Applied Energy 203 (2017) 723–736

Contents lists available at ScienceDirect

Applied Energy

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

Development of an energy atlas for renovation of the multifamily building stock in Sweden

Tim Johansson [a,*], Thomas Olofsson [a], Mikael Mangold [b]

[a] Department of Civil, Environmental, and Natural Resources Engineering, Luleå University of Technology, Luleå 971 87, Sweden
[b] Research Institutes of Sweden, City Development, Eklandagatan 86, 412 61 Gothenburg, Sweden

HIGHLIGHTS

- An energy atlas of the multifamily building stock in Sweden is presented.
- Its development is automated using Extract, Transform and Load technology.
- It can be used to support energy retrofitting on various spatial scales.
- The demand for renovation and energy retrofitting will peak in the coming decade.
- The use of energy in the existing building stock can be reduced up to 50% by 2050.

ARTICLE INFO

Article history:
Received 16 December 2016
Received in revised form 29 May 2017
Accepted 12 June 2017

Keywords:
Energy atlas
Extract transform and load
Renovation
Multifamily buildings
Energy performance certificate

ABSTRACT

Many studies have highlighted the importance of retrofitting to mitigate the energy use of building stocks. An important step in the development of renovation strategy and energy conservation advising is to gather information of the energy performance of the existing buildings. However, renovation strategies must also consider the socio-economic challenges associated with the cost of energy retrofitting. This paper describes the development of an energy atlas of the multifamily building stock in Sweden for visualizing and analyzing energy use and renovation needs. The atlas has been developed using Extract Transform and Load technology (ETL) to aggregate information on the energy performance, building ownership, renovation status, and socio-economic status of inhabitants from various data sources. The atlas can visualize the energy use and renovation status of multifamily buildings in 2D maps and 3D models, displaying data for either individual buildings or aggregated data on spatial scales ranging from 250 × 250 m squares through district and municipality to county areas. A demonstration of its use on national and city scales indicates that energy retrofits of multifamily buildings reaching a service life of 50 years can reduce the energy use of the existing building stock by up to 50% relative to 1990. However, costs associated with renovation and energy retrofits of multifamily buildings can be problematic, especially in economically weak suburbs. A good understanding of past and future renovation needs and socio-economic consequences is important in the development of a sustainable national renovation strategy.

1. Introduction

The building stock accounts for 30–40% of the primary energy usage and corresponding carbon footprint in most countries, and has been identified as a sector with high energy saving potential [1,2]. To achieve an EU objective of saving 20% of primary energy use by 2020, the European Directive 2012/27/EU requires member states to develop a renovation strategy in order to increase the energy performance of the building stock [3]. The Swedish government has also previously stated an ambition to reduce use of energy in the building sector by 20% by the year 2020 and by 50% by the year 2050, relative to its use in 1990 [4].

The building stock increased rapidly during 1950–1975 in many European countries [5]. A large share of the residential building stock in Sweden was constructed in the so-called Million Homes Program, named after a governmental initiative to build a million dwellings between 1965 and 1975 [6,7]. Most of the multifamily dwellings built during this period were rental apartments; ca.

* Corresponding author.
E-mail addresses: tim.johansson@ltu.se (T. Johansson), thomas.olofsson@ltu.se (T. Olofsson), mikael.mangold@ri.se (M. Mangold).

http://dx.doi.org/10.1016/j.apenergy.2017.06.027
0306-2619/

50% owned by municipalities, 20% by private landlords and 30% by residents [6]. During the next 10 years, the Million Homes Program buildings will reach a 50-year service life, greatly increasing the need for renovations and (hence) opportunities for energy retrofitting [8,9].

Previous authors have claimed that there is sufficient technical potential for reaching the national energy use target, but better communication and cooperation with actors capable of implementing changes is needed to succeed [1], and that energy use in the Swedish residential sector could be reduced by 53% [10]. Thus, improving dissemination of information about energy saving measures to property owners (particularly information on measures that can be applied to reduce energy use during renovations) is important for meeting meet energy use targets [11]. National statistics of buildings' energy use should be used to compare and monitor results of different energy saving measures [12], providing information to support the energy management of the building stock [13]. However, the market-driven incentives for energy retrofitting are low due to low energy prices and high labour costs; the payback period often exceeds 10–15 years, which is an unacceptable timeframe for many real estate investors [9,14,15].

