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Environmental Impact Analysis of Functional Retrofitting Measures in Buildings

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Environmental Impact Analysis of Functional Retrofitting Measures in Buildings

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Abstract

A large number of existing building stock in India was built before the implementation of government guidelines mandating the Green Building Codes. These buildings have been operating with various inefficiencies pertaining to their resource consumption and emissions. Literature suggests that the option of functional retrofitting of building has a potential to reduce this inefficiency by up to 50%. This paper investigates this potential by analysing actual cases of functional retrofitting of buildings (for achieving greater operational efficiency) in Indian context. The environmental impact analysis in this study includes the impact categories of primary energy demand, global warming potential, abiotic depletion potential, ozone depletion potential and water resource consumption for both pre-retrofit and post-retrofit scenario of building. The results are then correlated to the initial cost of functional retrofitting for each case in order to identify the inter-relationship and trend with respect to the level of intervention opted for the cases.

Keywords: functional retrofitting, operational efficiency, environmental impact.

Introduction

There is an understanding that the environmental impact of new construction is more than an alternative of retrofitting (Rodríguez, et al., 2017) (Power, 2008) However, there can be various configurations of building retrofitting (structural as well as functional), the environmental impact and cost implications of which can be studied and analysed in-depth for Indian context, a) To identify their variation across various retrofitting configurations for a building and, b) To understand the relationships of various environmental factors and parameters for decision-making.

The growing population and increase in the demand of infrastructure, housing and other buildings has resulted in enhanced construction activities, and caused a shortage of conventional building materials, and increase in the quantity of wastes and pollution levels. To ensure sustainable growth, urban areas and buildings need to provide environment-friendly, innovative, and productive techniques to ensure better quality of living. (Rastogi & Paul, 2020)

Buildings and construction projects are planned and developed to deliver the expectations of not only professionals, clients and stakeholders, but also the users of the buildings and the community. In addition to the fulfilment of structural and functional qualities, the buildings support daily user activities, and also need to ensure that they fulfil the environmental performance. It has been observed that retrofitting can significantly help an existing structure to improve its environmental performance efficiency. (Seshadhri & Paul, 2017).

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According to a report published by TERI in 2019, there is a need for building retrofitting as a large number of existing building stock of India was built before the green building market in India had access to advanced and efficient energy saving technologies and mandating compliance to green building code. Majority of the buildings within the typologies of commercial office spaces, health-care infrastructure and hospitality, were planned without major attention to climate responsive passive design strategies and environment friendly active systems (TERI 2019). This leads to an inefficient functioning of these buildings throughout their service life (60 years) causing monetary losses (which are unnecessary and avoidable) to the organizations. These inefficiencies in energy consumption can be reduced through retrofitting measures by up to 50%. (Khosla & Janda, 2019)

Such inefficiencies and inadequacies of construction projects and buildings, and the growing need for enhanced quality and environmental performance of the buildings provides opportunities for the enhancement of research and development of new, strengthened and augmented systems, with appropriate processes and methodologies and processes. (Paul & Seth, 2017).

These value-adding aspects can prove to be highly beneficial when considered to expedite the construction and retrofitting processes, and can further act as catalysts of growth in economic activities and help in the improvement of social indicators of the nation. (Mittal, Paul, & Sawhney, 2019)

And the fact that green building market share of retrofit measures is expected to rise to approximately 25-40% in the next decade (Green Building Retrofit and Renovation, 2009) (Word Green Building Trends, 2018) suggests that, there is a great potential for optimizing the operational efficiency of these building typologies by adopting various strategies of energy-retrofitting.

Even as standardization of designs, planning, methodologies and processes can aid in maximizing the value and benefit from an existing or new building, peculiarities of projects, site, environmental requirements can compel the project managers, architects and other professionals to improvise, modify and apply in different processes and needs of retrofitting in different buildings. (Paul, Khursheed, & Singh, 2017) It will also be useful for stakeholders, decision makers and project managers and decision makers to rearrange and prioritize their maintenance and management processes in accordance with importance, availability of funds, etc. (Seshadhri & Paul, 2018).

Existing literature pertaining to retrofitting compares and analyses specific components for building retrofitting with respect to cost and environmental impact parameters. However, there is a lack of a comprehensive study of the impact of different layers of retrofitting configurations (equipment, service systems, envelope and deep retrofitting) of buildings. (Bostenaru, 2004) (Konstantinou & Knaack, 2011) (El-Darwish & Gomaa, 2017) (Jafari, 2018).

Various international literatures discuss the economic implications and environmental impact of building energy retrofitting of detached and semi-detached row houses, and other residential establishments (Vrijders & Delem, 2009) (Jafari, 2018) However, results of these literatures are in various international contexts and only explore the system retrofit options pertaining to building heat demands. The literature suggests that additional results may be obtained by analysing other retrofit case scenarios.

Various literature indicates that there is a gap with respect to the assessment of environmental impact through Life Cycle Energy Analysis (including embodied energy, operational energy and demolition energy) of building retrofitting cases in Indian context (Power, 2008) (Rodríguez, et al., 2017) (Rawat, Divahar, & Kulshrestha, 2019) It also suggests a lack of an in-depth understanding of inter-relationship of cost, environmental impact and operational efficiency with the level of retrofitting intervention done for a building in Indian context.

Inefficiencies in supervision and assessment of the processes and materials used can lead to delays in retrofitting and construction processes. This may, in turn, impact project performance severely, leading to cost overruns, disputes, arbitration and even abandonment of the project. (Mittal, Paul, Rostami, Riley, & Sawhney, 2020).

Hence, this research focuses on analysing the environmental impact of energy efficient functional retrofit measures for buildings in Indian context. The research will also attempt to identify the relationship between various decision parameters including, level of intervention, achieved operational efficiency, environmental impact and incurred costs.

Retrofitting of Buildings

Retrofitting is a process of adding or providing something with a feature or a component which was not a part of it during its initial manufacturing or construction. In building construction paradigm, retrofitting can be defined as adding or providing an existing building with features or components to which were not the part of its original structure or building plan, when it was constructed. These new features or components can range from replacement of existing equipment of a building to strengthening of the entire building structure. In the context of built environment, it is described as substantial physical change (as compared to the existing building details) at building level. It is also used interchangeably with terms such as, 'refurbishment', 'conversion' or 'refit'.

