce energy consumption, which could be used for cooling, heating and/or lighting purposes. For instance, school buildings in Dubai is likely to consume more energy for air-conditioning, i.e. for cooling purposes, as the ambient temperature is very high in this hot and arid region [107]. By contrast, residential buildings in Australia and USA use most of their energy in heating appliances, due to their prolonged winter and lower average temperature than human body can endure [109]. So, countries with hot climate are likely to implement the cooling system for cooling purposes, and countries with cold weather are likely to install heating appliances for heating purposes.

A school in Turkey is likely to use solar panel or PV system to generate electricity during the summer season for cooling systems [110]. Some other countries with hot climate, such as Egypt, are also likely to implement the PV systems [91]. As PV systems absorb solar heat easily, countries or regions of hot weather can use it to generate electricity for their cooling systems. The use of this renewable energy can reduce their traditional energy consumption. Moreover, some regions in China have implemented the PV systems in the residential buildings to balance local electrical peak demand, e.g. in southern regions of Yangtze, where air-conditioning systems are used frequently during the summer season. It was experienced that the use of PV systems was cheaper and less disruptive than using electrical energy [92]. Also, some residential buildings are seen to implementing high performance lighting systems; energy-efficient equipment, such as motion sensor daylight systems; and solar panels, in order to adapting to the continental climate conditions, e.g. in Kazakhstan [93].

Table 5: Summary of countries implemented green features depend on its climate.

References	**Country**	**Climate**	**Green Features**
AlFaris *et al.,* [107]	UAE	Hot and arid	Air-conditioning systems
Allouhi *et al.,* [109]	Australia	Cold	Heating appliances
	USA	Cold	Heating appliances
Yilmaz *et al.,* [110]	Turkey	Hot	PV systems
			Cooling systems
Albadry *et al.,* [91]	Egypt	Hot	PV system
			Cooling systems
Rousseau and Chen [92]	China	Hot	PV systems
			Air-conditioning systems
Kim and Sun [93]	Kazakhstan	Cold	High performance lighting systems
			Energy-efficient equipment: motion sensor daylight systems
			PV systems
Aminuddin *et al.,* [111]	Malaysia	Hot and humid	Green roof
			Green wall
			Shading devices: double-glazed window and blinds
Pellegrino *et al.,* [115]	Italy	Cold and Hot	Shading devices: double glazed window
Bourikas *et al.*, [113]	UK	Cold and Hot	Energy-efficient equipment: camera detection to adjust window-opening
Besir and Cuce [78]	European	Cold and Hot	Green roof
			Green wall

Adapting to climate conditions is necessary, as the required thermal performance of buildings, and the mode of energy consumption, is determined by weather to directly affect the building energy efficiency. Countries with tropical climate, like Malaysia, are likely to implement either green roof or green wall in their office buildings, which can contribute to the low energy consumption that relates to lighting and cooling. Most of the windows in Malaysia are facing east and west, which encourages the full use of daylight, but also leads to direct absorption of heat into the buildings. Therefore, the office buildings are installed with double-glazed windows, which with shading devices, such as blinds, prevents direct sunlight for thermal comfort [111]. This is similar to schools in Turin, Italy, which used double-glazed window to improve daylighting performance [112].

Bourikas *et al.,* [113] reported the use of camera detection in office buildings in UK as one of the energy-efficient equipment to adjust the window-opening. The camera was positioned at approximately 45^{o} to the facade to enable side view of the windows. This equipment is used for the heating and lighting controls in summer period. When the camera detects high brightness of the sunlight, it makes the window to close automatically. Green roof and green wall were also installed in offices and residential buildings for reducing cooling and heating during winter and summer seasons in European countries [78]. During summer, the heat penetration from the buildings was seen to be mitigated by 80%, and in winter these greenery systems reduced the heating demand by 10-30%.

