USE OF ENERGY RETROFITS TO REDUCE THE ENERGY DEMAND OF EXISTING OFFICE BUILDINGS

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ABSTRACT

Continuous increase of energy demand is a common issue faced by people around the globe. Meanwhile, buildings have been identified as one of the major contributors for the ever-rising energy demand of the world. Consequently, buildings nowadays are built while giving more attention to the ways of reducing building energy demand. However, the existing buildings which are expected to occupy the majority of the total building stock for many years to come, are still being operated with a higher energy demand. Accordingly, building energy retrofits are identified as an efficient approach to reduce the energy demand of the existing buildings, and the aim of this research is to study the use of energy retrofits in office buildings of Sri Lanka.

The research approach was predominantly quantitative, which was followed by three case studies. A thorough literature survey was carried out to identify the prevalent retrofit techniques and the practicable enablers to enhance the use of energy retrofits. Findings of the literature survey was validated by a pilot survey before carrying out the questionnaire survey. Subsequently, three case studies were conducted to determine the costs and benefits of implemented retrofit techniques.

The results of the study showed that the use of energy retrofits in Sri Lankan office buildings sector is at a lower level. Further, the case study results depicted that the selected retrofit projects have generated significant energy savings which had led to better project feasibility. It was also established that the use of energy retrofits could be enhanced by implementing the identified enablers based on the perception of the building managers.

Keywords: *Energy Demand; Energy Retrofits; Office Buildings.*

1. INTRODUCTION

The world is currently facing an intense energy crisis due to the unavailability of energy sources to cope with the rising energy demand which is increasing at a rate of 1.6% on average annually (Öztürk *et al.*, 2013). According to Diakaki *et al.* (2008) building sector uses large amounts of energy and it is among the greater energy consumers in the world. Furthermore, office buildings have been identified as one of the highest energy consumers among the whole built environment (Gamage and Lau, 2015).

Various building designs and construction techniques have been evolved lately to improve the energy efficiency of the new buildings; however, the proportion of new buildings constructed every year is relatively smaller compared to existing building stock (Reed and Wilkinson, 2005). Consequently, constructing energy efficient buildings in the future would not reduce the present energy demand as the existing buildings have a significant effect on the total energy demand for many years to come (Asadi *et al.*, 2012). Hence, a rapid improvement of energy efficiency in the existing buildings is essential to reduce the global energy demand (Ma *et al.*, 2012).

Cost effective building energy retrofits are identified as one of the best methods of reducing the energy demand of the existing buildings (Huang *et al.*, 2012). Further, according to Mathew *et al.* (2005) improving the energy

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performance of existing buildings would yield an annual median savings of 16%. However, the selection of the most relevant retrofit is a challenging task due to the availability of numerous retrofitting options and their impacts on the building energy demand (Nik *et al.*, 2016). Hence this research was conducted with the aim of studying the use of building energy retrofits for the existing office buildings in Sri Lanka to reduce the energy demand. In order to achieve this aim, the current use of energy retrofits and the enablers to enhance the use of energy retrofits were identified. Further, the financial viability of the implemented retrofit projects was established through case studies.

Initially different categorisations of energy retrofit were identified, out of which demand side, conventional retrofits were chosen as the most effective and financially viable retrofit option in reducing building energy demand. Then a thorough literature review was conducted to identify available demand side energy retrofit techniques and the enablers to enhance the use of energy retrofits. Based on the literature findings, the level use of energy retrofits and the perception of building managers towards the identified enablers were established through the questionnaire survey. Finally, three case studies were conducted to establish the financial viability of implemented retrofit techniques.

2. TYPES OF ENERGY RETROFITS

Energy retrofitting is an area with a broad scope which covers energy efficiency measures from a minor alteration to a major refurbishment project, and hence there is a wide variety of energy retrofits used for buildings (Chunduri, 2014). Classifying energy retrofits based on the energy conservation method and the amount of energy saved are the two most popular classifying methods (Ma *et al.*, 2012).

Table 1: Types of Retrofits Based on Energy Conservation Method

Retrofit type	Energy conservation method
Supply side management	Generation of renewable energy
Demand side management	Reduction of building energy demand
Human factors management	Change of energy consumption patterns

Table 1 indicates the classification of energy retrofits based on the energy conservation method used. Here, the supply side management retrofits include renewable technologies like solar photovoltaics, biomass, wind energy and geothermal power systems (Pisello *et al.*, 2016). According to Ma *et al.* (2012) supply side retrofits provide alternative electrical and thermal energy to buildings. On the other hand, retrofit technologies for demand side management aims at implementing energy efficient equipment and low energy technologies to reduce overall energy demand of the building (Kromer, 2007). Moreover, Ma *et al.* (2012) have identified that energy savings could be achieved by optimising comfort requirements, occupancy regimes, occupant activities and access controls through proper human factors management.

