Sustainability in Public Works Conference
24 – 26 August 2016

Guidelines for Building Energy Efficiency Retrofitting

Morshed Alam[1], Patrick X.W. Zou[1], Jay Sanjayan[1], Rodney Stewart[2], Oz Sahin[2], Edoardo Bertone[2], John Wilson[1]

[1]Department of Civil and Construction Engineering and Centre for Sustainable Infrastructure, Swinburne University of Technology, VIC, Australia
[2]Griffith School of Engineering, Griffith University, QLD, Australia

Corresponding Author: Morshed Alam   Email: mmalam@swin.edu.au

Abstract

Retrofitting existing buildings for energy efficiency has been identified as an effective measure to reduce global energy consumptions and greenhouse gas emissions. Many governments and organisations have put significant effort towards energy efficiency improvement in existing buildings. In this research, a comprehensive review of the barriers to retrofitting, retrofitting guidelines and research progress to date has been carried out. The barriers to the uptake of energy retrofitting were categorised as Regulatory barrier, Economic barrier, Knowledge barrier or Social barrier. The review of existing guidelines showed that at least one important step in the building retrofitting process is missing, which is risk assessment and management. It was found that although existing research has shown the importance of conducting a risk assessment in the building retrofitting process, none of the currently available retrofitting guidelines of different countries includes risk assessment. Inaccurate predictions are becoming more problematic for the industry as new financing schemes such as Environmental Upgrade Agreements (EUAs) and Energy Performance Contracting (EPCs), relying on predicted savings are introduced locally, nationally and internationally. Risk assessment is important to ensure that the predicted energy saving is achieved once the building is retrofitted and in use. In addition, it was also found that some guidelines have no directions for post occupancy evaluation of installed retrofit measures. Based on the review, the essential steps of a building retrofit guideline are proposed, outlined and discussed in this paper.

1. Introduction

Energy and water scarcity, as well as environmental pollution, have become key challenges for sustainable development of the whole world. The building sector accounts for 40% of the global energy consumptions and contributes up to 30% of global greenhouse gas emissions [1]. Therefore, it becomes obvious that energy efficiency of buildings is a key component of reducing global energy use and climate harmful emissions. Currently the majority of the existing building stocks were built before the introduction of sustainability benchmarks and are energy inefficient. To achieve an energy use reduction in the building sector, the issue of energy inefficiency of existing buildings must be addressed [2]. The implementations of energy retrofit measures (ERM) for increasing the energy efficiency of the existing buildings have been shown to have a significant effect on reducing the total energy demand [3].

During the last decade, many governments and international organisations have put significant effort towards energy efficiency improvement in existing buildings. In 2011, the Chinese government strengthened the emphasis on retrofits of government and other public buildings by issuing "Notification on Further Implementation of Energy-efficiency Retrofits in Public Buildings" [4]. It requires a 10% reduction of energy consumption per m^2 for public buildings and 15% reduction for large public buildings with over 20,000 m^2 of floor area by the end of 2015. In 2010, the UK government made a significant commitment to upgrade the energy efficiency of 7.0 million British homes by 2020 aiming at reducing carbon emissions by 29% [5]. The International Energy Agency (IEA) has launched a set of Annex projects to promote energy efficiency of existing buildings, such as: Annex 46 – Holistic assessment toolkit on energy efficient retrofit measures for government buildings; Annex 55 – Reliability of energy efficient building retrofitting; and Annex 56 – Energy & greenhouse gas optimised building renovation [6]. These efforts provided policy guidance, financial assistance and technical support for the implementation of energy efficiency measures in existing buildings.

In the USA, the Energy Policy Act of 2005, expanded under the Energy Independence and Security Act of 2007, requires that all existing buildings must reduce energy consumption 30% by 2015, compared with 2003 levels, through building upgrades and efficient appliances. In Australia, Energy Efficiency in Government Operation (EEGO) policy was introduced in 2006 according to which minimum performance standard for government office buildings should be NABERS 4.5 star [7]. In 2008, the City of Melbourne launched a program to retrofit 1200 CBD buildings to achieve 4.5 NABERS star by 2020 [8].

While there are a number of policies with the requirement of reducing emission and energy consumption through building retrofitting, there is still a lack of a comprehensive strategy outlining how it can be achieved. Therefore, the aim of this paper is to propose a comprehensive guideline to guide the building retrofitting process efficiently and cost-effectively. In this process, potential barriers to the uptake of energy efficiency retrofitting have been identified. It is then followed by the evaluation of existing building retrofitting guidelines from different countries to understand their strengths and limitations. Then, research progress in the area of building retrofitting has been explored to see what a building retrofitting guideline should entail from research perspectives. Finally, based on the understanding of potential barriers, existing guidelines, and research progress a new retrofitting guideline have been proposed.

2. Barriers to implementing building retrofitting

Retrofitting existing buildings for energy efficiency is a big challenge because it involves substantial funding and decision-making from a wide range of stakeholders such as landlords, tenants, property managers, developers and local council. Potential barriers against uptake of energy efficient retrofitting may arise from any stakeholder or group of stakeholders. Therefore it is essential to understand the potential factors that may prohibit the uptake of energy efficient measures in buildings. This knowledge is also important to design and implement policies that will effectively promote energy efficiency investments. From the existing literatures [9-11], four main categories of barriers to retrofitting existing buildings have been identified which are presented in Table 1.

