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Assessment of costs and benefits of green retrofit technologies: Case study of hotel buildings in Sri Lanka

Elilvani Periyannan [a], Thanuja Ramachandra [a], Devindi Geekiyanage [b, *]

[a] Department of Building Economics, Faculty of Architecture, University of Moratuwa, Bandaranayake Mawatha, Moratuwa, 10400, Sri Lanka
[b] School of Science, Engineering & Environment, University of Salford, 43 Crescent, Salford, M5 4WT, UK

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ABSTRACT

With the rising impact of greenhouse gas emissions, resource depletion, and the global interest in sustainability advancements within all sectors, construction industry practitioners are also interested in incorporating sustainable features and practices into their buildings. Nevertheless, most of the commercial buildings in Sri Lanka had been constructed during the unprecedented urbanization between 1995 and 2010, thus, before sustainable concepts became more prominent. Therefore, existing buildings in Sri Lanka is experiencing ever-increasing energy consumption, resulting in higher utility costs, with which green retrofitting has become imperative, notably in hotel buildings. This study, therefore, conducted an economic evaluation of three existing hotel buildings to establish an account of the cost implications and saving potentials of different green retrofit technologies. The data collected through document reviews and site visits were analysed using net present value and simple payback period calculations. Although number of retrofitting technologies have been incorporated in the selected buildings, more weight has been given to incorporating technologies to achieve energy efficiency and indoor environmental quality. Considering the financial viability, all the implemented green retrofits have a positive return on investment and less than ten years of payback period, except LED televisions. Amongst the implemented retrofits, biomass boilers, energy-efficient chillers, and solar PV systems have the highest energy-saving efficiency, followed by VFDs and LED lighting, while LED televisions have the lowest. The study's findings contribute to industry practitioners identifying the appropriate green retrofits based on the cost implications and savings potential and enhancing the sustainability of the built environments by reducing greenhouse gas emissions and depletion of natural resources.

1. Introduction

Building construction sector is considered as one of the essential segments of the construction industry [1], with its consumption of 32% of the materials, 40% of energy, and 12% of portable water and being responsible for 40% of CO2 emissions during their operation [2]. In line with the above concern, hastening the ascendance of the construction sector in the world's total energy consumption and greenhouse gas emissions inevitably leads the world to focus on effective methods of sustainable development, like the green building concept [3]. Generally, green buildings encompass the practice of negating undesirable impacts on the environment and human health with effective planning on the whole life cycle of buildings, producing less amount of waste, the minimal influence of pollution and appropriate usage of the resources [4]. Green buildings are accounted for approximately 19% of lower aggregate operational costs, 25% of less energy, and 36% of fewer CO2 emissions (US General Services Administration [5].

* Corresponding author.
E-mail addresses: pvani.qs@gmail.com (E. Periyannan), thanujar@uom.lk (T. Ramachandra), d.geekiyanage@salford.ac.uk (D. Geekiyanage).

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Due to the utmost importance of environmental concern, green building development has rapidly started to practice all over various enterprises in most of the countries [6]. However, many existing buildings constructed earlier are yet to become green and sustainable. Demolish an existing building and build a new green building in its place is a counter-productive to the idea of energy conservation. As per estimates, it would take more than 65 years to regain the energy savings of demolishing an existing building and replacing it with a new green building [7]. However, most existing buildings will still be in use for the next 50–100 years due to their long lifespan nature [8]. Thus, green retrofits are more effective than constructing new green buildings by demolishing conventional buildings. However, green retrofitting is still not winning its place at the forefront due to the existing challenges [9]. According to Ref. [10]; building stakeholders are less likely to agree with green retrofitting due to the challenges of deciding whether to execute the retrofit project. The significant barriers affecting green building implementations are reported as higher costs for green design and energy-saving material, technical difficulty during the construction process, lack of understanding of the available retrofit technologies, poor building code enforcement, and conflict of interest between various stakeholders [11–13]. Moreover, issues such as long payback periods [14,15], high cost and limited access to capital [14,16,17] also hinder the retrofitting. The main challenge encountered is the willingness of building owners to pay for retrofits [18]. For instance, owners and investors who do not have access to enough financial information will not realize that green retrofitting is the best course of action to pursue high building productivity and sustainability in the existing structures. This is one of the main reasons for the practitioners to be reluctant. Besides, some owners see the certification as an opportunity to enhance their corporate image, making them more flexible with their budgets. Yet, the wrong perception regarding costs due to a lack of knowledge and experience leads to decisions not to implement green retrofit [9]. Considering the limited evidence of reliable financial information related to green retrofitting, this study evaluates the economic performance of green retrofit technologies, particularly in Sri Lanka.