The energy savings that could be achieved by changing occupant behaviour is comparatively less and are temporary in nature as the human behaviour could change rapidly. Whereas the savings from demand side and supply side management retrofits are bound to be high and tend to last for longer durations. However, according to Zhang *et al.* (1993) proper demand side management could altogether avoid the need for new sources of energy or in other words supply side retrofits. Further, the demand side retrofits require comparatively less cost investments compared to retrofit measures using renewable energy technologies (Kromer, 2007).

Table 2: Types of Retrofits Based on the Amount of Energy Saved

Retrofit type	Amount of energy saved
Existing Building Commissioning (EBC)	Up to 15%
Standard retrofit	15-45%
Deep retrofit	45% and above

Table 2 indicates the other most prominent retrofit classification, where the retrofits are classified based on the amount of energy saved. Wang *et al.* (2013) have defined EBC as a process which incorporates identification and implementation of energy saving opportunities of the existing equipment and operations to make the buildings work properly. Consequently, the energy saving opportunities of buildings could be maximised by improving building operation process and altering maintenance procedures (Trubiano *et al.,* 2014). On the other hand, conventional retrofits generally focus on upgrading individual systems to achieve the potential energy savings of each building system (Penna *et al.,* 2015). However, deep retrofits adapt a whole-building approach by addressing multiple building systems simultaneously (Moser *et al.,* 2012). Authors have further described deep energy retrofits as a combination of many EBC and conventional retrofits

EBC provides comparatively lower energy savings, although it is the easiest type of retrofit to be implemented. Moreover, according to Krieske and Hu (2014) despite the higher energy savings from deep retrofits, the risk involved is also significant due to the complexity and high cost of the implementation process. Consequently Ma *et al.* (2012) have described conventional retrofits as the most cost effective and low risk retrofit type for existing buildings in general.

According to the above clarifications it could be stated that the use of conventional retrofits for demand side management are expected to result in adequate energy savings at an optimum cost and risk to the building managers and owners. Hence this study is narrowed down to conventional energy retrofits to manage the energy demand of the buildings.

3. RESEARCH METHODOLOGY

The aim of this research was to study the use of energy retrofits in office buildings of Sri Lanka. Initially a literature survey was conducted to determine the available energy retrofit techniques and the enablers to enhance energy retrofit use. Subsequently, data collection was carried out in three phases.

3.1. PHASE 1 - PILOT SURVEY

The pilot survey was conducted to validate the findings of literature survey. Here the applicability of literature findings to the Sri Lankan building context was examined. Accordingly, for the pilot survey, a senior Facility Manager with industry experience of more than 20 years was interviewed.

3.2. PHASE 2 - QUESTIONNAIRE SURVEY

The questionnaire survey was conducted to identify the level of use of energy retrofits in office buildings of Sri Lanka and to establish the importance of enablers to enhance energy retrofit usage. For this purpose, office buildings in Colombo area, with more than 7 storeys which were built on or before 2010 were considered as the population of the study. Buildings having more than 7 storeys were considered as the identified energy retrofit techniques are highly effective in larger buildings. On the other hand, buildings built on or before 2010 were taken as the retrofit requirement arises only in older buildings. The combination of above two requirements revealed an adequate building population from which a sample of 41 buildings were selected randomly for questionnaire survey. Lists of buildings were taken from the records of Colombo Municipal Council and major construction contractors for random sample selection. The questionnaires were distributed to the building managers of the selected buildings. Out of the 41 distributed questionnaires only 35 were returned with a satisfactory response.

3.3. PHASE 3 - CASE STUDIES

The main focus of the case studies was to carry out a cost benefit analysis of the implemented retrofit techniques. For this purpose, three specimen case studies were conducted. The three cases were selected in a way to represent the most commonly used retrofit technique in each of the three categories; building facade, heating ventilation and air conditioning (HVAC) system and lighting system as identified in the questionnaire survey. For each retrofit technique, recently concluded largest retrofit project in terms of the project cost was selected. These projects were identified during the questionnaire survey. Further, the computed energy savings in the case studies were converted to monetary terms based on the tariff rates defined by the Public Utilities Commission of Sri Lanka.

4. ENERGY RETROFIT TECHNIQUES FOR BUILDINGS

Building facade and systems installed for HVAC and lighting are considered as the main energy aspects of a building (Dascalaki and Santamouris, 2002). Hence the building energy retrofits could be adapted to reduce energy demand of a building by addressing these three main energy aspects.

