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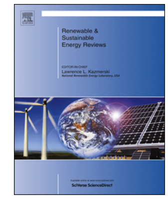

Improving the energy performance of residential buildings: A literature review

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ABSTRACT

Promoting energy efficiency improvements of residential buildings is considered to play an important role in achieving the Kyoto targets. That is because it allows us to reduce energy consumption without curtailing social welfare. It is worth noting that there is an increasing amount of literature on this topic that has been published in recent years. This paper therefore provides an updated review of the literature on improving the energy performance of residential buildings. The set of materials obtained has been examined according to the following topics: area of application and design variables, objectives and performance measures, type of analysis, solution methodology, software tools, case study location and type of building. Apart from trends related to the different topics, opportunities for future research are also presented.

Contents

1. Introduction

Global CO_2 emissions follow an upward trend and it is presumed that they will keep on growing. Without any further international policies, greenhouse gas (GHG) emissions will rise by 52% from 2005 to 2050, while energy-related CO_2 emissions are expected to climb by 78% [78]. More recent figures from IPCC [132] indicate that annual GHG emissions continued to increase yearly with 1 gigatonne carbon dioxide equivalent (Gt CO_2eq) from 2000 to 2010 as compared to 0.4 Gt CO_2eq from 1970 to 2010. CO_2 emissions from fossil fuel combustion and industrial processes made up about 78% of the total GHG emissions from 1970 to 2010 and from 2000 to 2010. Without additional efforts to reduce GHG emissions, they are presumed to keep on growing due to growth in global population and economic activities. The global economic crisis in 2007–2008 has only temporarily reduced emissions [132]. The increasing international concern related to these

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high emission levels has led to the Kyoto Protocol, an international treaty setting binding greenhouse gas emissions limitations to the signatories [98]. Promoting energy efficiency improvements is considered to play an important role in achieving these targets because it reduces energy consumption without curtailing social welfare [59,133].

The final level of energy consumption in the EU-28 for 2012 reached 1104 million tons of oil equivalent (Mtoe), of which 289Mtoe (26.2%) was attributed to the residential sector (i.e. approximately 2/3 of total energy use in buildings) [27,80]. Residential buildings account for 75% of the total building stock in the EU27 [117]. Energy in dwellings is mainly consumed by space heating (68.4%) and hot water production (13.6%) (EEA data 2008, climate corrected). The energy used for cooking (3.8%) and electricity for lighting and appliances (14.1%) is far less significant [122]. Improving the energy performance of dwellings could therefore be pointed to as an important opportunity in this energy challenge. Indeed, the building sector has a lot of potential for cost-effective energy savings equivalent to a consumption in the EU of 11% less final energy in 2020 [125]. For this purpose the European Commission has launched the Energy Performance of Buildings Directive (EPBD) (2002/91/EC and recast 2010/31/EU). This compilation of general principles and objectives aims to substantially augment investments in energy-efficiency measures within EU buildings, both residential and non-residential[101]. The EPBD requires member states to implement energy performance certification for existing buildings, inspection of heating and cooling devices and legally imposed performance requirements for new and thoroughly renovated buildings. For the latter, the EPBD recommends all EU member states to employ a methodology for calculating the energy performance of newly constructed buildings, considering at least thermal and insulation characteristics, space and hot water heating, ventilation and air conditioning (HVAC) systems, lighting installations, orientation of the building and indoor climatic conditions [80].

In addition to the regularitory approach such as implemented in the EU EPBD, many voluntary building environmental assessment schemes have emerged internationally, such as BREEAM, LEED, SBTool, CASBEE, BEAM Plus and ESGB. These voluntary building environmental assessment schemes cover multiple domains such as transport, waste and water. Some even extend to social and cultural aspects. There is a large variation amongst the building environmental assessment schemes, both on the actual performance criteria of the schemes, the weighting of scores of the multiple performance domains and the scope and organization of the certification systems. This allows to suit the assessment schemes to their respective local contexts, but complicates the benchmarking and comparison of different assessments [112,136]. The voluntary building environmental assessment schemes have a much broader approach compared to EPBD, but nonetheless energy performance of buildings generally accounts for a significant share of the credits [136]. In this review paper, the focus will be solely on the domain of energy in residential buildings.