Furthermore, socio-economic challenges associated with energy retrofitting must be considered to obtain a more holistic view of refurbishment solutions [16,17]. The Swedish Association of Public Housing Companies [18] has claimed that renovation of the Million Homes buildings in Sweden could not only substantially reduce energy use, but also make neighbourhoods more attractive and secure. However, increasing rents as a result of (deep) energy retrofitting could be problematic from a socio-economic perspective [19,20]. For example, inhabitant relocations associated with previous renovation programs have raised concerns about equity and social costs, raising proposals that social sustainability criteria should be included in any national renovation plan [3,21].

Numerous sustainability indicators, urban energy models and assessment tools, varying in both scope and geographic scale, have been proposed by various authors [22–25]. Most models of the energy use in the residential sector apply aggregated values on regional and national levels [23]. However, indicators designed for use at the national scale are not readily applicable for decision-makers and citizens wishing to promote local sustainability. Thus, there are requirements for both local indicators and city-centric measurements providing feedback for citizens and guidance to improve local sustainability [26], and complementary indicators of social equity and global environmental impacts to capture broader dimensions of urban sustainability [27]. Furthermore, modelling and decision support tools require further development to enable their use by decision-makers [28].

The objective of the study presented here was to develop and demonstrate use of an energy atlas of the multifamily building stock in Sweden, based on approved energy data, enabling effects of renovation strategies to be estimated and followed-up on local, regional and national levels. Two main research questions have been addressed:

- How can required information in the national atlas of the multifamily building stock be extracted, aggregated and integrated in an automated fashion at different levels of scale?
- How can a national atlas of the buildings stock be used to visualize and analyze renovation needs, effects of proposed renovations on energy use and their socio-economic consequences?

The paper is structured as follows. First, a review of energy models of the building stock is presented. Then, the developed method for automating integration of energy, property and socio-economic information into a national atlas of the multifamily building stock in Sweden is described. The method is based on previous work covering the collection, aggregation, integration and validation of data from multiple sources on multiple scales [29–31]. A socio-economic model developed in the cited study on retrofitting the building stock in Gothenburg [31] are then used to evaluate the cost of conducted and future renovations of the multifamily Swedish building stock. Renovation costs are estimated for various types of regions, real estate owners and groups of tenants with varying incomes. In addition, two main strategies to meet the 2050 national targets for energy use in the three metropolitan cities in Sweden (Stockholm, Gothenburg and Malmö) are evaluated. Finally, findings from the study regarding developed methods, quality of data and use of the renovation atlas are discussed, and conclusions are presented.

2. Energy models of the building stock

Two main categories of building stock models have been recognized: top-down and bottom-up [23]. The top-down approach is based on use of aggregated values of energy use in combination with econometric data and characteristics of the building stock, often on regional and national levels. Applications of a top-down approach include its use to analyze effects of low carbon investment on energy use and CO_2 emissions in the megacities of Beijing and Shanghai [32]. A top-down approach facilitates handling of regional- and national-level input data, but it cannot provide explicit representation of the end uses [23]. In contrast, bottom-up approaches are normally based on samples of the energy use of individual end-uses, buildings or groups of buildings. These values are then extrapolated and aggregated to represent a district, region or nation based on the representative weight of the sample(s). Engineering bottom-up models, based on estimations of the energy use of a representative set of buildings, enable investigation of the impact of new technology, but not the inclusion of socioeconomic effects [23]. An illustrative application of such an approach is the creation of a model to generate detailed thermal energy demand profiles, at an urban district scale [25]. Statistical bottom-up approaches utilize data from energy billing, surveys, property information, and socio-economic databases, to build aggregated models on various scales [23]. For example, bottom-up models have been developed to predict the energy use of 1.1 million buildings in New York city, based on machine learning algorithms using data for a sample of 23,000 buildings [33].

The EU's Directive 2007/2/EC, establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), and open source initiatives such as OpenStreetMap, have increased the accessibility of data regarding the built environment in Europe [34,35]. In addition, EU Directive 2002/91/EC [36] introduced requirements for Member States to prepare Energy Performance Certificates (EPCs) to help efforts to optimize energy use in the European building stock. In Sweden, the EPCs are prepared by independent energy experts and stored in the National Board of Housing, Building and Planning's EPC register. The certificates contain information on *measured* energy use, floor areas, service systems and suggestions for energy saving measures. The EPC data have been used by researchers to develop models of the energy usage, and both needs and potential for energy retrofitting of buildings in some European countries [37–40].

Geographical Information Systems (GIS) have high utility for energy-related renovation programs as they enable the visualization, analysis and planning of energy use in buildings on both local and regional scales. They have been used to support the visualization and efficient use of energy in urban districts [41] and to simulate the size and location of photovoltaic panels required to optimize energy production [42]. 3D/4D GIS models have been