During the literature survey, 19 building energy retrofit techniques belonging to the above three energy aspects were identified. Out of the identified 19 techniques, 2 techniques were invalidated during the pilot survey defining them as either preventive or corrective maintenance techniques but not as retrofit techniques. These two retrofit techniques were high albedo roof painting and the renovation of the window frame. The validated retrofit techniques and the level of use of these retrofit techniques in the established building sample is depicted in Table 3. Here the use of these techniques was identified in two aspects as to whether the techniques were available from the beginning (inherent) or whether the techniques were retrofitted later. Because, in some of the modern buildings these techniques were installed during the initial building commissioning. Hence it is identified separately from actual retrofit scenarios.

Table 3: Usage of Energy Retrofit Techniques

Technique	% of buildings where the techniques were inherent	% of buildings where the techniques were retrofitted	Total usage (%)
Roof Retrofits			
Roof Insulation	22.86	8.57	31.43
Green Roof Application	0	0	0
High-albedo Roof Paintings	-	-	-
Wall Retrofits			
Wall Insulation	14.29	5.71	20.00
Solar Shading Elements	11.43	20.00	31.43
Window Retrofits			
Low Emissivity Application	11.43	22.86	34.29
Multi Panel Glazing	5.71	14.29	20.00
Vacuum Tube Window	0	0	0
Renovation of Window Frame	-	-	-
HVAC Retrofits			
Optimum Start/Stop Controller	11.43	11.43	22.86
Variable Frequency Drives (VFD) for Motors	17.14	34.29	51.43
Free Cooling Applications	11.43	17.14	28.57
Energy Recovery Ventilator (ERV)	8.57	14.29	22.86
Demand Control Ventilation (DCV)	11.43	20.00	31.43
Lighting Retrofits			
Light Emitting Diode (LED) Lighting	5.71	28.57	34.29
Task Lighting	0	8.57	8.57
Occupancy Based Lighting Control System	0	0	0
Daylight Linked Lighting Control System	2.86	0	2.86
Lighting Controlled by Time Scheduling	5.71	14.29	20.00

5. ENABLERS TO PROMOTE THE IMPLEMENTATION OF ENERGY RETROFITS

During the literature survey, 8 enablers were identified in two levels as organisational level and national level. Further, 2 organisational level enablers and one national level enabler were added based on the findings of the pilot survey. However, the implementation of the enablers is solely dependent upon the attitude of the building managers of the organisation. Hence, the attitude of Sri Lankan building managers towards the importance of each of the organisational and national level enablers should be properly identified before enacting and empowering these enablers in to practice. Because, there is little use in implementing these enablers, if the building managers refuse to embrace these enablers in enhancing the energy retrofit usage to minimise the energy demand of the building facilities. However, it is not possible to implement all the enablers at once. Hence the established enablers of the two categories were prioritised based on the RII computed from the responses which is depicted in Table 5. For the prioritisation, a five-point importance level scale was used.

Table 5: Prioritisation of Enablers

Enabler	RII
Organisational level enablers	
Allocating higher budgets for energy improvements	0.908
Leniency on expected payback from retrofit projects	0.874
Energy performance measurement and verification protocol	0.846
Identifying and hiring competent contractors	0.806
Raising awareness of the building managers on energy retrofit techniques	0.754
National level enablers	
Energy Service Contracts (ESCOs)	0.938
Financial incentives from the government for energy improvements	0.914
Energy performance certification system for buildings	0.834
Financial assistance from banks to improve energy efficiency	0.822
Tax relief for energy efficiency related imports	0.766
Regulations on energy performance of existing buildings	0.726

The results clearly indicated that out of the organisational level enablers, the building managers have given the highest importance for the allocation of higher budgets for energy improvements which indicated a RII of 0.908. According to Mathews *et al.*, (2010) opportunities for building managers to carry out energy improvements are restricted by the limited funding allocations. Hence the increase in funding for energy improvements would provide the necessary freedom for the building managers to implements the relevant energy improvements. Further, the leniency on expected payback of energy improvement projects received a RII of 0.874 indicating that the building managers are conscious about the long-term benefits of energy improvements over higher payback periods. Moreover, the existence of an energy performance measurement and verification protocol and identifying and hiring competent contractors have both received RII values over 0.8 (0.846 and 0.806 respectively) which indicates a high importance. However, raising awareness of the building managers received the lowest importance with a RII of 0.754.