In Sri Lanka, the integration of greener potentials is assessed through two prominent green building certification programmes: (1) Leadership in Energy and Environmental Design [19] and (2) GREENSL (Green Building Information Gateway [GBIG], n.d.; Green Building Council of Sri Lanka [[3,20]. The GREENSL, instigated by the GBCSL, has been proposed as an alternative to LEED and considers the significant needs and requirements, particularly in the Sri Lankan construction industry [21]. As per the [22,23] (USGBC, 2021) databases, the profile of LEED O + M: Existing Buildings certifications in Sri Lanka includes nine (09) industrial manufacturing, one (01) warehouse and distribution, and two (02) office buildings and there are no any existing hotel buildings certified under LEED O + M category. However, seventeen (17) hotel and resort buildings have been certified under new constructions, lodging green space type. This gives the impression that the focus on green certification of existing hotel buildings is inevitable. Further, the hotel sector has been identified as a significant energy-consuming sector in Sri Lanka that contributes to 15–20% of total expenses for energy usage and possesses 25% of energy-saving potential (Sri Lanka Sustainable Energy Authority [24]. With these considerations, the study focuses explicitly on assessing the economic performance of green retrofitting of hotel sector in Sri Lanka. The study assessed the costs and benefits of green retrofits implemented in three five-star rated hotel facilities with similar climatic conditions and building characteristics. Further, the selected hotels have included retrofit technologies with compliance standards of Energy and Environmental Management, and green certification. The assessment of costs and benefits considered only the technologies implemented after green retrofitting.

2. Green retrofit technologies

Green technology is an umbrella term that describes the use of technology and science to reduce human impacts on the natural environment. Such technologies are incorporated into building designs to mitigate or reverse the effects of human activity on the environment and thereby make the end product sustainable [25]. Over the two decades, researchers have focused on various green retrofit technologies adopted in different types of buildings. Some of them have focused on investigating green technologies which are adopted during the design stage [25,26], while some others considered the adoption in the whole lifecycle [27,28]. In addition, many researchers have extensively researched green technologies for sustainable development, which enabled them to classify the green technologies into various types. For instance, while [27] categorised green technologies in terms of parameters like water, energy, material efficiency, indoor environmental quality, and operations and maintenance optimization, [26] classified based on design aspects, including architectural, mechanical, and electrical. Followed by a comprehensive literature synthesis, this study identified over 40 green retrofit technologies as presented in Table 1 and clustered them under seven (07) primary sustainability criteria of location and transportation (LT), sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (IEQ), and innovation (IN), as per the LEED v4.1 for Operations & Maintenance: Existing Buildings scorecard. This classification was found to be the appropriate choice for retrofitting assessment after investigating other versions such as LEED v4.1 for BD + C: New Construction and significant renovation in addition to older LEED versions such as LEED v2 for Historic Buildings. The reason is that the LEED v4.1 for BD + C: New Construction and Major Renovation is not applicable for an existing building that does not include major renovation, such as considerable building envelope modifications or major heating, ventilation and air conditioning (HVAC) enhancements.

As far as literature is concerned, authors have multiple opinions on the cost, performance and benefits of green retrofits. As indicated in the table, there is a range of technologies adopted in different contexts, which could be due to availability/affordability and their potential benefits/savings.

2.1. Location and transportation (LT)

According to the LEED Green Building Certification, the LT criteria is dedicated to promoting sitting and providing facilities that discourage the usage of gasoline-powered vehicles. Thus, the objective is to motivate bicycling as a means of reducing vehicle travel

Table 1
Green retrofit technologies.

	Green Retrofit Technologies	Sources
LT	Bicycle tracks, changing facilities, parking spaces, and alternative-fuel refuelling stations	[1], [2]
	CO2 emissions reduction	[3]
SS	Use of high emissivity roof and roof insulation	[1], [4]
	Green/vegetated/high albedo roof	[1]
	Open grid paving, light-coloured surface (white asphalt)	[2]
	Afforestation	[5], [6]
	Passive solar heating and controlling	[7]
WE	Efficient indoor plumbing fixtures and fittings	[2]
	Rainwater harvesting	[1], [2]
	On site wastewater/grey water treatments	[1], [2], [8]
	Meter installation	[1], [8]
	Heat pump water heater	[9]
	Permeable surface technology	[10]
	Waterless urinal	[8]
	High-efficiency irrigation technologies (moisture sensors, weather data-based controllers)	[2]
	Water-efficient, climate-tolerant plantings	[2]
	High-efficiency automatic water control systems	[2]
EA	Sustainable lighting solution	[11], [12]
	Smart windows- double/triple glazing technology	[1], [2], [11]
	Solar energy power generation system	[2], [10]
	Light control and smart meters	[2], [11]
	Biomass boilers	[2], [11]
	Modern combined heat and power (CHP) systems	[11]
	Geothermal technology	[2]
	Wind technology	[2]
	Green roof technology	[10]
	Sunshine shading appliance	[9]
	Ground source heat pump technology	[13]
	Key card system	[21], [22]
	Variable speed drives	[22], [23], [24]
	Biogas system	[25], [26]
	Sustainable chiller system	[19], [20]
MR	Waste management system	[1], [14]
	Sustainable material selection (e.g., green cement, fly ash bricks, eco wood)	[15], [16], [18]
	Resources Reuse	[19]
IEQ	Ample ventilation for pollutant & thermal control	[10], [18]
	Occupant control of ambient and task lighting	[2], [18]
	Air filtration media	[1], [2], [12]
	Exterior and interior permanent shading devices	[1], [2]
	Negative-pressure smoking rooms	[2]
	Low- maintenance vegetation	[2]
	Vertical plant	[12]
	Improvement of HVAC	[11]
IN	Hiring a LEED-accredited professional to integrate the LEED expertise with project management	[3]

[1] [29]; [2] [30]; [3] [31]; [4] [32]; [5] [33]; [6] [34]; [7] [35]; [8] [36]; [9] [37]; [10] [27]; [11] [13]; [12] [38]; [13] [39]; [14] [40]; [15] [41]; [16] [42]; [17] [43]; [18] [44]; [19] [45]; [20] [46]; [21] [47]; [21] [48]; [22] [49]; [23] [50]; [24] [51]; [25] [52]; [26] [53].

and improving public health [22]. In most cases, bicycle racks are widely implemented to achieve the LT criteria. [30]; using actual site measurement, highlighted that giving space for bicycle parks as an alternative transportation facility saves 26% of energy. In addition, buildings which target to earn credit under LEED for bicycles, now must provide showers and changing facilities to remove further barriers to bicycle commuting [29].