A building once constructed will continue to serve its purpose for a long period termed as the service life of a building (which can be 50-70 years). However, a building continuously deteriorates because of environmental wear and tear during its entire service life. This eventually results in weakening the building structure and renders it unsafe or not fit for public use. It is this stage, when the building is said to have reached its end-of-life phase. This situation might also arise because of a recent disaster (fire, earthquake, flood, etc.) and can make the building unfit for use well before its anticipated service life. In such scenarios, structural strengthening of such a building through retrofitting can be an option to prolong its service life and continue its usage.

Deterioration of a building structure is not the only reason for retrofitting. Current paradigm of sustainability and sustainable built environment demands the reduction of greenhouse gas emission, improving energy and resource consumption and reducing the overall environmental impact (as directed by the SDGs of UN). This resulted in development of a new typology of building retrofitting which is focussed in achieving energy efficiency and reduce environmental impact of the existing building stock of the cities, termed as building energy retrofits. This includes the replacement of existing equipment and service systems of building with energy efficient alternatives, improving the indoor environment quality for better physical and psychological comfort through changes in envelope, lighting, building material, etc.

Similarly, there can be various other reasons for retrofitting an existing building; however, the underlying purpose is to make the building fit for its existing or redefined use as well as enhance it. In order to achieve this purpose, a whole building retrofitting activity can be broadly divided into structural (strengthening the building structure) and functional (replacement and addition of building service systems) retrofitting. These broad categories can be further sub-divided on the basis of measures taken for retrofitting or the reason for which the building is retrofitted.

Functional Retrofitting

This category of retrofitting focuses on the replacement and modifications of building systems for its redefined use or enhancement of operational efficiency of the building. The measures of functional retrofitting of buildings can be broadly divided into equipment, service systems, building envelope and deep retrofitting, which is the optimized combination of other three measures. There are specific challenges associated to the analysis, design and execution of these retrofitting measures and can be an influencing factor for their selection. Functional retrofitting of a building might or might not be carried out along with structural retrofitting of an existing building and completely depends upon the requirements of building and its stakeholders.

Approaches of Functional Retrofitting of Buildings

The approaches of functional retrofitting of can be broadly divided into four categories, equipment retrofitting, service system retrofitting, building envelope retrofitting and deep retrofitting, which will be discussed in detail in this section of the report. These approaches can be implemented for a retrofitting project in isolation or in combination with other approaches to achieve and optimized solution. Selection of this combined optimized retrofit solution is based on various social, economic and environmental factors which are guided by the goals and need of the project itself.

Equipment Retrofitting

An equipment retrofit involves replacement and modification of existing service equipment or fixtures/appliances of an existing building such as, chiller, boiler, AC units (split, FCUs, AHUs, etc.), light fixtures, electrical fixtures, appliances, etc. This level of retrofit aims at reducing the energy consumption of the building as a whole by use of energy efficient (star rated) fixtures and equipment. The upgrades of fixtures and equipment pertaining to the plumbing and sanitation system help in efficient consumption of water and reduce waste generated by the building. These measures result in reduction in environmental degradation because of building operation.

Service System Retrofitting

A service system retrofit aims at achieving higher efficiency of building services by improving the design, typology and components of those services. This includes improvement and replacement of distribution system of various services of the building such as, HVAC, plumbing, electrical layouts, etc. These upgrades are focussed on designing the systems for future use of the building, which result in reduction of the resource consumption of the entire building. For example, upgrades of the HVAC system in hospitals might involve the usage of variable refrigerant volume (VRV) systems and a flexible chilled water distribution to cater to variable requirements of different building zones.

These new systems might be coupled with an integrated Building Management Systems (BMS) for their effective monitoring and control to continuously improve the resource consumption efficiency of whole building. BMS uses an automated computer-based control system which monitors a buildings ventilation, lighting, power systems, disaster response systems, fire systems and security systems, on predefined parameters, benchmarks and tolerances.

Building Envelope Retrofitting

Building envelope retrofit focusses on improving the indoor environment quality (IEQ) of a building. IEQ of a building includes factors such as, ambient temperature, relative humidity levels, wind speed, light intensity levels (lux), noise levels, etc. which are under the larger umbrella of thermal, visual and auditory comfort of building occupants. This typology of retrofitting modifies or replaces the existing exterior walls of the building with materials (of the wall section) which have better performance than existing features with respect to its thermal insulation (transmittance, U-Value), sound insulation, surface reflective index, etc.

Deep Retrofitting

DER, or Deep Energy Retrofit, can be understood as an energy conservation measure used in existing structures, which also serves the purpose of overall improvement of the performance of the building. A deep energy retrofit can also be defined as a construction process and whole-building analysis, the aim of which is to achieve minimisation of on-site energy use in a structure by 50% or more, in comparison to the baseline energy use (this uses utility bills analysis for calculation). The process makes use of existing materials, technologies and construction practices. This type of retrofitting process helps to achieve multi-fold benefits that extend beyond energy cost savings, as compared to conventional energy retrofits. The process can also involve remodelling of the building in order to achieve synchronisation in indoor air quality, energy, thermal comfort and durability.

Conventional energy retrofits typically emphasise on isolated system upgrades (i.e. HVAC equipment and lighting). While these retrofits have been observed to be fast and simple, they may often miss the opportunity to save more energy in a cost-effective manner. Both conventional and deep energy retrofits follow different approaches and methodologies, and lead to different outcomes.

Table 1
Project Processes of Functional Retrofitting of Buildings

1	**Pre-Planning Stage**
1.1	Establish Performance Baselines (Inspection, energy audit, energy baseline)
1.2	Develop Project Goals and Performance Metrics (annual energy target or reduction goal, establish non-energy goals)
2	**Planning Stage**
2.1	Analysis of Probable Retrofit Solutions
2.2	Design of the Best Valued Retrofit Solution (based on cost-benefit ratio or payback period and aligned with the objectives and goals)
2.3	Planning of the Construction Phase (schedule and cost baseline, procurement plan, monitoring and control plans)
3	**Construction Stage**
3.1	Procurement as per the Plan (execution agencies, service components, materials, etc.)
3.2	Monitoring and Control of the Construction
4	**Test Out and Inspection Stage**
4.1	Testing and commissioning of installed components
4.2	Verification of Installation and Performance of Retrofit Measures
5	**Post-Occupancy Stage**
5.1	Behavioral Adjustments and Short-term targets for Users/Occupants
5.3	Performance Feedbacks

Environmental Impact

A building affects the environment throughout its life, right from the construction (pre-use phase) to building operation (use phase) and eventually the end-of life phase. During pre-use phase the construction activities generate a significant amount of solid waste, embodied energy associated to building material is added and subsequent GHG emissions take place. During the operational phase, a building consumes energy and various resources to function effectively and cater to user requirements which also results in GHG emissions. The repair and maintenance activities during operational phase results in recurring embodied energy and the subsequent GHG emissions take place. Eventually, during the EOL phase of building, demolition waste is generated which requires energy for transportation and processing.

