INTEGRATED URBAN ENERGY MODELLING APPROACHES TO SUPPORT THE SWISS ENERGY STRATEGY 2050

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ABSTRACT

We present a discussion of the combined urban energy modelling research efforts that are being undertaken as part of the Swiss Competence Centres for Energy Research project "Future Energy Efficient Buildings and Districts" (SCCER FEEB&D) as well as other related activities at the Urban Energy Systems Laboratory at Empa. These cover a broad spectrum of topics, from urban microclimate analysis, renewable potential and building demand modelling to multi-energy system design, optimisation and control. The findings are intended to aid in the transition of the Swiss energy system in a more sustainable direction by helping to deliver commercially applicable, real-world solutions.

We give an overview of all topics detailing the contribution to the overall research, along with a report on current and expected progress. We highlight the key interactions and dependencies between research areas, and how these have been addressed. This covers data input requirements, model development efforts and application requirements. Links to the associated Holistic Urban Energy Simulation platform (HUES) are also discussed, though the details of the platform are given in a separate paper. A summary is given of the research findings and how these link to the needs of practitioners and industry. We conclude by summarising the current state of the research topics, and raise discussion points regarding possible future directions and lessons learned.

Keywords: urban, energy, modelling, overview, SCCER, FEEB&D

INTRODUCTION

The Swiss Energy Strategy ('Energiewende') 2050 calls for a reduction of CO_2 emissions to <1.5tCO2/p/a by 2050 (from 4.8t in 2011), and also a reduction in energy demand per capita of 43% by 2035 (compared to 2000). The "Future Energy Efficient Buildings and Districts" (FEEB&D) project will support this by enabling the reduction of the energy demand of the Swiss building stock by a factor of five over this period. This will be achieved through the development of new building-related materials, components and systems, and their combination into holistic concepts for implementation via industry partners. One of the key areas is the exploration of new forms of urban energy system, for example systems with decentralised and distributed elements with large fractions of renewables, and comparison to existing approaches. This paper focusses on the modelling work conducted to support this.

Simulation and modelling can be seen as an emerging paradigm that falls between induction (patterns in observed data) and deduction (deriving statements from established facts): facts are embedded in a model, which is interrogated to give data on optimal solutions, thus providing new information. As our recent review paper [1] has established, there is a huge diversity of models and software tools available in the area of urban energy systems.

Modelling the detailed behaviour of such systems is the only plausible method of obtaining the performance metrics needed to assess their technical, energetic and economic viability.

MODELLING FOCUS AREAS

Energy hubs

At the heart of the urban energy system modelling conducted is the energy hub concept [2]: the use of mixed integer linear programming to optimise the supply, conversion and storage of multiple energy streams. The first major development was the upscaling of the model to neighbourhoods [3] in conjunction with building energy simulations. Different components of the set of energy hub model formulations developed are used in all energy system assessments undertaken. The core model is very simple, but many improvements have been developed, and many more are underway. These include the treatment of part-load efficiency and system start-ups [4], incorporation of sizing and minimum permitted loads [5], [6], and the use of a rolling horizon approach [7]. The model has been validated against with dynamic simulations for integrating thermal energy storage [8]. A bi-level approach to the sizing of energy hub components has also proven successful [9]. Future work will follow the complementary strands of improving the underlying MILP formulations (to improve run times and solution accuracy) and increasing the accuracy of the models in reflecting the real systems under consideration (to increase the relevance and usefulness of the simulations conducted).

Networks

Links between buildings are an essential part of decentralised systems. These can be treated as idealised connections that aggregate many building loads, simplified energy transporters that link different hubs, or complicated systems that require detailed analysis. Heating network layout optimisation can be included in the energy hub models as part of the system sizing process [10]. Constraints on electrical connections are also of importance, particularly when exploring the balance between heat and electricity as the means of energy transport in a district, though their nonlinearity makes integration in an energy hub modelling approach more challenging [11]. Future research will aim to better understand the levels of network abstraction required, improve the modelling of detailed networks and further integrate their various constraints into existing models. Looped low temperature networks with bi-directional flow are of specific interest.