2.2. Sustainable Sites (SS)

Considering the SS feature, an experimental study on the energy and environmental performance of the green roof system by Ref. [32] found that the energy saving due to the reduction of the cooling load of the green roof system was ranging from 15% to 49%. In another instance, [54] using actual site measurement highlighted that providing bicycle parks as an alternative transportation facility enables 26% energy saving. SS comprises of several green retrofit technologies that could be incorporated when converting an existing building into green. However, the selected hotel buildings have already been incorporated with features of parking spaces, light-coloured roofing and paving surfaces, and low reflectance surfaces. This facilitated the transformation of the existing building into green with least cost and obtain green certification.

2.3. Energy and Atmosphere (EA)

In many instances, the primary concern of retrofitting is to achieve energy efficiency in building. The comprehensive literature review revealed that the retrofit buildings could achieve energy efficiency by applying technologies such as energy-efficient lighting, window, HVAC system, energy-efficient appliances, renewable energy systems (e.g., wind turbines, solar panels, and ground source [geothermal] heat pumps), and natural ventilation. For instance, Ref. [55] stated that energy-efficient lightings are cost-effective, resulting in energy savings of approximately 20%. In another study, [38] highlighted that around 15–30% of energy savings could be achieved through LED lighting. The utilization of wall and roof insulation and reflective double glass accommodates reduced window area and can diminish the consumption of energy in the building [56]. [57] indicated that integrating roof installation with effective glazing and heating systems can be a viable option to mitigate the exceeding energy consumption significant to residential buildings. Further, [58] identified solar shading devices which use natural sunlight and ventilation to decrease a building's energy consumption by a certain margin. Similarly, [44] indicated that the solar hot water system and the solar photovoltaic (PV) system together can contribute to 2–6% of the total energy consumption and saving of 16.8ton CO_2 emissions annually. [39,59]; and [60] signified the ground source heat pump as an alternative technology for increasing building energy efficiency as well. By examining five (05) different types of office buildings in four (04) different climatic zones of Europe, [61] concluded that the combination of building envelops, HVAC system, efficient lighting system, and passive retrofit techniques contribute to save 48–56% of energy with the payback period ranging from 9 to 33years.

2.4. Water efficiency technologies

The usage of water has a concern commercially and morally. Cost is identified as the primary factor in water usage, particularly in hotels, as it accounts for about 10% of utility bills [62]. Thus, technologies needed to manipulate water efficiency are important to reduce water usage. [54] showed that both implementing subsystem-level water meters and sensor faucets with low flow rates save 40% of water, while grey water recycling also saves 43% of potable water use for non-portable purposes by redirecting the treated grey water. Another study conducted on industrial factory in China using simple energy calculations and site readings indicated that rainwater harvesting through permeable pavement, garden space, roof greening, landscape pool, and other runoff control measures absorb 5716.3 kg carbon dioxide each year and 20% more rainwater absorb to the ground through the runoff water infiltration [44]. [63] indicated that rainwater harvesting technology was the prominent as well as client-preferred water-efficient retrofit technology in dwellings in Australia. In another instance, [64] concluded that water-efficient appliances could be one of the major green retrofit technologies in hotel buildings. Authors further added that this retrofit technology contributes to a 24% reduction in water use and a 20% cost savings on the water bill.

2.5. Material and resources

The LEED O + M: Existing Buildings (v2009) promotes sustainable purchasing of consumables and solid waste management. Therefore, retrofit technologies in this category are given the least priority. Retrofitting strategies include waste management systems, selecting sustainable materials and recourse reuse. [40] indicated that the waste performance score was achieved using an online waste data management program. Furthermore, harvesting sustainable materials such as green cement, green paints, fly ash bricks, and eco wood produces considerably less waste than other materials (e.g., plastics) [12]. In addition, most available green products should have several health and/or environmental attributes, such as promoting better indoor air quality (generally via reduced emissions of Volatile Organic Compounds (VOCs) and/or formaldehyde), being durable and low maintenance, incorporating recycled content, being salvaged from existing or demolished buildings for reuse, being made using natural and/or renewable resources, having a low embodied energy, not containing Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or other ozone-depleting substances, not containing highly toxic combustibles, and so on [43].

2.6. Indoor Environmental Quality technologies (IEQ)

IEQ technologies are another predominant technology that favours the building performance by affording fresh and quality air within the building [65]. According to Ref. [66]; IEQ technology which enhances natural ventilation was identified as a top-ranked technology related to sustainability in Ghana. On a similar note, [26] also indicated that technologies used to afford natural ventilation as one of the top five technologies for sustainable development. The IEQ technologies consist of enough ventilation for thermal and pollutant control, task lighting, exterior and interior shading devices, implementation of low emitting finishes, efficient HVAC and alike. The use of efficient task lighting can also improve IEQ performance [26,67]. [44] estimated the energy saving due to CO_2 sensors was 25.99 kWh/m^2, nearly 60% of the predicted usage. Moreover, [68,69] investigated the impacts of air tightening retrofits such as installing house wrap over the exterior walls; sealing leakage sites in the living space floor; tightening the insulated belly layer; sealing leaks in the air distribution system. The results showed that for the two studies, the energy consumption rate for heating and cooling was reduced by 11% and 10%, respectively.