Table 1 Barriers to uptake of building energy retrofitting

1. Economic Barrier	
Lack of Finance	Building owners or consumers do not have access to sufficient fund for retrofitting.
High upfront costs and payback expectations	Retrofitting existing buildings requires high upfront costs and the benefits accrue gradually over time which sometimes result in longer payback period.
Priorities in investments	Interested to invest the capital in other higher earning investments.
Price signals	Have a higher propensity to undertake energy retrofit investments, if the financial incentive associated with it is sufficiently large.
Split-incentives	Not interested to retrofit when the person who would pay the cost of retrofitting would not receive the full benefit of them
Minimize cost	Cutting the funds for energy efficiency generally comes first if cost minimization is required.
Uncertainties over financial gain	The difference between actual and predicted energy savings from retrofit influence cost savings and hence payback period.
Lack of attention and materiality	Incremental savings from retrofitting are quite small compared to the benefits from other investments and hence less attention is given.
2. Regulatory Barrier	
Fragmented market	In most cases, none of the involved professionals (during design, construction and operation stage) are expert in building energy efficiency, but the responsibility for achieving it is diffused among them which present a coordination challenge.
Institutional	There is a bias among institutional investors more familiar and comfortable with supply- side investments and large-scale financing, rather than generally smaller (and “more risky”) projects on the demand side.
Structural	Average age of the building

	stock is increasing because of a low demolition rate. Because of the age of buildings, the landlord-tenant dilemma makes it difficult to ameliorate the existing building stock.
Multi-stakeholder issues	It can be very difficult to agree on energy saving investments in multi-owner buildings if the owners have to either approve a decision or make a financial contribution.
Government not a strong driver	If the government demonstrate a strong commitment to policies that encourage sustainability, as well as lead by example, this can create a long-term positive impact on industry.
3. Knowledge Barrier	
Lack of Information and awareness	Sustainability is not usually understood well by owners or consumers. In some cases, they are not aware of current best practise or do not fully comprehend the effectiveness of energy efficient technologies.
Awareness of savings potential	While there is a general appreciation that energy saving is a "good thing", there remains a lack of understanding of the energy, cost and carbon savings from different measures.
Lack of Motivation	Some building owners are not interested in improving their buildings unless the equipment is about to break or there is a concerning high level of vacancy that is affecting his rental income.
Skills & knowledge related to building professionals	Skill shortages exist in both the contractor market responsible for the effective installation of energy saving measures, as well as in professional services, with few architects and designers familiar with energy efficient renovation.
Confusion in choosing the best option	If two or more professionals give supposedly conflicting advice as to the best way to renovate, this may lead to scepticism amongst the consumer over the installation of energy efficient measures.
Perception regarding energy efficiency	Some building owners have the perception that energy efficiency investment would not yield a return and see it as compliance and cost burden.
4. Social Barrier	
Interruption to building operation	The usual operation of a building is interrupted when a renovation is being undertaken. In the case of deep renovation, the entire building may need to be vacated which will involve practical and financial barriers associated with re-locating the occupant for the period of the retrofit.

3. Review of current guidelines

In order to carry out the building energy retrofitting process efficiently through minimizing the effect of potential barriers, a number of retrofitting guidelines have been developed in many countries around the world. Brief discussions of the available retrofitting guidelines have been presented below.

3.1 USA guideline

Figure 1 shows the flow chart of the retrofitting project according to advanced energy retrofitting guideline developed by the U.S Department of Energy [12]. The guide begins with an introduction to key concepts underpinning energy efficiency projects; discussions of goal setting, project planning, and performance tracking to illustrate the process for initiating energy efficiency projects. It also explains energy audits, financial analysis, and financing options, to provide the remaining elements needed for a strong business case. This section lays the foundation upon which energy efficiency project options are built in the subsequent sections. In the subsequent sections, three levels of upgrade approach have been presented: (1) Implementing operations and maintenance (O&M) improvements through Existing Building Commissioning (EBCx), (2) standard retrofits, and (3) deep retrofits. It was reported in this guide that up to 22% energy savings can be achieved through by improving building operations and restructuring maintenance procedures, with an average simple payback period of 1.1 years. Standard retrofit measures provide cost- effective and low-risk efficiency upgrade options including equipment, system, and assembly retrofits. Deep retrofit measures require a larger upfront investment and may have longer payback periods than EBCx or standard retrofit measures. In this guide, the proposed retrofit options are also customized for five different climates to consider the effect of local climate which has broadened its applicability. The guide concludes with a discussion of measurement and verification (M&V) strategies to ensure that improvements are operating as intended and operation and maintenance (O&M) activities to maintain and continually improve building performance

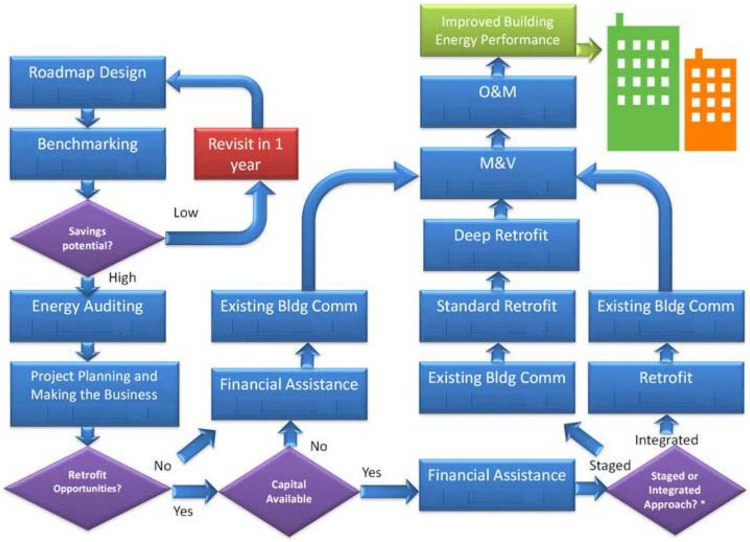

Figure 1 Project planning flow chart of the USA guideline [12]

