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APPLICATION OF GREEN RETROFIT TECHNOLOGY: A SYSTEMATIC REVIEW

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Green retrofitting is a valuable approach for upgrading existing buildings towards sustainable performances. However, the lack of knowledge about the true cost effects and potential savings of green retrofits distracts building proprietors from paying those retrofits. Therefore, the current study reviewed fourteen studies available in the extant literature and identified twenty-eight different green retrofits incorporated into various buildings with their cost effects and saving potentials through a subsequent desktop study. The results indicated that the majority of green retrofits offer savings related to energy consumption, CO_2 emissions, cooling load, and operating costs. Moreover, energy-saving lighting modifications are widely done in most buildings, while solar collectors, photovoltaics, and low-emission double glazing are used less often due to the long payback period and increased cost of implementation. Alternatively, the use of retrofits with lower costs and high savings, like BMS, lighting controllers, and boiler efficiency improvements, offsets the above setbacks. Furthermore, the highlighted retrofits include green roofing, bicycle parks, CO_2 sensors, and air tightening retrofits, which also save energy. Rainwater harvesting absorbs carbon dioxide and runoff water, where implementing subsystem-level water meters, appliances with low flow rates, and greywater recycling save and recycle the portable water. Accordingly, the study promotes the effective implementation of green retrofits in future buildings.

Keywords: Costs, Payback, Savings, Sustainability, Energy.

1 INTRODUCTION

The uptake of new green buildings is comparably less than the number of existing buildings constructed globally. For example, Ma *et al.* (2012) explained that the replacement of existing buildings by the new-build is only around 1–3% per annum. Also, Karolides (2011) stated that the consideration of existing building renovation must be derived before the new green building development. On this note, Menassa (2011) added that sustainable retrofit is an effective solution that extends the life span of a building while improving performance and preventing the early obsolete nature of the buildings. Similarly, Liang *et al.* (2016) indicated that this incremental improvement of buildings with the incorporation of sustainability concepts will be the justifiable solution for the problems in existing buildings. Further, the same authors defined this building improvement as a green retrofit. Particularly, green retrofit is "any type of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, improve comfort and quality of space in terms of natural lighting, air quality, and noise, all done in a way that it is financially beneficial to the owner" (USGBC 2003). The "green retrofit" differs from the generic "retrofit" by its focus on improving sustainability aspects in the existing buildings. For example, Egbu (as cited in Al-Kodmany 2014) defined the "retrofit" as "refurbishment to encompass renovation, rehabilitation, extension, improvement, conversion, modernization, fitting out and repair which is undertaken on an existing building to permit its reuse for various specified purposes."

Building owners and occupants are motivated by attractive savings in energy costs for green retrofits (Aktas and Ozorhon 2015). Nonetheless, there are conflicting opinions regarding the possible cost-benefit effects of green retrofits. According to Rehm and Ade (2013), a higher capital expenditure is required to improve existing space into the green, while Kasivisvanathan *et al.* (2012) argued that green retrofits take long payback periods, and, therefore, industries are not enthusiastic about their implementation. Another line of argument is often presented to support the viability of green retrofits in terms of construction costs (Zhai *et al.* 2014) and higher returns within a short payback period (Bond 2010).

Additionally, despite the wide availability of green retrofits, determining the most profitable retrofit for the project remains a significant challenge. Noticeably, the application of these retrofits demands knowledge of the dynamics of the individual and combined retrofit measures and their associated costs and savings. Yet, there is a lack of systematic review on the existing body of knowledge on green retrofitting, which is critical for future research. For example, Ma *et al.* (2012) suggested further review studies on the assessment of costs and savings of individual retrofits to support the identification of cost-effective green retrofits. Therefore, the current study aims to identify the most suitable green retrofit options to implement in existing buildings through reviewing cost effects and saving potentials of green retrofits.

2 METHODS

This paper aims to review the research studies that are directly or indirectly related to the cost and saving outcomes of green retrofits and identify the cost of significant green retrofits that could be applied to existing buildings. A literature review and subsequent desk study referring to existing studies were carried out to achieve the research aim. The review highlights the different types of green retrofit measures and their cost effects and potential savings highlighted in previous studies. Computerized databases such as Web of Science, Scopus, and Google Scholar that have access to indexed publications were used to obtain studies published in the area of the cost and savings of green retrofits. Publications are identified according to keywords such as "green retrofit", "energy retrofit", and "sustainable retrofit". Fourteen (14) studies that researched the cost effects and potential savings of green retrofits were selected and reviewed in this paper.