B. Saving potential

Table 6 summarizes the green features/technologies and their reported savings. Implementing green technology/features can reduce total energy consumption, which can also lead to increased saving of money, e.g. at office buildings in Indonesia, with the replacement of old lamp with LED lamps, and installation of high-efficiency performance chiller, the cost of energy consumption was reduced by 11–14% [100]. Furthermore, installation of shading devices with automatic controller system in office buildings in Ottawa reduced electricity consumption for lighting, cooling and heating by 54%, 49% and 12%, respectively, which reduced 35% of total energy usage [114]. Moreover, office buildings in Cyprus with green roof technologies observed reduction of almost half of the energy consumption in cooling and heating and enhanced environmental benefits, compared to offices without green roofs [68].

Installation of energy-efficient technologies or green features, such as water heating, ventilation systems and high-efficiency lighting, resulted in to a saving of USD628.40/year, or about 43% of annual expenditures for energy for typical residential buildings in USA [115]. Hospitals in USA are not only practicing recycled and environmentally friendly materials, but also installing new/emerging technologies like water-sensing equipment, high-efficiency lights with motion sensors, and high-efficiency HVAC systems. As such, hospitals in Wisconsin managed to reduce their energy consumption by 10% and saved USD409,000.00/year, and those in California saved about USD14,330.00/year only in practicing recycled materials [104].

The initial average electricity consumption with old technology in schools in Israel was 180,700kWh/year, compared to 139,824kWh/year after installing new/emerging technologies like highly efficient air-conditioning systems, high-efficiency lights and double glazing window, which saw a saving of about USD6,401.00/year. Thus, it showed that implementing energy efficient new or emerging green features or technologies in the schools reduced the amount of energy consumption and saved operational cost [45].

A study conducted in Reggio Calabria, Italy reported that the investment amount in a building for the traditional features was only €112.900.00. However, the amount was higher (i.e. €144,000.00) for replacing traditional features like single glazing window with emerging/green technologies like double-glazed window and installing PV systems. Nevertheless, the additional investment cost was expected to be recovered within 2-5 years, and with a significant annual saving of about €31,100.00 on energy bills [90].

Table 6: Summary of green features focus on energy-efficiency and its saving potential.

References	Green Features	Cost/Savings
Anisah *et al.,* [100]	LED lamps High efficiency performance chiller	Cost of energy consumption reduced by 11–14%
Huchuk *et al.*, [114]	Shading devices Energy-efficiency equipment: automatic controller system	Energy consumption reduced by 35%
Ziogou *et al.*, [68]	Green roof	Energy consumption reduced almost to 50%
Zhao *et al.,* [115]	Water heating system Ventilation systems High efficiency lighting	Saved USD628.40/year Energy consumption reduced by 43%
Johnson [104]	High efficiency lighting Energy-efficient equipment: motion sensor High-efficiency HVAC systems	Energy consumption reduced by 10% Save USD409,000.00/year
Meron and Meir [45]	Shading devices: glazing Highly efficient air-conditioning systems High-efficiency lights	Save USD6, 401.00/year
Massimo *et al.,* [90]	Shading devices: double-glazed window PV systems for cooling and heating systems	Energy consumption reduced by 40%

