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A FRAMEWORK FOR COMPARATIVE ANALYSIS OF BELGRADE HOUSING STOCK – DETERMINANTS OF CARBON REDUCTION STRATEGY

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ABSTRACT

Approximately 33% of total annual energy consumption and carbon emission in Belgrade (Serbia) are related to the housing sector. As such, the housing sector represents a key determinant in the development of an overall national carbon reduction strategy. The development of an effective carbon reduction strategy increasingly requires use and development of detailed predictive tools. The aims of this paper are twofold: (a) to review the state of the art bottom-up housing stock models, and briefly comment on the use of various building simulation tools in building stock modelling focusing on the housing sector, (b) to provide a conceptual algorithm for the disaggregated physically based bottom-up energy and carbon emission modelling of the housing stock in Belgrade. The suggested algorithm has been constructed around three separate components which will be created and analysed during the course of this project: a) a data module which contains information on various energy related characteristics of Belgrade's housing stock, such as urban layout, building envelope and building services; b) a data module based on a comprehensive monitoring campaign of selected dwellings in Belgrade, and c) a data module based on comprehensive modelling scenarios which will be carried out using a whole building zonal model such as 'Energy Plus'. The suggested algorithm has been designed having in mind that the results of the modelling have to be easily translated into an easy to implement carbon reduction policy.

Keywords: carbon reduction strategies, building stock modelling, bottom-up carbon emission models

INTRODUCTION

European residential and commercial buildings consume more than 40 % of the final energy use and produce nearly one third of the overall emission of greenhouse gases. Likewise, Belgrade housing sector is responsible for around 33% of the total annual energy use. As such, it can offer significant reductions in energy consumption and CO_2 emissions. In order to promote change and improve sustainability of the building stock, Serbia has recently ratified the Kyoto Protocol. In addition, Serbia has also signed the EU Stabilisation and Association Agreement with the EU Commission committing itself to adopt most of the EU Directives by 2014 including the Directive on Energy Performance of Buildings. However, the full implementation of this directive would require a complete restructuring of the current prescriptive building regulations not updated since late 1970s. Therefore, a bottom-up energy and carbon emission model of the housing stock in Belgrade needs to be developed having in mind that the modelling results have to be easily translated to an easy to implement carbon reduction policy. The model described in this paper has been constructed by adapting the various conceptual components of the well established bottom-up energy and carbon emission models.

Use of building simulation tools within bottom-up energy and carbon emission housing stock models

Over the last 40 years, a broad spectrum of building simulation tools, for design, analysis and prediction of the distribution of temperature, airflow and heat transfer between the inside and outside of a building, and/or between different zones of the building have been developed (Megri, 2007). They range from simplified to more sophisticated tools. Building load and energy simulation tools can be classified as mono-zone thermal models (e.g. TRNSYS and CODYBA) and multi-room thermal models (e.g. HOT2000, DOE, Type 56 of TRNSYS, and EnergyPlus) (Megri, 2007). Nevertheless, just a few building simulation tools have been used for construction of bottom-up energy and carbon emission housing stock models. To develop a conceptual algorithm of the model described in this paper, and to comment on use of building simulation tools within bottom up energy and carbon emission housing stock models a detailed assessment of 12 different physically based bottom-up models has been carried out. However, taking into account the limited space available for discussion, the characteristics of three representative models have been highlighted in this paper, namely: Johnston (2003), Huang and Brodick (2000) and Farahbakhshf et al. (1998). One of the most detailed attempts to predict future housing stock energy consumption was made by Johnston (2003) who developed an alternative selectively disaggregated physically-based bottom-up energy and CO2 emission model which explores the technological feasibility of reducing CO_2 emission by more than 60% within the UK housing stock by 2050. The delivered energy use attributable to a series of 'notional' dwellings has calculated by a modified worksheet version of BREDEM Version 9.60. Three illustrative scenarios namely, 'Business-as-Usual'; 'Demand Side'; and 'Integrated' scenario were developed. At the individual building scale, the BRE Domestic Energy Model (BREDEM), developed in the early 1980s, is the most widely used model for estimating the energy requirements of domestic buildings and for the estimation of savings resulting from energy conservation measures in the UK (Anderson et al., 1985; Shorrock and Anderson, 1995). Considerable data input is required for the programme. There are many versions of the program, such as BREDEM-8, which makes use of monthly energy balance equations, and a simplified annual version of the model, BREDEM-9. The BREDEM calculation algorithms form the basis of many software packages and projects. For instance, BREDEM-9 underpins the Standard Assessment Procedure (SAP) used to assess compliance with the UK Building Regulations. In addition, the NHER (National Home Energy Rating) Evaluator Software is also based on BREDEM. During the 1980s and 1990s, the model has been subjected to extensive tests against measurements from the monitoring of real dwellings and against more detailed and complex simulation models used. Results produced by BREDEM were always similar to the results of other simulation models. However, BREDEM is not available in the public domain, not enough information is available on the structure and operational characteristics of the model and mainly it is applicable for the UK housing stock (Johnston, 2003).