3 ANALYSIS AND DISCUSSION OF REVIEW FINDINGS

3.1 An Overview of Empirical Studies on Green Retrofits

The methodological overview of previous research on green retrofits in terms of green retrofit research trends, the regional context of studies, the type of buildings, and methods to assess retrofits are reviewed considering a random sample of studies to identify the limitations of previous studies and is provided in Figure 1.

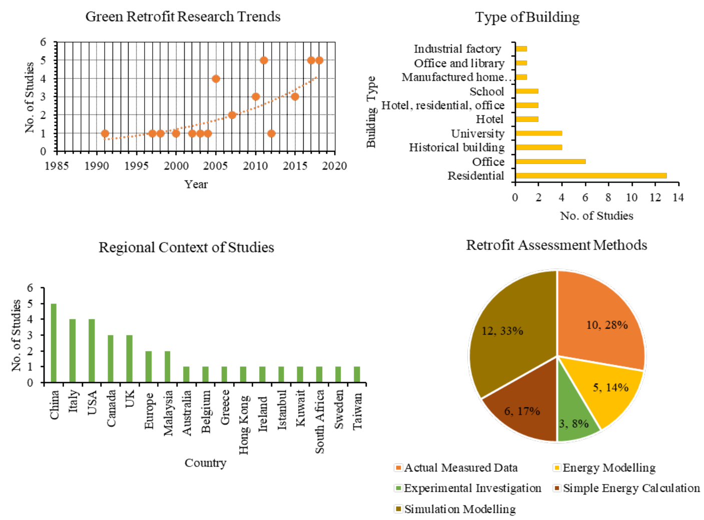

Figure 1. Methodological overview of reviewed studies.

As shown in Figure 1, from the 1990s to 2004, the uptake of studies on green retrofits is at a minimum level, and throughout those 15 years, only a few studies were published in the study area. A boom of research on green retrofits is visible from the year 2005 and onwards, marking peaks at years 2010, 2017, and 2018. The research studies have been focused on applying green retrofits in different types of buildings such as residential, office, historical building, university, hotel, school, manufactured home, library, and industrial factory. Most of the reviewed studies focus on residential buildings. Considering the regional contexts of the studies, most of the reviewed studies related to China, the USA, Italy, Canada, and the UK. In terms of retrofit assessment methods, the majority of reviewed studies have used building simulations and energy modeling followed by studies that used actual measured data. Many of these studies are limited to residential buildings with a focus on implementing green retrofits in the domestic buildings, while average focus could be seen in the office, historical buildings, and universities. However, the focus on hotel, school, and, especially, industrial buildings are less compared to that on other building types. Additionally, most of these studies were conducted based on simulation and modeling rather than reporting the actual cost effects and potential savings of green retrofits. However, more researches that are based on actual case studies could help increase the building owners' willingness to optimize the sustainable performance of their buildings through various green retrofits.

3.2 Cost Implications and Saving Potentials of Green Retrofits

In this section, important green retrofits are reviewed in different contexts, and key outputs according to possible savings and cost effects are summarized in Table 1.

As seen from Table 1, individual green retrofit items are categorized into the Four (04) sustainable features: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), and Indoor Environmental Quality (IEQ), and greenest retrofits were in the EA category and contribute to the reduction of energy consumption and CO_2 emission, while green retrofits related to WE, SS, and IEQ are comparatively less. Among the green retrofits chosen, retrofitting of energy-efficient lighting is important for most buildings, while photovoltaic cells, solar collectors, heat recovery, low-emission double glazing, wall insulation, heating, ventilation, air conditioning, and air filtration systems are not the most financially sound.

Table 1. Individual cost and saving effects of green retrofits.

