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DEVELOPING A DECISION-MAKING MODEL FOR SELECTING SMART RETROFITS

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ABSTRACT

The world is now experiencing a large environmental crisis, particularly buildings contributing significantly to the problem. Hence, building energy demand has been continuously growing in parallel with the rise in occupant energy demand. Smart retrofitting has been highlighted as one of the most effective ways to reduce energy consumption. However, the selection of suitable smart retrofits (SRs) has become a challenging task, from a range of SRs. A qualitative research approach was used in this research to identify relating to smart retrofits (SRs) for office buildings and establish governing factors for their selection. Semi-structured expert interviews were conducted to collect data related to SRs techniques, and content analysis was carried out to establish governing factors for selection of each SR. Out of 18 identified SRs from literature, fan cycling, ventilation control, and LED luminaires are the most implemented retrofit technique during the operational stage of the office buildings in Sri Lanka. Further, fan cycling, and ventilation controls were identified as commonly used types. Those findings were used to develop the decision-making model. Although SRs implementation is a comprehensive process, the recognized governing factors can be used to select suitable forms and features of SRs based on proposed decision-making model. This research further establishes metrics to benchmark the performance of SRs. The proposed model and the metrics could be valuable tools for building owners and facility managers to optimize facility operations.

Keywords: *Decision Criteria Model; Performance Evaluation; Smart Retrofits.*

1. INTRODUCTION

The primary source of global climate change in the atmosphere is human influence and environmental perturbation that is mainly caused by pollution associated with energy use (Karkare, et al., 2014). From 1984 to 2004, the rate of primary energy consumption and the amount of c discharged grew by 49% and 43%, respectively (Omar, 2018). According to Ahmad, et al. (2017), the non-residential building stock worldwide consumes about 46% of energy consumption and account for 30% of total CO_2 emission and 36% of the greenhouse gas emission. Hence, European Union (EU) decided to reduce CO_2 emission and greenhouse gas emission by 80% before 2050 (Khan, et al., 2021). The "smart retrofitting" concept has been introduced as the newest sustainable approach to reduce emission outputs while improving energy efficiency (Jaspert, et al., 2021). Approximately, 61% reduction in national CO_2 emission was found possible through

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implementing SR in building stock (Hirvonen, et al., 2021). Davies and Osmani (2011) viewed SR as the foremost approach in attaining sustainability in existing buildings at comparatively low cost compared to building lifetime and high uptake rates.

Smart retrofitting focuses on cost-effectively expanding existing assets' digital capabilities and functions to allow their adoption into smart environments and create value with existing physical support by integrating the sensor, connection, and data layer (Hassan Al-Maeeni, et al., 2020). In other words, SR aims to provide environmentally friendly, energy-efficient, and comfortable transformation of the current state in the building into smart assets (Jagarajan, et al., 2017). Pueo, et al. (2020) viewed SR as a process of upgrading, updating, or refurbishing existing physical assets. In this research, SRs are described as converting an existing building into the most advanced automated process by enhancing energy saving, human comfort, and green attributes with BMS integration used to monitor and control building facilities sustainably. A wide range of retrofitting technologies are available, including ventilation control, electricity demand limiting, optimum start-stop, vacuum glazing windows, smart windows, LED luminaires, sensors, elevator group optimization, and green roof (Gluszak, et al., 2019).

However, the implementations for SRs are at a marginal level due to the difficulty in selecting efficient retrofits options according to the type of buildings (Jagarajan, et al., 2017). Since various smart retrofitting technologies are available, selecting a cost-effective retrofit has become challenging (Ma, et al., 2012; Si, et al., 2016; Fasna and Gunatilake, 2019). Further, lack of knowledge of energy efficiency, lack of financial incentives, lack of communication between stakeholders, specific legal obstacles, and negative attitudes and their effects are forwarded difficulties in selecting the most appropriate SRs (Davies and Osmani, 2011; De Silva, et al., 2019). Also, standards to benchmark the performance of SRs are critical needs for facility managers.

