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A differentiated description of building-stocks for a georeferenced urban bottom-up building-stock model

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ABSTRACT

Several building-stock modelling techniques have been employed to investigate the impact of energy efficiency measures (EEM), where the description of the building-stock generally consists of an age-type classification to specify building characteristics for groups of buildings. Such descriptions lack the appropriate level of detail to differentiate the potential for EEM within age groups. This paper proposes a methodology for building-stock description using building-specific data and measured energy use to augment an age-type building-stock classification. By integrating building characteristics from energy performance certificates, measured energy use and envelope areas from a 2.5D GIS model, the building-stock description reflects the heterogeneity of the building-stock. The proposed method is validated using a local building portfolio (N = 433) in the city of Gothenburg, where modelled results for space heating and domestic hot water are compared to data from measurements, both on an individual building level and for the entire portfolio. Calculated energy use based on the building-stock description of the portfolio differ less than 3% from measured values, with 42% of the individual buildings being within a 20% margin of measured energy use indicating further work is needed to reduce or quantify the uncertainty on a building level.

1. Introduction

Buildings worldwide account for 32% of the global final energy use and 19% of energy-related greenhouse-gas (GHG) emissions. At the same time, they provide a large potential for cost-efficient energy efficiency measures (EEM) [1–4]. With the aim to harvest these efficiency opportunities, the European Energy Performance of Buildings Directive defines a set of efficiency standards for both new and existing buildings [5,6]. On a national level, Swedish governmental policy aims at considerable reductions in energy use by 2020 and 2050 [7,8]. Resulting from the EU energy efficiency directive [5], energy performance certificates (EPC) were introduced in Sweden in 2006 in order to promote energy efficiency in buildings. On a local level, cities and municipalities have gone further and voluntarily adopted more ambitious targets on energy savings, reductions in GHG emissions and increase in renewable energy through frameworks such as the Covenant of Mayors.[1] The city of Gothenburg has adopted such goals and aims to reduce energy consumption in residential buildings by 30% by 2020 compared to 1995 levels [9]. For the developed world, it is estimated that 80% of the building stock in 2050 will consist of buildings already built [10], which implies a need for application of EEM in the existing stock if the above-mentioned targets are to be met.

There are many examples of building-stock modelling (BSM) being used to evaluate the energy demand of the existing building-stock [11–16]. According to two in-depth review papers by Swan and Ugursal [17], and Kavgic et al. [18], a general distinction can be made between top-down and bottom-up modelling approaches. Top-down models cannot be used to assess the effects from individual EEM and, thus, have not been in focus of this work. Bottom-up models can be divided into two sub-groups; Statistical models and bottom-up engineering models. Statistical models use aggregated data as input, which through regression methods are used

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[1] The Covenant of Mayors was launched by the European Commission to support efforts by local authorities to implement sustainable energy policies.

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to account for specific end-uses based on the energy consumption of the dwellings. A bottom-up engineering model, which is used in this paper, uses a heat balance model to estimates the energy consumption for individual buildings. The buildings used as input to bottom-up models are defined by building properties such as geometry, U-values, climate data, indoor temperature and use of appliances. Thus, to apply a bottom-up engineering model requires detailed input data. Due to aim, data availability and computational time-constraints the building stock is normally represented by sample buildings or archetype buildings, where it is assumed that similar buildings with regard to year of construction, use of the building, type of heating system and building geometry can be represented by an average building. Sample buildings use detailed data for a number of buildings (e.g. as obtained from measurements on individual buildings) combined with weighting factors derived so that the sample buildings reflect the entire building stock. Similarly, archetype buildings use representative theoretical buildings, often defined by construction year and the type or use of the building, to represent all buildings with similar characteristics to allow for assessment of the entire stock. These methods of building description have been successfully used to calculate the potential for EEM in existing residential building-stocks on a national scale [19,20] as well as on an urban scale [21–23].