Huang and Brodick (2000) developed a bottom-up engineering based estimate of the aggregated cooling and heating loads for the total US building stock. Examined building stock comprised of 112 single-family, 66 multi-family housing and 481 commercial buildings. With the information on vintage, dwelling type and total building stock in each region, the overall energy use of U.S. housing stock is calculated by DOE-2.1E simulation tool. In addition, DOE-2, developed by James J Hirsch & Associates in collaboration with Lawrence Berkeley National Laboratory (Reilly, 1992; Winkelmann et al, 1993; DOE-2, 2007), is a building energy consumption and cost analysis programme. This programme has ability to model a wide range of commercial buildings and systems by performing an hourly simulation of the building to predict energy consumption and costs (Megri, 2007). It uses a weighting factor method and a sequential approach that includes: systems and plant models, loads model, and an economic model (Megri, 2007). Results produced by DOE-2 have shown reasonable or excellent agreement to both results from other programs and measured data (Haberl, 2004). However, the use of weighting factor method can cause that a hasty user, who allows many keywords to default, end up in effect modelling a building which differs from the one desired (DOE user news).

In order to investigate the impact of the large numbers of measures included within two standards namely, R-2000 (CHBA/NRCan, 1994), and NECH standard (NRC, 1996), Farahbakhshf et al. (1998) developed the Canadian Residential Energy End-use Model (CREEM). Even though, houses were primarily divided into four vintage categories: pre 1941, 1941-66, 1967-78, 1978 or later, it has been assumed that the refurbishment would be done by implementing the NECH and R-2000 standards to 10, 20, 30, 50 and 90% of the houses built in 1961 or later. The delivered energy use attributable to single-detached and single-attached dwellings is calculated by HOT2000 simulation program. HOT2000, developed by the Canada Center for Mineral and Energy Technology (CANMET), Natural Resource Canada, the Canadian Home Builders Association, and UNIES Ltd (NRC, 1995; HOT2000, 2003), is a 'three-room' (attic, main floors, and basement) energy analysis and design programme for low-rise residential buildings (Megri, 2007). In Canada it has been used to qualify houses for energy-efficiency certification (Megri, 2007). Over last 14 years HOT2000 has been validated extensively by both empirically monitored data and the three more advanced simulation programs such as BLAST, DOE and SERIRES (Haltrecht and Fraser, 1997). Nevertheless, the major limitation of HOT2000 is that it can not model energy analysis room-by-room and size HVAC equipment (Fung, 2003). Unfortunately, there are several characteristics associated with the models developed by Johnston (2003), Farahbakhshf et al. (1998), and Huang and Brodick (2000) which were not suitable for inclusion within the conceptual algorithm of the disaggregated physically based bottom-up energy and carbon emission model of the housing stock in Belgrade.

There are three characteristics of Johnston's model which have not been found suitable for the development of the suggested algorithm. Firstly, Johnston's model has been constructed around only two 'notional' dwelling types (pre- and post-1996).