With the aim of finding a solution for the gap as mentioned above, the research is conducted to develop a SR decision criteria model for selecting the best SRs for the office buildings in Sri Lanka. Further, the metrics to set benchmarks were established to assess the performance of the SRs.

2. LITERATURE FINDINGS

2.1 INTRODUCTION TO SR

The smart building concept was initiated in the United States in the early 1980s. The growing need for sustainable designs and environmentally friendly architecture has pushed the industry to create the SR concept.

Ghaffarianhoseini, et al. (2016) stated that the effectiveness of SR depends on their capability of managing critical systems and establishing necessary coordination between essential systems of building to provide desired technical performance, operational cost-saving strategies, and flexibility. Thus, usage of automation and high technology are prime elements of SRs.

2.2 SRS TECHNIQUES

Numerous SRs forms are used to improve building performance in existing buildings (Jiangjiang, et al., 2008). They include HVAC, air quality control, lighting, shading, window opening, elevators, and other electrical devices and applications (Park and Rhee, 2018). The literature reveals that 18 SR techniques apply to an office building in the Sri Lankan context, and they can be categorized into five forms as follows:

HVAC retrofits (T1) - Mathews, et al. (2001) identified HVAC retrofits methods as regulating indoor temperature set-point at an acceptable level, air-bypass and reset control on AHUs, setback control on spaces, controlling start-stop timings, consisting of economizer cycle combined with all the above, and CO_2 control.

Elevator retrofits (T2) - The elevator retrofits could have a significant impact on the use of zones as well as their numbers, and to segregate the different modes of traffic heading to other parts of the building, with overall savings resulting from the group's elevators sharing capacity (Missler, et al., 2016).

Lighting retrofits (T3) - Sensing techniques for smart lighting control and LED retrofits are commonly used (Ab Halim, et al., 2017). Optimizing daylighting with LED luminaires can achieve approximately 40% energy saving in office buildings (Sun, et al., 2018).

Building façade retrofits (T4) - Heat insulation solar glass, wall insulation, and green roof are common SRs for building façade of an office building (Cuce and Riffat, 2017; Simona, et al., 2017; Shafique, et al., 2018).

Window retrofits (T5) - Low emissivity applications, vacuum glazing windows, and smart windows are the most common SRs to reduce the thermal transaction through windows in office buildings (Han, et al., 2010; Ye, et al., 2013; Cuce and Cuce, 2016).

2.3 GOVERNING FACTORS FOR SR SELECTION

Governing factors for SR selection can be grouped into 3, including energy-saving, human comfort, and green attribute as follows:

Energy-saving (F1) - energy-saving techniques such as using renewable energy sources to achieve Nearly Zero energy buildings and reduce CO_2 emissions are considered (Morelli, et al., 2012; Pikas, et al., 2014).

Human comfort (F2) - allowing users to task-based interaction without getting any troubles and understanding smart technologies' capabilities are ensured (Gelazanskas and Gamage, 2014; Galinina, et al., 2018)

Green attributes (F3) - The ability of a building to provide flexibility is determined by physical characteristics such as thermal insulation and building layout, technologies and controlling its demand and generation in response to local climate conditions, user demands, and grid requirements (Reynders, et al., 2017; Parrish, et al., 2019; Al Dakheel, et al., 2020).

2.4 SR PERFORMANCE BENCHMARKS

Performance benchmarking provides organizations a better understanding of competitive organizations' success and the factors that can be optimized to succeed (Weicker, 1990). On the perspective of SR, it is estimated the performance such as energy-saving, human comfort and green attributes of the building is compared to other similar buildings (Ho, et al., 2000; Menezes, et al., 2013). Hence, the benchmarking process leads buildings to keep with regular monitoring and altering to achieve success.

The benchmarking process is a good practice that can help facility managers in intervention decision-making to select suitable techniques (Pestana, et al., 2021). Table 1 depicts the applicable metrics for energy saving, human comfort, sand green attributes of office buildings.