3.1.1 UK guideline

International engineering consulting firm ARUP [13] has developed a 5 step survival strategies for the existing building stock of UK (Figure 2) to turn a tired asset into one that benefits users, communities, the environment, business and the balance sheet. The first step towards upgrading an existing property is baseline assessment to see how the building is positioned against the current code and regulatory requirements. At this step, energy auditing is carried out to determine the areas of largest consumption and target areas for improvement. In addition, a condition audit is also carried out to determine the current condition and expected remaining economic life of a building's component. This guide has presented four levels of refurbishment (as opposed to three levels from USA guideline) approach where the degree of intervention required is decided on the reports of building condition and performance.

The second step is maintenance and purchasing review step which doesn't cost much but can lead to significant performance improvements (Similar to EBCx of USA guideline). The next step is establishing targets and goals which will serve as a driver in developing a specific upgrade plan for a given property. The subsequent step is about the identification of optimum upgrade initiatives. There is no one solution or approach for any building upgrade; each initiative needs to be assessed based on its merits and the building in question. The key parameters that are considered while selecting the optimum retrofitting options are the level of refurbishments, capital cost and qualitative benefit of the initiative to sustainability, building occupants and owner. A list of 195 initiatives has been provided to help the owner to get started. The final step is to implement the selected retrofit options. Decisions have to be taken regarding the sequence of retrofitting implementation whether the upgrades be phased progressively or carried out at once.

Figure 2 UK's Five step survival strategies for existing buildings in the UK [13]

3.1.2 Singapore guidelines

In Singapore, a six step process has been developed by Building and Construction Authority of Singapore [14] in conjunction with ARUP which has been presented in Figure 3. The difference between this Singapore guideline and the ARUP guideline for the UK is that in the latter one decisions regarding the level of refurbishment required is taken in step one whereas in the former one the decision is made at step 4. In the Singapore guideline, the lists of suggested initiatives have been updated for Singapore perspective.

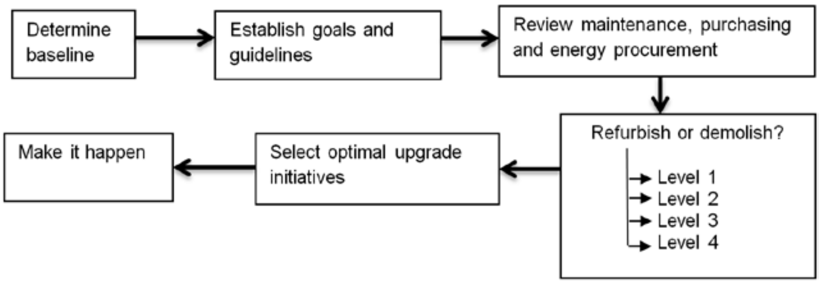

Figure 3 Singapore's six-step building retrofitting process [14]

3.1.3 Australian's guidelines

The Australian guideline, developed by ARUP and property council of Australia [15], is mostly similar to that of Singapore except that step 3 in the Singapore guideline is now step 2 in Australian guideline and step 2 in Singapore guideline is step 3 in Australian guideline. The City of Melbourne council also developed a building retrofit map under their 1200 Buildings program which is shown in Figure 3. The baseline assessment step determines how much energy and water the building consumes undertaking an energy/ water benchmarking tools NABERS and Green Star. The retrofit action plan stage explores different retrofit strategies, selects optimum strategies through necessary analysis and determines funding sources. The next stage is the "undertake retrofit works" where retrofit action plan is implemented. At this stage, one has to communicate with tenants (if applicable), apply for planning/building approval if necessary, organize builder to carry out the work etc. In the annual update stage, the progress of retrofit implementation is monitored and compared with the retrofit action plan to see whether the project is on the right track. Once the retrofitting is completed, commissioning of the retrofitted building is undertaken to achieve the best result in the complete work stage. The building tenants/managers and contractors are trained to ensure optimum ongoing operational efficiency. Finally, the building is re-assessed one year after the completion of final works to quantify the extent of savings.

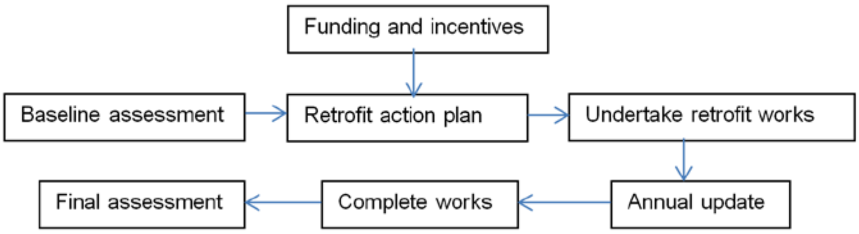

Figure 4 City of Melbourne's 1200 building retrofitting process [15]

3.1.4 Indian guidelines

There are six main steps in this roadmap for energy efficiency retrofits which are presented in Figure 5 [16] . The internal assessment is a preliminary energy use analysis which includes 1) determining the building total built-up area, 2) Collecting utility bills to calculate total energy used. 3) Calculation of energy performance index (EPI) which is the ratio of total annual energy used to the total built-up area (kWh/sq.m./year) and 4) Comparison of the calculated EPI having similar characteristics with climatic zones. The second step is to carry out detailed energy survey with the help of energy auditing team to identify potential areas of improvement. Next is the technical analysis step which studies the data from the energy survey, including energy consumption and peak demand analysis. Based on the analysis, an action plan is formulated to improve the building performance. The action plan includes a review of mechanical and electrical systems design, installed condition, maintenance practices and operating methods. From the benchmarking analysis, if there is a need to improve the energy levels is detected, a detail energy simulation is carried out to determine the energy savings from different retrofit technologies. This step is then followed by cost-benefit analysis to choose the best retrofit option as per the user requirement and budgetary constraints. Two types of financing model: Self-financing and Partnering with energy services company (ESCO) have been discussed for funding the building retrofit activities.

