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BUILDING ARCHETYPE DEVELOPMENT FOR AGGREGATED BUILDING MODELS - METHODOLOGY AND CASE STUDY RESULTS

Summary

Aggregated building models are defined as urban building energy models (UBEM) in which model complexity is reduced through the use of building archetypes. Building archetypes are aggregated groups of buildings from a diverse building stock that are classified and clustered based on shared energy-related characteristics such as size, age, and energy supply system. The aggregated building models are important tools for analyzing heating, cooling, and electricity demand at district- to city-level. An extended aggregated building model that refines national building archetypes on local building archetypes is proposed. The approach is embedded in a social dialogue process with heterogeneous stakeholders and aims to support information-based decisions for climate-neutral energy systems. Stakeholder surveys, as part of a toolbox of automated routines, are used to collect input data, like the characteristics of buildings and energy supply systems, as well as user behavior. The use of local building archetypes derived from this data increases the validity of the resulting simulated heating, cooling, and electricity demand profiles compared to the use of national building archetypes. A comparison of the simulation results with national building archetypes, building-specific stakeholder data, and local building archetypes is presented.

Keywords: Urban Building Energy Modeling, Aggregated Building Models, Local Building Archetypes, Stakeholder Surveys

Field of application for the findings: Urban Energy Planning of Residential, Non-Residential and Mixed Used Districts, Citizen Participation, Sustainable Energy Transition

Addressed audience: Urban and Specialist Planners, Interdisciplinary Teams in Cities and Municipalities, Researchers

1. Introduction

A far-reaching transformation of our energy system, i. e. the heating, cooling and electricity supply, is necessary in order to achieve the federal state, national and European climate targets. In addition to the technical complexity and diversity of future energy systems, this transformation process is particularly challenging due to social frictions, conflicts, and the involvement of a broad range of heterogeneous stakeholders.

To address these challenges and support the successful implementation of the energy transition, in two case studies a social dialogue on the transformation of urban energy systems will be performed. The overarching aim of the social dialogue process, structured as a series of workshops, is to support stakeholders in reaching information-based decisions and in implementing concrete measures to transform the local energy systems towards climate neutrality. The initial phase of these workshops focuses on developing a shared knowledge base and fostering mutual understanding among the stakeholders. In subsequent workshop formats, the aim is to identify the parameters and results most relevant to stakeholders' decision-making.

To perform the social dialogues, a toolbox with automated routines of various energy system analysis models with different focus, as well as interactive workshop formats, and virtual and augmented visualization techniques is being developed and used. Part of the toolbox with automated routines, are the following described aggregated building models, which enable building stock and potential analyses, similar to municipal heat planning, but address the combined heating, cooling and electricity demand and supply also at individual building-level. With the toolbox different variants of energetic refurbishment measures, as well as energy supply systems are simulated, guided by parameters defined through the dialogue process. As a result of the dialogue process, stakeholder-specific questions are answered, stakeholder-preferred variants can be identified, and concrete measures are derived. Thus, the basis for achieving consensus on the further implementation of the measures is provided.

2. Aggregated building models

For a building stock and potential analyses, it is in principle possible to calculate the heating, cooling, and electricity demand of all individual buildings in a case study at any given time using detailed physic-based dynamic building and energy systems simulations. Such detailed simulations, known as simulations with Building Energy Models (BEM) or Building Energy Performance Simulations (BEPS), would, for example, be necessary to adequately account for the high diversity of the energetic refurbishment states of the building stock (Kong et al. 2023). However, this approach faces practical limitations, for instance, the computational cost to model all individual buildings. Additionally, the input data required to simulate the thermal behavior of all individual buildings separately are often unavailable or prohibitively expensive to obtain.

Therefore, so called Urban Building Energy Models (UBEM) has established itself as a field of research in the past 15 years, for modeling and simulating the heating, cooling, and electricity demand of all buildings in a case study on district- to city-level. This field of research addresses the complex overall energy demand and supply structure from individual buildings to entire cities, as well as interdependencies between buildings. In addition, urban building energy models are used to anticipate the resulting non-trivial future developments in the overall energy demand and supply structure and to evaluate the effectiveness of energetic refurbishment measures, which includes the integration of renewable energies and other changes in the energy supply structure. According to scientific literature UBEM can be classified in two methodological approaches, which would be the top-down and the bottom-up approach. As the top-down approach is based on long-term historical relationships between energy demand and technologic and socio-economic developments on a macro-level, this approach is suitable for strategic urban planning or recommendations for political action but not suitable for high-resolution temporal and spatial analyses of energy demand and supply, for deriving energetic refurbishment measures or strategies to integrate renewable energy, especially not for individual buildings. The bottom-up approach being suitable for this purpose is divided into physics-based, statistical or data-driven, and hybrid methods. An exclusively data-driven method behaves like a so-called black-box model and provides a relationship between input and output data. For physically interpretable simulation results, physics-based methods or hybrid methods are cited in scientific literature as the most suitable methods. Hybrid means e. g. that a physics-based method is used in combination with data-driven methods for various aspects of modeling, such as adjusting model parameters to improve the agreement between simulated and measured data, or dealing with data gaps (Ferrando, 2020; Li et al., 2023; Swan and Ugursal, 2009). To enable the application to contribute as part of the toolbox of simulation models for decision-making by the stakeholders described above, a physics-based bottom-up UBEM is used as the basis for the aggregated building models.

