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Simplified model to predict the thermal demand profile of districts

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ABSTRACT

Extensive research works have been carried out over the past few decades in the development of simulation tools to predict the thermal performance of buildings. These validated tools have been used in the design of the building and its components. However, limited simulation tools have been developed for modeling of district energy systems, which can potentially be a very laborious and time-consuming process. Besides many associated limitations, providing a realistic demand profile of the district energy systems is not a straightforward task due to high number of parameters involved in predicting a detail demand profile.

This paper reports the development of a simplified model for predicting the thermal demand profile of a district heating system. The paper describes the method used to develop two types of simplified models to predict the thermal load of a variety of buildings (residential, office, attached, detached, etc.). The predictions were also compared with those made by the detailed simulation models.

The simplified model was then utilized to predict the energy demand of a variety of districts types (residential, commercial or mix), and its prediction accuracy was compared with those made by detailed model: good agreement was observed between the results.

1. Introduction

Evidence from a variety of research suggests that the built environment contributes to the global energy consumption and to the production of greenhouse gases that impact climate change. In particular, building sector uses about 40% of the world-wide total energy [1]. This fact highlights the importance of targeting building energy use as a key strategy to minimize energy consumption. Hence, district generation and cogeneration systems together with energy storage technologies and energy efficient buildings have been suggested as approaches to achieve the future goal of energy road map defined by IEA [2].

There are number of challenges in the design, construction, and operation of energy-efficient district heating system; simulation tools are addressed among one of the essential lacks when such systems are designed and implemented. Over the past few decades, many simulation tools have been developed for predicting the performance of energy efficient buildings such as Energy plus [3], TRNSYS [4], eQUEST [5], etc. These simulation tools are broadly used to investigate the effectiveness of integrating energy storage and renewable energy resources to the building [6–9]. Nonetheless, only limited research can be addressed toward the development of simulation tools associated with the prediction of the energy demand at the district level [10,11]. Furthermore, detailed building simulation tools (e.g., TRNSYS, EnergyPlus) are utilized for the energy analysis of the district energy networks; while other tools, such as HOMER Pro [12], utilize the predicted demand profile from other software or measured data in the form of a user-defined profile as an input to the DHS. In both scenarios, existing tools cannot satisfy the current need for a dynamic, reliable, and accurate tool that can envisage a demand profile of a large-scale district network in a timely manner. As a result, the simplified methods emerged as popular options for prediction of demand profile of district networks.

Development of a practical and simplified demand load model for a building stock is a complex task and requires a high level proficiency. Since the demand profile of a building is varying as a function of a time. This variation has a stochastic behavior than a deterministic behavior and as a result increases the level of the complexity of the model [13–15]. In a district heating system (DHS), with the high level of the building heterogeneity, particularly in terms of urban settings, and also diverse properties and corresponding demand. Thus developing an accurate and reliable model that could predict the heating demand of the entire district in a timely manner is essential. Different methods have been developed to predict the demand of district systems, which can be categorized as (1) historical methods [16,17], (2) deterministic methods, and (3) time series predictive methods [18].

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Historical (times series) methods have been widely used at the building level while deterministic methods are more favorable at the district level due to their high level of dependency to data for training proposes, especially in the case of large DHSs with a diverse building type [10]. Many studies have also addressed the utilization of simplified deterministic models to predict the demand profile of DHSs as can be seen in Table 1.

These methods have mainly been adopted to predict buildings' total energy consumption and maximum demand (e.g., [19,21–23,26,27]) while predicted the actual demand of the system in a smaller interval such as an hourly basis (e.g., [20,25]). Even though DHSs are mainly designed based on the total energy consumption and the maximum peak system demand, detail demand profile of the network is further required to improve the system efficiency and to enhance the energy distribution management. Aside from the complexity of the prediction, the accuracy is another limitation of the existing models. Table 2 compares the prediction accuracy of some related studies at both building and district levels.

Three primary sources of discrepancies identified for the existing models are occupant behavior, neighborhood interference, and scaling effect. Since most of the models do not directly take into consideration the occupant behavior influence, the accuracy of the prediction, particularly at the building level, is observed to show a much lower value in many cases. In contrast, the accuracy is significantly higher at the district level with more diverse building types due to the fact that several building influencing parameters at a district level overlap one another and therefore they compensate the accumulated error at some points; As a consequence of this misleading schedule prediction, most of the previous works are only focused on one type of building in order to improve their simulation accuracy.