Therefore, as noted by the author of this model, this approach makes it difficult to explore what reductions in energy consumption and CO_2 emissions could be achieved if different age classes of the UK housing stock were selectively upgraded or demolished (Johnston, 2003). Secondly, the model did not account for the cost of energy saving from conservation measures. Consequently, extra expenditures and cost savings of the proposed scenarios cannot be estimated. Finally, as in most cases, the model lacks transparency, not allowing the reader to examine the model in more details.

The first limitation of work of Huang and Brodick (2000) is rather small number of residential prototypical buildings used to represent the entire U.S. housing stock. Secondly, as noted by the authors of this model, the totals for the non-space conditioning end use such as water heating, lighting were modelled very simply (Huang and Brodrick, 2000). Thirdly, only gas was considered as the household primary fuel for space and water heating, even though significant percentage of households use electricity (space heating:29.1%, water heating:39%), and some other fuel types as their primary fuel source for space and water heating (Residential Energy Consumption Survey, 2001). Fourthly, comparison of the developed prototypes was done only against the Residential Energy Consumption survey (1982) and Non-residential Buildings Energy Consumption Survey (1989), but outside of this check no calibration has been done. Finally, this model also lacks transparency.

The work of Farahbakhshf et al. (1998) is also limited in a number of respects. First of all, mid and high-rise multi-family residential building stock are not included within the model, even though these households comprises around one third of the entire Canadian residential stock. Secondly, houses built before 1967 are not taken into consideration. Consequently, the upgrading measures were applied only to a fraction of newer houses in Canada. Thirdly, analysis of multi-fuel heating systems is not incorporated into the model. Particularly wood supplementary heating system should be included since, according to a 1993 Survey of Household Energy Use (SHEU), more than 30 % of entire households use wood for supplementary space heat (Fung, 2003). Fourthly, CO2 emissions saving attributable to upgrading of Canadian housing stock to NECH and R-2000 standards are not quantified. Finally, it lacks transparency.

OVERALL STRUCTURE AND FORM OF THE SUGGESTED MODEL

The overall structure and form of the model is illustrated in Figure 1. As Figure 1 indicates, the model has been constructed around three separate but inter-related components. The first component is a data module on variety of factors, including urban layout, building envelope and building services, population projections and various other energy related characteristics of Belgrade housing stock. After formulating the most important criteria of the Belgrade housing stock, the sample size is determined. The second component is a data module based on a comprehensive monitoring campaign of the selected dwellings. The final component is a data module based on comprehensive modelling scenarios. After developing these scenarios, relevant information relating to each building category will be fed into a whole building zonal model such as ‘Energy Plus’. This model is primarily demand side orientated. Nevertheless, Scenario 5 (see Table 1), not only includes the demand side energy efficiency measures, but it also considers the supply side shift from carbon-intensive towards more clean fuels. The building zonal model will be then used to calculate the delivered energy use and CO2 emission attributable to each representative dwelling of corresponding building category. Once the delivered energy use and CO2 emission per representative dwelling is known, the calculation of the total energy consumption and CO2 emission is straightforward. Firstly, for each building category energy use and CO2 emission will be obtained by multiplying annual energy consumption of representative dwelling with the total number of dwellings within that category. Finally, overall energy consumption and CO2 emission of Belgrade housing stock will be calculated by summing up annual energy consumptions and CO2 emissions attributable to each building category. Validation of the model output data will be done by comparing total energy use of Belgrade housing stock to top-down consumption provided by Belgrade Energy Management Office.