Table 1: Selected metrics for benchmarking of office buildings

Metrics	Unit of measure	Benchmark	Reference
Energy Saving			
Total energy consumption per area (Building energy index)	kWh/m^2	The low value is better (120 kWh/m^2)	Energy Conversation Building Code
Lighting system energy consumption per area	kWh/m^2	The low value is better	(Balbis-Morejón, et al., 2021)
HVAC energy consumption per area	kWh/m^2	The low value is better	(Balbis-Morejón, et al., 2021)
Human comfort and green attributes			
The average value of indoor illumination level	Lux	250 – 500 Lux is desired with 40 Lux for access areas and walkways	OSHA 1915.82
The average value of indoor temperature	°C	A low value more than 24°C and above 10.5°C is better	ASHRAE Standard 55-2017
Average value of indoor CO_2 concentration	ppm	600 - 1000 ppm	EN 13779:2007
The average value of indoor RH	%	40%-60%	EN 13779:2007
No complaints per area per annum	no./m^2	The low value is better	

3. RESEARCH METHODOLOGY

A qualitative approach was selected to achieve research objectives. The qualitative approach is the best technique if the author intends to learn about respondents' thoughts and opinions based on their experiences, expertise, and behaviour (Brayer, 2008). This research design includes a comprehensive literature review, semi-structured interviews, data analysis, and discussion of research findings, respectively. Since, this study focuses on the causes behind the factors used for retrofits selection and how they can be mapped with the existing building conditions. According to Yin (2011), the case study is used in this research. Hence, the researcher needs an in-depth investigation in a particular area and focuses on understanding the full scope of the problem, not on quantifying the problem.

Restrictions in accessibility due to COVID-19 pandemic at the time of data collection and the time constraints, six cases were selected, and the unit of analysis for this study was considered more than six years old office buildings. Since retrofitting are used in older buildings and further the retrofitting technology has been improved during last five years (Streicher, et al., 2020). The building older than six years were selected, with the aim of selecting retrofitted buildings. Hence, this research was used the purposive sampling technique to select buildings with the retrofits. The expert interviews were conducted in the individual cases to collect data on available SRs of HVAC, lighting, building Façade, window, and elevator retrofits to develop the decision criteria model. The profile of the selected office buildings and experts are tabulated in Tables 2 and 3, respectively.

Further, energy bills, datasheets, and retrofit proposals were reviewed to analyze energy consumption. Content analysis using NVivo 12 software was used to analyze interview transcripts. Finally, cross-case analysis was carried out based on the created themes to propose the decision criteria model for selecting the most suitable SRs in conventional office buildings in Sri Lanka.

Table 2: The profile of the selected office buildings

Case	Description	Used SRs type
C1	Bank building, 10 years old	HVAC retrofits, Lighting retrofits
C2	Commercial type office building, renting office blocks to their tenants, 20 years old	HVAC retrofits, Lighting retrofits, Elevator retrofits
C3	Bank building with Green Building Certification, 10 years old	HVAC retrofits, Lighting retrofits, Window retrofits
C4	Commercial type office building with Green Building Certification, 25 years old	HVAC retrofits, Lighting retrofits, Building façade retrofits, Window retrofits, Elevator retrofits
C5	Bank building, 36 years old	HVAC retrofits, Lighting retrofits, Elevator retrofits
C6	Government building consists of ministry complex, 10 years old	HVAC retrofits, Lighting retrofits, Building façade retrofits, Window retrofits, Elevator retrofits

Table 3: Profile of experts

Case	Respondent	Description
C1	C1R1	Head of Facilities Management with 6 years of working experience in banking buildings and responsible for all maintenance activities
	C1R2	Facility Executive with 2 years of working experience in the banking sector and responsible for energy reduction of building operation
C2	C2R1	Facility Manager with 10 years of working experience in commercial and office buildings
	C2R2	Facility Engineer with 8 years of working experience in building automation projects
C3	C3R1	Senior Facility Manager with 8 years of working experience in especially green development projects