2.7. Innovation

As ascertained by the literature, green building projects lacked innovation credit as the failed to hire a LEED-accredited professional to integrate the LEED expertise with project management [31].

The review further evidences that most green retrofits are in the EA category and aiming at reduction of energy consumption and CO_2 emission, while WE and IEQ related retrofits are in limited applications. Among the selected green retrofits, energy-efficient lightings are one of the widely implemented retrofit measures for any kind of building, while solar collectors and PV cells, Low-E double glazing, heat recovery, wall insulation, HVAC systems, and air filtration are not commonly seen due to their high initial costs and long payback periods.

Although these identified green retrofit technologies have more or less equal potential for energy saving, clients and industry practitioners need to have a sound understanding of their cost implications [70]. However, the selection of retrofits has been solely based on a single parameter, either potential savings or cost implications, and the trade-off between initial investment commitments and saving potentials seems to have been given less priority in integrating the retrofit technologies. Given that most of the researchers have adopted cost simulation exercises to replicate the cost implications and saving potentials of green retrofits, this study, by employing a more realistic approach, aims to account the actual cost and savings of green retrofits.

3. Research methods

This study aims to assess the cost and savings potential of green retrofits towards selecting appropriate retrofits for a building. Accordingly, three hotel buildings with green certification were selected as they incorporate green retrofit technologies. The LEED O + M: Existing Buildings certification was initially considered as it is the most commonly used green building certification in Sri Lanka. As of April 2020, there was only one LEED-certified green hospitality building in Sri Lanka. As the study demands multiple case studies, the next optimum consideration was sought to identify hotel buildings certified with other standards such as ISO 50001-Energy Management Systems and ISO 14001-Environmental Management towards identifying energy and environmentally sustainable retrofit technologies as ISO certifications ensure that the selected buildings are green to a certain extent. Accordingly, three five-star rated hotel facilities with almost similar building characteristics and performance were included in the study as presented in Table 2. Although the hotels are situated in three different locations within the country, all three of them represent almost similar climatic conditions (temperature, humidity range) of tropical. Hence, it is expected that the effects of those on the performance of selected technologies will be very minimal. Although, there is a substantial difference in the size of H2 and H3 buildings, it would expect to impact the study findings marginally as this study intends to aid the retrofit technology selection via comparison of technologies available in 3 similar range of hotels. Table 2 provides a summary profile of the selected hotels. Of the three hotels, H2 is relatively new, with the age of 25 years, compared to the other two, which are 50 years old. However, H2 and H3 went through retrofitting in the similar time period while H1 was retrofitted earlier. In terms of capacity also, H2 is more petite than H1 and H3.

In assessing the technologies, a quantitative approach was adopted where the data related to cost and benefits were collected by referring to building operational records such as hotel logs, monthly utility bill records, energy meter reading records, and invoices. Using the collected data, the cost and potential benefits of selected retrofits were assessed, and finally, NPV (Formula 2) and Simple Payback Period (SPB) (Formula 4) calculations were used to prioritize the retrofits.

The following assumptions were made in assessing the cost and benefits of selected retrofits:

- Primarily cost and benefits assessments were based on the past five years' (2015–2019) records of monthly energy and fuel consumption.
- Cost savings due to the reduction of energy (electricity, water, and fuel) consumptions through the implemented green retrofits were considered as cash inflows, and the initial implementation cost was considered as cash outflows of the projects.
- Energy savings from retrofits were considered as the difference between the pre- and post-retrofitting energy consumptions of respective technologies.
- The average monetary savings from the retrofits were assumed constant throughout the lifetime and had no salvage value at the end of life.
- The selected buildings were retrofitted in different years; thus, the relevant inflows and outflows were converted to a base year (2020).
- Life cycle savings due to retrofits were obtained considering the lifetime of the respective retrofits. The average lifetime was considered based on the market information.

Table 2
Profile of the selected hotel buildings.

Field	H1	H2	H3
Certifications	LEED (in 2000) ISO 50001, ISO 14001	ISO 50001, ISO 14001	ISO 50001, ISO 14001
Location	Dambulla	Galle	Negombo
Temperature	25.7 °C	26.3 °C	26.6 °C
Humidity	77%	86%	87%
Floor area of the buildings	–	10,860 sqm	36,421 sqm
Number of rooms	152 luxurious rooms and suites are housed in two wings	85 rooms (with 5 suit rooms), three restaurants, two outdoor pools, spa, conference hall and banquet hall	112 elegantly furnished rooms, suites, an open-air restaurant, two swimming pools, a fully equipped gym and a spa.
Age of the building	50 years	25 years	50 years
Average occupancy	Around 77%	Around 70%	Around 70%
Retrofit implementation	2009	2014	2014

- NPV of retrofits were calculated considering the highest life span of the considered retrofit in the study. Accordingly, a lifetime of 25 years (for Solar systems) was considered for the NPV comparison of all retrofits.
- The discount rate (r) of 4.26%, obtained from the Annual report of Central Bank Sri Lanka, was considered in the calculation of life cycle savings as well NPVs of retrofits.
- In calculating energy savings due to the use of energy-efficient lighting and key card for guest rooms, it was assumed that 70% of bulbs were used for 6 h per day.
- In calculating energy savings due to dual set point thermostats, it was assumed the unit worked for 4 h per day on stand-by mode.
- In calculating energy savings due to LED televisions, it was assumed that the unit worked for 3 h per day.
- The difference between diesel consumption and biomass consumption was considered in calculating the saving due to biomass boilers.
- The formulas provided in Table 3 were used for calculations.