C. Awareness, Policy and Leadership
It is usually considered that setting a national or institutional policy on green building helps its wider implementation. Such policy may set targets and leadership for executing organizations, e.g. in terms of generating awareness and undertaking greening measures to set examples, with or without sponsorship. Such initiatives have been seen to be effective in practicing greening activities.
For example, Chinese government is sponsoring a program of applying green features in different universities to create awareness and demonstrating relevant benefits among staffs and students, so that they can learn on saving potentials and practice the techniques in their future work places. Tan *et al*., [116] reported that one of the factors that influenced Tongji University in Shanghai, China to practice the concept of green university was the green campus policy of the university, along with the use of campus energy management system (CEMS) approach. A strong leadership and coordination by the university allowed to smoothly achieving the energy and resource-efficient campus. Moreover, CEMS allows real time monitoring of energy uses of the campus buildings. It shows the users data of the energy usage both numerically and visually, which in the end helps to develop the awareness and to promote the benefits of energy saving to the students and staffs working on the campus. The work was supported by two national-level plans, as well as and one National Foundation of China.
Chinese government is also sponsoring the concepts and practices of resource efficient campus in another university [117]. The practice of resource- and energy-efficient campus is labelled as a mission or goal to be achieved by the university. In addition to that, university of Shenyang is undertaking green projects, such as water recycling system and recycled materials, due to a comprehensive plan with strong leadership and support of the Chinese government through its, "one hundred talent program", and United Nations University's Institute of Advanced Studies [118]. In Malaysia, Zen *et al*., [119] demonstrated how the support from top-level management can achieve the aim of green campus to minimize waste by reducing the use of paper and practicing recycling. Under this initiative, the top-level management in each faculty is responsible for the monitoring of paper consumption. It encourages the staffs to reduce, reuse and recycle of the paper.
Based on an initial awareness, a school in Iran aimed to encourage initiatives towards sustainable improvement of the entire society [66]. Similarly, in Mexico and USA, libraries began with small green activities, for example using recycled and environmentally friendly materials, energy-efficient and water-efficient appliances, to develop awareness and support the sustainability practices for the community [102, 120]. Under the 'Practice Green-health' policy [104], hospitals in USA target to save energy by installing green features/technologies. They intend to create awareness of the staffs and users in the hospital, which they call as 'green-health role'. Office buildings in Norway are set to the practices to follow and align with the principles of green building [121]. Moreover, Baldwin *et al*., [122] reported that China has established a policy to implement green movement, along with a set of targets on retrofitting the existing residential buildings. This policy emphasizes reduced energy consumption through green/emerging technologies and promotes methods on how to save energy.

VII. CHALLENGES OF GEB

Although the practice of GEB is beneficial and effective in reducing energy consumption, and thereby CO_2 emission, there seems to be some challenges that limit its wider implementation. These are discussed in this section.

A. Limited or lack of research
This review study reveals that only a limited number of countries have adopted certain types of green features, to suit their own requirements. This has been mainly guided by 'local' climate and saving potential. As such, the use of green features in different countries or climate zones are different, e.g. cooling system in hot and arid climate zone [107] compared to heating system in USA [109], and green roof or green wall in tropical Malaysia with hot and humid climate [112]. Clearly, those experiences cannot be replicated elsewhere. Also, more research has been conducted in developed countries, implying the need for research in developing countries. A country/region specific research will help to identify the suitability of using certain green features. However, conducting such research in many countries may not be easy, due to technological and skill shortages. Many countries enjoy considerably low energy tariff, where GEB is very difficult to be cost-effective, if not impossible.

B. Lack of resources
Greening will be difficult if there are limited resources in terms of technology, equipment and materials [75]. Most of the countries in the world do not produce energy-efficient green features, so they need to import, implying the need for spending more for greening. This may considerably affect the cost-effectiveness. Moreover, there may be lack of information on sourcing green features, to add more difficulties even to interested parties [123]. International trade and business associations can surely play an important role in this case, which probably needs to be supported by national priority and initiative [124].

C. Lack of skills and professional
Lack of awareness of mass people might be due to the lack of skills/knowledge of relevant groups of professionals on GEB and green features [124]. Implementing GEB requires specific skill sets and knowledge for professionals to plan, motivate, guide and help installing green features. However, most developing countries do not have such professionals, so those countries still use the traditional techniques and technology [123].

D. High initial cost
High initial cost of certain green features may be the main challenge for their adoption, e.g. green roofs [75]. If considered with saving potential and cost effectiveness, such green features might be highly unpopular in countries with low energy tariff system [125]. Government subsidy or any kind of initial financial support under any suitable policy may be the way forward to use such green features [124].

E. Technical difficulties

One frequent barrier of GEB is the availability of technical information of the buildings, e.g. in terms of structural ability, which is the key to use green roof [75]. Frequently, no drawings and specifications are readily available. Sometimes, structural health of buildings needs to be examined. Close collaboration between different professional parties seems necessary for such assessment [23]. Measuring the thermal performance of buildings is another challenge, especially the impact of the improvements from GEB on whole life costs (WLC). Clearly, more research works need to be carried out on WLC against the benefits [23, 75].

