Energy demand models for buildings in a smart cities context

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Energy is one of the major drivers in smart cities along with smart environment and smart living. The role that buildings can play in the development and operation of smart energy cities is important, due to the large share of energy use they are responsible for and the smart energy solutions they can potentially integrate. The increasing number of smart cities initiatives and their focus on city level energy policy management has emphasised the need to move from the traditional micro-level building energy modelling towards the development of aggregated energy demand models. To accomplish that, methods that can be scalable to higher levels of aggregation, ranging from clusters of buildings to neighbourhoods and cities are needed.

The present thesis aims at providing enhanced modelling methodologies that provide building energy demand related insights in a high spatial and temporal resolution, which can help to evaluate energy policies and demand side management strategies. The main objectives of the thesis are to propose and investigate engineering-based approaches, statistical methods and data mining techniques that can contribute to the accurate building energy demand modelling at urban scale; to determine the potential that buildings can have on the stabilization of the energy grid and the flexible operation of the energy system -considering a smart energy cities context- both at building level and urban level; and finally, to indicate the suitability of each category of proposed modelling methodologies and provide guidelines for future investigations.

The most important findings of the research performed in this thesis are summarized in the following:

- Aggregation of building energy demands is enhanced with archetypal approaches that significantly reduce the modelling and computation time. The minimum information level to model reliably a housing stock contains basic typological information including knowledge about building construction characteristics and floor areas, as well as current refurbishment state that greatly affects the overall heat transfer coefficient of the building envelope. Uncertainty in input parameters is decisive and may exceed uncertainties that are induced by model simplifications.
- The availability of measured energy data at large scale enables the application of simplified thermal models on housing stocks to gain insights concerning building characteristics and indoor conditions. The heating setpoint temperature is key assumption of occupant behaviour that determines heating demand in cold climates. The use of an urban dataset to determine temperature setpoints and thermal transmittance for thousands of buildings is demonstrated. The distributions of these parameters at urban scale can be particularly beneficial for urban building energy models and for determining energy refurbishment measures that have been applied to the thermal envelope. The use of this thermal modelling approach at urban scale can be adopted by utilities and authorities that aim at estimating or validating basic characteristics of buildings at urban or national level.
- The application of data mining methods to smart meter data unveils hidden correlations between energy demand and its influencing factors, as well as identified consumer behaviour patterns and variability over time. A clustering-based analysis is proposed that consists of three main modules: data preparation, clustering and load profiling analysis. District heating residential customers are classified into different groups based on their consumption intensity and representative patterns. Typological building characteristics such as building age and floor areas are found to be more correlated with heating data rather than family size and age of occupants, hence they can still be used in new classification schemes for housing stocks with regards to energy use intensity. The high energy intensive groups of the examined consumers have more predictable and regular behaviour than the low energy intensive ones and are therefore suitable for predictive analysis.
- In the smart energy city context, where the increased penetration of volatile energy sources calls for balancing the supply and demand sides, buildings can actively contribute to the stabilization of the grid. The thermal flexibility potential that the building stock can offer to the grid varies significantly mainly based on the thermal transmittance of building envelope, heat capacity of internal wall mass, solar gains and ambient temperature. The quantification of thermal flexibility potential is done in terms of the degradation of indoor comfort that people perceive after a specified heating control strategy and the energy savings or peak load that are created after this event. Optimized scheduling of a grid-connected heat pump is proposed based on a price signal that reflects the lack or excess of renewables to the grid, which can lead to peak shaving and cost savings that are highly dependent on the input prices.
- When optimizing the whole energy system operation, the utilization of the thermal mass of buildings for heat storage is introduced as an additional source of flexibility to the system. An archetypal approach to characterize the building stock according to the construction age and refurbishment level is employed to better represent the respective flexibility potential of each building category. A flexibility indicator representing the viability of the different scenarios of the system setup is introduced and shows that the utilization of the building thermal mass would be more beneficial to future energy systems than current district heating systems, due to the larger capacities of intermittent generation that can be successfully integrated in the district heating supply.

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