Data module 1: Characteristics of Belgrade housing stock

Belgrade covers 3.6% of the territory of Serbia, and 21% of the Serbian population lives in the city. Belgrade is the centre of Serbian economic hub, and the capital of Serbian culture, education and science. According to recent statistical data, there are 1,576,124 registered inhabitants (inner city population: 1,273,651) living in Belgrade today, in 17 city municipalities (10 urban and 7 sub-urban) with a total of 567325 households (Census, 2002). In addition, there are 577,079 apartments located in 229,645 buildings, which in an ideal distribution would be enough to provide a home for each family (Census, 2002). The data model has been constructed using a variety of external data sources. Examples of such information include: Census 2002, Building Regulations, related research studies, and Statistic Office Households Survey. Even though, Census 2002 contain information on population social characteristics and some characteristics of housing stock, such as the year of built, the type of heating system (central heating and gas only), urban layout, building height, and existing installations (plumbing, sewage, and electricity), it gives no detail on the thermal characteristics and performance of the housing stock, type of space and water heating systems, appliances, etc. Nevertheless, intersection of the year of built and the active Building Regulation enabled estimation of thermal characteristics and performance of buildings. Information on the type of heating systems and the total households’ final energy consumption are obtained from the project entitled “Review of Existing Energy Conditions in Belgrade”, done on the part of company Energoprojekt Entel by request of Belgrade Energy Management Office

(Energoprojekt Entel, 2006). Unfortunately, these data are for the year 2006 and there is no more recent one. Taking into consideration available external data sources, the foremost characteristics for qualitative building classification are: (1) urban layout (urban and sub-urban municipalities), (2) timeframe (1946-1970, 1971-1980, 1981-1990, 1991-2002), (3) type of heating system (central heating, gas, electricity, wood, coal), and (4) building height/number of floors (individual housing units and multi-apartment buildings) Buildings built pre -1946 are not considered for several reasons. Firstly, they are important part of architectural and cultural heritage and their refurbishment demands specific and more complex approach. Therefore, any conclusions and findings obtained by analysing these types of buildings could not be extrapolated to the entire or at least large portion of housing stock. Secondly, they represent relatively small portion of the existing housing stock (less than 15%). Thirdly, a great variety of architectural styles and construction types demands different guidelines and approaches for each of the building type. Finally, any renovation of these buildings would require authorization of Belgrade Institution of Protection of Cultural Heritage. In addition, buildings built after 2002 are also not included due to non-existing data. The next step in this stage was determination of the sample size for monitoring. There are several methods to determining the sample size such as: applying formulas to calculate a sample size, a census for small populations, imitating a sample size of similar studies and using published tables. Even though, all these approaches, but census for small populations, could be applied, it seemed that utilization of the Cochran's sample size formula for categorical data would be the most appropriate method (Cochran, 1977).

$$n_o = \frac{Z^2 \cdot p \cdot q}{e^2} \tag{1}$$

Where: n_o is the sample size, Z^2 is the abscissa of the normal curve that cuts of and area α at the tails (1-α equals the desired confidence level, e.g., 95%), e is the desired level of precision or margin of error, p is the estimated proportion of an attribute that is presented in the population, and q is 1-p. Confidence level and margin of error are set at 95% and ±10%, respectively. The Z-value, obtained from statistical tables, is 1.96. The variability in the proportion is unknown, and therefore maximum variability of 0.5 is adopted. The resulting sample size is demonstrated in Equation 2.

$$n_o = \frac{(1.96)^2 \cdot 0.5 \cdot 0.5}{(0.1)^2} = 96 \text{ housing units} \tag{2}$$

The final phase is the selection of the sampling units. Random sampling and stratified sampling are the most commonly used sampling techniques (Shrock, 1997). Although, each of two methods has its advantages and limitations, proportionate stratified sampling (the sample size of each stratum is proportionate to the population size of the stratum) has been chosen. This method enables division of Belgrade housing stock into subgroups called 'strata' according to the defined building characteristics and almost always leads to increase in survey precision. Using the following equation sample size within each 'strata' has been obtained.

$$n_h = \left(\frac{N_h}{N}\right) \cdot n \tag{3}$$

Where: n_h is the sample size for stratum *h*, N_h is the population size for stratum *h*, N is total population size, and n is total sample size. Variables N_h and N are obtained from Census 2002, while n is 96 (see Equation 2). Housing units will be selected utilizing the random sampling.