However, the environmental impact of buildings includes various other categories and parameters apart from the energy consumption and GHG emissions which are discussed below.

Environmental Impact Categories / Parameters

Following are the indicators for various categories of environmental impact for a building during its construction, operation and demolition phases.

The below stated parameters can be assessed by breaking down all the processes into sub-processes and various products used within those processes for the construction (or retrofitting) of a building. The inputs and outputs within these sub-processes help in quantitative assessment of the various impact parameters and analyse the overall environmental impact potential of a building. Systematic approach for such an assessment is the Life Cycle Assessment (LCA) approach as defined by the ISO 14040 for environmental impact analysis.

Table 2

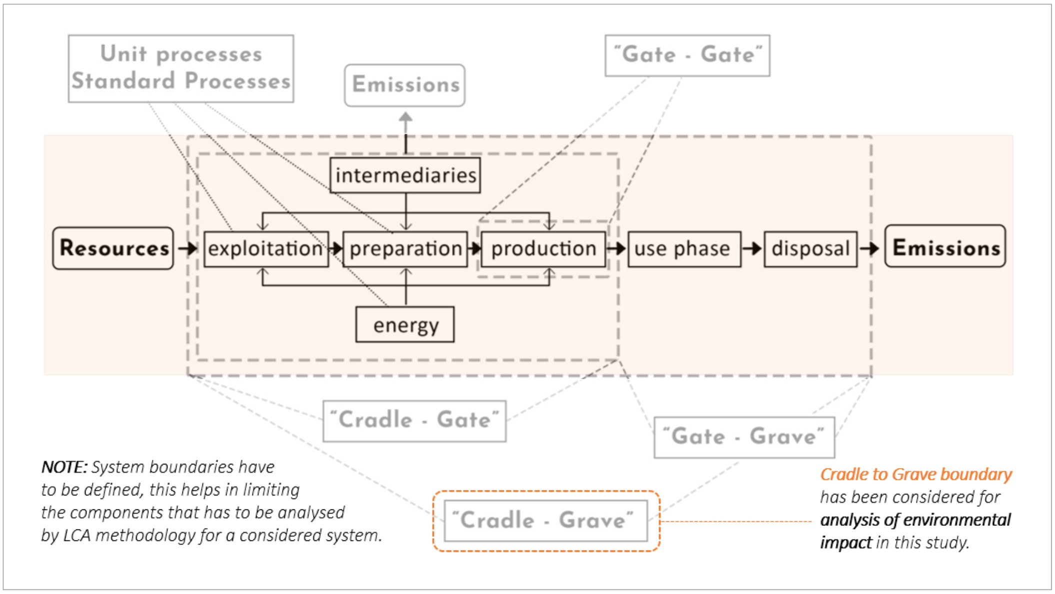
Environmental Impact Categories

Impact Category	Impact Parameters
Energy Consumption (Abiotic Depletion Potential)	Life Cycle Energy Demand, Cumulative energy demand
Global Warming Potential	Life cycle GHG emissions (CO_2, CO, CH_4 in gaseous state)
Acidification Potential	Emission of SO_2, NO_x, HCl (in gaseous state)
Eutrophication Potential	Emission of NO_x (gaseous) and PO_4, NH_3 (aqueous)
Ozone Depletion Potential	Emissions of chlorofluorocarbons and hydrochlorofluorocarbons
Water Consumption	Resource depletion

Table 3

Definitions and Formulas

Abiotic Depletion potential (ADP) This includes the depletion of natural non-renewable resources of the planet in the terms of oil, gas and coal reserves.	$E_1 = \sum_{k=1}^{K} \frac{B_k}{ec_{1,k}}$
B_k = quantity of resource utilized per functional unit; $ec_{1,k}$ = total world reserves of that resource	
Global Warming Potential (GWP) It is calculated as a sum of GHG emissions multiplied by their respective GWP factors.	$E_2 = \sum_{k=1}^{K} ec_{2,k}.B_k$
B_k = emission of GHG 'k'; $ec_{2,k}$ = GWP factor relative to CO_2	
Acidification Potential (AP) It is based on contributions of SO_2, NO_X, HCl, NH_3 and HF to potential formation of H^+ ions.	$E_4 = \sum_{k=1}^{K} ec_{4,k}.B_k$
B_k = emission in kg per functional unit of gas 'k'; $ec_{4,k}$ = AP factor relative to SO_2	
Eutrophication Potential (EP) It is defined as potential of a product or process to cause over-fertilization of a land or water resource.	$E_5 = \sum_{k=1}^{K} ec_{5,k}.B_k$
B_k = emission of Nitrogen and Phosphorous based species 'k'; $ec_{5,k}$ = EP factor relative to PO_4^{2-}	
Ozone Depletion Potential (ODP) This indicates the potential of emissions of CFCs and HCs which deplete the ozone layer of atmosphere.	$E_3 = \sum_{k=1}^{K} ec_{3,k}.B_k$
B_k = emission ozone depleting gas 'k'; $ec_{3,k}$ = ODP factor relative to CFC-11	



NOTE: *System boundaries have to be defined, this helps in limiting the components that has to be analysed by LCA methodology for a considered system.*

Cradle to Grave boundary *has been considered for* ***analysis of environmental impact*** *in this study.*

Fig. 1

System Boundary of LCA Study (Source ISO 14040)

Environmental Impact Analysis of Functional Retrofit Cases

Adopted Framework for Environmental Impact Analysis

The approach of Life Cycle Energy Analysis (LCEA) is adopted to assess the primary energy demand (in GJ) and ADP of the buildings for post retrofit scenario. This approach is based on the general principles of LCA as outlined in ISO 14040 and is used to quantify the effects of a product or process on the environment during the different stages of its life cycle.

Life cycle energy of the building is the sum of the all the energies incurred in its life cycle as evident from the above diagram (**Fig. 2**). It is thus expressed as: LCE = EEI + EER + OE + DE.

Where, LCE = Life cycle energy, EEI = Initial embodied energy, EER = Recurring embodied energy, OE = Operational energy, DE = Demolition Energy (Demolition + Transportation + Disposal).

