Energy Policy 52 (2013) 819–831

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Innovation in the U.S. building sector: An assessment of patent citations in building energy control technology

Joy E. Altwies [a], Gregory F. Nemet [a,b,*]

[a] Nelson Institute Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Madison, WI 53706, USA
[b] La Follette School of Public Affairs, University of Wisconsin-Madison, 1225 Observatory Drive, Madison, WI 53706, USA

HIGHLIGHTS

- ► We investigate the innovation process for buildings in the U.S. using patents.
- ► We use commercial and residential building controls technology as a case study.
- ► Patenting peaked around 1980, declined, and then increased in the past decade.
- ► Commercial building control patents account for most of the recent increase.
- ► Inventions in electronics and computers have led to innovation in building controls.

ARTICLE INFO

Article history:
Received 7 June 2012
Accepted 21 October 2012
Available online 11 November 2012

Keywords:
Energy management
Building automation
Patents

ABSTRACT

Buildings are crucial to addressing energy problems because they are large consumers of end-use energy, and potential exists to dramatically improve their efficiencies. However, the pace of innovation in buildings is generally characterized as inadequate, despite the implementation of an array of policy instruments aimed at promoting efficiency. The literature on innovation in the building industry provides several explanations including: fragmented decision-making, principal agent problems, inadequate information, and limited learning across heterogeneous projects. We investigate the innovation process for buildings in the U.S. with a case study of patenting in energy management control systems (EMCS) for commercial buildings and programmable thermostats (PT) for residential buildings. Using U.S. patent data, we find that: (1) patenting activity peaked around 1980, subsequently declined, and then increased considerably in the past decade; (2) commercial, rather than residential, buildings account for the recent increase; and (3) building control technologies have benefitted from inventions originating outside the industry, notably from electronics and computers, with a shift toward the latter in recent years.

1. Introduction

Improving the energy-efficiency of buildings is central to efforts to address climate change and other energy related problems (GEA, 2012). Building efficiency is important in part because such a large portion of final energy is consumed in them, and in part because the costs of energy savings there tend to be among the lowest. The IPCC comprehensively reviewed worldwide building sector mitigation opportunities and found “substantial reductions in CO_2 emissions from energy use in buildings can be achieved” using existing technologies, and with net benefits rather than costs (Levine et al., 2007). Ürge-Vorsatz and Metz (2009) characterize building energy efficiency as the “most important lever” available for climate stabilization in the near term. Pacala and Socolow (2004) list emissions reductions from buildings as one of the 15 climate stabilization “wedges,” of similar magnitude to massive deployment of solar, wind, and nuclear energy.

A wide variety of public policies have been implemented to encourage innovation and adoption of energy-saving technologies in residential and commercial buildings. While they have had varying degrees of success, the opportunity for further efficiency improvements is consistently found to be large. United Nations Environment Programme & CEU (2007) summarize the many policy options available for reducing emissions from building sector energy use and analyze policy effectiveness in over 80 case studies from 52 countries. Ürge-Vorsatz et al. (2007) find that it is

* Corresponding author at: La Follette School of Public Affairs, University of Wisconsin-Madison, 1225 Observatory Drive, Madison, WI 53706 USA.
Tel.: +1 608 265 3469; fax: +1 608 265 3233.
E-mail address: nemet@wisc.edu (G.F. Nemet).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.10.050

possible to achieve a 30% reduction in buildings' emissions with carefully designed combinations of policy measures. International Energy Agency (2008) recommends that governments take immediate action to implement policies related to energy use, including a list of policies specific to the building sector. Geller et al. (2006) review the past 30 years of energy intensity data from OECD countries, demonstrating that energy efficiency policy efforts across all sectors of the economy resulted in 49% less energy use by 1998 than without those efforts. The gains have not been uniform, however. They note that energy intensity in the Japanese housing sector has actually increased over this timeframe, albeit from low levels relative to other countries. Ryghaug and Sorensen (2009) find that newer buildings in Norway use more energy than older ones—a situation they do not attribute to differences in the buildings themselves, but to a combination of ineffective policies and building industry culture. van Bueren and Priemus (2002) also find a lack of progress toward energy efficiency in the Netherlands' building sector.