Data module 2: On-site survey

Similarly to other Eastern European countries Serbia has little or no data available from previously monitoring campaigns on domestic energy consumption. Therefore, a comprehensive monitoring campaign that will be undertaken with this research project represents a pioneering attempt to provide qualitative information on households' energy use. The data model has been constructed around three components: a) monitoring, b) collection of the households' utility bills, and c) questionnaire. Monitoring campaign will last for one full year and will include installation of two HOBO data loggers in each housing unit. One data logger will be set in a living-room while the other will be placed in a bedroom. HOBO data loggers will provide information on internal temperature, relative humidity, and relative indoor light level. Adopted measuring methods and instruments are in accordance with International Standard ISO 7726: Ergonomics of the Thermal Environment-Instruments for Measuring Physical Quantities (ISO 7726, 1998). On the other hand, monthly utility bills will give insight into the households' energy consumption such as space and hot water heating, and electricity. Finally, distribution of rather extensive questionnaire will provide information on socio-economic and demographic structure of households, occupants' behaviour, appliances and their usage, lighting, heating and water systems, air-conditioning, the current energy use, and the physical form, type and construction of the house. In addition, a smaller sample of about 10 homes will be selected from total sample, in which detail monitoring of building envelope will be conducted.

Data module 3: Modelling scenarios

The developed model will be used to evaluate several illustrative carbon reduction scenarios. However, in this stage of the project it is difficult to perceive all possible upgrading measures that can be applied to Belgrade housing stock. Therefore, only the frameworks of potential illustrative scenarios, which in the future might be subjected to change, are presented within Table 1. In addition, new scenarios might be considered later during this project. The central assumptions of all these scenarios are continuation of rise of standards of living, economic growth and transition towards more sustainable and energy efficient technologies. In addition, scenarios are based on currently available technologies only. Energy simulation software such as 'Energy Plus' will be used to perform energy evaluation, that is to calculate annual energy consumption of representative housing units, that will be selected from the total sample, after application of certain improvement measurement proposed within each of scenarios. In this way, benefits of each upgrade will be obtained. Moreover, the exact number of housing units for modelling will be determinate later during this project. In the end, recommendation in form of set of energy efficiency measurements, designed to balance between greatest energy savings and cost-effectiveness, for each representative building type will be defined.

CONCLUSION

This paper has described an algorithm for the disaggregated physically based bottom-up energy and carbon emission modelling of the housing stock in Belgrade, and has shown how this has been used to develop several illustrative scenarios for possible future energy use consumption and CO2 emissions. The suggested model uses data from two main sources such as information on various energy related characteristics of Belgrade's housing stock, and data based on a comprehensive monitoring campaign of selected dwellings that will be carried out. In addition, three bottom-up energy models, that use different building simulation tools, have been presented and analysed.

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Table 1
The illustrative scenarios

SCENARIOS	DESCRIPTION
Reference	This scenario is based upon the 'Reference Case' scenario developed by Shorrock et al. (2001).Under this scenario no significant changes are made to existing Serbian trends in energy efficiency policy and no additional policy regulations are implemented beyond those that already exist. In addition, no improvements of existing building stock are made. Therefore, current trends in building fabric performance, end-use efficiencies and the carbon intensity of electricity generation are continued. Supply sector continues to be primarily based upon the consumption of fossil fuels such as oil, and coal.
Scenario 1	Under this scenario demand side varies, while supply side sticks to current trends. The most cost-benefit measurements will be applied to housing stock such as replacement of windows, lights and appliances and cooking. These measures are derived from detailed literature review, which has been previously done.
Scenario 2	Under this scenario demand side varies, while supply side sticks to current trends. The more demanding and expensive measurements will be introduced such as changing of wall, roof, and bottom insulation, tank and pipe insulation.
Scenario 3	Under this scenario demand side varies, while supply side sticks to current trends. Even more demanding and expensive measurements will be introduced such as replacement of space and water heating system and control improvements.
Scenario 4	Under this scenario demand side varies, while supply side sticks to current trends.
Scenario 5	Both demand and supply side varies. On the supply side shift from carbon-intensive fuels such as coal and oil towards more clean fuels such as gas or renewables will be considered.

