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URBAN ENERGY MODELLING APPROACHES: A LITERATURE REVIEW

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Abstract
The energy efficiency of buildings at district and neighborhood level are limited availability, however there are multiple ways followed to evaluate the energy performance at the urban scale. The current methodologies on the energy efficiency strategies for the future cities are various depending on the project. The aim of this paper to provide an overview on two distinct energy modelling approaches: top-down and bottom-up. The paper is based on observations from the case studies following the top-down and bottom-up approaches. Each approach requires different level of information and analysis technique and provides different outcomes with various feasibility. The literature review provides several researches focusing on their targets, strengths and shortcomings.
Key words*: Urban modelling; Bottom-up; Top-down; Building energy consumption*

1. Introduction

Buildings, as the keystones of cities, have an important role for the sustainable development. According to European Commission, buildings are responsible for 40% of global energy consumption [1]. Even though the majority of the performance analyses are on single-building energy strategies, it is crucial to widen the energy saving strategies from building to building stock at a neighborhood and district scale in order to reduce greenhouse gas emissions (GHG) and global energy consumptions.

There are multiple ways followed to evaluate the energy performance at the urban scale. Each methodology requires different level of input data to calculate or simulate the energy efficiency of the buildings. In fact, both inductive and deductive attitudes, either start from detecting and categorizing the group of building to be analyzed or defining the benchmarking to be followed for evaluation of analyses results. The building stock, building archetype and energy benchmarking are important terms and necessary indicators on building and district scale energy efficiency analyses. The building stocks are defined in the category of reference buildings or defined archetypes with the aim of determination of the building energy demand. Building archetypes are the theoretical buildings classified based on their similar attributes, so as to be modeled as a building stock. This approach is especially important for analyzing of the existing buildings as groups and also implementation of several energy scenarios for district retrofits and future energy projects in urban scale [2]. The energy benchmarking models are the tools derived from the energy efficiency indicators to evaluate the usage of energy in a more efficient way for targeted buildings. Energy rating systems, energy policies are considered to qualify and improve

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the energy efficiency of buildings such as BREEAM (Building Research Establishment's Environmental Assessment Method), the Leadership in Energy and Environmental Design (LEED) [3], Green Building Rating System, 2000-Watt Society Benchmark. They are generated through comparison with standards such as climate conditions, historical energy uses, and following the researches [4]. For instance, a study outlines an energy benchmark for schools in England to determine their energy use intensity by classifying as 'good practice' and 'typical' performance [5].

This paper provides an overview for two main approaches; top-down and bottom-up, so as to analyze the building energy consumption at urban level. The current studies about district level energy efficiency have different phases and follow varied approaches. The district level energy analyze steps for the top-down and bottom-up approaches can be classified under the three main steps with a different order for each approach, to obtain a robust analysis.

- Data collection and investigation: The relevant data and input parameters are collected to be process at the further steps. The corresponding data is gathered for assessing the benchmarks and the energy policies. The relevant information such as site maps, building data, historical archives, are used to estimate the past, current or future energy performance of buildings.
- Identification of variables and modelling: The identification and classification of collected data are variable processes based upon the existing building information. In order to conduct the analysis through modelling, determination of each archetype is required.
- Broadening the model scope at district and neighborhood scale: Each unit of archetypes determines the energy consumption by lightening, cooling and heating demands etc. By using the archetypes, the building stocks are created to estimate the overall energy consumption. The detailing of each archetypes has a crucial role on estimation of an extensive urban energy consumption analyses of the building stock.

Even though both approaches follow similar steps as mentioned above, each of them requires different level of detail of information, uses different modelling techniques and follows different policies and data to estimate the energy consumption at urban scale. A literature review allows to have an exhaustive overview on building and district energy modelling. This paper intends to analyse several researches followed top-down and bottom-up approaches, focusing on their purposes, strengths or shortcomings. After a brief explanation of the each approach, the researches analysed in the context of top-down and bottom-up models separately. The paper concludes with a comparison of the approaches.