In the project implementation step, a retrofit implementation plan is developed including appropriate timelines of retrofit process, commitment, and finance mechanism so that the implementation is seamless. The final step Operation and maintenance is there to ensure recurring energy savings from the retrofitted building.

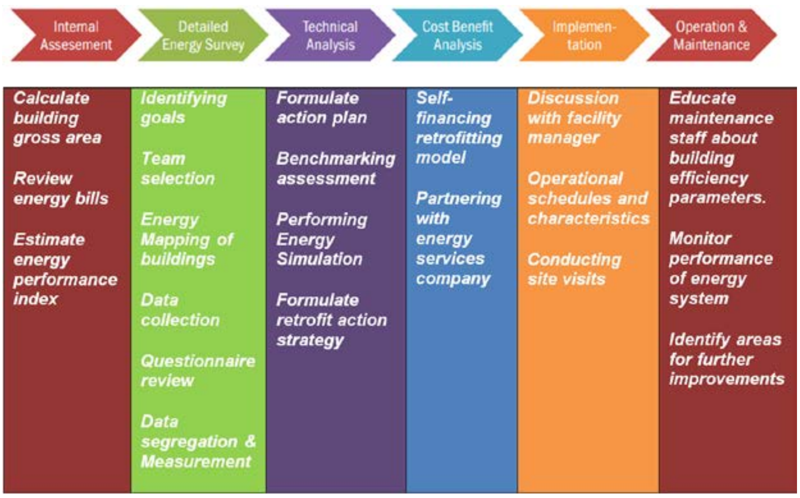

Figure 5 Building retrofitting roadmap India [16]

4. Review of relevant research

A number of studies have been undertaken by previous researchers to investigate the effectiveness different retrofit measures in improving the energy performance of existing buildings and develop a guideline for the retrofitting process. Griego et al [17] indicated that over 49% annual energy savings can be achieved cost-effectively for both retrofit and new construction commercial office buildings by reducing office equipment loads and more efficient lighting technology and controls. A reduction in primary energy consumption by 40% was achieved in the case study of Aste and Pero [18] through improving building envelope only, without intervention on HVAC plant, lights or other technical systems. Fiaschi et al [19] showed that installation of PV modules guarantees annual savings of 4.5% and 5% with respect to the annual cost of electricity. Upgrade of wall insulation lead to energy savings of approximately 40–50%, which agrees with the average values available in the literature for similar buildings. Virote and Neves-Silva [20] reported that human behaviour plays a very important role in the overall building energy consumption. Careless behaviour can add one-third to a building's designed energy performance, while conservation behaviour can save a third. Saelens et al (2011), showed that encouraging people to actively switch off the lights reduces lighting and cooling energy demand.

A building retrofit is subject to many challenges such as uncertainty in savings estimation, energy use measurements, weather forecast, the changes of energy consumption patterns, system performance degradations, etc. Uncertainty parameters can be divided into three categories: physical (uncertainties in physical properties, such as conductivity, thickness of materials etc.), design (design variations that occur during the planning process) and scenario uncertainty (changes in parameters during the operating stage such as, occupancy pattern, behaviour, weather) [21]. Taking scenario uncertainties into account is very important when considering design robustness and future adaptability of the building.

In a recent case study by Silva and Ghisi [22], up to 19.5% and 36.5% of uncertainty was reported in the prediction of heating energy consumption for physical and user behaviour parameters, respectively. In the case of cooling energy consumption, up to 43.5% and 38.0% of uncertainty was reported for physical and user behaviour parameters variation, respectively, in the same study. Variation in HVAC operation was found to result in -15.3% to 70.3% variation in annual energy consumption for a medium sized office building [23]. Daly et al. [24] reported more than 50% variation in the predicted energy consumptions for all studied locations in Australia, due to the inconsistencies in the assumptions of 'hard-to-measure' building and occupant behaviour input parameter values. These types of inaccurate predictions are becoming more problematic for the industry as new financing schemes such as Environmental Upgrade Agreements (EUAs) and Energy Performance Contracting (EPCs), relying on predicted savings are introduced locally, nationally and internationally.

Risk analysis/assessment/evaluation is, therefore, essential to transform risk in practice to simulations and provide decision makers with a sufficient level of confidence to select and determine the best retrofit solutions. A typical risk analysis method consists of sensitivity analysis, probability analysis of the input parameters, Monte Carlo simulation and risk assessment steps [25]. Sensitivity analysis is required to identify the most uncertain and influential parameters in the risk analysis. The next step is the quantification of uncertainties using probabilistic approach. After assigning a probability distribution to selected input parameters, values from within their probability distribution are picked randomly and one simulation is undertaken. Simulations are repeated with new randomly selected values each time. Values are picked from distributions of each parameter by possibility, which generates thousands of combinations. This is known as Monte Carlo approach. Those combinations are treated as possible cases that might occur in practice. In the risk assessment steps, the results from Monte Carlo simulation are used to generate a probability distribution curve of energy performance. The distribution curve, for both energy performance and utility cost, presents the possibility of different scenarios in reality, thus can be used for assessing risks involved in energy savings and payback period predictions.