Sustainable Features	Green Retrofits/Technologies	Potential Savings				Cost Implications				Sources	Country
		Energy	CO_2 emission	Cooling load	Water	Cost-saving	PB (years)	Additional cost	Investment cost		
Sustainable Sites (SS)	Provide bicycle racks	26%								Aktas and Ozorhon (2015)	Turkey
	Green/Vegetated roof			15-49%						Santamouris *et al*. (2007)	Greece
	High albedo and vegetated roof			6-33%							
Water Efficiency (WE)	Subsystem-level water meters				40%					Aktas and Ozorhon (2015)	Turkey
	Sensor faucets with low flow rates				40%						
	Graywater recycling	43%									
	Rainwater recycling		5716.3kg		20%					Li *et al*. (2017)	China
Energy and Atmosphere (EA)	Electronic ballasts	13.9%	13.9%							Stefano (2000)	Australia
	T8 magnetic ballasts	20.5%	20.5%								
	T8 electronic ballasts	24.4%	24.4%								
	T5 electronic ballasts	64.9%	64.9%								
	Replacing incandescent bulbs by 25%, 50% and 75% of CFL					$37-$111 M				Mahlia *et al*. (2005)	Malaysia
	Replacing T8 with T5 lamps	378 kWh					8		£440	Si (2017)	UK
	30W halogen lamps	1800 kWh					0.8		£298		
	Time-scheduled lighting controls	1620 kWh					1.2		£240		
	Wall insulation	2%							€18,600	Ascione *et al*. (2011)	Italy
	Replacing/upgrading windows	2-5%				>$15/GJ				Cohen *et al*. (1991)	USA
	Replacing/insulating claddings					10%				Stovall *et al*. (2007)	
	Heating and preheat upgrades	19-34 GJ				<$2.70/GJ				Cohen *et al*. (1991)	USA
	Floor insulation							30-100¥/m^2		Zhang, *et al*. (2011)	China
	Heat recovery	5%							€17,000	Ascione *et al*. (2011)	Italy
	Ground source heat pump compared to electrical heating		11.3 tons				0.25			Doherty *et al*. (2004)	UK
	Boiler efficiency improvement	64.3%				74%	0.64			Ciampi *et al*. (2015)	Italy
	Low-e double glazing	12%							€76,000	Ascione *et al*. (2011)	Italy
		20,160 kWh					16		£11,200	Si (2017)	UK
	Building management system	18,413 kWh					2.4		£3,000	Si (2017)	UK
	Solar collectors and PV cells	25%						75% of NPV		Verbeeck and Hens (2005)	Belgium
		2-6%	16.8 tons							Li *et al*. (2017)	China
Indoor Environmental Quality (IEQ)	CO_2 sensors	60%								Li *et al*. (2017)	China
	Air filtration, air sealing of ventilation system	11%	11%						€7600	Ascione *et al*. (2011)	Italy
		10%								Nabinger and Persily (2011)	USA

Furthermore, a lack of integration of retrofits of the material and Resources (MR) category is visible from the earlier studies. As evidenced by the review and summarized in the table, retrofit technologies vary widely in terms of their effects on initial cost, operational costs and savings, and, finally, their contributions to overall sustainability. However, in most of the previous studies, retrofits are assessed based on a single parameter—either potential savings or cost effects—and the trade-off between initial investment commitments and saving potentials seemed to have given less priority in integrating the retrofit technologies. Furthermore, considering the regional context of these studies being conducted, most of the retrofits were implemented and assessed in a moderate/mild climate that consists of four seasons: winter, spring, summer, and autumn, except for one study being conducted in a tropical country—Malaysia—and no studies being conducted in extremely cold regions. Therefore, these retrofits and their cost effects and saving potentials can be generalized for a moderate climate.

4 CONCLUSION

Though there is a significant amount of green retrofit publications available in major research databases, there is still a lack of review of current knowledge. To this end, this article provides a comprehensive review of the widely used green retrofits, including their cost effects and saving potentials. Review shows that the sustainable performance of existing buildings can be significantly improved if retrospective green retrofits are chosen and properly implemented. Accordingly, energy retrofits are the most efficient that gives a lot of savings in energy, CO_2 emissions, cooling load, and associated operating costs. Most financially sound retrofits that can be implemented with lower costs and save higher energy are energy-efficient lighting, lighting controllers, BMS, boiler efficiency improvement, etc. These green retrofits are suitable to be applied in the existing buildings in moderate climates. Building owners and decision-makers can benefit from the current review by identifying the most economically sound green retrofits for their buildings. Furthermore, only a few previous studies have analyzed the NPV and payback period for retrofits based on actual cost, but of high importance for a reliable and accurate assessment of the overall cost-effectiveness of green retrofits.