Case	Respondent	Description
C4	C4R1	Head of Facilities Management with 12 years of working experience in leading commercial sector buildings
C5	C5R1	Maintenance engineer with 15 years of working experience in banking sector buildings
C6	C6R1	Maintenance engineer with 6 years working experience in mechanical engineering (both factory and commercial sector buildings)

4. RESEARCH FINDINGS AND DATA ANALYSIS

4.1 SRs TECHNIQUES USED IN OFFICE BUILDINGS

The details of SRs used in selected cases are summarized in Figure 1. Out of 18 identified SRs, findings show fan cycling, ventilation control, and LED luminaires are the most implemented retrofit technique during the operational stage of the building. In comparison, fan cycling and ventilation controls are reported as commonly used types. Conversely, night purge, image sensoring, green roofs, and smart windows have not been implemented in any of the cases used for the study.

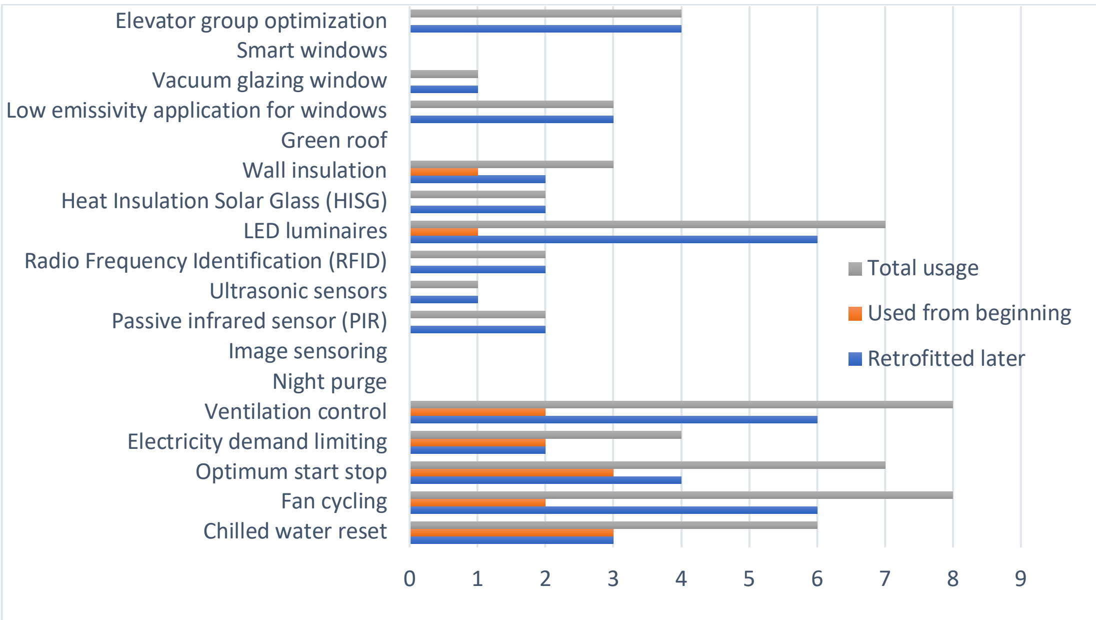

Figure 1: Current usage of SR techniques

**Total Usage = Used from beginning + Retrofitted later*

4.2 ENERGY SAVINGS ACHIEVED FROM DIFFERENT FORMS OF SRs

Results showed that the most implemented SR forms are HVAC retrofit and Lighting retrofit applications. Further, the highest saving has been obtained by adapting HVAC retrofits, compared with other forms (Table 4). That may be since HVAC is the highest energy consumer for office buildings (Fong, et al., 2006).