In order to select the optimum retrofit strategies for maximum energy and cost savings a number of retrofit analysis toolkits have been developed by previous researchers. The CBES (Commercial Building Energy Saver) retrofit analysis toolkit of Hong et al [26] calculates the energy use of a building, identifies and evaluates retrofit measures in terms of energy savings, energy cost savings and payback period. CBES includes 100 configurable energy conservation measures (ECMs) that encompass IAQ, technical performance and cost data, for assessing 7 different prototype buildings in 16 climate zones in California, USA. The tool developed by Hillebrand [27] evaluates retrofitting combinations according to energy, ecology, and economic criteria. The results show that a generally preferred retrofit option cannot always be identified. Each evaluation criterion may deliver different retrofit orders, which points out the necessity of a multi-criteria evaluation. A description of decision making model based on multi-criteria evaluation methodology can be found in Shao et al [28]. Almeida et al [29] showed that a decision making model based on life cycle cost benefit analysis considering both technical and economic uncertainties parameters provide more realistic economic evaluation and reveal the investment risk. Hopfe et al. [30] proposed a methodology using Fuzzy-AHP (Analytical hierarchy process). The conventional AHP protocol that handles only deterministic information was enhanced to include uncertainties. Their proposed method presented a viable means of collaboratively ranking complex design options based on the multi-criteria analysis.

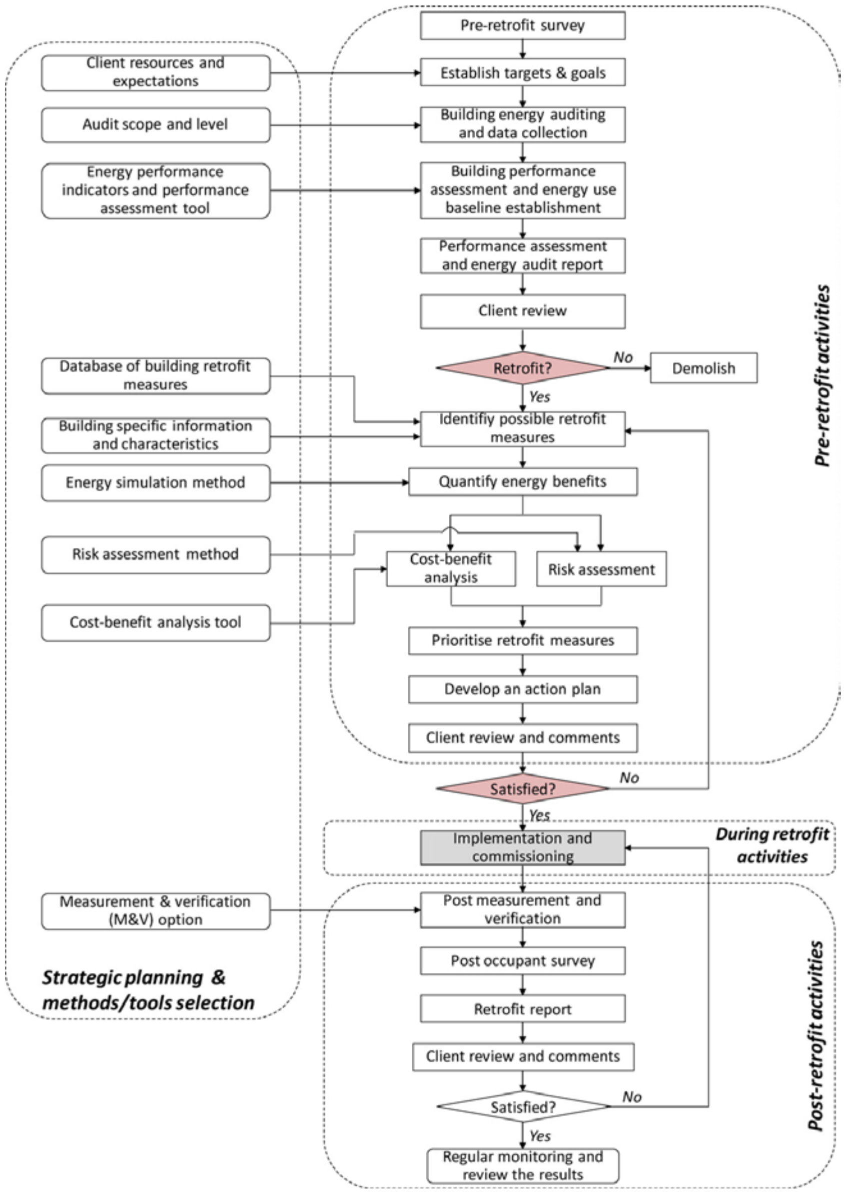

Figure 6 A systematic approach for sustainable building retrofits. (Ma et al 2012 [2])

From the review of existing research Ma et al [2] developed a systematic approach to identifying, determining and implementing the best retrofit measures for existing buildings as shown in Figure 6. The retrofitting starts with establishing goals, building audit and energy performance monitoring of an existing building. Latter, audit data is used to develop a base-case simulation model. If audit data is positive for retrofitting, the base case simulation model is used to quantify the energy benefits of different retrofit measures. After that, appropriate economic analysis tools and risk assessment methods are used to quantify the performance of a range retrofit options. The next step is the selection of optimum retrofit option based using appropriate decision support tools as discussed above. The selected retrofit measures are then implemented on-site. Test and commissioning (T&C) is employed to tune the retrofit measures to ensure the building and its services systems operate in an optimal manner. The final phase is measurement and verification of energy savings. A post occupancy survey is also recommended by Ma et al (2012) to understand whether the building occupants and building owners are satisfied with the overall retrofit result.