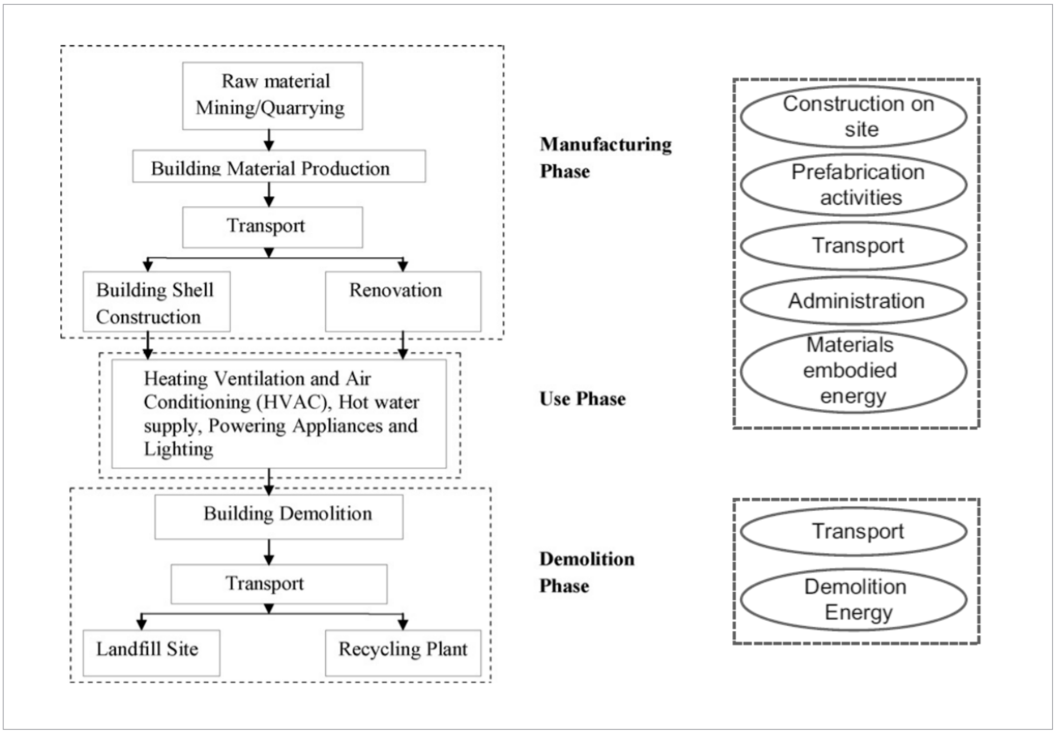


Fig. 2

Life Cycle Energy of a Building (Cabeza et al. 2014)

A similar approach was adopted for analysing the GHG emissions to determine the Global Warming Potential of the buildings for post-retrofit scenario. This includes the assessment of emissions during; a) Construction phase (embodied carbon calculations) which involves the emissions associated to demolition process (demolition activities and waste disposal) & construction activities, transportation of demolition waste (away from site), and emissions associated to consumed materials; b) Operation phase which involves emissions because of fuel usage of building by assessing energy consumption of building using simulation software, and recurring embodied carbon because of maintenance and repair activities of building; c) End of Life phase of building which involves emissions associated with demolition process (demolition, transportation & waste disposal). Hence, GHG emissions were calculated for the entire life cycle of building.

The ozone depletion potential of buildings is calculated with respect to the refrigerant charge of HVAC systems (centralised AC systems as well as the unitary systems) and also includes the additional refrigerant required because of 2% leakage per year. Water resource consumption was calculated in kL/year for the building which included the domestic and flushing water demand, irrigation water demand, and cooling tower make-up water demand.

The life cycle calculations for above environment impact categories were done with an assumption that the buildings will continue to operate for the next 50 years. This calculation is done for both pre- and post-retrofit scenario of considered cases to assess the change in environmental impact. And this calculation does not include the structural strengthening or structural retrofit that the building might require in order to extend its service life.

Basis of Selection of Cases

Building retrofit cases having major interventions in three different levels of retrofit interventions (building envelope, equipment & service systems & deep retrofitting) were considered. Cases with a primary goal of improving energy efficiency or transforming the building into an environment friendly building were considered.

Details of Functional Retrofit Cases

Table 4

Functional Retrofit Cases

Sr. No.	Typology	Year of Completion	Retrofitting type
Case-1	Private Office Headquarters (*Mumbai*)	2009	**Deep Retrofitting** (HVAC [equipment and distribution system], Lighting equipment, Support systems, Envelope changes, Interior layout change)
Case-2	Private Office Headquarters (*Mumbai*)	2013	**Equipment | Service System | Building Envelope** (HVAC [equipment and distribution system], Lighting equipment, Support systems, Envelope enhancements)
Case-3	Office Space for lease (*Delhi*)	ongoing	**Equipment | Service System | Building Envelope** (HVAC [equipment], Lighting, Envelope (façade) replacement)

Table 5

Functional Retrofit Case Project Details

	Case-1	Case-2	Case-3
Age of building	82 years (1939)	49 years (1972)	21 years (2000)
Retrofitting of building	Initiated – 2009 Completed – 2010	Completed – 2010	Initiated – 2019 Ongoing project
Location	Churchgate, Mumbai, Maharashtra	Churchgate, Mumbai, Maharashtra	New Friends Colony, Delhi
Climate Zone	Warm and Humid	Warm and Humid	Composite
Total Built-up Area	10,250 sqm	3,826 sqm	7840 sqm
Number of Floors	1 Part Basement + Ground + 6 Storey | Height – 23m	2 Basements + Ground + 6 Storey | Height – 19m	2 Basements + Ground + 9 Storey | Height – 35m
Cost of Retrofitting	24.75 crore INR 24150 INR/sqm	5.82 crore INR 18476 INR/sqm	6.5 crore INR 8300 INR/sqm
Occupancy	450 people	100 people	375 people

Environmental Impact Analysis of Considered Retrofit Cases

Retrofitting Configuration of Case-1 consists of, the building envelope changes involving replacement and redesign of external fenestrations to doubly glazed aluminium frame windows with enlarged size, and changes in the central shaft of the building which was converted to an atrium. There were changes in the HVAC system including replacement of water-cooled chiller to air-cooled chillers, and change in the HVAC layout including ducts, shafts and equipment. There were major changes in the internal layout of the building in order to enhance daylight penetration within the building. There were minor changes in the MEP systems of building, with energy efficient fixtures replacing the conventional fixtures (lighting and plumbing).