These results give rise to several questions of interest to policy-makers. If current technology can be used to reduce buildings' energy use at low or negative costs, why is the building industry not adopting it more quickly? Do particular characteristics of the building industry make innovation and adoption of energy-efficient technologies different from other sectors? Resolving these questions would provide policy-makers with greater understanding of what motivates building industry decision-makers and would help them design and select effective policy measures that drive more rapid energy efficiency improvements.

This study addresses these questions in two ways. First, we review the literature related to innovation in the building industry. We include literature addressing the innovation process, challenges of reducing energy use in buildings, the role of government and policy, and the need for greater research emphasis on the buildings sector. Second, we contribute to this knowledge by investigating the innovation process of an energy-saving building technology. Using U.S. patent data, we trace the development of building control technologies known as energy management control systems (EMCS). We identify patents for this commercial building technology, along with a similar one for control of the residential building environment, programmable thermostats (PT). We use the patent data to characterize trends in inventive activity over the past 40 years. We also use patent citations to identify important patents and to assess the extent to which these technologies benefitted from technology developed in other sectors, such as information technology.

Section 2 reviews the literature related to the process of technological change, the challenges of improving energy efficiency in the building sector, and the role of government and policy. Section 3 reviews the use of patents for studying innovation, and the selection of building controls as a case study. Section 4 describes the approach to the patent analysis focusing on the methods used to define the technology and identify relevant patents. Section 5 presents the results of the patent analysis, including descriptive statistics and trends. The paper concludes with a discussion of the results and implications for policy and future research.

2. Technological change, building energy consumption, and the role of policy

The need to reduce energy use in the building sector is a recurring finding in the literature. Buildings represent 40% of primary energy consumption in most countries (IEA 2008), and continued growth is expected in this sector (Levine et al., 2007; Energy Information Administration, 2011; International Energy Agency, 2011a). By 2050, International Energy Agency (2011b) projects that residential households worldwide will grow by 67%, while commercial floor space increases by 195%. Improvements in energy end-use technologies, including those in the building sector, are necessary in order to meet even the least stringent emissions stabilization targets (Kyle et al., 2011). Stimulating the process of technological change in buildings is therefore a growing area of concern for policy-makers. This section reviews the literature related to the innovation process, challenges posed by the building sector, and the role of government in correcting market failures in energy efficiency.

2.1. The process of technological change

The process of technological change – commonly called "innovation" – involves invention, innovation, and diffusion (Grubler et al., 2012). Note that it is often confusing that the process of "innovation" includes a stage called "innovation". The invention and innovation stages, often studied together, involve the development of new products or processes, while diffusion describes the adoption of a new technology by individuals or firms. The efforts to create and continually develop new technologies – invention and innovation – are distinctly different from diffusion in the marketplace, which involves adoption decisions by end-users (Noailly, 2011; Noailly and Batrakova, 2010). However, Wilson et al. (2012) show that these processes are not independent, but in fact interconnected in an overall "innovation system." They offer examples of successful policy approaches that addressed both technology development and market adoption. The authors show that successful innovation incorporates end-user feedback throughout the stages of technology development. Kiss and Neij (2011) provide a relevant example in building sector technologies. Their investigation into the development history of window technologies in Sweden shows how policies can promote learning processes, leading to improvement in the technology. Further, consumer acceptance is also part of this innovation systems perspective. Darley (1978) highlighted the challenge of getting consumers to adopt new thermostats.

Recent work argues that systemic analysis of each phase is necessary for the process of technological change to be understood, and ultimately used to inform policy (Gallagher et al., 2012). For example, a policy that promotes invention of energy-saving technologies will have little impact if the various actors in the building industry do not adopt them. Conversely, policies that generate demand "pull" from the marketplace can stimulate inventive activity by creating strong incentives for new technologies (Nemet, 2009).

2.2. Characteristics of the building sector that affect energy efficiency

The building sector is commonly divided into residential and commercial categories based upon the primary usage of the building. A "commercial building" is defined as any building devoting at least 50% of its floor space to commercial activities, while a "residential building" includes any structure used primarily as a dwelling for one or more households (Energy Information Administration, 2012). The commercial building sector excludes industrial and agricultural buildings, and can be further subdivided into many types, such as office space, hospitals, public institutions, retail, warehousing, and many more. Decisions regarding energy use and related technology adoption are made by a wide variety of actors, depending on the age and type of structure. For example, in a new commercial building, the developer or owner, architect, engineers, and construction contractors will all have influence on the design and equipment