Further, the results clearly indicated that, out of the established national level enablers, the highest importance was given to ESCOs with a RII of 0.938. As indicated in literature, Vine (2005) has stated that in an ESCO arrangement, the initial capital cost of a retrofit implementation borne and the process of project implementation is looked after by the energy service company. Hence, it is not essential for the client to tie up significant amount of capital at the start of the project. Furthermore, according to (Sorrell, 2007) the ESCOs are PAYS arrangements, where risk of under realisation of estimated savings is also transferred to the contractor, which would attract the building managers even more. Financial incentives from the government was ranked second in the list of national level enablers with a RII of 0.914. According to Menassa (2011), even the repayable incentives from the government usually involves very low interest rates which are almost negligible for a profitable energy retrofit project. However, the risk of failure lies with the building managers and the owners and hence would demand a higher certainty of the savings of each retrofit technique to be implemented.

Moreover, when the priority order of the enablers is observed, it is noticeable that the enablers which result in financial assistance have gained a higher RII. However, the building energy performance certification system has gained a slightly higher a RII (0.834) compared to financial assistance from banks which has received a RII of 0.822. According to Wang *et al.* (2012), obtaining a building performance certification from an accredited organisation or the government would result in more positive implications on the public image of the organisation. Conversely, tax relief for energy efficiency related imports received a comparatively lower RII (0.766) as it is helpful only when a building manager takes the responsibility of implementing an energy retrofit improvement in-house which is not that frequent. However, building regulations on energy demand of buildings was placed at the bottom end of the prioritised national level enablers as it gained a RII of 0.726. Pan and Garmston (2012) have stated that the building regulations force the building managers to enhance the energy performance of existing buildings by incorporating retrofit techniques, which could moreover result in fines and compensations if the minimum requirements are not attained. Hence the building regulations are more of a hostile approach in facilitating building retrofit implementation, which have received a lower importance level from the respondents.

6. COST BENEFIT ANALYSIS OF THE RETROFIT TECHNIQUES

It was evident from the analysis of questionnaire data that the use of energy retrofit techniques of the existing office buildings of Sri Lanka is not at a satisfactory level. Albeit this lower retrofit usage, still there are facilities which have successfully implemented retrofit projects. Following case studies have discussed the costs and benefits of the implemented retrofit techniques. Costs and benefits were analysed by using two project appraisal techniques which are simple payback period (SPP) and net present value (NPV). Here, the two techniques analyse two different attributes of the retrofit projects. SPP indicates the speed of recovering the initial capital cost while NPV depicts the life time profit of the project by considering the time value of money. The monetary savings achieved due to the reduction of energy demand, as a result of the implemented retrofit techniques were used as the cash inflows of the projects.

As mentioned in section 2, case studies were used for an in-depth study of the most commonly used retrofit technique of each of the three categories; building facade, HVAC and lighting systems. According to the outcomes of the questionnaire survey, the most utilised retrofit technique in each of the three categories were as follows.

- HVAC system- Variable frequency drivers (VFD) for motors (51.43%)
- Lighting system- LED lighting (34.29%)
- Building Facade- Solar control low emissivity application (34.29%)

6.1. CASE STUDY 1- VFD RETROFIT PROJECT

Chilled water of the HVAC system of the selected facility was pumped and transferred throughout the building using four 55 kW pumps. Initially the pumps have been installed to match full load capacity, accounting for the general public who visit the premises for various purposes. However, as the occupancy level of premises varies frequently, the cooling system was found to be working at a part load on majority of the duration. Hence 55kW VFDs were retrofitted to all four chilled water pumps to save energy by operating pumps below the maximum capacity during part load conditions. Costs, benefits and the project feasibility values are depicted in Table 6.

Table 6: Cost Benefit Analysis of VFD Retrofit Project

Project Cost (LKR)	Average Annual kWh Savings (LKR)	Average Annual kVA Savings (LKR)	SPP of the project (years)	NPV of the project (LKR)
4,800,000	7,094,800.8	1,240,080	0.58	53,744,202.74

In addition to the energy savings, the VFD retrofit project has result in several additional benefits as well. After the VFD retrofit implementation, the occupant comfort level has been identified to be improved. Moreover, a better control of the pump operations has been achieved through the project with the enhanced opportunity of carrying out a more in-depth analysis of the pump faults. Further, the VFD has been highly helpful in planning preventive maintenance of different elements of the chilled water pumps. Consequently, the better preventive maintenance of the elements of the pumps is expected to pro long the useful life time of the pumps.