Recent improvements in data availability have allowed greater focus on urban settings in BSM and include a spatial dimension by integrating geo-referenced data using geographical information systems (GIS) [24–26]. Using GIS in BSM has several advantages: it facilitates merging of data from several databases that is often required by engineering models, it facilitates further analysis and communication by spatially differentiating and visualizing results, and finally it provides a repository for storing and exchanging data through interconnected urban models. The addition of a GIS component to BSM has been carried out to analyse energy policy scenarios in an urban context [24], to assess the urban heat island effect on energy demand [25] as well as to assess environmental impacts of building stocks and potential for EEM [26]. While the introduction of GIS in BSM has allowed an increase in spatial resolution and enabled focus on urban settings, the description of the building-stock using representative buildings has not been adapted to take full advantage of the improved spatial resolution. The method of deriving and scaling a description based on representative buildings to account for the entire stock is based on the assumption that buildings with similar year of construction and use have similar energy performance characteristics. This can be problematic, typically so for older parts of the stock where energy renovations have been applied to varying degree which may result in significant differences in the energy performance for the same type of buildings [27].

As the scope of the above work [24–26] has been to evaluate targets and scenarios at a city or district level, representative buildings have been sufficient to describe the building-stock. In addition, measured data on energy supply that allow for validation and calibration of the building-stock description is commonly only available for a small number of buildings or at a district level, often due to lack of data availability or due to data not being publicly available [17,28]. As a result, validation and calibration of the building-stock description is limited to levels of aggregation set by available data [21]. Obviously, such descriptions should only be used at their intended level of aggregation [29], which in turn calls for a revised method of describing building-stocks for stakeholders needing building specific information such as property portfolio owners and managers. Furthermore, the increase in spatial resolution provided by a differentiated description reduces uncertainties on a stock level as representative buildings may over- or underestimate the energy demand of a specific building, which could result in inaccurate estimates of the potential for energy savings from applying different EEM. In order to increase the accuracy to allow for prioritizing EEM for individual buildings within a stock, measured energy use must be known to allow for validation on a building or property level. The lack of measured consumption data at a disaggregated level has been identified as the single most important obstacle for handling uncertainty in BSM [17,21,28,30,31].

The aim of this paper is to present a methodology for describing urban residential building-stocks that fits analysis of local building portfolios, i.e. where a greater detail in analysis is required compared to modelling a building stock of an entire country or a large region. Thus, the aim is to include a spatial resolution of individual buildings by using building-specific data and to assess data needs and, in particular geo-referenced data, for such a description.

2. Methodology

Building-specific data, envelope area and measured energy use from EPC are linked to each individual building using GIS to achieve a differentiated description of the building-stock of Gothenburg. Preparation and cleaning of the data are done and previously identified quality issues regarding how the heated floor area (HFA) is derived in the Swedish EPC [32,33] are corrected. As the U-value for the buildings are not known from any of the datasets, an age-type classification is developed based on historical building regulations and a historic construction and architectural classification [34] and linked to individual buildings. The proposed methodology is applied to a property manager's regional portfolio of buildings in the city of Gothenburg, consisting of 433 multi-family dwellings[2] with a total HFA of 1 million m^2.

The energy performance of each building in the portfolio is calculated with the building-stock model ECCABS [35] and, to validate the differentiated description of the building-stock, the modelled energy use for space heating (SH) and domestic hot water (DHW) is compared to measured energy consumption data which is based on billing data or measured on site. Finally, a sensitivity analysis for the most relevant input parameters considered uncertain is performed.

2.1. Building-specific datasets and processing

The building-specific data used in this work are retrieved from (a) EPC, (b) GIS data and (c) the property register. Building characteristics from EPC include type of heating, ventilation and air-conditioning (HVAC) systems, number of stories (above and below ground), number of staircases, attachment to other buildings (detached, semi-detached or attached), construction year and HFA. Furthermore, measured energy consumption values are given for non-domestic electricity use, SH and DHW. All EPC available for the city of Gothenburg were retrieved from the National Board of Housing, Building and Planning.

Building characteristics from the GIS data are geometrical data such as building footprints and building height. The City Planning Office of Gothenburg supplied the GIS-data. As the EPC and GIS-data do not contain any common unique identifier, data from the property register were collected from the Swedish National Land Survey to match the building or property ID from EPC to mid-point coordinates of buildings. This was then spatially linked to building footprints that were extruded to create the 2.5D representation shown in Fig. 1, which is used to retrieve the envelope area of each building. The property register also contains information on year of refurbishment and value year, which is an estimate of equivalent age for taxation purposes calculated based on year of construction and year of refurbishment [36]. The value year is weighted based

[2] A multi-family dwelling is for the purpose of this paper defined as a building with 3 or more apartments.