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Energy usage and technical potential for energy saving measures in the Swedish residential building stock

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HIGHLIGHTS

- ► Analysis of year 2005energy use and CO2 emissions of Swedish residential buildings.
- ► Includes all single-family dwellings and multi-family dwellings.
- ► Bottom–up modeling of building stock represented by 1400 buildings.
- ► Technical effects of 12 energy saving measures are assessed.
- ► Energy demand can be reduced by53% and associated CO_2 emissions by 63%.

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ABSTRACT

This paper provides an analysis of the current energy usage (net energy and final energy by fuels) and associated carbon dioxide (CO_2) emissions of the Swedish residential building stock, which includes single-family dwellings and multi-family dwellings. Twelve energy saving measures (ESMs) are assessed using a bottom–up modeling methodology, in which the Swedish residential stock is represented by a sample of 1400 buildings (based on data from the year 2005). Application of the ESMs studied gives a maximum technical reduction potential in energy demand of 53%, corresponding to a 63% reduction in CO_2 emissions. Although application of the investigated ESMs would reduce CO_2 emissions, the measures that reduce electricity consumption for lighting and appliances (LA) will increase CO_2 emissions, since the saved electricity production is less CO_2-intensive than the fuel mix used for the increased space heating required to make up for the loss in indirect heating obtained from LA.

1. Introduction

In addition to its obligations under the Kyoto Protocol agreement[1], the European Union (EU) is committed to reducing its overall greenhouse gas (GHG) emissions by at least 20% by 2020, as compared with the levels in 1990. Based on bottom–up studies, the IPCC (2007) has calculated and shown that the building sector, among all the sectors examined, currently has the greatest potential for low-cost carbon dioxide (CO_2)[2] mitigation in the short- to medium-term through the application of technological options. Despite the large potential, the energy usage and associated CO_2 emissions of the building stock in the EU continue to grow. Since turnover of the building stock is low in developed countries, the main opportunities for energy efficiency and GHG emission reduction arise from retrofitting the existing stock (Dineen and Ó Gallachóir, 2011). Thus, there has been a shift in focus from optimizing the efficiency of new buildings to efficiency measures that are applicable during the refurbishment process (Bradley and Kohler, 2007; Balaras et al., 2007). Nonetheless, much work remains to be done to assess systematically the potential and costs associated with applying energy saving measures (ESMs) for entire building stocks, e.g., the stock of an entire country (Ürge-Vorsatz et al., 2009; Kavgic et al., 2010). Such type of work requires both a description of the building stock and the development of modeling tools to assess the effects of ESMs. The work presented in this paper is part of a larger study (Pathways to Sustainable European Energy Systems; see Johnsson, 2011) and is developing a methodology for assessing ESMs for the European building stock.

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[1] Industrialized countries agreed to reduce collectively their GHG emissions by 5.2% for the period 2008–2012, relative to their emission levels in 1990.

[2] As CO_2 is the most abundant GHG, the work in this paper considers CO_2 exclusively.

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Nomenclature

End-use — *End-use* is the ultimate specific use for energy. In the building sector, the end-use categories are: space heating, hot water, and electricity (for lighting, appliances, and cooking).

E_{net} — *Net energy* is the energy required to satisfy the specific energy end-use in a building, excluding conversion losses in the technical systems of the building. It is also commonly referred to as '*useful energy*'.

E_{final} — *Final energy* is the energy supplied to the building, including conversion losses in the technical systems within the building. It is also commonly referred to as '*delivered energy*' or '*end energy use*'.

A_{temp} — *Heated floor area* is the floor area to be heated to a temperature above 10 °C; it is limited by the inner side or the envelope.

BOA — *Residential floor area* is the total area of the dwellings, excluding common areas (e.g., staircases) and the area occupied by walls.

