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Metamodeling energy indicators in neighborhoods with growing deployment of heat pumps and rooftop photovoltaics

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Abstract

This paper evaluates simple metamodels to predict local electricity demand and grid restrictions, in residential neighborhoods with heat pumps and photovoltaics. The procedure and challenges of developing such models are described. Modeling is based on results obtained from detailed simulation of buildings and the grid. Linear and logistic regression models are developed for electricity demand and minimum voltage respectively, as a function of neighborhood characteristics, related to both building and electrical network properties. The paper shows that linear regression can be used for a first evaluation of electricity demand. For voltage violations, logistic regression gives acceptable results; however, more complex models are needed to approximate voltage levels.

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Keywords: metamodeling ; linear regression; logistic regression; grid impact; electricity demand; residential neighborhood; heat pump

1. Introduction

Evaluation of building-related energy policy measures, such as refurbishment and renewable energy utilization, is typically performed at building stock level. The challenge in this approach is to account for local technical aspects, such as interactions at the electricity distribution grid, as they can influence the feasibility and effectiveness of policy measures, by limiting, for instance, the permissible penetration rate of heat pumps or distributed generation. Comprehensive dynamic models of building and energy systems at a district level can provide insight into these effects, but are computationally intensive. To overcome the resource and time constraints of detailed simulations, and

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to allow for faster and simpler policy evaluation, surrogate models (*metamodels*) could be employed. This paper, therefore, develops and evaluates basic regression models as metamodels to predict local annual electricity demand and grid voltage violations from detailed simulation results. The response variables are modeled as a function of neighborhood characteristics, related to buildings, as well as electrical network properties for the voltage violations. Data and detailed simulation models for this purpose were available from previous work, for a Belgian residential context, and statistical modeling was performed with the Matlab statistics toolbox. The paper aims to discuss the procedure and challenges of creating such metamodels, and to evaluate their performance.

2. Methodology

Metamodels are often used in engineering problems to approximate computationally intensive processes and to provide better understanding of relationships between predictors and the response. Wang and Shan [1], and Simpson et al. [2] give an overview of the most common metamodeling strategies and methods. First, a simulation experiment based on the complex model was performed to produce the data for metamodeling. This experiment is described hereunder. At this stage, a full factorial experimental design was used to better distinguish the effect of each factor. Various metamodel types exist, differing in fitting algorithms, simplicity and flexibility, with performance depending on the problem. Polynomial regression has been extensively studied and used in many applications, as it is easy to interpret and implement in any statistical software. Such model has the form $y = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + \varepsilon$, $\varepsilon \sim iid\ \mathcal{N}(0, \sigma^2)$, where y is the response variable, x_1 to x_k are the explanatory variables or predictors, β_0 is the intercept, β_1 to β_k the regression coefficients corresponding to the predictors, and ε is the random error term. The model is linear in the coefficients β, but predictors may include interactions and quadratic or higher degree polynomial expressions of the variables x. Logistic regression is a generalized linear model, using the same basic formula and the logit link function to model the probability of a categorical outcome. Both models were employed in this paper. To test model performance and select among variants, 10-fold cross-validation was used.

Two indicators have been selected for metamodeling, namely the total annual feeder electricity demand (E_D), and the feeder absolute minimum voltage (U_{min}). The first is a measure of the average expected load for feeder sizing. U_{min} can be used to detect feeders with potential overloading due to heat pumps and back-up electric elements. Standard EN 50160 [3] prescribes lower voltage limits at 0.85 pu at all times, and 0.9 pu during 95 % of time each week.

2.1. Simulation experiment

The entire simulation framework for analysis of grid impact in residential neighborhoods has been developed previously. All information on models and assumptions can be found in Refs. [4] and [5]. The framework provides the models and experimental design to simulate residential distribution grids for a variety of household loads and generation, and evaluate grid performance indicators. All simulations of buildings with heat pumps, the PV generation and the network are carried out in Dymola, using the Modelica `IDEAS` library, while stochastic occupant behavior is included from the StROBe package of openIDEAS [6]. This approach allows for detailed models of thermal systems, capturing their dynamic behavior in high resolution to provide input for the electrical simulations. One-year simulations are carried out for typical Belgian weather conditions.

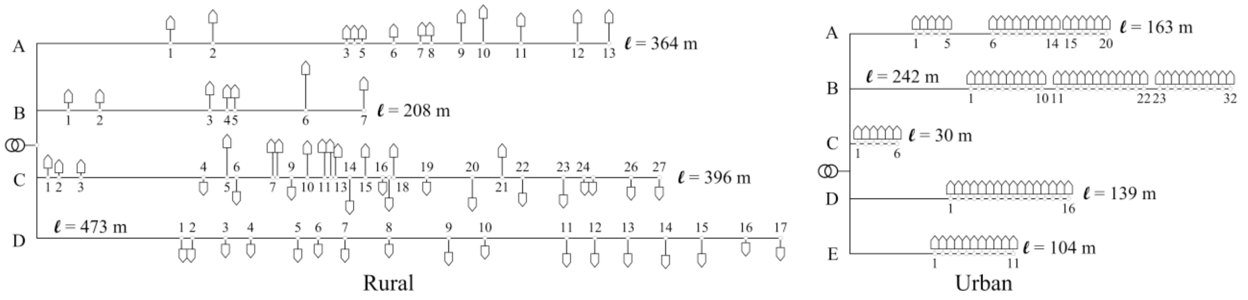

Fig. 1. Simulated rural (left) and urban (right) distribution islands with 4 and 5 feeders respectively, representing typical Belgian grids [7].