2. Modelling Approaches

In general, both top-down and bottom-up approaches are implied to improve the processing of information in methodical way for the different types of fields such as software development, architecture, management etc. This paper mainly presents the implementation of these two approaches for the purpose of the reduction of energy consumption and carbon emission of cities, in the fields of engineering and architectural. Depending on the available data, each building stock model follows a different approach. The top-down models start by analyzing the energy demands of a region and process by dividing them into smaller building stocks [6]. But this approach is challenging when the number of buildings are too much in the region or when the focus is on a specific neighborhood. Unlike the top-

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down approach, the bottom-up approach requires a building level information to obtain the overall consumption of the focused area. The aim of this section is to outline the descriptions of the top-down and bottom-up modelling approaches over the case studies and previous researches in an effort to better understanding of each technique.

2.1. Overview of the top-down approach

The top-down approach is a deductive method as it is understood from the name of the approach. Swan and Ugursal et al. defines the residential sector as an energy sink in the case of top-down approach, which means determination of energy consumption in the sector is not degraded on account of the individual end-uses [7]. The selection of the approach is conducted by the available input data. In this approach, mainly the long-term changes and historical data including climate conditions, population etc. are considered. So that, the drawback of this approach comes from the absence of the up-to-date data or information of the future changes.

2.1.1 The top-down model

The top-down approach can be used to derive energy benchmarking. As it is shortly described before, benchmarks are an effective way of describing an energy performance of a group of buildings with reference to the building stock.

An example of benchmarking based upon the top-down approach is studied in central Argentina [8]. The study examined 15 school building in Santa Rosa. The top-down approach is implemented to predict the energy consumption of the sampled school buildings and then the comparisons of the energy performances and GHG emissions are made with the other schools in northern hemisphere to obtain the performance benchmarks and regional standards. Similar approach was used to analyse the effect of energy management through a regression analysis [9]. The top-down approaches appraise the overall energy consumptions and energy savings at the national or regional level.

In Europe, Odyssee is a database includes energy saving studies based on top-down approach. The database tool provides also comparison facility between the selected countries. It includes the databases from all EU countries as well as Norway, Switzerland and Serbia [10].
Another example study follows the top-down approach is the annual delivered energy, price, and temperature (ADEPT) with the aim of controlling the household delivered energy and benchmarking the performance of domestic energy sector. The model uses multiple linear regression based on two variables that are temperature and energy price. The study is important for detection of the changes in the energy prices [11].

With the aim of investigation of available energy data and visualisation of environmental performance of the buildings in Goteborg, an energy model has been developed by Tornber and Thuvander [12]. The model uses Geographic Information Systems (GIS) to visualize the energy data related a building stock and follows the top-down approach to estimate the energy use of the stock. The study does not provide the energy consumption of individual buildings.
Saha and Stephenson [13], developed a model for residential buildings in New Zealand by utilizing national level data in order to achieve an energy efficient environment.

The top-down population-based approach is used for a representative study of seasonal diurnal anthropogenic heating profiles of six US cities. [14], [15]. But since the diurnal data for energy survey was obtained from the historical data as is the case of top-down approach, the analysis was limited to change in building technologies and human behaviours.

2.2. Overview of the bottom-up approach

The bottom-up approach is an inductive method depending on the input data used. It is based on the calculation of the individual energy consumptions of particular end-uses and then the total sum of them to represent region.

Swan and Ugursal [7], showed that the bottom-up approach can be divided into two groups; the statistical approach and engineering approach. The statistical approach is based on the historical data. The analyses are made to define the relationship between end-uses and energy consumption. The engineering approach defines the energy consumption of end-uses according to usage of engineering systems. Unlike the top-down approach, the calculation of the energy consumption of buildings does not fully depend on the historical data. But since the amount of the information is more detailed than the information required for the top-down approach, the calculations of bottom-up models can be more challenging. Hence, the bottom-up approach models can be classified in micro-scale studies, the top-down approach studies can be involved in the macro-scale ones considering the level of detail of input data. The bottom-up models generally start with analysing of the energy consumption of a single or a couple of buildings, after the results are extrapolated to the building stock level. Since the bottom-up models analyse individual building in detail, the approach allows to be traced and examined the effects of new technological changes on building stock as they do not rely on historical data alone.