4. Data analysis and results

This section presents the technologies implemented during retrofitting.

4.1. Green retrofit technologies implemented in the selected hotel buildings

Initially, the green retrofits implemented in the selected three hotels were identified with reference to the major sustainability criteria of LEED V4. Table 4 presents those retrofits and their specific design features. As summarised in Table 4, although a range of technologies are being adopted in countries as evidenced from the literature findings (Table 1), the selected hotels have incorporated only 13 retrofits and of which, 7 were common for all 3 hotels. As seen from the table, from the sustainability perspective, those retrofits implemented were related to the sustainable criteria of EA and IEQ. As the literature indicated, the hotels have incorporated technologies such as LED lights, LED TVs, solar PV systems, solar hot water systems, key card systems and biomass boiler systems to optimize energy efficiency, while dual set point thermostats and vapour absorption chiller to improve the ventilation of the buildings. However, some of these technologies served dual purposes. For example, a dual set-point thermostat aids in the electricity demand control as well as air infiltration of ventilation systems.

However, some of the WE, SS, and MR related retrofits have already been incorporated prior to retrofitting the hotels. Use of dual flush toilets, sensor taps, sub-metering (for water, electricity, diesel and furnace oil), water-saving (low flow) showerheads and cis-

Table 3
Formula used for calculations.

No.	Formula	Purpose
1	$Unit\ Cost = \frac{Total\ cost\ incurred}{Quantity\ purchased\ or\ used}$	Unit costs of items such as electricity, fuel, water, wood etc.
2	$PV = FV\ X1/(1+r)^n$ PV- Present value, FV- Future value, r- discount rate, n- number of years	To convert the case inflows and outflows to the selected base year
3	$Year's\ purchase = Annual\ Saving.\ \left[(1+i)^n - 1\right]/[I\ (1+i)^n]$	To calculate the life cycle saving using annual savings of retrofits
4	$SPB = \frac{Investment}{Average\ annual\ financial\ savings}$	To calculate the payback period

Based on the calculations, green retrofit technology with the highest NPV and the lowest SPB is considered the most appropriate technology for economic sustainability.

Table 4
Summary of green retrofits technologies implemented in the selected hotel buildings.

Technologies	H1	H2	H3
EA/IEQ			
Energy-efficient lighting instead of incandescent/florescent/CFL lamps	LEDs	LEDs	LEDs
Energy-efficient chiller	180 RT	200 RT	300 RT
Solar hot water system (Savings in diesel)	Solar water heaters	Each 2 × 2m sized 22 flat solar hot water panels	Each 2 × 2m sized 90 flat solar hot water panels
Biomass boiler instead of diesel boilers **(hot water/steam generation)**	925 kg/h biomass boiler	1000 kg/h biomass boiler	2000 kg/h biomass boiler
LED television instead of non-LED television	40″ sized	40″ sized	40″ sized
EA			
Solar PV system **(lighting)**	N/A	125 kW, 433 nr of solar panels with 4 × 27kW inverters & 1 × 15kW inverter	300 kW, 215 nr of solar panels with three-phase invertors
Key card for guest room	Available	Available	Available
Dual set point thermostat	Available	Available	Available
Variable Frequency Drives (VFDs)	Available	N/A	Available
Biogas system	N/A	N/A	70 m3 capacity
Variable Speed Drives (VSD) for freshwater pump	N/A	4 kW capacity	N/A
VSD for chilled water pump	N/A	4 kW capacity	N/A
VSD for hot water pump	N/A	4 kW capacity	N/A

terns, water treatment plants (sewage, greywater), solid waste management, rainwater collection tanks, skylights, composting bins, green roofing, low reflectance surfaces, bicycle tracks, and use of environmentally friendly materials are some of the sustainable technologies implemented prior to retrofitting. Apart from implementing these environmentally and economically sustainable technologies, the selected hotels engage in activities such as purchasing locally available materials from suburbs, using local transport services, and conducting training on cleaning programmes to ensure social sustainability.

Although there have been 13 different technologies incorporated in the selected hotels, there seems to be no proper basis being followed by the hotels in selecting retrofits, as evidenced in Table 4. The hotels have made their own choice of technologies. For example, amongst three hotels, the biogas system was available only in H3 while the solar PV system of different capacities were seen in H2 and H3. Further, last three technologies listed in Table 4 are available only in H2, while the use of VFDs for pumps and motors has been adapted only in H1 and H3. Therefore, it is believed that a detailed cost-benefit analysis of available retrofits would provide a sound basis for the selection of appropriate retrofit technologies. Often, one of the challenges in green retrofitting is lack of awareness about capital commitments and resulting benefits, subsequently. This warrants the current study to assess the costs and savings of implemented green retrofit technologies as it would render a basis for the retrofit selection in future investments. The following section presents the analyses of the costs and savings of the implemented retrofits.