5. Discussions

In this paper, a comprehensive analysis of building retrofitting guidelines of different countries as well as research to date on building retrofitting strategy have been carried out. Table 2 shows the comparison of different building energy retrofitting guidelines discussed in previous sections. The table points out that the “Advanced Energy retrofit guide” from U.S. department of energy covers all steps of the required guideline components except risk analysis. The guidelines for UK, Singapore, and Australia are developed based on the same source of *“existing building survival strategies”* from ARUP. Similar to the one of the USA, these guidelines does not provide any direction for considering risks involved in retrofitting projects. In addition,

Table 2 Comparison building retrofit guidelines of different countries and proposed strategy

Guideline components	USA	UK (by ARUP)	Singapore (by ARUP)	Australia (by ARUP)	Australia (City of Melbourne 1200 Buildings retrofitting Program)	India	Research (Ma et al 2012)
Baseline assessment	√	√	√	√	√	√	√
Energy Audit	√	√	√	√	√	√	√
Project planning • *Establish targets* • *Analyse potential barriers and challenges*	√	√	√	√	√	√	√
Exploration of retrofit measures • *Level 1* • *Level 2* • *Level 3 etc.*	√ √ √ √	√ √ √ √	√ √ √ √	√ √ √ √	√ √ √ √	√[2]	√[2]
Making business case of retrofit • *Cost-benefit analysis using simple payback period* • *Life Cycle Analysis*	√ √	√	√	√		√	√
Risk analysis *Investment risk* *Performance risk*							√
Selection of optimum retrofit measures	√[1]	√[1]	√[1]	√[1]		√[1]	√
Financing	√				√		
Implementation	√	√	√	√	√	√	√
Measurement and Verification	√				√		√
Operation and maintenance	√				√	√	√

[1]Without considering risks, [2] did not divide retrofit measures into different levels.

there is no discussion regarding financing mechanism for funding the retrofitting project, M&V and O&M strategies for post-retrofitted buildings. In Australia, the retrofit process developed by 1200 buildings program includes financing, M&V and O&M strategies. However, their proposed retrofit process does not include any methodologies for risk analysis and selection of optimum retrofit measures. The retrofit guideline of India has touched almost every step of the proposed retrofit guideline except, risk analysis, financing and M&O strategies. Although the guideline discussed the selection of different retrofit measures, no differentiation was made between the levels of retrofit options as it is in the case of the USA and other ARUP based guidelines.

Finally, the retrofitting guideline proposed by Ma et al [2] based on existing research, is found to cover every component except financing. The inclusion of financing mechanism in retrofitting guideline is very important because the lack of financing is a strong barrier to the uptake of energy retrofitting as reported in section 2. Also, the guideline does not include any discussion regarding different levels of retrofitting measures. The inclusion of different levels of retrofit in a retrofitting guideline is important, particularly, when there is a budget constraint.

6. Development and implementation of a new guideline

From the review of available retrofitting guidelines adopted in different countries, the guidelines in the existing research and barriers to uptake energy retrofitting, a new retrofit guideline has been proposed. In the proposed guideline, an attempt has been made to overcome barriers to retrofitting as well as include all necessary steps mentioned in Table 2. The proposed guideline has been presented in Figure 7. It shows the need to introduce policies to overcome knowledge barriers and help stakeholders in establishing retrofit targets and goals. It also shows policy requirements for auditing and performance monitoring of the building. This can be in the form of training materials to generate skilled professional which will make sure that the auditing and performance monitoring are carried out in accurate and consistent manner. The proposed guideline also shows policy requirements for finance mechanism to fund the retrofit project which is reported to be No. 1 barrier to retrofitting in the previous studies [9]. The level of retrofitting to be carried out will be decided depending on the available finance. The risk analysis step calculates the possible uncertainties and minimizes the gap between predicted and actual savings. In this guideline, the optimum retrofit measure is selected based on stakeholders' preferences, life cycle cost benefit analysis, and probabilistic energy savings. In other words, a multi-criteria decision making tool should be used for selecting optimum retrofit measures. The next step is the implementation of retrofit measures which requires a management plan to manage the contractors, suppliers, and building tenants during the implementation process. A proper retrofit management plan can overcome the uncertainties/risks that may arise from inaccurate installation of retrofit measures as well as minimize the interruption to building occupants. The final steps are measurement and verification (M&V) and operation and maintenance (O&M).

Several case studies are recommended to test the applicability of this new guideline. It should be noted that although the existing research has developed a number of models for retrofitting existing building, uptake of these models in the retrofitting industry is rare. This is because, very rarely, these models are tested to see whether it is feasible or not to use in a real retrofitting project. Zou and Sunindijo [31] presented research-practise nexus approach to promote the findings from research in to existing industrial practise. This approach can be followed here to ensure that the proposed retrofit guideline is suitable for industrial application. Figure 8 shows the framework of research practise nexus approach proposed by Zou and Sunindijo [31]. In the current research, Steps 1 to 3 has already been completed. Figure 7 shows the proposed retrofit guideline (Step 3) which was developed based on past studies (Step 1) and industry needs (Step 2). According to the framework, Step 4 is action research which means the proposed guideline will be put into practise in real building retrofitting project. The findings from the action research will be used to modify and improve the proposed guidelines in Step 5. Step 6 is the integration of modified final retrofitting guideline relevant policies to ensure its maximum usage. A training module may need to be developed to train the users to use this guideline. The final step is the periodical review of the guideline for further improvement when necessary.