The overall environmental impact benefit received because of implementation of these retrofit measures is shown in Table 6.

Table 6

Environmental Impact Analysis for Case-1

Environmental Impact Category		Pre-Retrofit Scenario	Post-Retrofit Scenario	Benefit
Primary Energy Demand(GJ)		1,71,575.29	1,41,839.28	– 29,736.01 (21.13%)
Abiotic Depletion Potential	**Coal**	7.28E-10	5.48E-10	Overall Reduction of 24.67%
	Oil	9.35E-10	7.05E-10	
	Gas	4.60E-09	3.46E-09	
GHG Emissions (GWP) (MT of CO2eq)		21,352.64	16,441.65	– 4,910.99 (23.00%)
Ozone Depletion Potential (w.r.t. CFC-11)		40.10	0.00	– 40.10 (100%)
Water Consumption (Litres per year)		81,11,876	30,94,608	– 50,17,268 (61.85%)

Retrofitting Configuration of Case-2 consists of, the HVAC system changes in which the water-cooled chillers were replaced by more efficient chillers with high COP. The HVAC distribution is modified by using AHUs for each floor as opposed to the original system which consisted of 2 AHUs for entire building. There were minor changes in building envelope involving replacement of single glazed windows with double glazed windows for the building.

The overall environmental impact benefit received because of implementation of these retrofit measures is shown in Table 7.

Table 7

Environmental Impact Analysis for Case-2

Environmental Impact Category		Pre-Retrofit Scenario	Post-Retrofit Scenario	Benefit
Primary Energy Demand (GJ)		92,830.47	78,916.31	-13,914.16 (14.99%)
Abiotic Depletion Potential	**Coal**	4.00E-10	3.34E-10	Overall Reduction of 16.5%
	Oil	5.14E-10	4.29E-10	
	Gas	2.53E-09	2.11E-09	
GHG Emissions (GWP) (MT of CO2eq)		11,638.76	9,777.74	-1,861.02 (15.99%)
Ozone Depletion Potential (w.r.t. CFC-11)		17.82	0.00	-17.82 (100%)
Water Consumption (Litres per year)		38,23,024	36,02,150	-2,20,874 (5.78%)

Retrofitting Configuration of Case-3 consists of major changes in building envelope involving replacement of single glazed structural glazing with double glazed structural glazing for the building.

The overall environmental impact benefit received because of implementation of these retrofit measures is shown in Table 8.

Table 8

Environmental Impact Analysis for Case-3

Environmental Impact Category		Pre-Retrofit Scenario	Post-Retrofit Scenario	Benefit
Primary Energy Demand (GJ)		1,37,110.49	1,19,776.47	-17,334.02 (12.64%)
Abiotic Depletion Potential	**Coal**	7.35E-10	6.32E-10	Overall Reduction of 13.92%
	Oil	9.44E-10	8.13E-10	
	Gas	4.64E-09	4.00E-09	
GHG Emissions (GWP) (MT of CO2eq)		21,160.22	18,306.22	-2,854.00 (13.49%)
Ozone Depletion Potential (w.r.t. CFC-11)		35.64	0.00	-35.64 (100%)
Water Consumption (Litres per year)		67,92,524	65,53,063	-2,39,461 (3.52%)

Results and Discussions

Primary Energy Demand | Global Warming Potential (GWP)

In Case-1, the substantial changes were observed in building envelope, HVAC equipment and distribution as well as the lighting system (in relation to the changes in internal layout of building) resulted in a reduction of energy consumption and GWP during the operational phase of building. Recurring embodied energy and embodied carbon for post retrofit configuration of building is significantly lower than the original configuration. This results in reduction of primary energy demand and GWP of building.

In Case-2, the substantial changes included, building envelope, HVAC equipment and distribution. These resulted in an overall reduction of primary energy demand and GWP of building, however, not as significant as in Case-1. Similarly in Case-3, the substantial changes were seen in building envelope. This results in lower benefits (lowest among the three cases) for the post retrofit scenario of building.

Abiotic Depletion Potential (ADP)

ADP only included the resource consumption (coal, oil and gas) during the operational phase of building for post retrofit scenario and is directly related to the energy consumption of building. The graph above shows the average reduction in consumption of resources and follows a similar trend as the primary energy demand and GWP with highest reduction being achieved in the Case-1 and lowest being achieved in Case-2.

Ozone Depletion Potential (ODP)

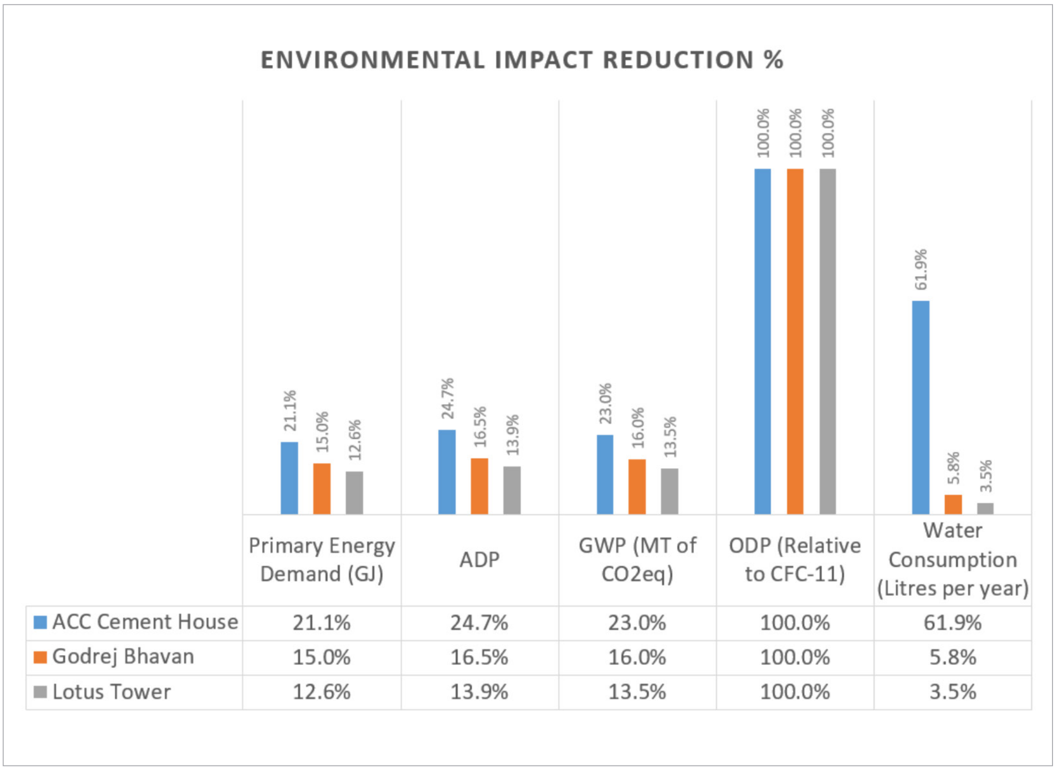
The ODP is dependent upon type of refrigerant used and its total replacements during operational phase of building. For all the three cases, old HVAC equipment was replaced. This resulted in a change of refrigerant from R-22 to r134a, in which the latter has ‘0 ODP’. Hence, this resulted in a reduction of 100% for all the three cases for their post retrofit scenarios.

