# A bottom-up model for energy, carbon, and costs assessment of building stocks

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## Aims and research question

To develop energy efficiency strategies for building stocks, there is a need for simplified methodologies and tools for assessing different options and selecting the best option. Bottom-up modelling of buildings, whereby each building is modelled separately, is required to determine the impacts of new technologies or retrofit measures with appropriate spatial and time resolutions. In addition, in developed regions, such as the EU (the main application of the present work), most buildings are already built, which means that the main challenge in the coming decades is to improve the existing building stock. Therefore, a bottom-up modelling methodology has been designed to assess energy efficiency and $CO_2$ mitigation strategies in the existing building stock. The model meets the following objectives:

- to be simple with respect to both the descriptions of the buildings and model complexity, so as to reduce computational time and the amount of input data;
- to allow modelling of the building stock of an entire region or country on a level that allows aggregation for Europe as a whole;
- to allow assessments of the effects of different energy efficiency measures, including market realism, when it comes to the achievement of the potentials;
- to include behavioural issues;
- to allow assessments of the direct and indirect costs per unit of energy and $CO_2$ saved (meeting certain criteria, e.g., discount rate, baseline year, target year); and
- to allow for easy and quick changes of inputs and assumptions in the model.

## Method description

The ECCABS (Energy, Carbon, and Costs Assessment for Building Stocks) model was developed to comply with above-mentioned objectives. The model is described in detail by Mata et al. (2010a). The simulation model consists of two parts: 1) a Simulink model, which solves the energy balance for buildings; and 2) a code written in Matlab, which handles the input and output data from the Simulink model (Mathworks, 2010). The model uses a bottom-up engineering approach in which the energy demand of individual buildings is calculated based on the physical and thermal properties of the buildings, existing heating and ventilating systems, type of building (i.e., single-family houses or multi-family houses), and climatic conditions. The analysed buildings can be either existing sample buildings or so-called archetypes, i.e., representative of a group of buildings with similar structure, service systems, and purpose as the building stock to be investigated.

The model provides two energy outcomes: 1) end-use demand, i.e., the energy demand for heating, ventilation, and hot water in buildings; and 2) the final energy demand, which takes into consideration the efficiency of energy supply systems to the buildings. The results for individual buildings are then scaled-up to represent a country´s building stock by multiplying the results by the number of buildings that fit the description of each building modelled. The potential energy savings from various energy efficiency measures are always related to a reference energy demand, which is calculated and recorded for a certain year for the existing buildings of the stock to be analysed.
In addition, the model results include estimates of costs and carbon intensities of fuels and the estimated direct costs (i.e., investments, operation and maintenance costs) for the efficiency measures. Input data regarding future energy prices and $CO_2$ emissions are provided by scenarios for world wholesale energy prices for the industrial sector (Axelsson and Harvey, 2010; see also Chapter 20), future electricity prices (see Chapter 1 in the *European Energy Pathways* book) and $CO_2$ emissions from electricity production (see Chapter 10 in *European Energy Pathways* book). The input data are complemented with information on distribution costs and excise taxes from the IEA (2009), and VAT rates for the residential sector based on current rates (EC, 2010). The inclusion of indirect costs is currently under development.

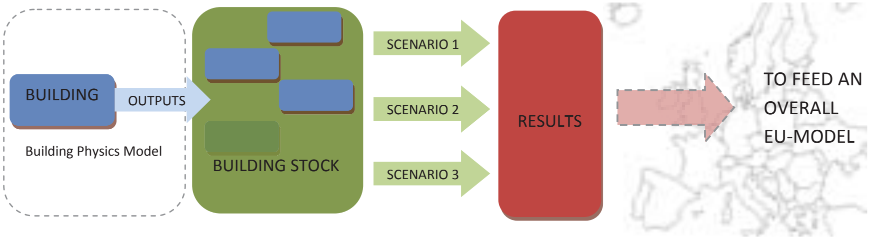

**Figure 14.1.** Overview of the calculation steps in the ECCABS model.

Obviously, the results obtained depend on the characteristics of the buildings, as well as on the energy/carbon intensity of the building sector studied. Thus, although the model was applied using a relatively high number of residential buildings in Sweden and validated as described in the next section, it is dependent upon the inputs. Therefore, the possibility to apply this model to countries and regions other than Sweden will depend on the availability of data on buildings (i.e., data for a sufficiently high number of sample or archetypal buildings).

## Validity and reliability of ECCABS

The accuracy of the energy balance model (in Simulink) was tested and validated for two buildings: an office building located in Barcelona, Spain; and a residential building in Köping, Sweden. For the Spanish office building, for which the cooling demand is covered by natural ventilation only, the indoor temperature during a warm week was calculated and compared to the measured indoor temperatures. The modelling results were reasonable, albeit not in full agreement with the measurements. This discrepancy is partly explained by uncertainties regarding some of the input values, given the characteristics of the building (i.e., large glass façades, ventilated basement, natural ventilation, and extensive exposure to the sun). However, the discrepancy is also due to the simplified nature of the modelling approach. The latter explanation was verified by comparing the results from the ECCABS model to results obtained using another model, DesignBuilder (DB, 2010), which performs a more detailed simulation of natural ventilation. In the comparison between the more simplified ECCABS model and the more complex DesignBuilder model, the latter provided results that were closer to the measured values. Nonetheless, the ECCABS-modelled heating demand was within the range of measured heat consumption, as described by Mata et al. (2009). As for the Swedish residential building, the calculated heat demand was in a good agreement with the measured values (within 1% difference) (Mata et al., 2009).