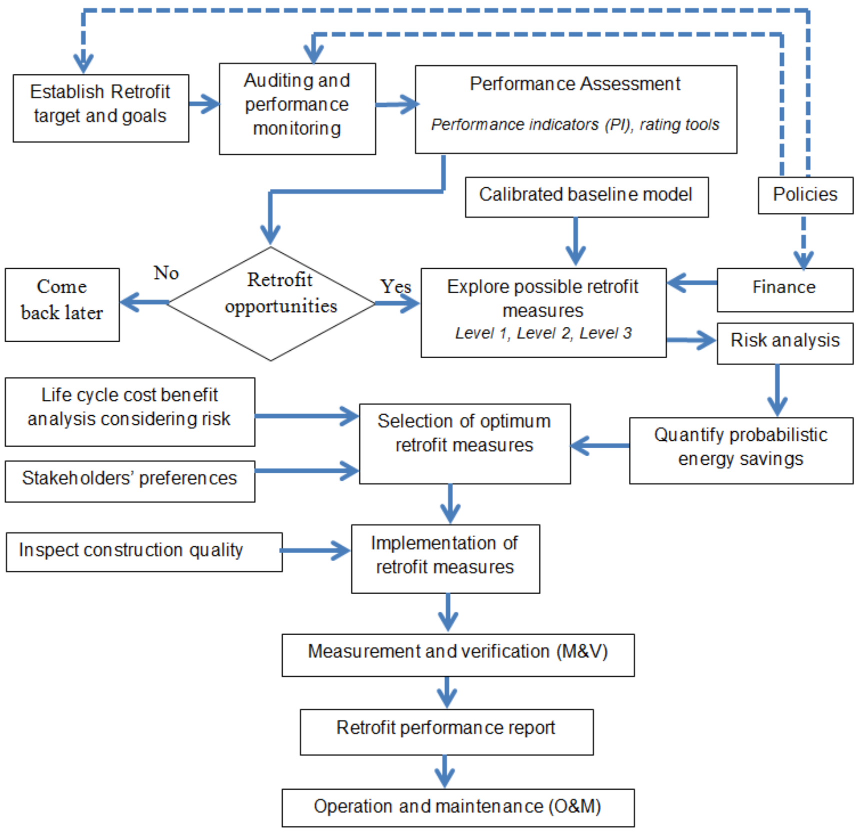

Figure 7 Proposed building energy efficiency retrofit guideline

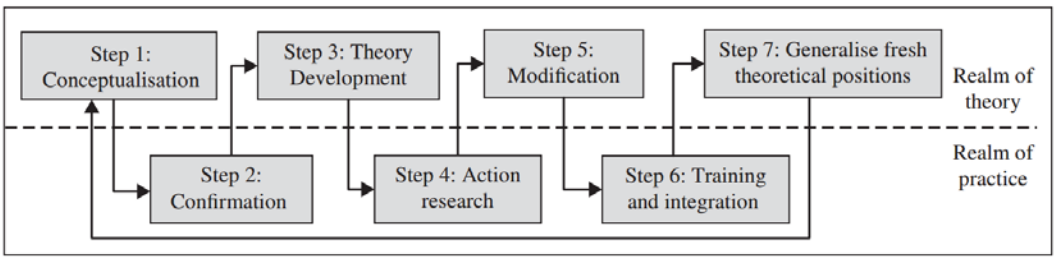

Figure 8 Research-practise nexus approach[31]

7. Conclusion

In this paper, existing building energy retrofitting guidelines, and research progress in the field were reviewed. In addition, potential barriers to the uptake of energy efficiency retrofitting were explored. Four categories of barriers were identified which either prohibits or slows down the uptake of energy efficient retrofitting. These are Economic, Regulatory, Knowledge and Social barriers. The evaluation of existing retrofitting guidelines from different countries showed that the guideline of USA is superior then others and includes all the steps of a required guideline components presented in Table 2 except risk assessment. In addition, other retrofit guidelines except the USA did not include some important retrofitting steps in their guidelines. The review of existing research showed the benefits of the retrofitting existing buildings using different energy efficient measures. In addition, the existing research also showed a number of different decision-making models to select the optimum retrofitting methods. The most important finding from the existing research is the need for risk assessment of building retrofitting project. None of the existing guidelines from different countries include risk assessment although a review of existing research have pointed out the importance of considering the risk assessment, particularly in the cases where investments are made through financing such as Environmental Upgrade Agreements (EUAs) and Energy Performance Contracting (EPCs).

Considering the deficiencies of existing guidelines, research progress and barriers to uptake energy retrofitting, a new retrofit guideline was proposed. In the proposed guideline, the effort was made to identify the areas where policies are required to overcome barriers to retrofitting, how risk assessment may be conducted and to include all necessary steps mentioned in Table 2. In order to finalise the proposed retrofit guideline and ensure its maximum effectiveness in the industry, use of research-practise nexus approach has been recommended.

