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Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings

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ABSTRACT

The building stock in the world consumes approximately 40% of the energy and emits one third of the total greenhouse gases emissions (GHG). Improving the energy efficiency in buildings is vital to address the climate change and achieve energy independence (i.e. to become net-zero energy). Improving energy performance in existing buildings has been receiving significant attention recently, which entails reducing energy demand for building operations, without affecting the health and comfort of its occupants. This approach requires strategies beyond mere technical advancements. However, there is limited published literature which has comprehensively addressed these issues.

The aim of this paper is to critically review existing body-of-the-knowledge on improving energy efficiency of operating both commercial and institutional buildings. Peer-reviewed journal articles published from year 2000 to 2014 in reputed journals were reviewed. This review investigated contemporary energy efficiency approaches including technical, organizational, and behavioural changes. Based on the comprehensive literature review, a strategy map was developed as a pathway for achieving better building energy performance. It was noted that even though the existing studies predominately focused on technical advancements, approaches such as building behavioural changes have been largely overlooked. Findings of this study provide an important basis for setting up a national and organization wide strategy for improving the energy efficiency of commercial and institutional buildings.

Contents

Abbreviations: AC, alternating current; BIPVT, building integrated photovoltaic/thermal; BMP, best management practices; CAD, Canadian dollars; CHP, combined heating and power; CO_2, carbon dioxide; ERV, energy recovery ventilators; ETRC, Existential Technology Research Center; DC, direct current; DG, Distributed generation; GCHP, ground-coupled heat pumps; GHG, greenhouse gas emissions; GHP, ground-coupled heat pumps; HVAC, heating, ventilation, and air conditioning; LED, light emitting diode; LEED, leadership in energy & environmental design; PJ, peta joules; PV, photovoltaic; SSPCM, Shape-stabilized phase change material; TABS, thermally activated building systems

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1. Introduction

Commercial and institutional buildings are a key indicator of the socio-economic development of any nation. Despite numerous benefits to the society, dramatic environmental and social consequences are created throughout the life cycle of buildings [1,2]. The building stock in the world consumes approximately 40%, 25% and 40% of the energy, water and resources, and responsible for emitting one third of the total greenhouse gases emissions (GHG) [3]. Energy use forecasts show that in the future energy consumption portion of commercial buildings is expected to increase while the energy consumption portion of residential buildings is expected to decrease [4]. Commercial and institutional buildings create significant impact on social, environmental and economic sustainability. Statistics Canada reveled that in 2012, the total operational energy expenditure of commercial and institutional buildings exceed CAD 24 billion, which is ~3% of the Canadian gross domestic product [5]. The total energy use within commercial and institutional buildings was 1057 petajoules (PJ) which is 12% of the Canada's secondary energy use. Same buildings are responsible for emitting 11% of the total GHG emission in Canada [6]. Similar statistics are observed in other developed countries in the world. The heat discharged from the buildings in an urban settings creates the heat island effect, which is a noteworthy issue for urban centers in warm climates [7]. Apart from the aforementioned environmental and economic consequences, buildings create intense effect on the society. As an example, Canadians spend 90% of their time within buildings, by being involved in indoor activities [2].

Improving the energy efficiency of functional buildings is an important step in minimizing the environmental effects of the building stock [8]. The basic principle of the building energy efficiency is to use less energy for operations (i.e. for heating, cooling, lighting and other appliances), without impacting the health and comfort of its occupants. This approach would eventually reduce primary energy use and CO_2 [9,10]. Improving the energy efficiency of functional buildings entails many environmental and economic benefits such as reduced GHG emissions and operational cost savings [11].

Increased awareness on climate change, with other macro-economic changes (i.e., increase in energy prices, technology advancements) spurred the demand for high performing buildings that enable reduced energy use and costs, minimal use of natural resources and higher-quality indoor environment [9]. Environmental impacts of buildings are mainly determined from the life cycle impacts of building material and energy consumption during the operational phase [12]. Consequently, recent legislation and standards are pushing new construction towards sustainable and energy efficient buildings [9,13]. However, new buildings are only a small percentage of the national building stock. Therefore, improving the existing buildings provide the greatest opportunity for sustainable development [14].

Building energy efficiency is a popular stream of research in the recent past [8,15–23]. Energy performance of buildings can be improved using various techniques such as, through awareness programmes among building users [22], improving the building energy management [22], incorporating technical measures for the energy efficiency [22] and use of renewable energy [10,22–24]. In practise, a systematic technical and management change is required to achieve greater environmental and energy targets for the future [25]. Energy efficiency and resulting cost savings are created from the interaction among the behavioural, organizational and technological changes (Fig. 1). These elements and their interactions facilitate in achieving optimal and holistic energy performance targets [26].

However, the literature review and the industry analysis (e.g. energy efficiency retrofits used by public/private entities) show that, so far, building energy efficiency improvements projects have been conducted in ad hoc basis without a systematic decision making process [27]. The basic ground rules such as life cycle cost and building level of service have been neglected in many of present day energy efficiency improvement projects. Therefore, a consolidated knowledge base is required to inform the decision makers about the best course of action to suit their situation, prior to opting for detailed analysis for retrofit alternatives.

The objective of this article is to review the status of energy efficiency approaches available for operating buildings. Poor energy performance of existing buildings is a commonly observed issue around the world [28]. Hence, renovating the existing building stock is a main priority in improving the energy performance of building stock of a country [25]. It is important to have a combination of technologies to achieve superior energy performancce within buildings [29]. Zuo and Zhao, state that even though research on green buildings has expanded into various areas and contexts, still there is a lack of systematic review of the widespread knowledge [30]. The literature reviews on building energy efficiency can frequently be observed in the literature. However, as per researcher's knowledge there are no comprehensive studies specifically focused on improving energy performance of operating buildings.

This study looks at various energy efficiency approaches discussed in the literature with regards to commercial and institutional buildings. A systematic approach is adopted to identify relevant literature for this study. In addition, this research will show contemporary approaches and trending research areas with regards to energy efficacy of commercial and institutional buildings. This paper provides insights for industry practitioners and researchers who are keen on bringing about energy efficiency improvements in buildings and striving for green buildings.

2. Methodology

Keyword search in subject-specific databases is a commonly used and widely accepted methodology for review articles [31–34]. Hence, in this study "Compendex engineering village"

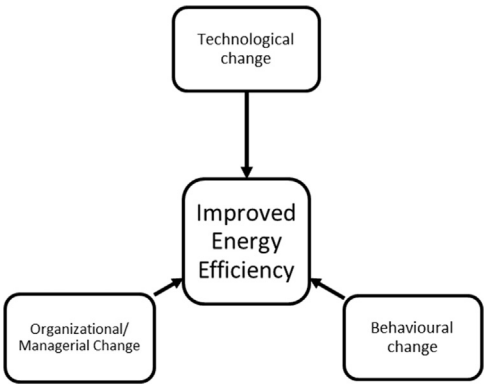

Fig. 1. Paradigms for energy performance improvement in existing buildings.