2.2.1 The bottom-up model

A study follows the bottom-up statistical approach for energy retrofit of building that is important for carbon mitigation and energy savings at city scale. The energy retrofit based on Geographical Information System (GIS) is implemented in Rotterdam for approximately 300,000 dwellings by using a multiple linear model to estimate the natural gas and electricity consumption of the city. For the study, the bottom-up engineering approach provided a fast and simple way of the prediction of the energy consumption at a large scale [16].

Protopapadaki et al. [17] examined the dynamic behavior of a building stock in Belgium. The research provides a comparison of the two typologies to determine the effects of the different identifications of dwellings in the building stock and the results of those variations on the model outcome. The results of the typologies show the significant difference in the case of comparison of the dwellings. The study emphasizes the importance of the sufficiency of the provided database for a bottom-up approach model.

Despite the fact that, many studies focus on energy savings and GHG reduction by retrofitting of building stocks, it is required to consider the LCA of a building stock to obtain a comprehensive assessment. LCA allows to estimate the energy efficiency of a building within its lifecycle including from production, transportation and installation to the material for retrofitting [18]. A case study in Luxemburg is developed a data model for life cycle environmental assessment of a building stock retrofitting by following the bottom-up approach. An elaborative archetype technique is used by the utilization of geospatial data and a spatio-temporal database. The study provides a base for retrofitting measurements at urban scale also gives the local authorities the opportunity to simulate different retrofitting scenarios on the building stock [19].

Fonseca and Schlueter [20], developed a new hybrid model with the integration of GIS for the city of Zug in Switzerland, that collects the data from local archetypes as input data for a dynamic energy model. The paper is an example for the integration of two subcategories of the bottom-up approach, that are statistical and analytical methods. The database of detailed archetypes is provided from the combination of these two methods. In this study, 172 building archetypes are grouped into sixteen occupancy types, six construction periods and six renovation period. Addition to analyzing the current energy performance of the archetypes, the model provides a dynamic urban zoning analysis for the urban planners in the case of an urban transformation by creating different urban scenarios for any possible urban development. For this study, 10 different scenarios were implemented and the potential energy consumptions for each scenario were calculated for the implemented zone.

The Urban Modeling Interface (UMI) is an urban modelling platform, developed by Sustainable Design Lab at MIT with the aim of the environmental performance of the neighborhoods and cities respecting building energy, daylighting and outdoor comfort, and walkability with the bottom-up approach [21].

Wang et al. [22], presented a building stock modelling based on bottom-up modelling approach for the buildings in Switzerland. The CESAR modelling tool was used to simulate three types of districts. The bottom-up approach is used to evaluate the future building performance and climate change scenarios. The results were discussed in this paper based upon the introduced transformation scenarios and their efficiency on achieving targets for primary energy and GHG emissions until 2050.

3. Comparison Of The Top-Down And Bottom-Up Approaches

Depending on the available data and the project scale, the top-down and bottom-up approaches represent many similarities and differences in terms of required information as input data and the results as output data [7].

The studies are analyzed in this paper for the top-down approach generally based on benchmarking. As it is also seen from the studies mentioned above, the top-down approach uses the historical data as input for the analyses which ensure an easily improvable large-scale project. But at the same time, the top-down model relies on antecedent information and does not provide the possible chances or future technologies.

The bottom-up models analyzed in this paper are based on energy analysis and modelling. The reason is that, the energy models require a detailed analyse process and technical information unlike the top-down approach which utilizes macro level parameters. Energy bills or surveys can be others source of the bottom-up models to evaluate the energy consumption of district buildings. Determination of the effects of future implication scenarios or technological changes requires the usage of bottom-up model.

Detailed information issue is one of the main distinctions between two approaches which has both negative and positive effects. While requiring more detailed information provides more reliable results, but also at it can be challenging in the case of lacking adequate information. Moreover, relying on the historical data can be seen as a negative feature for the projects were renovated in the recent past or planning to be renovated in the future. There are also some models are introduced as a mixed model arising from the integration of the bottom-up and top-down models [23], [24]. The models incorporate the macroeconomic parameters with future technological changes [25].

All in all, it can be deduced that the combination of the two modelling approaches can become a very important tool in the case of need an alteration only for the particular buildings by taking advantage of bottom-up model and using the rest of the avaible data comes from the top-down model without having any change.

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