In accordance with energy performance legislation and building environmental assessment schemes, several building design optimization studies have been carried out. The optimization methods used in these studies consider both low-emission levels and energy-efficiency performance through modifying different characterics of buildings and in doing so seek to minimize energy consumption and costs [28]. Financial limitations and important uncertainties in this retrofit problem, such as climate change, governmental policy change and occupant behavior, can easily influence the selection between proposed measures and thereby define the success of adjustments. It is certain that the complex whole of interactions between all components of a building and its environment need to be considered in finding the most energy-efficient solution that meets the needs of energy and non-energy related issues such as financial, legal and social factors [68].

In recent years, an increasing amount of literature on optimizing energy efficiency in residential buildings has been published. In these studies, different kinds of quantitative models have been developed and examined to find a solution for this optimization problem. Researchers investigated different fields of application such as the building envelope insulation thickness, window characteristics, HVAC systems, etc., utilizing specific constraints and parameters. These methods mostly focus on developing an approach for “designing” the most economically profitable residential building by, for example, minimizing life cycle costs (LCC). This paper will discuss the available literature concerning the extensive range of possibilities for improving the energy efficiency in the residential sector.

Complementary to literature on methods for optimizing energy efficiency in residential buildings, a lot of research on specific parameters influencing the actual energy performance of a building has been published. Despite the advanced energy calculation tools available nowadays, a significant mismatch between predicted energy performance and actual energy consumption of a building is frequently revealed. This is often referred to as the ‘performance gap’ [120,138]. Apart from modeling errors or faulty construction, this performance gap is largely due do to the substantial impact of several parameters, of which actual values are hard to predict. These parameters include the influence of occupant behavior [128,142], day lighting control strategies [116], uncertainty in material properties and design parameters [131], and climatic data [115]. The study of these parameters is not part of this literature review. Nonetheless, these parameters are often implicitly present as boundary conditions in the examined literature. Assumptions on parameters such as climate and occupant behavior can have a big impact on the energy performance of a building, hence interpretation and mutual comparison of research data should be performed with care.

When browsing scientific databases for other available literature reviews concerning optimizing energy efficiency in residential buildings, we were able to find reviews mainly focusing on one specific field [58,88,126,130,140] within the domain of energy improvement of (residential and/or commercial) buildings. Kaynakli [58] for instance, reviewed all available literature on determining the optimum thickness of the thermal insulation material of a residential building and its influence on energy demand. More recently, Stevanović [88] reviewed existing studies on several passive solar design strategies, but both in the case of residential and commercial buildings.

The goal of this literature review is threefold. First of all we aim at providing an updated overview of recent developments in the literature with regard to studies concerning the improvement of building energy efficiency. This review focuses on the literature that explicitly deals with residential buildings only. Non-residential buildings such as offices, shops, industrial buildings and health related buildings often apply specific construction methods and HVAC installations which are tailored to the function of the building. The particular characteristics which are related to the function of a non-residential building – such as increased ventilation rates or high internal heat gains – induce the need for specific design methods depending on the actual function and use of the building. This is out of the scope of this review paper, therefore literature on non-residential buildings will not be taken into consideration. Second, we want to examine this literature from different perspectives in order to classify important information. This should make it possible for researchers who are interested in a specific field to link and compare studies based on several topics. Third, delving into the available literature in great detail enables us to identify trends in this research field and to propose opportunities for future investigation. In Section 2, we will outline the structure of this paper and provide a brief description of the following sections. We will end the paper with a section discussing the opportunities for future research followed by a conclusion.