Water Consumption

In Case-1, the water consumption reduction is maximum because of the change in cooling tower make-up water demand. As the new HVAC system consists of an air-cooled chiller for the building as opposed to the water-cooled chiller for pre-retrofit phase of building. This removed the component of ‘make-up water’ for post retrofit scenario of building, thereby reducing the total water consumption. However, in Case-2 and Case-3, there was no significant reduction in total water demand and the slight reduction which can be observed from the graph above is because of reduction in the cooling tower operation time for post retrofit scenario.

Overall Variation in Environmental Impact

Hence, Highest environmental benefits (21-25%) were observed for Case-1 with deep retrofitting involving changes in internal layout of building, the external envelope, equipment of service systems and distribution. Environmental benefits (15-16%) for Case-2 with service systems and building envelope retrofitting, are significantly lower as compared to Case-1. Least benefits (12-14%) were observed for Case-3 with building envelope retrofitting), which is not a significant decrease as compared to case-2. The Energy Performance Index (EPI) reduces by 25% for Case-1 (to 66.97 kWh/ sqm/year), 16% for Case-2 (to 109.34 kWh/sqm/year), and 14% for Case-3 (to 83 kWh/sqm/year).



	Primary Energy Demand (GJ)	ADP	GWP (MT of CO2eq)	ODP (Relative to CFC-11)	Water Consumption (Litres per year)
🟦 ACC Cement House	21.1%	24.7%	23.0%	100.0%	61.9%
🟧 Godrej Bhavan	15.0%	16.5%	16.0%	100.0%	5.8%
⬜ Lotus Tower	12.6%	13.9%	13.5%	100.0%	3.5%

Fig. 3
Environmental Impact Variation Across All Cases

Conclusion

As per the analysis of considered cases, functional retrofitting of building for energy efficiency provides significant benefits of up to 25% for the deep retrofitting case with respect to environmental impact reduction and resource consumption reduction. Substantial component of these benefits is associated with the operational phase of the building which is a direct result of implementing energy efficient retrofits in considered cases. It was also observed that the environmental impact reduction (with respect to PED, ADP and GWP) increases with the increase in level of intervention for building retrofitting.

This study explores the potential of environmental impact reduction of building through implementation of functional energy retrofit measures in buildings in Indian context. Large number of existing building stock in India will require retrofitting interventions in the next couple of decades. And the retrofitting measures for energy efficiency in buildings will prove to be significantly beneficial for reducing the environmental impact of the old buildings. This study helps in developing an understanding of the achieved environmental impact reduction and operational efficiency with the incurred initial costs for implementing the energy efficiency functional retrofitting measures in buildings, and prove to be beneficial in decision making process.

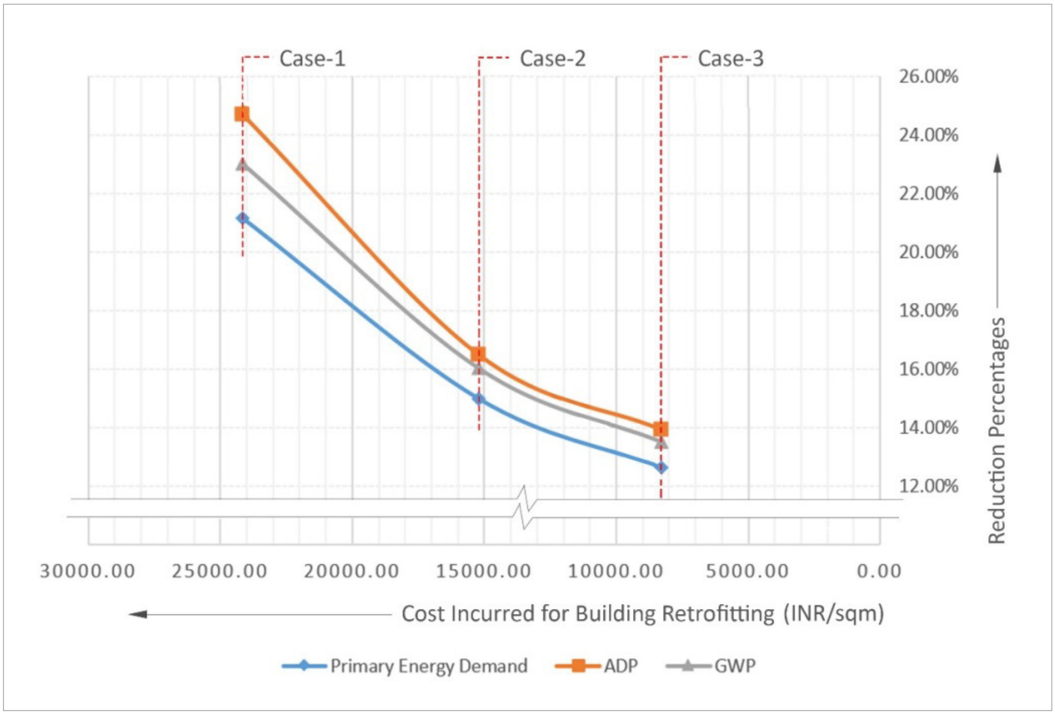


Fig. 4

Interrelationship graph between environmental impact reduction and incurred cost

Future Scope of the Study

Results in this study cannot be generalized to all retrofitting cases as they are based on three considered cases. Hence, similar analysis can be conducted for more cases of building retrofitting in India in order to generalize the result for each climatic zone in India. Results in this study can be validated by studying other examples of functional retrofitting of buildings for energy efficiency and relating it to the inter-relationship graph obtained in this study.