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References

Aktas, B., and Ozorhon, B., *Green Building Certification Process of Existing Buildings in Developing Countries: Cases from Turkey*, Journal of Management in Engineering, 31(6), 050150021-29, 2015.
Al-Kodmany, K., *Green Retrofitting Skyscrapers: A Review*, Buildings, 4, 683-710, 2014.
Ascione, F., Rossi, F., and Vanoli, G. P., *Energy Retrofit of Historical Buildings: Theoretical and Experimental Investigations for The Modelling of Reliable Performance Scenarios*, Energy and Buildings, 43, 1925–1936, 2011.
Bond, S., *Lessons from the leaders of green designed commercial buildings in Australia*, Pacific Rim Property Research Journal, 16, 314-338, 2010.
Ciampi, G., Rosato, A., Scorpio, M., and Sibilio, S., *Energy and Economic Evaluation of Retrofit Actions on an Existing Historical Building in the South of Italy by Using a Dynamic Simulation Software*, Energy Procedia, 78(November 2015), 741-746, 2015.
Cohen, S., Goldman, C., and Harris, J., *Energy Savings and Economics of Retrofitting Single-Family Buildings,* Energy and Buildings, 17(1991), 297-311, 1991.

Doherty, P., Al-Huthaili, S., Riffat, S., and Abodahab, N., *Ground Source Heat Pump Description and Preliminary Results of the Eco House System*, Applied Thermal Engineering, 24(17/18), 2627-2641, 2004.

Karolides, A., *Green Building Approaches: Green Building Project Planning and Cost Estimating,* John Wiley and Sons, New Jersey, 2011.

Kasivisvanathan, H., Ng, R. T. L., Tay, D. H. S., and Ng, D. K. S., *Fuzzy Optimisation for Retrofitting a Palm Oil Mill into A Sustainable Palm Oil-Based Integrated Bio Refinery*, Chemical Engineering Journal, 200, 694-709, 2012.

Li, Y., Ren, J., Jing, Z., Jianping, L., Ye, Q., and Lv, Z., *The Existing Building Sustainable Retrofit in China-A Review and Case Study*, Procedia Engineering, 205, 3638–3645, 2017.

Liang, X., Peng, Y., and Shen, G. Q., *A Game Theory Based Analysis of Decision Making for Green Retrofit Under Different Occupancy Types*, Journal of Cleaner Production, 137, 1300-1312, 2016.

Ma, Z., Cooper, P., Daly, D., and Ledo, L., *Existing Building Retrofits: Methodology and State-Of-The-Art*, Energy and Buildings, 55, 889–902, 2012.

Mahlia, T. M. I., Said, M. F. M., Masjuki, H.H., and Tamjis, M. R., *Cost-Benefit Analysis and Emission Reduction of Lighting Retrofits in Residential Sector*, Energy and Buildings, 37, 573–578, 2005.

Menassa, C., *Evaluating Sustainable Retrofits in Existing Buildings Under Uncertainty*, Energy and Buildings, 43(12), 3576-3583, 2011

Nabinger, S. and Persily, A., 2011. *Impacts of Air Tightening Retrofits On Ventilation Rates and Energy Consumption in A Manufactured Home*, Energy and Buildings, 43, 3059–3067.

Rehm, M., and Ade, R., *Construction Costs Comparison Between "Green" and Conventional Office Buildings,* Building Research and Information, 41, 198–208, 2013.

Santamouris, M., Pavlou, C., Doukas, P., Mihalakakou, G., Synnefa, A., Hatzibiros, A., and Patargias, P., *Investigating Performance and Analysing the Energy and Environmental of an Experimental School Green Roof System Installed in A Nursery Building in Athens, Greece*, Energy, 32, 1781–1788, 2007.

Si, J., *Green Retrofit of Existing Non-Domestic Buildings as A Multi Criteria Decision Making Process*, PhD Thesis, University College London, 2017.

Stefano, J. D., *Energy Efficiency and The Environment: The Potential for Energy Efficient Lighting to Save Energy and Reduce Carbon Dioxide Emissions at Melbourne University, Australia,* Energy, 25, 823–839, 2000.

Stovall, T., Petrie, T., Kosny, J., Childs, P., Atchley, J., and Sissom, K., *An Exploration of Wall Retrofit Best Practices*, Thermal Performance of the Exterior Envelopes of Buildings X Proceedings of ASHRAE THERM X, Clearwater, December, 1-10. 2007.

USGBC, *Building Momentum: National Trends and Prospects for High Performance Green Buildings*, United States Green Building Council, Washington, DC, 2003.

Verbeeck, G., and Hens, H., *Energy Savings Viable, In Retrofitted Dwellings: Economically*, Energy and Buildings, 37, 747–754, 2005.

Zhai, X., Reed, R., and Mills, A., *Addressing Sustainable Challenges in China: The Contribution of Off-Site Industrialisation,* Smart and Sustainable Built Environment, 3(3), 261-274, 2014.

Zhang, X., Platten, A., and Shen, L., *Green Property Development Practice in China: Costs and Barriers,* Building and Environment, 46(11), 2153-2160, 2011.