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A framework for agile optimization of district energy systems

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Abstract

This paper presents an approach to tackle output uncertainty in District Energy Systems' performance for variable time horizons and progressive changes in urbanization processes and energy policy, which we define as agile optimization of District Energy Systems (DES). Multi-objective optimization of DES provides non-dominated tradeoff solutions among conflicting objectives in the form of a Pareto-front. A single solution needs to be chosen from the Pareto-front to proceed further in the urban design process. To facilitate this, an uncertainty analysis is performed on the parameters corresponding to equipment lifetime and operational costs of DES. The method is tested on an existing neighborhood with 24 buildings in the city of Zug. The energy systems configuration of the neighborhood was optimized and uncertainty analysis was performed on the Pareto-front to identify the most reliable system configuration. The final solution chosen, has the highest frequency (30.8%) of being the most stable solution. It also has the highest probability (96%) of being below the Cutoff point of Total Annualized Costs.

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1. Introduction

District Energy Systems (DES) consists of thermal and electrical supply systems designed to attend the energy requirements of a neighborhood or a district. For a given system configuration (number of buildings and street layout), the design of DES comes with a wide range of options to choose from such as technology, equipment size, and dispatch strategy. Each of these options is to be evaluated in order to provide the solution which has minimal costs and minimal CO_2 emissions.

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Planning of a DES is riddled with uncertainties due to demographic growth, demand uncertainties, uncertainties due to climatic change along with technological uncertainties. As DES is planned for a long time-horizon, the energy system to be in place needs to be robust to handle such uncertainties. One approach is to design for the worst-case scenario, which inherently faces two issues. Firstly, to predict the worst-case scenario over such a long time horizon (e.g., 60 years) is deemed to have its drawbacks in terms of 'confidence'. Secondly, even if the worst-case scenario is predicted, it might not occur often. This makes the solution too conservative and thus cost for the efficiency of the system [1].

A new generation of agile optimization algorithms could facilitate the design of more adaptive and/or robust DES. These systems should be able to cope with morphological changes in districts as they are transformed and constructed in time. This involves that energy systems are constantly re-optimized in relation to plausible changes in urban form, building technology, and decentralized/centralized energy production. The approach has the potential to reduce financial risk and general uncertainty in the decision-making process of urban development and underlying energy structure.

2. Methodology

The City Energy Analyst (CEA) [2] is used to model, simulate and optimize the DES. CEA is an integrated framework to evaluate the performance of a neighborhood from the perspective of energy efficiency and supply systems in the context of urban transformation. CEA provides a holistic view of demand and supply of DES using modeling techniques and spatiotemporal visualization model. For more details on CEA, readers are referred to the paper on CEA [3]. In this work, CEA framework is expanded to consider sensitivity analysis.

In CEA, the design of a DES is divided into three levels (Figure 1), namely, Urban Designer Level, Energy Systems Level Optimization (ESLO) and the Network Level Optimization (NLO). In the Urban Designer Level, the parameters such as number of buildings, street layout are decided by the urban designer based on the plot area, purpose of the neighborhood, and the budget constraints imposed on the project. These details are then input to the ESLO which in turn returns the performance of the design in terms of the objectives such as costs, emissions and the amount of risk involved with the design. This level uses heuristics and the design acumen of the urban designer in making design decisions.

During the ESLO step, the energy system configuration is chosen. This provides information of which buildings are connected to the centralized district heating/cooling network, and which buildings are decentralized. As a first step, the building demand in terms of heating, cooling, electrical loads is calculated using the demand module developed in [3]. Based on the buildings' demand, the configuration of buildings selected in the urban designer level, the energy systems configuration is optimized with the approach of [3]. This configuration details the technologies used to meet the individual building demand. The energy systems configuration is then sent to NLO which in turn returns the thermal loss and hydraulic losses incurred in the network. Details from NLO along with the energy systems configuration of ESLO are used to calculate costs, emissions, and primary energy.

In NLO, based on inputs from ESLO, (i.e., buildings connected to the various production plants like District Heating/Cooling) the piping network is detailed following the street layout or service tunnels (pipes are laid under the streets). Along with this, the size of production plants is decided based on the demand of the buildings connected in the piping network. If the demand of any building is not satisfied by the centralized network, then individual heat pumps are installed to meet the demand. To quickly identify the network based on the connected buildings, minimum spanning tree algorithm is used.

Multi-objective optimization (MOO) is used to solve the various levels in the design of DES. MOO is done using non-dominated sorting genetic algorithm (NSGA-II), which uses the evolutionary operations like mutation, crossover, and selection [4]. Table 1 summarizes the various decision variables used by the optimizer. In MOO, the solutions are provided as a Pareto-front which represents non-dominated trade-off solutions of multiple objectives used in the optimization. Thus for a design configuration developed by the urban designer, there will be multiple solutions corresponding to the trade-off of costs, emissions, and primary energy. As all these solutions are non-dominated, there