Shifting from physics-based BEM to bottom-up physics-based UBEM requires simplifications in the modeling of building geometry, thermal properties of the building envelope, zoning, internal heat gains, and the building's energy supply system or the technical building equipment, as described in detail by Piro et al. (2023). An established simplification for non-geometric modeling parameters is the use of the archetype method. This method is used in connection with all bottom-up approaches described above. A building archetype is based on classifying and characterizing aggregated groups of buildings from a highly diverse building stock. The classification is based on similar characteristics of buildings related to the energy demand such as building size class, building age class and energy supply system, that are then aggregated to a group, for example by clustering algorithms. The aggregated group of buildings is then characterized by statistical average values of e. g. heat transfer coefficients, as well as structures and surface areas of envelope components and energy expenditure coefficients of energy supply components within the group of similar characteristics. An archetype typology for the European residential building stock frequently used in UBEM is defined in the TABULA research project and the follow-up project EPISCOPE (Institute for Housing and Environment et al., 2016a). Here, the building archetypes for Germany are classified according to the parameters of building size class and building age class and characterized by the concept of “synthetic average buildings”. A synthetic average building is a virtual building that corresponds to the statistical average data of the building group it represents.

The basic concept behind the use of building archetypes in UBEM is to reduce the complexity of modeling. This is achieved, on the one hand, by requiring only a small amount of data to be collected for each individual building, namely the parameters for archetype classification, and, on the other hand, by requiring fewer building characteristics to be modeled, namely only those of the number of archetypes (Kong et al., 2023; Li et al., 2023) instead of modeling each building individually. In this article, an aggregated building model is therefore defined as an urban building energy model, in which model complexity is reduced through the use of aggregated groups of buildings characterized by synthetic average buildings in the form of building archetypes.

3. Development of local archetypes through stakeholder surveys

In addition to the aforementioned advantages of using building archetypes in terms of reducing model complexity, this method has a positive effect on the comprehensibility of the results and the transparency of the input data and assumptions, particularly when used with stakeholders. However, through grouping heterogeneous buildings into homogeneous archetypes, information about actual variability is lost. This simplification leads to systematic errors whose magnitude depends on heterogeneity within building archetype classes (Institute for Housing and Environment et al., 2016b). A synthetic average building derived from an aggregated group of buildings smooths extremes. Within a building archetype, buildings with particularly low or particularly high energy demands are inadequately represented, which can e. g. result in failures to identify buildings in critical need of refurbishment or in overestimation of energetic refurbishment potentials of individual buildings. Additionally, according to the data classification proposed by Malhotra et al. (2020), three input data categories for UBEM can be distinguished. Primary input data includes data that can be used directly for energetic building simulations, such as heat transfer coefficients of building envelope components. Secondary input data consists of classifiers, such as building size classes and building age classes. Tertiary input data includes statistical sources, such as censuses or the national building archetypes described above. As Rehmann et al. (2025) note, even secondary data is often unavailable, leading to one of the critical sources of error, namely the incorrect assignment of buildings to archetypes due to incomplete or estimated input data. This error is one that exists alongside the systematic error inherent to the archetype method itself, and that results, as mentioned, from data gaps.

Taking into account the systematic deviations described by the so-called energy performance gap, which is caused one the one hand by user behavior concerning e. g. set-point air-temperatures, ventilation behavior, hot water consumption profiles and the use of shading devices and on the other hand by deficient or faulty energy supply system operation that, for example, leads to lower efficiency and can be attributed to incorrect installation, improper control settings, or lack of maintenance, simulated energy demands from UBEM using the archetype method with national archetypes of measured energy consumption deviate on an annual basis, as reported by Oraiopoulos and Howard (2022), between less than 10 % and up to 100 % at the building-level, and in some cases even up to 1.000 %. The higher the spatial aggregation level, the lower the corresponding deviations. On district or city level the deviations are reduced to a few percent, in the same studies, as differences between individual buildings are balanced out.

The accuracy for smaller scales down to the building-level should therefore be increased by extending the bottom-up physics-based UBEM with the archetype method. For this purpose, the national building archetypes should be refined into local building archetypes using input data from stakeholder surveys gathered during the stakeholder process. The developed stakeholder surveys shall be part of the toolbox with automated routines. The resulting bottom-up physics-based UBEM with the archetype method will be elaborated in the full article as the **extended aggregated building model**. The significance of the results of the extended aggregated building models shall be increased towards the existing approach due to the more valid input data. The results shall be used in appropriate visualization methods to answer stakeholder-specific questions and derive concrete energetic refurbishment measures for the building envelope and energy supply system that aim at a climate-neutral energy system at the building-level as well.

The initial results of a stakeholder survey in the first case study, the methodology to derive local building archetypes from them and a comparison of the simulation results with national building archetypes, building-specific stakeholder data, and local building archetypes will be presented for selected buildings in the proposed article.

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