8. Acknowledgement

The authors would like to acknowledge the Sustainable Built Environment National Research Centre (SBEnrc) and its partners for funding this project under SBEnrc Project 1.43 “Retrofitting Public Buildings for Energy and Water Efficiency”.

9. References

[1] United Nations Environment Programme. *Sustainable Buildings and Climate Initiative*. 2016; Available from: http://www.unep.org/sbci/AboutSBCI/Background.asp.

[2] Ma, Z., et al., *Existing building retrofits: Methodology and state-of-the-art.* Energy and Buildings, 2012. **55**: p. 889-902.

[3] Chidiac, S.E., et al., *A screening methodology for implementing cost effective energy retrofit measures in Canadian office buildings.* Energy and Buildings, 2011. **43**(2–3): p. 614-620.

[4] MOF and MOHURD. *Notification on Further Implementation of Energy-efficiency Retrofits in Public Buildings.* . 2011; Available from: http://www.gov.cn/zwgk/2011-05/11/content_1861716.htm.

[5] DECC. *Warmer homes, greener homes: a strategy for household energy management, UK Department of Energy and Climate Change*. 10.01.12]; Available from: http://www.decc.gov.uk.

[6] IEA. 16.06.2016]; Available from: http://www.iea-ebc.org/projects/.

[7] Department of the Environment and Water Resources, *ENERGY EFFICIENCY IN GOVERNMENT OPERATIONS (EEGO) POLICY* 2007.

[8] The City of Melbourne. [cited 16.06.2016; Available from: http://www.melbourne.vic.gov.au/business/sustainable-business/1200-buildings/Pages/1200-buildings.aspx.

[9] BPIE (Buildings Performance Institute Europe), *Europe’s buildings under the microscope - A country-by-country review of the energy performance of buildings.* 2011.

[10] Initiative), C.C.P., *Buildings Energy Efficiency in China, Germany, and the United States*. 2013.

[11] Ernst & Young, *Mid-tier commercial office buildings in Australia*. 2015.

[12] U.S Department of Energy, *Advanced Energy Retrofit Guide for Office Buildings- Practical Ways to Improve Energy Performance*. 2011.

[13] Arup United Kingdom, *Existing Buildings Survival Strategies: A Toolbox for Re-energising Tired Assets and reducing operating cost.* 2008.

[14] Building and Construction Authority (BCA) Singapore, *Existing Building Retrofit.* 2010.

[15] Arup and Property Council of Australia, *Existing Buildings Survival Strategies: A Toolbox for Re-energising Tired Assets, Victorian Division.* 2008.

[16] The energy and resource institute (TERI), *Roadmap for Incorporating Energy Efficiency Retrofits in Existing Buildings*. 2013: New Delhi.

[17] Griego, D., M. Krarti, and A. Hernandez-Guerrero, *Energy efficiency optimization of new and existing office buildings in Guanajuato, Mexico.* Sustainable Cities and Society, 2015. **17**: p. 132-140.

[18] Aste, N. and C. Pero, *Energy retrofit of commercial buildings: case study and applied methodology.* Energy Efficiency, 2012. **6**(2): p. 407-423.

[19] Fiaschi, D., R. Bandinelli, and S. Conti, *A case study for energy issues of public buildings and utilities in a small*

municipality: Investigation of possible improvements and integration with renewables. Applied Energy, 2012. **97**: p. 101-114.

[20] Virote, J. and R. Neves-Silva, *Stochastic models for building energy prediction based on occupant behavior assessment.* Energy and Buildings, 2012. **53**: p. 183-193.

[21] Hopfe, C.J. and J.L.M. Hensen, *Uncertainty analysis in building performance simulation for design support.* Energy and Buildings, 2011. **43**(10): p. 2798-2805.

[22] Silva, A.S. and E. Ghisi, *Uncertainty analysis of user behaviour and physical parameters in residential building performance simulation.* Energy and Buildings, 2014. **76**: p. 381-391.

[23] Wang, L., P. Mathew, and X. Pang, *Uncertainties in energy consumption introduced by building operations and weather for a medium-size office building.* Energy and Buildings, 2012. **53**: p. 152-158.

[24] Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings.* Energy and Buildings, 2014. **75**: p. 382-393.

[25] Sun, S., et al., *A method of probabilistic risk assessment for energy performance and cost using building energy simulation.* Energy and Buildings, 2016. **110**: p. 1-12.

[26] Hong, T., et al., *Commercial Building Energy Saver: An energy retrofit analysis toolkit.* Applied Energy, 2015. **159**: p. 298-309.

[27] Hillebrand, G., et al., *Development and design of a retrofit matrix for office buildings.* Energy and Buildings, 2014. **70**: p. 516-522.

[28] Shao, Y., P. Geyer, and W. Lang, *Integrating requirement analysis and multi-objective optimization for office building energy retrofit strategies.* Energy and Buildings, 2014. **82**: p. 356-368.

[29] Almeida, R.M.S.F., N.M.M. Ramos, and S. Manuel, *Towards a methodology to include building energy simulation uncertainty in the Life Cycle Cost analysis of rehabilitation alternatives.* Journal of Building Engineering, 2015. **2**: p. 44-51.

[30] Hopfe, C.J., G.L.M. Augenbroe, and J.L.M. Hensen, *Multi-criteria decision making under uncertainty in building performance assessment.* Building and Environment, 2013. **69**: p. 81-90.

[31] Zou, P.X.W. and R.Y. Sunindijo, *Research Methodology and Research–Practice Nexus*, in *Strategic Safety Management in Construction and Engineering*. 2015, John Wiley & Sons, Ltd. p. 180-213.