4.2. Comparison of initial cost implications of green retrofit technologies implemented in the hotel buildings

The initial costs of implemented technologies were obtained from the hotel logs as of the year of retrofitting. Yet, the year of retrofitting differed between hotels. Thus, the collected costs were converted to a common base year of 2020. Table 5 presents the initial costs comparision of the technologies implemented in the selected three hotels.

As seen from Table 5, in considering the initial cost of retrofit technologies, although some of the retrofits are unavailable in hotels, the use of solar PV systems, energy-efficient chillers and biomass boilers are the top three expensive retrofit technologies. Amongst the hotels, H1 has not incorporated a solar PV system; instead, a green roof system has been embedded prior to retrofitting as an energy-efficient technology as well as to achieve an enhanced aesthetic performance of the building. In terms of the cost of solar PV system, there is a significant difference between the systems in H2 and H3. Similarly, the cost of energy-efficient chillers was comparatively higher in H3, while the cost of biomass chiller has been in a similar range between hotels. Further, the cost of key card for the guest rooms and LED televisions are significantly higher in H1 compared to H2 and H3. These initial cost differences of technologies are attributed to the capacity differences of the retrofits.

Comparatively, technologies such as key card systems, VFDs, and VSDs for freshwater, chilled water and cold-water pumps are less expensive. Despite, those technologies were not available in two of the three hotels considered. For example, H1 and H3 have not incorporated a VSD for freshwater, chilled and hot water pumps, while H2 has not incorporated a VFDs for pumps and motors. The Biogas system is one of the technologies contributing to energy savings in terms of LP Gas. However, only one of the hotels has incorporated such technology as there was a provision in terms of space required for the system as well as the technology was considered as a strategy for sustainable food waste management.

These inconsistencies in the selection of technologies could be partly due to a lack of awareness about the available technologies, their costs and the benefits of operational saving potentials. In addition, clients'/building owners' preferences also influenced the selection of retrofits. However, irrespective of size/capacity and occupancy of hotels, when prioritizing the retrofits in terms of initial cost, use of key cards for guests, LED lights, dual set-point thermostats, LED televisions, solar hot water systems, biomass boilers, energy-efficient chillers, and solar PV system are in ascending order of their cost-effectiveness in all three hotels are considered together, as evidenced by Fig. 1. Although some of these technologies have a higher initial cost, they might counterbalance these higher initial costs with operational savings over the life of these retrofits. Thus, comparing the initial cost of these retrofits with operational benefits would provide a sound basis for selecting appropriate retrofits.

Table 5
Comparison of initial costs (LKR) of green retrofit technologies in 2020.

Item	Retrofits	H1	H2	H3
A	Biomass boiler	16,922,015	13,416,167	19,834,190
B	Energy-efficient chillers	28,003,582	20,634,950	41,762,674
C	LED lights	1,372,732	1,081,025	1,524,522
D	Biogas system	–	–	2,463,875
E	Key card for the guest rooms	820,969	372,661	491,035
F	Dual set-point thermostat	2,768,229	1,466,005	1,931,678
G	Solar hot water system	9,864,852	3,235,067	12,319,373
H	LED televisions (40″ sized)	11,761,939	5,790,105	7,391,624
I	Solar PV system	–	21,682,096	61,596,865
J	VFDs for pumps and motors	1,555,611	–	431,178
K	VSD for freshwater pumps	–	431,178	–
L	VSD for chilled water pumps	–	1,133,382	–
M	VSD for hot water pumps	–	401,692	–

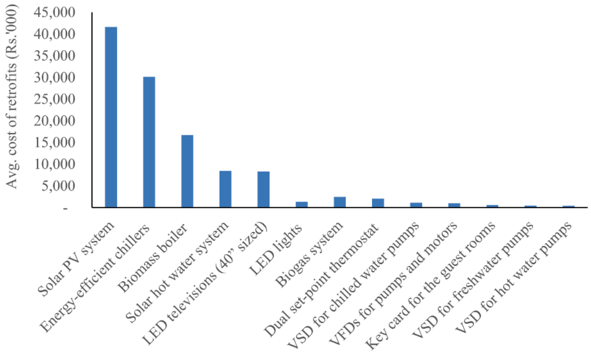

Fig. 1. Ranking of initial cost of green retrofits. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.3. Comparison of saving potentials of green retrofit technologies implemented in the hotel buildings

To assess the operational saving achieved through the implementation of retrofits, initially, annual energy consumption of each retrofit was calculated in terms of physical quantities. Then the annual saving (using Formula 3) was derived as the difference between the energy consumption of existing technology and the implemented retrofit technology. Table 6 presents the annual energy savings from green retrofit implementation in the selected hotel buildings.

Technology A and D contribute to savings on diesel and LPG gas consumption, respectively, while all remaining technologies contribute to electricity savings. As seen from the table, the use of an energy-efficient chiller is placed at the first rank in contributing to the electricity-saving in all selected hotels. When considering the electricity savings of energy-efficient chillers in all three buildings, they are ranked in descending order as H3, H2, and H1, corresponding to the capacity of the equipment. The solar PV system is the second most contributor to electricity savings, but only in H2 and H3, where the difference in electricity savings is attributed to the capacity and the number of solar PV panels. Similarly, the energy savings due to biomass boiler is almost double in H3 compared to H1 and H2, which is also for a similar reason of increased system capacity in H3. LED lights, solar hot water systems, and VFDs for pumps and motors are also responsible for a reasonable amount of electricity savings in hotels. The technologies such as key card system, dual set point thermostat, LED television, VFDs, and VSDs are the least contributors to electricity savings.