Building demands

Modelling of building energy demands is an established and active research domain, and an emerging focus is the performance and interaction of multiple buildings, ranging from small districts to whole cities. We focus on aspects that are critical to urban energy system design. One is the variability between different buildings caused by occupant behaviour and other factors [12], since this affects the concurrency of the loads and thus the magnitude of the peaks. For large numbers of buildings it is impractical to consider them individually in the urban system, thus clustering and aggregation in spatial and temporal terms becomes an important part of the analysis [13]. In future this will be extended to the issue of how many buildings from a large area must be modelled in detail in order to approximate the demands of the district, and how these archetype buildings should be selected. Together with partners in FEEB&D we work on the geo-dependant representation of building demand data, see also below. Where measured data is available, it’s use in the generation of typical hourly demand profiles has been investigated [14].

Renewable energy generation potential

Alongside the energy demands to be met, the potential to supply energy using renewable technologies must be assessed. PV and solar thermal collectors require careful geometric modelling, since in the urban realm many obstructions can affect the solar radiation available. Borehole systems, used in combination with heat pumps for supply and storage, also present significant modelling challenges. Methods have been developed for the evaluation of renewable energy potential integration in neighbourhoods [15] as well as the evaluation of the trade-off between costs and renewable share maximization [16]. Current work is focussed on the development of a method for generating hourly solar potentials for neighbourhoods [17].

INTERACTIONS BETWEEN RESEARCH AREAS

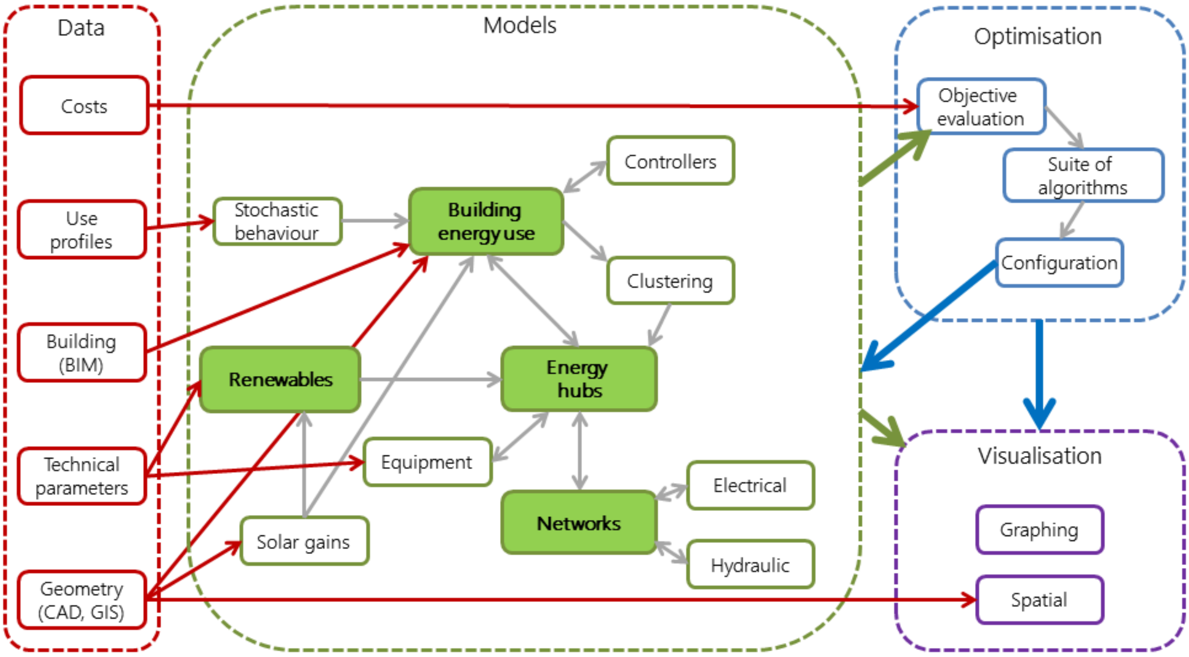

Figure 1: An overview of the interactions between modelling areas (core topics are shaded), and to other key activities. The current state of the HUES platform follows a similar structure.

It is an important part of the modelling philosophy employed here that the urban energy system should be treated as a whole; the interactions that are made explicit in this holistic approach are highly significant. For example, the buildings that make up the urban area must be modelled concurrently with the district energy system so that the exact matching of demand with supply can be established. This is important at a design level when comparing options like the retrofit of buildings against improvement in supply efficiency. Coupling the use of energy in buildings with the supply system model would allow demand-response techniques to be incorporated, however this is computationally much more demanding.

On-going development efforts are focussed on the integration of the modelling areas discussed above as well as the improvement of individual models. The ambition is to facilitate model reuse and integration [18] so that new problems can be addressed more effectively and efficiently. This is achieved via the Holistic Urban Energy Simulation platform (HUES), outlined and demonstrated in [19]. This approach is in contrast to the development of a unified, homogenised program that can assess many domains at once; this may become unmanageably complex and hard to maintain over time, though there are clearly benefits regarding computational integration of the domains.