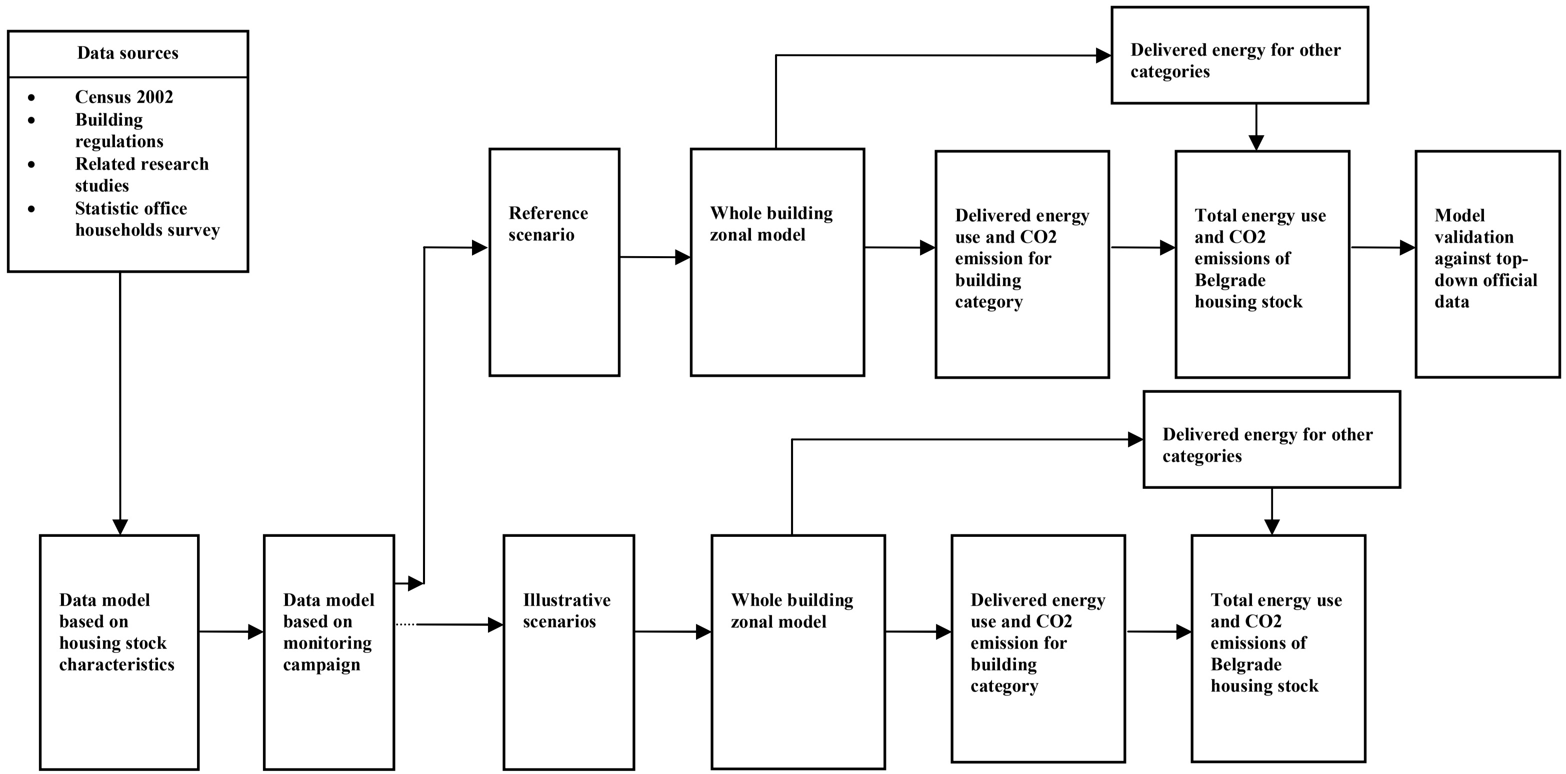

Figure 1 Structure and form of the energy and CO2 emission model