Table 4: Current forms of SR practices

Smart Retrofit Area Based on Model	**Approximate % of Saving**	**Cases**					
		C1	**C2**	**C3**	**C4**	**C5**	**C6**
HVAC retrofits (T1)	55%-70%	✓	✓	✓	✓	✓	✓
Lighting retrofits (T3)	10%-12%	✓	✓	✓	✓	✓	✓
Window retrofits (T5)	6%			✓	✓		✓
Building façade retrofits (T4)	4%-5%				✓		✓
Elevator retrofits (T2)	2%-6%		✓		✓	✓	✓

Table 5: Energy consumption of selected case studies

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Total energy consumption (Monthly)	316,520.7	2,003,878.8	3,630,600.0	7,608,759.0	7,500,000.0	637,100.0
GFA	4645.2	25292.0	60,000.0	117,057.8	50,000.0	5,000.0
Unit cost	68.1	79.2	60.5	65.0	150.0	127.4

4.3 FACTORS CONSIDERED FOR SRS TECHNIQUES SELECTION

Knowledge of experts was elicited to establish factors under three areas: energy saving, human comfort, and green attributes. All experts showed that energy consumption per gross floor area (GFA) is the main factor when selecting SRs. Expert C4R1 stated that the thumb rule used in choosing suitable forms of retrofitting is *"…implementing retrofitting technologies into a system that consumes more energy …"*. When analysing on multiple data sources at the same time, NVivo is a realist approach that can help structure the iterative under qualitative approach (Dalkin, et al., 2021). Accordingly, one of the SR forms examined was illustrated in Figure 2.

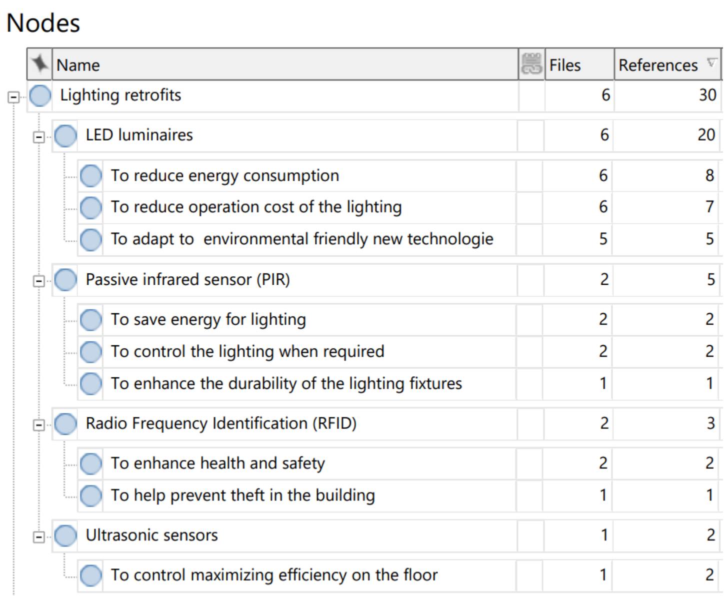

Figure 2: Factors governed for lighting retrofits

Summary of the code-based content analysis using NVivo 12 software was analysed. Twenty-seven factors are extracted to select five forms of SRs, as shown in Table 6.

Table 6: Governing factors for SR selection

Forms of SR	Factors governed for selection	No of References
HVAC retrofits (T1)	To avoid freezing the chiller	7
	To increase safety to the chiller	6
	To reduce peak energy consumption	6
	To get smooth performance	2
	To tally with building operation time	5
	To compute the usage pattern of the buildings	5
	To reduce the total cost for energy consumption at once	5
	To provide cooling and heat simultaneously	7
	To enhance human comfort	5
	To comply with the IAQ requirements	2
Lighting retrofits (T3)	To save energy	2
	To control the lighting when required	2
	To enhance the durability of fixtures	1
	To maintain maximizing efficiency on the floor	2
	To improve health and safety	2
	To help of preventing theft	1
	To reduce operation cost	7
Window retrofits (T5)	To get shading and sunray controls	2
	To get thermal comfort	3
	To avoid sound transmission	1
Building façade retrofits (T4)	To control UV rays through applying UV wall stickers	1
	To avoid solar heat coming to building inside	2
	To reduce energy for HVAC system operation	1
	To reduce thermal transaction	2
Elevator retrofits (T2)	To reduce the waiting time of the queue	6
	To enhance the performance	6
	To provide human comfort	2

4.4 PROPOSED DECISION MODEL

The SR selection criteria model is proposed by considering the type of SRs, governing factors for SRs selection, and energy savings achieved from different forms of SRs. Figure 2 illustrates the proposed model.