6.2. CASE STUDY 2- LED LIGHTING RETROFIT PROJECT

Existing inefficient lamps of the common areas of the selected facility were replaced by LED lamps. Subsequently, previously existed Tube-in-Tube, sodium vapour, halogen, fluorescent lamps of the common areas of the building were replaced with more efficient LED units. However, the expected maximum demand saving value was minute compared to the overall maximum demand of the building and hence not taken to appraise the project. Computed costs, benefits and the project feasibility values are included in Table 7.

Table 7: Cost Benefit Analysis of LED Retrofit Project

Project Cost (LKR)	Average Annual kWh Savings (LKR)	Average Annual kVA Savings (LKR)	Simple payback period of the project (years)	Net present value of the project (LKR)
4,480,398.25	2,605,202.04	-	1.72	18,302,093.59

The LED retrofit project has resulted in an elevation of the illuminance level in the common areas. The reason for this illuminance enhancement has been explained as the uni-directional nature of the LED lamps. Further a minor reduction of heat load has also been expected as the heat emission of LEDs are lower compared to all the other traditional lamps that existed in the facility. As a rule of thumb in the industry, 1 kWh of air conditioning energy is saved for every 3 kWh of lighting energy saved. Moreover, extended life span of the LED lamps is another additional benefit. The expected life span of an LED lamp is 14 years and it is significantly higher than the other traditional lamps. Hence, a replacement cost is also saved for the organisation, due to the reduced frequency of replacements.

6.3. CASE STUDY 3- LOW EMISSIVITY COATING RETROFIT PROJECT

Main factor that has motivated the incorporation of low emissivity coating was the east-west orientation of the building. This orientation embraces a higher solar thermal load in to the building which in turn increases the cooling load for the air conditioning system. All the windows of the east and west faces of the building facade were applied with law emissivity coatings. However, similar to LED retrofit project, the expected maximum demand saving value was minute compared to the overall maximum demand of the building and hence not taken to appraise the project. Costs of the project, benefits due to realised energy savings and the resulting project feasibility values are depicted in Table 8.

Table 8: Cost Benefit Analysis of Low Emission Retrofit Project

Project Cost (LKR)	Average Annual kWh Savings (LKR)	Average Annual kVA Savings (LKR)	Simple payback period of the project (years)	Net present value of the project (LKR)
184,860	385,946.28	-	0.48	1,397,519.75

Low emissivity retrofit project has helped in minimising the penetration of UV rays, which would protect the internal equipment like furniture from fading. Further, the reflectance of UV rays also creates a better indoor environment quality which is suitable for the occupants. However, the reflectance of solar heat would not impact the illuminance level as the visible rays are allowed to pass through the low emissivity coating. Moreover, the shatter resistance of glass is also expected to be enhanced by the addition of low emissivity coating.

7. DISCUSSION

The results of the case studies clearly indicate that the financial viability of the implemented retrofit projects is at a highly satisfactory level. All three retrofit projects had SPP of less than 2 years, which indicate that the initial cost investment is recovered in very quick time. Moreover, the life time savings of all 3 retrofits projects were massive which is indicated from the NPV of each project. In addition to the direct monetary savings, all three retrofit projects were expected to generate additional benefits which could result in indirect monetary savings. The success of these real retrofit scenarios would be good examples for energy conscious building managers.

8. CONCLUSIONS

The energy demand for buildings are continuously rising with the increasing occupant expectations. In order to manage the increased user requirements, the modern buildings are constructed with sophisticated technologies aimed at reducing building energy demand. However, the portion of energy demanded by the existing older buildings are significant. Hence, improving the energy efficiency of existing buildings to bring down the energy demand is really important in solving the current global energy crisis. Energy retrofitting is one of the key approaches of reducing the energy demands of the existing buildings.

The aim of this study was to study the use of energy retrofits in the existing office buildings of Sri Lanka to reduce the building energy demand. During the data collection, it was revealed that the use of energy retrofits in Sri Lankan office buildings are at a lower level. The most commonly used retrofit technique was VFDs which had a total usage of only 51.43%. The level of use of all the other retrofit techniques were way below 50%. However, the use of energy retrofits could be enhanced by the implementation of enablers, both at the organisational level and the national level. According to the perception of the building managers the most preferred enabler strategy was to implement ESCOs which had a RII value 0.938. Moreover, the profitability of energy retrofit projects as demonstrated through the three case studies were acceptable, due to the reduction of energy demand of each respective building facility by significant amounts. All three cases had SPP of less than 2 years for the respective retrofit projects which shows the viability of those projects. Hence, by implementing energy retrofits with aid of the established enablers, the energy demand of Sri Lankan office buildings could be reduced. Thus, the findings of the research could be benefit for energy mangers or facility mangers towards taking decisions on energy management.

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