In order to assess the annual savings gained due to the implementation of the retrofits, the actual quantities presented in Table 6 were converted to their equivalent monetary values using the unit cost (Ucost) derived as per the Formula 1 provided in the research methodology. Subsequently, these annual savings were brought to the base year 2020 using the present value formula given in the methodology section. Then the energy savings throughout the life cycle were calculated for each technology based on the lifetime of the respective technology and the maximum lifetime assumed, as explained in the research methodology. For example, the monthly financial saving on the use of biomass boiler instead of diesel boiler was calculated as follow:

Financial savings (Rs/month) = [Avg. monthly diesel consumption] x [Ucost Diesel] - [Avg. monthly biomass consumption] x [Ucost Biomass].

Further to the energy savings displayed in Table 6, Table 7 presents the equivalent energy savings of the retrofits in monetary values. As discussed previously, Table 7 evidences that overall, in all hotels, Biomass boiler, Energy-efficient chillers, Solar PV system, VFDs for pumps and motors, and LED lights are the top five (05) retrofits with the highest energy-saving potential as illustrated in Fig. 2. In terms of all these five technologies, H3 has higher savings compared to H2 and H1, owing to the increased capacity of the systems such as Energy-efficient chiller, Solar hot water system, biomass boiler, and solar PV system.

Table 6
Comparison of annual savings (in energy-saving units) of green retrofits.

No.	Retrofits	Unit	H1	H2	H3
A	Biomass boiler	Litre	106,756	108,882	203,362
B	Energy-efficient chillers	kWh	297,126	692,064	1,310,319
C	LED lights	kWh	86,125	74,885	107,163
D	Biogas system	Kg	–	–	8382
E	Key card	kWh	18,776	17,546	11,562
F	Dual set-point thermostat	kWh	47,875	17,546	26,094
G	Solar hot water system	kWh	80,300	31,118	156,967
H	LED televisions (40″ sized)	kWh	15,984	2771	10,052
I	Solar PV system	kWh	–	141,965	412,775
J	VFDs for pumps and motors	kWh	104,080	–	111,000
K	VSD for freshwater pumps	kWh	–	11,640	–
L	VSD for chilled water pumps	kWh	–	74,650	–
M	VSD for hot water pumps	kWh	–	18,386	–

Table 7
Annual savings of retrofit technologies as @ 2020.

No.	Retrofits	Annual avg. saving (LKR)		
		H1	H2	H3
A	Biomass boiler	10,787,839	9,833,273	15,592,953
B	Energy-efficient chillers	6,606,259	4,484,732	11,912,631
C	LED lights	1,914,899	1,682,419	2,408,032
D	Biogas system	–	–	950,871
E	Key card	417,481	394,214	259,805
F	Dual set-point thermostat	1,307,876	394,214	586,351
G	Solar hot water system	1,279,623	400,320	1,923,727
H	LED televisions (40″ sized)	355,386	62,274	227,953
I	Solar PV system	–	2,562,176	7,627,696
J	VFDs for pumps and motors	2,211,427	–	2,494,230
K	VSD for freshwater pumps	–	210,077	–
L	VSD for chilled water pumps	–	1,347,274	–
M	VSD for hot water pumps	–	331,828	–

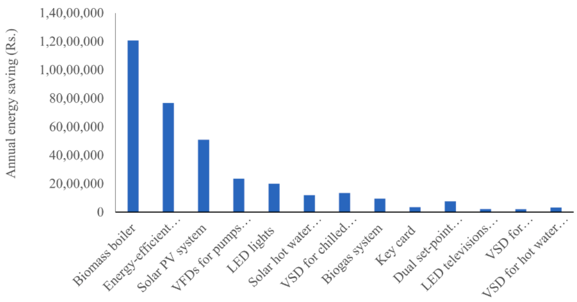

Fig. 2. Ranking of annual savings of green retrofits. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Though the annual performance of some of these retrofits is significant, their lifetime performance may differ based on the initial investment and lifetime of technologies. Thus, selecting appropriate retrofit technology is to be based on the comparative assessment of lifetime benefits over cost of technologies. Thus, the following section discusses the NPV (calculated using Formula 2) and SPB (calculated using Formula 4) of all retrofits considered.

4.4. Comparision of green retrofit technologies implemented in the hotel buildings: Saving potentials vs initial cost

Combining the initial costs and annual savings presented in Tables 5 and 7, respectively, the net effect, NPV of each technology was calculated considering the lifetime of each technology as well the longest life time of the technologies considered. Table 8 presents the NPVs of each technology available in the selected hotels.

As seen from Table 8, except for LED television, all other technologies have positive NPVs, indicating the potential of having substantial savings compared to the initial cost incurred in implementing those retrofit technologies.

Table 8
Summary of NPVs and SPBs of green retrofits (@2020) (Note: Average exchange rate 1 USD = 185 LKR for 2020).