Common data input requirements determine one aspect of integration between modelling areas, as it is highly desirable to use the same data source for multiple aspects of the system to ensure comparability. For example, the same data on geometries, surroundings, topology and weather should be used for analysing solar gains to buildings as for analysing the potential for PV generation. This requires a means of accessing common datasets from different models, and the data storage requirements needed to achieve this amongst multiple project partners is an ongoing challenge. The geo-dependence of demands and supplies is another example of this, and the use of GIS tools for both demand and supply aspects is also under development.

The computational optimisation of building designs for low-energy performance is a topic of significant and growing interest [20], and this is now being extended to problems concerning urban-level issues, including energy systems. Recent research in this area has used genetic algorithms in combination with MILP to form a bi-level optimisation process that addresses design and operational aspects using the best tools for the respective problems [9]. Other work in this area includes speeding up the process of finding good building-level parameters by using different resolution models [21], and investigating optimal urban forms for multiple buildings to minimise energy use across the district [22].

APPLICATION EXAMPLES

Typical neighbourhood configurations within Switzerland have been used as application cases to demonstrate potentials and possibilities towards achieving the goals of the Swiss Energy Strategy 2050. The methods and models developed as described above have been specifically tailored to address these research questions, and in a further step are being deployed on demonstration cases. So far demonstration cases include a rural neighbourhood [15], a new city quarter [23], an existing semi-rural neighbourhood [24], industrialized and office areas [25] and more urban locations. The results will be used to make recommendations on how the envisioned goals can be achieved, and in a second step to provide industry and practitioners with guidelines and methods to translate the research results into practice.

Building demands

The current energy consumption of buildings in Switzerland will be reduced by increasing renovation rates. The reference model approach developed [14] has been deployed on various cases (e.g. [24]) to demonstrate the renovation actions (e.g. window replacement, façade insulation, system replacement) and timeline that would be necessary to achieve the goals by 2050. The energy hub approach has also been used for a sensitivity analysis exploring the impact of climate change on building energy demands, and the affect this has on urban energy system design [26].

Renewable energy generation potential

Renewable energy sources available include photovoltaic and solar thermal collectors, biomass based electricity and heat production, and small hydro power installations. However, the potentials vary significantly depending on geographic location and type of buildings and neighbourhoods. As demonstrated for a rural neighbourhood in the mountains, hydro power offers a huge potential for electricity generation for this specific location, whereas photovoltaic installations are limited to those roof surfaces where buildings are not historically protected [15]. The energy hub approach combined with the assessment of hourly photovoltaic potentials can evaluate which roof surfaces are most beneficial for photovoltaic installations in terms of costs and emission reduction; the ideal trade-off between local electrical storage sizes and electrical grid feed-ins are also demonstrated [16].

Update of urban energy systems

Existing energy systems in neighbourhoods offer significant potential for improving energy efficiency, reducing CO_2 emissions and reducing the import of fossil fuels. A study on the village of Zernez demonstrates to what extent the village can be energy sustainable (with no energy inputs from outside), and how building-related CO_2 emissions can be dramatically reduced [15]. Another study conducted in the city of Rheinfelden demonstrates the potential for integrating local thermal energy storage, and investigates the ideal size, type and location of the storage [8], [24].

Present modelling work has focused on the design and performance assessment aspects of urban energy systems, however, operational aspects are also important. In the energy hub in the presently built NEST[1] building at Empa, control aspects are the main focus.

CONCLUSIONS

We have outlined the significant research contributions delivered so far regarding urban energy system modelling within the FEEB&D project and the Swiss Energy Strategy 2050. We highlight the core modelling activities undertaken, the need for a holistic approach and the critical interactions this exposes, and the assessment cases used. This summary may be of use to others undertaking such a programme of model development in other contexts.

The control of energy hubs poses many challenges, including how to match the different time scales for thermal (years to hours) and for electric microgrids (μs), and will be at the core of future research. NEST will be an important test bed for these issues, and also for the comparison and verification of energy hub results with measured data as well as with more detailed models.

Expected future contributions in line with the roadmap of the FEEB&D project[2] include the further development these models within the framework of the HUES platform. These will support the assessment of new urban energy concepts, their comparison with existing systems, and development of best-practice guidance for their implementation in industry.

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