References

Bostenaru, D. M. (2004). Multi-Criteria Decision Model for Retrofitting Existing Buildings. Natural Hazards and Earth System Sciences, 4(4), 485-499.https://doi.org/10.5194/nhess-4-485-2004

Dodge Data Analytics. (2018). Word Green Building Trends. Dodge Data Analytics.

El-Darwish, I., & Gomaa, M. (2017). Retrofitting Strategy for Building Envelopes to Achieve Energy Efficiency. Alexandria Engineering Journal, 579-589. https://doi.org/10.1016/j.aej.2017.05.011

Jafari, A. (2018). Decision Making Framework for the Selection of Sustainable Alternatives for Energy-Retrofits. University of New Mexico.

Khosla, R., & Janda, K. (2019). India's Building Stock: Towards Energy and Climate Change Solutions, Building Research & Information. Building Research & Information, 1-7. https://doi.org/10.1080/09613218.2019.1522482

Konstantinou, T., & Knaack, U. (2011). Refurbishment of Residential Buildings: A Design Approach to Energy-Efficiency Upgrades. Procedia Engineering, 666-675. https://doi.org/10.1016/j.proeng.2011.11.2063

McGraw Hill Construction. (2009). Green Building Retrofit and Renovation. McGraw Hill Construction.

Mittal, Y. K., Paul, V. K., & Sawhney, A. (2019). Methodology for Estimating the Cost of Delay in Architectural Engineering Projects: Case of Metro Rails in India. Journal of the Institution of Engineers (India), 311-318. https://doi.org/10.1007/s40030-019-00366-y

Mittal, Y. K., Paul, V. K., Rostami, A., Riley, M., & Sawhney, A. (2020). Delay Factors in Construction of Healthcare Infrastructure Projects: A Comparison amongst Developing Countries. Asian Journal of Civil Engineering, 21(1), 649-661. https://doi.org/10.1007/s42107-020-00227-1

Paul, V. K., & Seth, V. (2017). Benchmarking and Objective Selection of Technologies for Housing in India Using Quality Function Deployment. Journal of Construction in Developing Countries, 22(1), 63-78. https://doi.org/10.21315/jcdc2017.22.supp1.4

Paul, V. K., Khursheed, S., & Singh, R. (2017). Comparative Study of Construction Technologies for Underground Metro Stations in India. International Journal of Research in Engineering and Technology, 6(3), 55-63. https://doi.org/10.15623/ijret.2017.0603009

Power, A. (2008). Does Demolition or Refurbishment of Old and Inefficient Homes Help to Increase Our Environmental, Social and Economic Viability? Energy Policy, 4487-4501.https://doi.org/10.1016/j.enpol.2008.09.022

Rastogi, A., & Paul, V. K. (2020). A Critical Review of the Potential for Fly Ash Utilisation in Construction-Specific Applications in India. Journal of Environmental Research, Engineering and Management, 76(2), 65-75. https://doi.org/10.5755/j01.erem.76.2.25166

Rawat, V. S., Divahar, R., & Kulshrestha, P. (2019). A Review: Impact of Retrofitting in Term of Sustainability Development and Green Building. International Research Journal of Engineering and Technology.

Rodríguez, A., Desirée, M., Martínez-Rocamora, A., González-Vallejo, P., Ferreira-27 Sánchez, A., & Marrero, M. (2017). Building Rehabilitation versus Demolition and New Construction: Economic and Environmental Assessment. Environmental Impact Assessment Review, 115-126. https://doi.org/10.1016/j.eiar.2017.06.002

Seshadhri, G., & Paul, V. K. (2017). Intervention Strategy for Enhanced User Satisfaction Based on User Requirement Related BPAs for Government Residential Buildings. New York: International Conference on Sustainable Infrastructure 2017.

Seshadhri, G., & Paul, V. K. (2018). Validation and ranking of user requirement related building performance attributes and sub attributes for government residential buildings. Facilities. https://doi.org/10.1108/JFM-11-2016-0047

Vrijders, J., & Delem, L. (2009). Economical and Environmental Impact of Low Energy Housing Renovation. LEHR Final Workshop.

Bibliography

Akande, O.K., D. Odeleye, A. Coday, and C. Jimenez-Bescos. 2016. “Performance Evaluation of Operational Energy Use in Refurbishment, Reuse, and Conservation of Heritage Buildings for Optimum Sustainability.” Frontiers of Architectural Research 5 (3): 371–82. https://doi.org/10.1016/j.foar.2016.06.002.

Alba-Rodríguez, M. Desirée, Alejandro Martínez-Rocamora, Patricia González-Vallejo, Antonio Ferreira-Sánchez, and Madelyn Marrero. 2017. “Building Rehabilitation versus Demolition and New Construction: Economic and Environmental Assessment.” Environmental Impact Assessment Review 66 (September): 115–26. https://doi.org/10.1016/j.eiar.2017.06.002.

Albatici, Rossano, Alessia Gadotti, Christian Baldessari, and Michela Chiogna. 2016. “A Decision Making Tool for a Comprehensive Evaluation of Building Retrofitting Actions at the Regional Scale.” Sustainability 8 (10): 990. https://doi.org/10.3390/su8100990.

Alshehri, Ayman, Ibrahim Motawa, and Stephen Ogunlana. 2015. “The Common Problems Facing the Building Maintenance Departments.” International Journal of Innovation, Management and Technology 6 (3): 234–37. https://doi.org/10.7763/IJIMT.2015.V6.608.

Amaral, Rosaria E.C., Joel Brito, Matt Buckman, Elicia Drake, Esther Ilatova, Paige Rice, Carlos Sabbagh, Sergei Voronkin, and Yewande S. Abraham. 2020. “Waste Management and Operational Energy for Sustainable Buildings: A Review.” Sustainability 12 (13): 5337. https://doi.org/10.3390/su12135337.

Apeksha Shandilya, Dr. Wolfgang Streicher, and Technical University of Innsbruck. 2017. “Performance and Cost Analysis of Retrofit Strategies Applied to a Sample Single Family House Located in New Delhi India Assisted by TRNSYS Energy Simulation Tool -A Case Study.” International Journal of Engineering Research and Technology 6 (11): 304–12. https://doi.org/10.17577/IJERTV6IS110138.

Borzouie, J, M Yekrangnia, A Mahdizadeh, H Seyri, and M Raissi. 2012. “Financial Analysis of Retrofitting Projects and Its Role in Decision Making.” In , 10. Lisbon, Portugal.