The unmeasured effects of the district/community on buildings such as shared walls between them and also the solar blockage by the adjacent shadow casted from surrounding buildings significantly impact on the prediction of the heating demand schedules. Most of the existing models are designed as a standalone building, barely representing the complexity of an urban/district setting. Indeed, the first assumption in the modeling of a standalone building is that the entire building shell receives solar radiation and exchanges heat with the surrounding environment.

Finally, many of the recent studies are utilizing scaling methods to represent the entire housing stocks (see Tables 1 and 2), which is another source of discrepancy in the demand schedule prediction of DHSs. Commonly used methods are area weighted scaling method; in which the demand profile of the reference building has been multiply by the total district area over reference building area ratio in order to predict the demand profile of the entire district or number based in which, the demand profile of the reference building has been multiplied by the number of buildings within an archetype. In such approaches, the level of simplification in the representation of the building stock modeling is observed to be very high. For example, the orientation and other geometrical diversity of the buildings are mainly neglected compared to the reference building within a defined archetype. The above addressed shortcomings in demand profile prediction are more magnified in the case of having larger DHSs with more uniform building type. For instance, in the case of Japanese district [19], German district [28] or Swiss district [27], with more homogeneous building type, the simulation accuracy is presumably much lower compared with Italian district [23] which has more heterogeneous building archetypes. To this end, this paper aims to propose a new procedure for predicting the heating demand schedule of the DHSs using simplified models. For this purpose, autoregressive multiple linear regression (MLR) and autoregressive multiple non-linear regression methods (MNLR) are utilized to develop a series of demand schedule for a case study of validated DHS.

Table 2
Accuracy level at district level vs. building level.

District level			Building level		
Ref.	Country	Error (%)	Ref.	Country	Error (%)
[19]	Japan	18%		USA	11–23%
[20]	USA	10–13%	[25]	Greece	12–55%
[21]	Italy	10%	[28]	Germany	5–50%
[23]	Italy	4%	[28]	Germany	18–31%
[24]	Italy	8%	[29]	Germany	1–60%
[28]	Germany	21%	[30]	Switzerland	6–88%
[28]	Germany	7%	[27]	Switzerland	8–99%
[30]	Switzerland	8%			
[27]	Switzerland	9–66%			

2. Methodology

The first step in defining the new procedure to predict the heading demand profile of a district is to identify the entire building stock and to segment it into different building archetypes. In order to have different building archetypes, a reference building has been defined for each archetype, which represent all the buildings within that category. Using the geometrical properties and actual demand schedule of the reference building, either determined from a measurement campaign or using a verified detailed model, two linear and nonlinear regressive models have been developed to predict the demand profile of a entire district.

Using these regressive simplified models (linear and nonlinear), the heating demand of two random buildings (**R1** and **R2**) and three different district energy systems have been predicted. Results from the simplified models then compared with the one obtained from a detailed modeling of the same buildings.

2.1. Building stock model (BSM)

To develop a simplified model to predict the energy demand profile of buildings, the entire building stock is initially segmented into predefined building archetypes to represent a group of similar buildings. In general, building segmentation in a building stock requires a thorough identification of the attributed parameters in

Table 1
Summary of simulation methods in the DHS.

Ref.	Country	Method	Scaling	Building type	Output
[19]	Japan	Archetype/survey	No. per archetype	Residential	Total EUI
[20]	USA	eQUEST/comprehensive modeling/archetype	Area weighted	Mixed	Hourly/total consumption
[21]	Italy	Regression analysis of measured data	Area weighted	Residential	Total consumption
[22]	Finland	Archetype/linear development using REMA	No. per archetype	Mixed	Total consumption
[23]	Italy	Archetype/comprehensive modeling	Area weighted	Mixed	Total consumption
[24]	Italy	Simplified equivalent resistance	Area weighted	Residential	Total consumption
[25]	Greece	Archetype/comprehensive modeling	Area weighted	Residential	Hourly/total consumption
[26]	Germany	Simplified equivalent resistance/degree day	Bldg. by bldg.	Mixed	Total consumption
[27]		Archetype/simplified model/adjusted HDD	Area weighted	Residential	Total consumption