F. Lack of policy support

Absence of government involvement in implementing GEB might be the biggest barrier. With appropriate national/institutional policy, countries and organizations can undertake suitable initiatives to generate public awareness through demonstrations, e.g. as in China [116-117] and contribute to energy saving. Leung [16] argued for a policy allowing subsidy and financial incentives from the government and financial institutions for initiatives involving high start-up cost, for wider implementation of GEB.

G. Lack of cooperation between stakeholders

Probably the most critical challenge against wider implementation of GEB is the absence of information sharing due to lack of communication between parties/stakeholders across different levels and different fields, which originates from the lack of cooperation between different parties, namely architects, structural/civil/environmental engineers, contractors and occupants [75]. More sensible solution to this is to overcome such traditional way of working. Different parties need to cooperate and collaborate among themselves for successful implementation of GEB practices, e.g. by sharing source information, cost estimates, potential environmental benefits and cost/energy savings [125].

VIII. CONCLUDING OBSERVATIONS

Greening existing building is the alternative to construct new green buildings, which is achieved through retrofitting and adaptation of old/existing buildings, using a range of new or emerging green features/technologies. This paper conducted a structure review of literature and identified ten types of green features/technologies that focus on improving energy efficiency. They include: high performance lighting, energy-efficient equipment, solar water-heating system, HVAC system, PV system, green roof, smart lighting system, green wall, shading devices and energy consumption monitoring devices. These were tallied in six different types of buildings, namely school, office, residential, university, hospital and library buildings. It is seen that all the identified green features/technologies have benefits of different degrees, but they all are not installed in every building type. It appears that selection of green feature/technology for a certain building type broadly depends on a number of motivating factors, including the climatic conditions of the location/area of the building, degree of saving potential (e.g. energy or cost) from the intended installation, and underlying policy and leadership that drive greening of existing buildings with emerging green technologies or features. On the other hand, many challenges against wider implementation of such greening have been anticipated. This includes high initial costs of such greening with some features/technologies, limited ‘local’ research, technical difficulties relating to buildings, cost-effectiveness, collaboration between different parties, awareness in the society, availability of source information, and the existence and implementation of a sound policy under the top-level leadership. There is, therefore, a need for country/zone specific further research, including in-depth real experimental work on each type of green feature/technology, and identifying barriers and enablers of their use, appreciating underlying wider sets of economic, environmental, social, cultural and/or behavioral issues.

IX. FUTURE SCOPE

As has been echoed above, this study demonstrates that GEB can effectively reduce energy consumption in buildings and save money spent on energy bills. However, relevant research conducted, and consequent applications made, only in a limited number of countries, most of which are in developed countries. So, there is a clear knowledge gap between the developed and developing countries. Also, experience from one country/climate zone may not be suitable for other places. More localized research is necessary for using various green features or new/emerging technologies in different climate zones and geographical areas, and with different energy tariff structures. Developed countries should help developing countries with technological assistance and more research for justifying GEB, targeting global energy efficiency. More research should also include identifying the country or zone relevant and climate-specific barriers/challenges and enablers/motivators of GEB, appreciating relevant underlying wider sets of social, environmental, cultural, economic and behavioral issues, and including any localized in-depth experimental work. Lastly, occupants' attitude and compliance to the global and/or regional target of energy saving should be integrated in the overall decision-making process.

As such, and as far as the present study is concerned, the next step will be to further refine and/or extract the identified broad sets of motivators and challenges, in order to incorporate local context and priorities, and assess them with two broad groups of (i) stakeholders, namely the dwellers who usually take the decision on such greening, and (ii) experts, i.e. the construction industry participants like clients, contractors and contractors. It will then follow examining how best the emerging green technologies or features can be adopted, and finally develop a framework for wider adoption of GEB. This study is still at the beginning stage, so necessary changes will be made through the course of the study, as and when needed.

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