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Review

Existing building retrofits: Methodology and state-of-the-art

Zhenjun Ma*, Paul Cooper, Daniel Daly, Laia Ledo

Sustainable Buildings Research Centre (SBRC), Faculty of Engineering, University of Wollongong, New South Wales (NSW) 2522, Australia

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ABSTRACT

Retrofitting of existing buildings offers significant opportunities for reducing global energy consumption and greenhouse gas emissions. This is being considered as one of main approaches to achieving sustainability in the built environment at relatively low cost and high uptake rates. Although there are a wide range of retrofit technologies readily available, methods to identify the most cost-effective retrofit measures for particular projects is still a major technical challenge. This paper provides a systematic approach to proper selection and identification of the best retrofit options for existing buildings. The generic building retrofit problem and key issues that are involved in building retrofit investment decisions are presented. Major retrofit activities are also briefly discussed, such as energy auditing, building performance assessment, quantification of energy benefits, economic analysis, risk assessment, and measurement and verification (M&V) of energy savings, all of which are essential to the success of a building retrofit project. An overview of the research and development as well as application of the retrofit technologies in existing buildings is also provided. The aim of this work is to provide building researchers and practitioners with a better understanding of how to effectively conduct a building retrofit to promote energy conservation and sustainability.

Contents

* Corresponding author. Tel.: +61 02 4221 4143.
E-mail address: zhenjun@uow.edu.au (Z. Ma).

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1. Introduction

The construction of buildings and their operation contribute to a large proportion of total energy end-use worldwide [1–3]. In the building sector, most energy is consumed by existing buildings while the replacement rate of existing buildings by the new-build is only around 1.0–3.0% per annum [4–7]. Therefore, rapid enhancement of energy efficiency in existing buildings is essential for a timely reduction in global energy use and promotion of environmental sustainability.

During the last decade, many governments and international organisations have put significant effort towards energy efficiency improvement in existing buildings. The federal government of the United States, for example, has provided significant financial assistance to support existing building retrofits [8,9]. In Australia, the Commercial Building Disclosure (CBD) programme, which came into effect on the 1st November 2010, requires the owners of Australia's large commercial office buildings to provide energy efficiency information to potential buyers or lessees [10]. In their 2009–2010 state budget, the Queensland government invested $8.0 million to progressively retrofit existing government buildings to increase their energy efficiency [11]. 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% [12]. 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 50 – Prefabricated systems for low energy renovation of residential buildings; Annex 55 – Reliability of energy efficient building retrofitting; and Annex 56 – Energy & greenhouse gas optimised building renovation [13]. These efforts provided policy guidance, financial assistance and technical support for the implementation of energy efficiency measures in existing buildings.

At the same time, a significant amount of research has been carried out to develop and investigate different energy efficiency opportunities in order to improve energy performance of existing buildings [1,14–23]. The results have showed that energy use in existing buildings can be reduced significantly through proper retrofitting or refurbishment [17–23], which is described as work required to upgrade an aged or deteriorated building [14]. Building retrofitting or refurbishment is being considered as one of main approaches to realistically achieving reduced building energy consumption and greenhouse gas emissions.

Retrofitting of existing buildings has many challenges and opportunities. The main challenge encountered is that there are many uncertainties, such as climate change, services change, human behaviour change, government policy change, etc., all of which directly affect the selection of retrofit technologies and hence the success of a retrofit project. The subsystems in buildings are highly interactive. Different retrofit measures may have different impacts on associated building sub-systems due to these interactions, which results that the selection of the retrofit technologies becomes very complex. Dealing with these uncertainties and system interactions is a considerable technical challenge in any sustainable building retrofit project. Other challenges may include financial limitations and barriers, perceived long payback periods, and interruptions to operations [24,25]. The willingness of building owners to pay for retrofits is another challenge if there is no financial support from the government, particularly since the issue of "split incentives" is often a key factor where the cost of the retrofit generally falls to a building owner whereas the benefit often flows primarily to the tenants. On the other hand, retrofitting of a building offers great opportunities for improved energy efficiency, increased staff productivity, reduced maintenance costs and better thermal comfort. It may also help to improve a nation's energy security and corporate social responsibility, reduce exposure to energy price volatility, create job opportunities and make buildings more liveable [26,27]. Ernst and Young [26] has estimated that in New South Wales (Australia) between $25 million and $99 million in total economic activity could be realised by the year 2020 within the building energy efficiency market.

Nowadays, there is a great number of building retrofit technologies that are readily available in the market. However, the decision as to which retrofit technology (or measure) should be used for a particular project is a multi-objective optimisation problem subject to many constraints and limitations, such as specific building characteristics, total budget available, project target, building services types and efficiency, building fabric, etc. Financial benefit is not the single criteria for the selection of the retrofit technologies. The optimal solution is a trade-off among a range of energy related and non-energy related factors, such as energy, economic, technical, environmental, regulations, social, etc.

This paper aims at providing an overview of recent research and development in this field as well as the application of retrofit technologies to existing buildings. The generic building retrofit problem and a systematic approach to proper selection of cost effective retrofit measures are presented. Key retrofit activities, such as energy auditing, building performance assessment, economic analysis, risk assessment, measurement and verification of energy savings, etc., involved in a building retrofit, are also discussed.

2. Generic building retrofit problem

The building retrofit optimisation problem is to determine, implement and apply the most cost effective retrofit technologies to achieve enhanced energy performance while maintaining satisfactory service levels and acceptable indoor thermal comfort, under a given set of operating constraints. The following issues addressing the nature of a building retrofit problem should be carefully considered in a building retrofit project.

2.1. Key phases in a sustainable building retrofit programme

The overall process of a building retrofit can be divided into five major phases (Fig. 1). The first phase is the project setup and pre-retrofit survey. In this phase the building owners, or their agents, need to first define the scope of the work and set project targets. The available resources to frame the budget and programme of work can then be determined. A pre-retrofit survey may also be required in order to better understand building operational problems and the main concerns of occupants. It is common practice for building owners to select an experienced Energy Services Company (ESCO) to take responsibility for planning and implementing the building retrofit.

The second phase comprises an energy audit and performance assessment (and diagnostics). Energy auditing is used to analyse building energy data, understand building energy use, identify areas with energy wastes, and propose no cost and low cost energy conservation measures (ECMs). Performance assessment is employed to benchmark building energy use by using selected performance indicators or using green building rating systems. Diagnostics can be used to identify inefficient equipment, improper control schemes and any malfunctions happened in the building operation. Details of building energy auditing and performance assessment (and diagnostics) are briefly presented in Sections 3.2 and 3.3, respectively.

The third phase is the identification of retrofit options. By using appropriate energy models, economic analysis tools and risk assessment methods, the performance of a range of retrofit