Bradshaw, A, P Rajeev, and S Tesfamariam. 2011. “Multi Criteria Decision Making Tool for the Selection of Seismic Retrofitting Techniques.” In , 8. Barossa Valley, South Australia.

Brown, Philip, and William Swan. n.d. Retrofitting the Built Environment.

Bureau of Energy Efficiency. n.d. “Energy Benchmarks for Commercial Buildings.” Bureau of Energy Efficiency. Accessed February 11, 2021. https://beeindia.gov.in/sites/default/files/Flyer_22nd%20Jan.pdf.

Cabeza, Luisa F., Lídia Rincón, Virginia Vilariño, Gabriel Pérez, and Albert Castell. 2014. “Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA) of Buildings and the Building Sector: A Review.” Renewable and Sustainable Energy Reviews 29 (January): 394–416. https://doi.org/10.1016/j.rser.2013.08.037.

Chang, Yuan, Robert J. Ries, and Yaowu Wang. 2013. “Life-Cycle Energy of Residential Buildings in China.” Energy Policy 62 (November): 656–64. https://doi.org/10.1016/j.enpol.2013.07.053.

Costa, Aníbal, António Arêde, and Humberto Varum, eds. 2018. Strengthening and Retrofitting of Existing Structures. Vol. 9. Building Pathology and Rehabilitation. Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-5858-5.

Dias, W.P.S. 2013. “Factors Influencing the Service Life of Buildings.” Engineer: Journal of the Institution of Engineers, Sri Lanka 46 (4): 1. https://doi.org/10.4038/engineer.v46i4.6801.

Hovde, PJ. 2002. “The Factor Method For Service Life Prediction From Theoretical Evaluation To Practical Implementation.” In , 10. Rotterdam, Netherlands. http://www.irbnet.de/daten/iconda/CIB9332.pdf.

Itard, L C M. 2009. “Embodied and Operational Energy Use of Buildings.” In Lifecycle Design of Buildings, Systems and Materials, 77–84. Delft, Netherlands: International Council for Building Research Studies and Documentation.

Janjua, Shahana, Prabir Sarker, and Wahidul Biswas. 2019. “Impact of Service Life on the Environmental Performance of Buildings.” Buildings 9 (1): 9. https://doi.org/10.3390/buildings9010009.

Junnila, Seppo, and Arpad Horvath. 2003. “Life-Cycle Environmental Effects of an Office Building.” Journal of Infrastructure Systems 9 (4): 157–66. https://doi.org/10.1061/(ASCE)1076-0342(2003)9:4(157).

Khairi, Muhammad, Aini Jaapar, and Zaharah Yahya. 2017. “The Application, Benefits and Challenges of Retrofitting the Existing Buildings.” IOP Conference Series: Materials Science and Engineering 271 (November): 012030. https://doi.org/10.1088/1757-899X/271/1/012030.

Khoukhi, Maatouk, Abeer Fuad Darsaleh, and Sara Ali. 2020. “Retrofitting an Existing Office Building in the UAE Towards Achieving Low-Energy Building.” Sustainability 12 (6): 2573. https://doi.org/10.3390/su12062573.

Kofoworola, Oyeshola F., and Shabbir H. Gheewala. 2008. “Environmental Life Cycle Assessment of a Commercial Office Building in Thailand.” The International Journal of Life Cycle Assessment 13 (6): 498–511. https://doi.org/10.1007/s11367-008-0012-1.

Less, Brennan, and Iain Walker. 2015. “Deep Energy Retrofit Guidance for the Building America Solutions Center.” Technical LBNL 184443. United States: Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States). https://doi.org/10.2172/1248926.

Li, Ziwei, Borong Lin, Shanwen Zheng, Yanchen Liu, Zhe Wang, and Jian Dai. 2020. “A Review of Operational Energy Consumption Calculation Method for Urban Buildings.” Building Simulation 13 (4): 739–51. https://doi.org/10.1007/s12273-020-0619-0.

Marteinsson, Björn. 2005. “SERVICE LIFE ESTIMATION IN THE DESIGN OF BUILDINGS A DEVELOPMENT OF THE FACTOR METHOD.” Gävle, Sweden: Department of Technology and Built Environment, University of Gävle.

Miller, Evonne, and Laurie Buys. 2008. “Retrofitting Commercial Office Buildings for Sustainability: Tenants’ Perspectives.” Edited by Tim Dixon. Journal of Property Investment & Finance 26 (6): 552–61. https://doi.org/10.1108/14635780810908398.

Ramesh, T., Ravi Prakash, and K.K. Shukla. 2010. “Life Cycle Energy Analysis of Buildings: An Overview.” Energy and Buildings 42 (10): 1592–1600. https://doi.org/10.1016/j.enbuild.2010.05.007.

Rauf, Abdul, and Robert H. Crawford. 2015. “Building Service Life and Its Effect on the Life Cycle Embodied Energy of Buildings.” Energy 79 (January): 140–48. https://doi.org/10.1016/j.energy.2014.10.093.

Senel Solmaz, Aslihan, Fahriye H Halicioglu, and Suat Gunhan. 2018. “An Approach for Making Optimal Decisions in Building Energy Efficiency Retrofit Projects.” Indoor and Built Environment 27 (3): 348–68. https://doi.org/10.1177/1420326X16674764.

Suffian, Ahmad. 2013. “Some Common Maintenance Problems and Building Defects: Our Experiences.” Procedia Engineering 54: 101–8. https://doi.org/10.1016/j.proeng.2013.03.009.

TERI. 2019. “Existing Commercial Building Retrofit Guidelines.” New Delhi: The Energy and Resources Institute.

Torgal, Fernando Pacheco, Claes-Göran Granqvist, Bjørn Petter Jelle, Giuseppe Peter Vanoli, Nicola Bianco, and Jarek Kurnitski, eds. n.d. Cost-Effective Energy-Efficient Building Retrofitting: Materials, Technologies, Optimization and Case Studies. Woodhead Publishing Series in Civil and Structural Engineering 77.

United Nations Environment Programme, ed. 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. Nairobi, Kenya: UNEP.

X.W. Zou, Patrick, Rodney Stewart, Morshed Alam, Edoardo Bertone, and Oz Sahin. 2016. “Retrofitting Public Buildings for Energy and Water Efficiency.” 1. SBEnrc Project 1.43. Australia: Sustainable Built Environment National Research Centre. https://sbenrc.com.au/app/uploads/2015/11/SBEnrcP1.43_ProgressReport1May2016_RetrofitGuidelines_FORWEB.pdf.

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