The simulation of energy consumption for the baseline year serves as a large-scale validation of the model. The results of the ECCABS model relate energy efficiency measures to a baseline energy use (also referred to as “useful energy”) in the year 2005, while the statistics only report final energy use (also referred to as “delivered energy”). The difference between the statistics and the total energy use resulting for this work, recalculated as delivered energy, was 5% (taking into account the types and efficiencies of the heating and electricity systems in the housing stock, i.e., the percentages of oil, gas, pellets, wood, electricity and district heating for heating and hot water demand). Thus, the baseline energy use is considered validated. The modelled final energy by fuels was also validated against data available in the ODYSSEE and GAINS databases (Enerdata 2010; IIASA, 2010).

The modelling results for the Swedish case have been compared to the results of previously published studies on the topic. This is not a straightforward task, since the studies differ in terms of assumptions, possible efficiency options and approaches in the modelling. To start with, there are several definitions of "energy-saving potentials"; in Sweden they are generally related to the definition of cost savings (see box below).

First, the total technical potential derived in the present study is up to 65% higher than that reported by other sources (Sandberg, 2007), while our calculated techno-economic potential saving is 30%-50% lower than those previously reported (BFR, 1996; Dalenbäck et al., 2005, Pettersson and Göransson, 2008). Second, bottom-up modelling approaches generally tend to provide higher potentials than top-down assessments (see Swan and Ugursal, 2009). Third, the number of measures studied influences the total potential (e.g., some studies do not include reduced indoor temperature as an efficiency option). In addition, the interest rate used obviously influences the results (in the present case, 4% was applied). Finally, the data used for the description of the building stock influence the results. Our work is the first assessment based on a description of the Swedish buildings as they were in year 2005, while all the other studies are based on the Swedish building stock in 1995. For a detailed comparison of the present and other reports and models, see Mata et al. (2010b).

The investment required to implement all the measures assessed in the present work is much lower than that estimated in a previous national report (BFR, 1996). A possible reason for this discrepancy is that in the present study, some investment costs have been set at zero when the measure is assumed to take place in any case (mainly due to regulation/standards), e.g., changes in lighting and some appliances. In addition, there have been developments in technologies

### DEFINITIONS OF ENERGY-SAVING POTENTIALS

The most common distinctions in the definition of the costs for energy savings have been found to be:

The *technical potential*, which is defined as the amount by which it is possible to reduce energy demand or $CO_2$ emissions by implementing already demonstrated technologies and practices without specific reference to costs.

The *techno-economic potential*, which is the cost-effective (i.e., profitable) technical potential to reduce energy demand or $CO_2$ emissions. The costs are calculated as the net annual cost to apply the measure minus the cost of the energy saved, divided by the energy saved or $CO_2$ avoided due to the application of the measures.

### IN SWEDEN:

*Cost savings* are defined as the sum of the investment and the present value of the annual maintenance cost of the efficient alternative, divided by the present value of the cost of the annual energy savings (GB, 1977). These savings were used as the basis for the first Swedish energy-saving plan, and have subsequently been used in all Swedish energy efficiency assessments.

(and costs) since 1996. As for the assessment of $CO_2$ abatement opportunities, none of the other available studies details the methodology used and the specific measures that were included.

## Application of the tool

The ECCABS model has been used to assess the energy savings and $CO_2$ mitigation of retrofitting measures in the Swedish housing sector (see Chapter 45 in the *European Energy Pathways* book and Mata et al., 2010b,c). The model has also been used together with two top-down models (see Chapters 19 and 23) to provide a comprehensive overall assessment of energy efficiency and $CO_2$ mitigation strategies in the existing European building stock under different scenarios up to the year 2050 (see Chapters 44 in the *European Energy Pathways* book). The end-use energy model was initially developed under the name ”Energy Assessment of Building Stocks - EABS” (Mata and Sasic, 2009) to estimate the effects of a number of measures for reduced energy use in the Swedish residential stock, as represented by a number of buildings. That task was commissioned by Boverket and the results are published in part in Boverket (2009).

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## Further reading:

Mata, É. and Sasic, A., 2009. Calculation of the energy use in the Swedish housing. Description of the building energy simulation model: EABS Energy Assessment of Building Stocks, Report 2009:4, Chalmers University of Technology, Gothenburg.

Mata, É., Sasic, A. and Johnsson F., 2010. Energy, Carbon and Cost Assessment for Building Stocks: Description of the bottom-up model ECCABS, Report A 2010-01, Chalmers University of Technology, Gothenburg.