No.	H1		H2		H3		Lifetime (Yr)
	NPV (LKR)	SPB (Yr)	NPV (LKR)	SPB (Yr)	NPV (LKR)	SPB (Yr)	
A	83,265,770	1.57	95,131,886	1.36	152,022,966	1.27	20
B	35,506,470	4.24	28,375,986	4.60	85,966,523	3.51	18
C	7,499,984	0.72	8,219,288	0.64	11,782,653	0.63	8
D	–	–	–	–	8,252,274	2.59	20
E	1,094,358	1.97	1,599,811	0.95	855,119	1.89	7
F	1,533,625	3.23	712,311	3.72	1,261,483	3.29	7
G	6,317,125	7.71	2,313,746	8.08	13,737,8078	6.40	25
H	(6,357,931)	33.10	(3,934,979)	36.52	(4,899,993)	32.43	7
I	–	–	14,015,938	8.46	44,121,871	8.08	25
J	8,680,943	0.70	–	–	13,136,220	0.17	8
K	–	–	785,881	2.05	–	–	8
L	–	–	6,364,670	0.84	–	–	8
M	–	–	1,468,120	1.21	–	–	8

Amongst the implemented retrofits, biomass boilers, energy-efficient chillers, solar PV systems, VFDs for pumps and motors, and LED lightings are the top five technologies with the contribution of substantial annual as well as lifetime savings.

It is also to be noted that these top technologies, except solar PV systems, require less than 5 years to set off the original investment in technologies. Solar PV systems require 8 years to recover its initial investment. Similarly, a solar hot water system contributes to energy saving considerably annually as well as lifetime with an equal pay-off period of 8 years. Further, all three hotels have incorporated dual set-point thermostats and key cards that contribute to savings in energy over its lifetime with a short payback of less than four years.

5. Discussion and conclusions

An in-depth analysis of three similar rated hotel buildings in Sri Lanka confirms that in line with the global view of retrofitting, the hotels have incorporated technologies which are confined to improving energy and indoor environment quality. In contrast, some of the technologies related to WE, SS, and MR aspects have already been incorporated prior to retrofitting the selected buildings. Still better, during the retrofitting, a range of different technologies have been implemented, depending on the requirements of the selected hotels. The identified hotels are unique in their geographical location, the number of rooms, occupancy rate, and the capacity of technologies (Refer to Tables 2 and 7). Similarly, the geographical location can also impact the purchasing rate of the materials, hence the NPV values. Accordingly, each technology's initial cost, annual savings, and NPV values vary among hotels. Therefore, the overall performance of technologies is considered based on three hotels.

All the implemented technologies, except LED televisions, yield positive net savings (NPVs) over their lifetime with a comparatively lower payback period of fewer than five years in the case of most of the technologies implemented. Although those technologies require very high initial investment commitments, they are recoverable within a life span of fewer than five years, except for a few technologies like Solar hot water systems and Solar PV systems. Especially, technologies like LED lights, VFDs for pumps and motors, Biomass boilers, Key cards, VSD for chilled water pumps, VSD for freshwater pumps, and VSD for hot water pumps require a short payback period of fewer than 2 years to repay the initial commitments. Interestingly, the higher the initial investment in technologies, the higher the operational saving potential is. As evidenced in Tables 5 and 8, respectively, technologies in the descending order of their initial costs are in a similar descending order in terms of their NPVs. The top three expensive retrofit technologies among the 13 available in the selected hotel buildings are Solar PV systems, Energy-efficient chillers, and Biomass boilers. According to NPVs, Solar PV systems and Energy-efficient chillers are the top two technologies with higher operational saving potential, while Biomass boiler is the fourth top technology after Solar PV systems and VFDs for pumps and motors in the selected hotels. Further, Solar PV systems and Biomass boiler technologies have a payback period of fewer than 1.5 years, while Energy-efficient chillers take 4 years on average to repay the initial investment. Although the Solar PV system is one of the most feasible technologies, hotel A has not implemented the Solar PV system as the roof of the building has already been adopted with vegetation. Further, none of the buildings has implemented the rainwater harvesting system owing to the availability of space and initial substructure requirements. It shows that the availability of space for implementing technologies significantly affects the decision on selecting technologies. Further, all three selected hotels have implemented LED television which gives negative NPV with a high payback period. The availability of technology in the market and its durability are the reasons for selecting this technology. In terms of average SPB, except for solar hot water system, solar PV system, and LED television, all the other technologies have less than 5 years of SPB. Solar hot water system and solar PV system have less than 10 years of SPB, while LED television has a very high SPB, nearly 53 years.

Overall, the technologies considered in the study are recommended as feasible retrofit technologies as they offer positive NPVs. The study further concludes that the initial cost of technologies is not a significant factor in selecting retrofit technologies. The study has considered three different hotels with different ranges/capacities of technologies; still, the findings are consistent across the considered case buildings. Hence, the findings are more reliable and convince the investors of the feasible retrofit technologies. However, the NPV assessments are based on each technology's given lifetime and initial cost recorded in the selected hotels. In addition, it is expected that maintenance cost of technologies could impact the saving potentials. Hence, a further study is recommended to carry out a market survey to explore the possible range of initial cost as well as maintenance aspects, and lifetime of each technology and to decide their sensitiveness on influencing the NPVs of the selected technologies.

Author contributions

Conceptualization: EP, TR; Data curation: EP; Data analysis: EP, TR; Investigation: EP; Methodology: EP, TR; Supervision: TR, DG; Visualization: TR; Roles/Writing - original draft: EP; and Writing - review & editing: TR, DG.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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