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Workflow automation for combined modeling of buildings and district energy systems

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In many urban contexts, energy systems are undergoing fundamental change towards more interconnected system layouts. Appropriate planning tools are necessary to guide this transition towards more energy efficient system designs. Thus, the aim of this paper is to present workflow automation approaches to model buildings and district energy systems for dynamic simulation and integral system analyses. For data collection and management, we use a Geographic Information System coupled with a PostgreSQL database. In this paper, we present the software tools TEASER and uesmodels which use this data to automatically generate dynamic building and district energy system models in the modeling language Modelica.

To demonstrate the application of these tools for workflow automation, we analyze a university campus with 39 buildings. In one scenario, an optimization led to an improved heating curve, with which yearly primary energy demand in the model was reduced by 0.9%. In a second scenario, the retrofitting of all building envelopes in the district energy system reduced primary energy demand by 16.0%. These examples showed that the presented approach is suited to evaluate options for improving district energy system, ranging from improved operation to changes in system design, and a combination of both.

1. Introduction

In many countries the energy supply of buildings accounts for a major share of primary energy demand [1]. In many urban contexts, energy systems involving buildings are undergoing fundamental change that leads to a more flexible and interconnected system layout. Reasons for such change lie in the increased distributed generation of electricity [2,3], integration of renewable energy sources [4], and the blurring boundaries between systems using different energy forms. These blurring boundaries lead to multi-energy systems, which try to make best use of all available forms of energy including interconnections and transformations between energy forms like electricity, heat, and cooling [5].

Appropriate planning tools are necessary in order to guide this transition towards more energy and cost efficient system designs [6,7]. Yet, one of the major challenges for such planning tools is the system complexity [8,9], which significantly increases with scope and scale of the energy systems analysis. As a result, different approaches for simplification in district energy system analyses have been investigated. In order to simulate and optimize the system, some studies have reduced the number of buildings by lumping similar buildings together as a representative consumer station (see e.g. Refs. [10,11]). Also, simulation time can be limited to representative periods, which can be seasonal, monthly or daily (see e.g. Refs. [12,13]).

Nevertheless, a detailed dynamic system model could help to prototype different control and energy management concepts and compare different retrofit options on a district scale. Important challenges on a way to such a model are to provide reliable results and reduce manual effort as well as computation times. As a contribution towards a dynamic system model, the aim of this paper is to present workflow automations for simulation-based analyses of district energy systems. For this presentation we will focus on the thermal energy supply, distribution, and demand of a university campus with 39 buildings.

2. District energy system modeling approach

In this chapter, we will present workflow automation tools to evaluate different options of district energy system design and

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operation by simulating the dynamic system behavior. This process involves data collection of the current system design, the creation of a system model for each considered option, and the analysis of results from dynamic simulation of the entire system. For data collection and management, we use a GIS (Geographic Information System) coupled with a PostgreSQL database. Basic information about the building stock from this database is used to parameterize low order building models and simulate each building's heat demand. The network modeling routine uesmodels combines these heat demand time series with network information from the database to automatically create a full district energy system model. To facilitate this modeling approach, we designed component models for buildings, substations, pipes, and supply plants in the modeling language Modelica. This allows us to fully automate the model parameterization and the system modeling by connecting instances of the modular component models.

2.1. Data collection with GIS

As pointed out above, one problem with the high complexity of district energy systems is the large amount of data necessary to describe the entire system. In order to prevent efforts for collection and management of this data from becoming prohibitively cumbersome, we rely on limiting the amount of data close to a needed minimum and the use of appropriate data management tools. Using a GIS representation of the district creates a user friendly interface to collect and display the data and put it into a spatial context. Coupling the graphical GIS representation of the district with a database system allows for fast access to the data, which helps with automating its analysis and its use in automated modeling routines.

For the presented implementation we use the software tool QGIS for visualization of the city district and as an interface for the data collection process. QGIS is developed open source, freely available and widely used. It offers a wide range of GIS features, among them the possibility to couple it with a PostgreSQL database by means of a software plug-in. As PostgreSQL itself is also an open source project and provides a fully functioning SQL database solution, this coupling provides a powerful data management tool that is freely available and well suited for the application presented in this paper.

The database collects information about the supply plants, buildings, and the network's pipe segments. Another important part of the data is information about the connections between individual components. In order to describe these connections, we use a graph notation, in which each pipe segment is represented by an edge connecting two nodes. Each node represents a location in the district. Thus, buildings, supply plants and pipe junctions are all represented by nodes. The different types of nodes can thus be interpreted as sub-graphs without edges, with each type having a different set of data associated to it.

This data structure allows the user to mark buildings, supply plants, and junctions on the graphical representation of the district in QGIS as nodes and connect these nodes by edges to define pipe paths. By adding information like year of construction to building nodes or length and diameter to the pipe edges, the user can create a functional description of the entire system. As the data is all stored in the SQL database, it can easily be retrieved by automated queries. This approach facilitates the use of data in the automated steps described in the following sections. In order to further facilitate the use of this database concept with other districts and cities, the database schemes are built following the CityGML [14] structure with slight modifications and using the extensions of the Energy ADE and the Utility Network ADE. Thus, the database can be prepared to exchange data in CityGML format more easily in the future.

2.2. Automated simulation of building heat demands with TEASER

Buildings' heat demands are a key aspect of a detailed district energy simulation, as these demands determine the system's heat load and, as a result, its dynamic operation. Several building models and software tools are available to simulate a building's heat demand given information about the building and the outdoor conditions. Useful data about the building includes the building's size, heat transfer properties of its envelope, and its patterns of usage. Considering the building stock of a city district, such data is often not available in the required level of detail for each building. Therefore, we use a simplified building model that can be parameterized with available data and assumptions derived from statistical analyses for unknown values.

To model the buildings' heat demands, we implemented the modeling approach described in German guideline VDI 6007 [15] in the modeling language Modelica. The model is freely available and has been described in Ref. [16]. For illustration, Fig. 2 shows the resistance-capacitance network with which the buildings thermal energy balance is modeled. In this approach, all outside walls are aggregated into one representative capacitance, which is connected to the outdoor air and the indoor air via one thermal resistance each. All inside walls without connection to the outdoor environment are similarly modeled by one capacitance and a thermal resistance towards the indoor air volume. Inner loads and solar radiation are also connected to this indoor air volume, which by itself is again represented as a thermal capacitance.

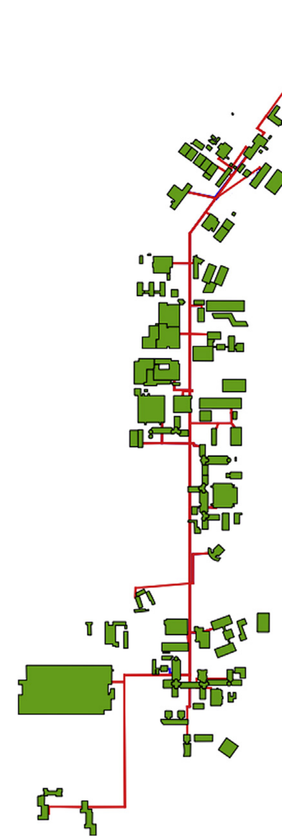

Fig. 1. Graphical GIS representation of the buildings and the district heating network for the investigated university campus.

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