Acronyms

ESM — energy saving measure
GHG — greenhouse gas
HW — hot water
LA — lighting and appliances
MFD — multi-family dwelling
SFD — single-family dwelling
SH — space heating

The aim of the present study is to assess the effects of applying a set of ESMs to all residential buildings in Sweden. In the 1990s, the investment costs and opportunities for energy efficiency in the Swedish building stock were calculated by the Swedish National Council for Building Research, BFR (Byggforskningsrådet in Swedish) (1996). They used the MSA model (BFR, 1984, 1987) for residential buildings and the ERÅD model (Göransson et al., 1992) for commercial buildings. BFR (1996) also considered how the potential for ESMs could be achieved up to the year 2020, including new buildings that had yet to be built. However, these two models (MSA and ERÅD) are not readily available.

Current goals for the reduction of energy use in buildings in Sweden, as stated in the program of the Swedish Environmental Objectives Council (Miljömålsrådet in Swedish), are given as 20% less net energy usage per heated floor area by the year 2020, and 50% less consumption by the year 2050, both relative to the reference year of 1995. To begin to address these targets, the Swedish National Board of Housing, Building and Planning (Boverket, in Swedish) carried out in 2005 a field study (Boverket, 2009) that focused on the building stock in terms of energy usage, technology status, indoor air quality, and maintenance.[3] This study was facilitated by data from a high number of sample buildings, chosen as representative of the Swedish residential building stock. Some of the work presented in this paper was initially performed as part of a study commissioned by Boverket, which had the aim of evaluating net energy potential savings in the existing Swedish residential buildings, and those results have been published in part (Boverket, 2009, 2010). The work presented in the present paper advances the initial work and has the following aims: (a) to describe in detail the current energy usage of Swedish residential buildings, and (b) to assess ESM with respect the technical energy savings associated with implementing the measures in the Swedish residential stock. In addition, the paper provides a brief comparison of the cost-effectiveness of the ESMs investigated. The assessment includes all end-uses, i.e., space heating, hot water, and electricity (for lighting, appliances, and cooking).

The present paper starts with a brief description of the Swedish energy system and of energy usage in the residential stock, based on energy data from statistical databases. Thereafter, the information on the present Swedish stock (from statistical sources) is complemented with the results of the modeling, in which the building stock is characterized in detail (using the parameters of net energy, final energy, and CO_2 emissions), together with the data disaggregated into Single-Family Dwellings (SFDs) and Multi-Family Dwellings (MFDs). Finally, the paper presents technical potentials for energy savings and reduction of CO_2 emissions as identified from the modeling.

2. Swedish residential building stock

The characteristics of the building stock in Sweden have been thoroughly mapped in various investigations conducted over the last 20 years. Although the energy usage of the Swedish building sector is just below the average value for the EU, associated CO_2 emissions are low owing to the characteristics of the Swedish energy system. With 46% of the electricity produced from hydro power and 45% from nuclear power, CO_2 emissions from electricity generation in Sweden are very low (2005 data; Swedish Energy Agency, 2011). In addition, district heating, which accounts for 30% of the final energy of the building sector (Enerdata, 2010), is mostly produced from biomass and waste combustion (59%), heat pumps (12%), and waste heat (11%) (data for Year 2005; Swedish Energy Agency, 2011).

2.1. Energy usage in buildings

The Swedish residential sector accounts for 21% of the overall final energy use, a value that is slightly below the average of 26% for EU-27 countries (EC, 2011). This difference is attributable to: (1) the superior building envelopes used in northern European countries (Balaras et al., 2007), which mainly relates to the colder climate in these countries, and (2) the use of more efficient energy supply systems. Fig. 1 shows that final energy use for the Swedish residential sector has remained almost constant over the past 20 years, while switching towards fuels with lower levels of CO_2 emissions has resulted in *decarbonization* of the Swedish building sector (as well as of the energy system in general).

The levels of CO_2 emissions associated with the production of electricity and district heating, which are the energy carriers that account for the largest share of final energy use in the Swedish residential sector (Fig. 1), are 15 g CO_2/kWh (based on a Swedish mix) and 70 g CO_2/kWh, respectively (Johnsson, 2011; Recyclingnet, 2012). These values are much lower than the average values for the EU-27 countries. Therefore, despite similar final levels in energy use, CO_2 emissions from the residential sector represent only 10% of the

[3] Further data on the survey is given in Section 2.2.