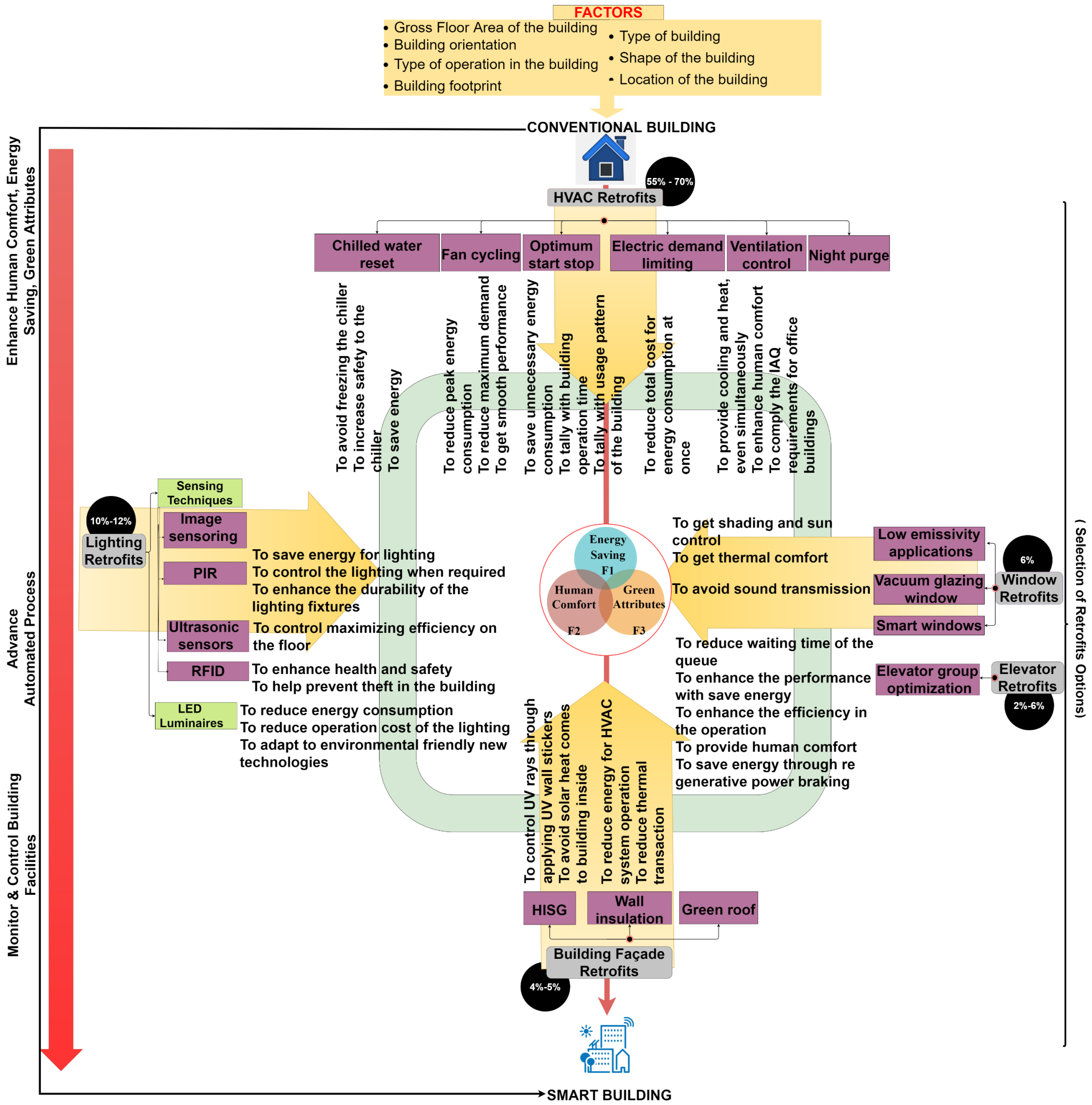

Figure 3: Proposed decision-making model

4.5 PERFORMANCE EVALUATION OF SR

In Sri Lanka, there are no specified standards to set benchmarks for the performance of SRs. Therefore, as per the experts, the metrics for SRs were established considering high energy consumption and human comfort in the built environment (see Table 7). Table 7 shows the values derived from energy consumption levels, human comfort parameters, and green attributes. Arrows indicate that those SRs need more improvements to achieve the best performing level. Results show that C2, C5, and C6 require further improvements in their SRs, compared with their peers when considering total energy consumption. Accordingly, when comparing the performance SRs used in case studies, the average value can be used as the benchmark for further improvements.

Table 7: SR performance matric

	Metrics	C1	C2	C3	C4	C5	C6	Average Value
Energy Saving	Total energy consumption per area (Building energy index) (kWh/m^2)	68.14 ↓	79.23 ↑	60.51 ↓	65 ↓	150 ↑	127.42 ↑	73.69
	Lighting system energy consumption per area (kWh/m^2)	21.19 ↑	12.9 ↑	7.2 ↓	6.5 ↓	22 ↑	12.74 ↓	12.82
	HVAC energy consumption per area (kWh/m^2)	24.23 ↓	33.65 ↓	33.28 ↓	34.45 ↑	79 ↑	76.45 ↑	34.05
Human comfort and green attributes	Average value of indoor illumination level (Lux)	250 ↓	400 ↓	600 ↑	500 ↑	450 ↓	525 ↑	475
	Average value of indoor temperature (°C)	22.77 ↑	23.2 ↑	22 ↓	22.5 ↓	22 ↓	23 ↑	22.64
	Average value of indoor CO_2 concentration (ppm)	988 ↑	1428 ↑	768 ↓	800 ↓	800 ↓	1120 ↑	894
	Average value of indoor RH (%)	51 ↓	55 ↑	50 ↓	55 ↑	55 ↑	50 ↓	53
	No of complaints per year (Relating to building performance) (No./year)	50 ↓	120 ↓	250 ↑	300 ↑	750 ↑	70 ↓	185

5. CONCLUSION

SRs are known for converting conventional buildings to eco-friendly, automated facilities by optimizing resource consumption. Among applicable SRs, fan cycling, ventilation control, and LED luminaires are the most implemented SRs techniques, while fan cycling and ventilation control are the most commonly used SRs techniques during the operational stage of office buildings in Sri Lanka. Further, HVAC retrofits could save more energy than other forms of retrofitting. In this regard, the HVAC system has various parameters to adjust and integrate to reduce energy consumption and wastage. Moreover, lighting retrofits give the most adapted form due to easy implementation with few changes to the existing systems.

However, identifying and deciding to select effective SR techniques should be done by considering various factors. Thus, a decision criteria model was developed to select the most suitable smart retrofits for office buildings in Sri Lanka. The proposed model can be used to choose the best way of taking the decision on SRs techniques selection.

Further, this research was established metrics to set benchmarks for the performance of SRs. The findings show that SRs used in C2, C5, and C6 need further improvements to achieve their best performing level when considering total energy consumption. Having a benchmark for SRs can compare the performance of SRs in similar buildings. Further facility managers can use those findings to adopt alternative technologies to enhance the existing performance of SR to minimize the over-resource consumption and environmental impact of Sri Lankan office buildings.

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