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Towards a multi-energy multi-user monitoring and decision-making tool for district heating networks

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KEYWORDS – District Heating, Demand-side management, Supply-side management, Monitoring, Smart controlling, Thermal load management, Renewable Energy Sources

ABSTRACT

Advancements in thermal systems has led to the necessity of large-scale thermal energy management layouts, such as the District Heating Networks (DHN). However, with the addition of multiple types of thermal load producers in those networks (prosumers, seasonal storages, Renewable Energy Source (RES) systems), their complexity also increases. Therefore, tools are also necessary for their optimized operation. The purpose of this work is to examine and develop the concept of a decision-making tool used in multi-energy DHNs. Its core aspects are the monitoring and controlling of the consumer substations. The main concept is that thermal producers attempt to create thermal load schedules for the consumers, while optimizing criteria set by the producers. At the same time, consumers and their needs are also considered, essentially affecting the thermal load schedules. In short, the tool could achieve a bidirectional communication between thermal load producers and consumers, until a consensus is reached about the thermal load schedule that is to be used at any time. More specifically, its function revolves around the thermal load management, and more specifically the demand-side and supply-side categories. Concerning the former, optimized demand-side management requires the evaluation, enhancement, and exploitation of the thermal flexibility of the DHN. Recent works have inferred that primary parameters for that purpose are the controlling strategies, thermal mass existing in the substation, as well as knowledge of the thermal comfort of the consumers. It is important that both the monitoring and the controlling ability of the proposed tool contribute appropriately to meet those demands. Furthermore, the controlling aspect of the tool requires that each substation is able to simulate and assess the thermal load schedules proposed by the producers, so that feedback is given back to the latter ones. For this purpose, simulation models of the substations should be available for use. Study of the literature has shown that the best approach is to implement surrogate modeling techniques, in combination with the monitoring aspect of the tool, as it is cost-effective and requires significantly lower computational power. Finally, regarding the optimal supply-side management, it can be achieved by exploring the multi-energy system options available, since the usage of RES systems is highly encouraged. Currently, the methodology layout of the proposed tool provides the starting point for setting a supply-side management optimization approach.

1. INTRODUCTION

Over the past century, advancements in District Heating Network (DHN) technologies have led to the implementation of thermal network that enables the large-scale energy production and distribution to end-users (consumers), which provide economic and environmental benefits [1-3]. The latest generations of DHNs have the potential to integrate Renewable Energy Source (RES) systems for the production of required thermal energy, have their operating temperature levels reduced [3, 4], as well as enable the decentralization of the heat producers in the thermal grid [5]. However, challenges also emerge, like the delayed heat propagation which affects the proper planning of heat demand provision [6]. Consequently, thermal network load management has become a significant issue to be looked into [7, 8].

Thermal load management in DHNs can be split into the supply-side and the demand-side management. More specifically, the supply-side management is related to using different energy resource systems to provide the required heating loads. On the other hand, demand-side management concerns the ability to shift the loads throughout a daily thermal network operation, according to set optimization criteria.

Furthermore, thermal load management is dependent on the thermal flexibility of the system. Thermal flexibility can be described as the ability of a system to change its operational load injection/extraction by exploiting the variable thermal system power and adaptability speed [9], as well as thermal mass of buildings/network/storages [10]. In other words, DHN flexibility depends on thermal capacity and the controlling strategies that are used in the network [10-12]. There are multiple works that seek to enhance and exploit the existing thermal flexibility of the system [13, 14], as well as several studies that examine controlling strategies [15, 16]. However, there is a need for the combination of the above approaches in a methodology of decision support system for managing the thermal loads of a DHN.

In addition, attention must be given on the ways concerning on the energy mix that should be provided in order to produce the necessary heating loads of a DHN. Several important criteria that are to be considered on that matter are minimizing the carbon footprint and reducing energy consumption [17], as well as maximizing contribution of available RES energy [18]. Moreover, some criteria may relate with economic and environmental cost reduction [19].

Therefore, the purpose of this work is to provide information concerning the concept of a decision support system for the management of the heating loads in DHNs. As it is, the concept can be divided into two categories, i.e., the controlling and the monitoring aspects of the tool. The following section provides information on both of those. In Section 3, a discussion regarding the thermal load management using the proposed tool takes place, analyzing the results that have emerged from existing works, as well as the lessons learned so far.

2. THE OVERALL CONCEPT

2.1 Overview of the decision-making tool

The proposed decision-making tool of a DHN is viewed in Figure 2.1. Its main function is to:

- Provide information on the available heating load to the consumers.
- Get feedback from the consumers regarding the adequacy of the available load that could be provided to them.

This tool features bidirectional communication between the thermal energy producers/distributors and the consumers in a network, in order to reach a consensus about the load schedule that will be implemented.

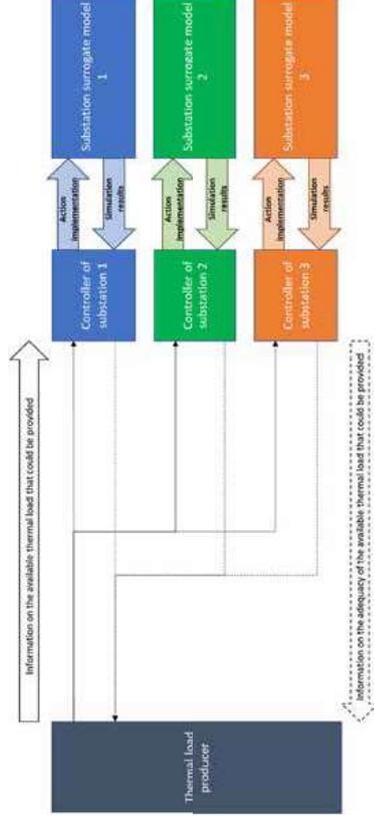


Figure 2.1: Overview of the support tool concept

The algorithmic procedure of the tool is provided in Figure 2.2. Briefly speaking, the steps can be summarized as follows: Initially, the thermal load provider proposes a thermal load schedule to provide to the consumers. This information is transmitted to the consumers, which use controller-embedded simulation models (subsections 2.3.1 and 2.3.2) to examine whether the heating energy over the course of the schedule is adequate. It is noted that the controller utilizes any controlling strategies it has at its disposal (subsection 2.3.3). Depending on the feedback that the thermal load provider receives, the schedule may be altered according to the needs of the consumers before it is finalized.

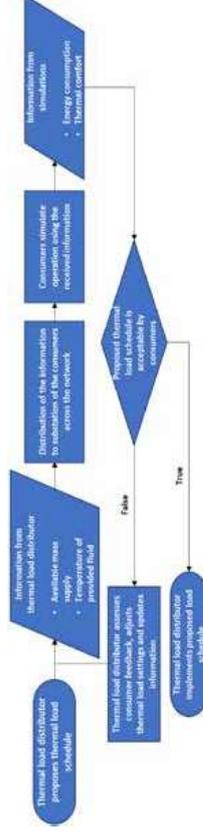


Figure 2.2: Flow chart displaying the algorithmic procedure of the tool

2.2 Monitoring aspect

In order to implement smart controlling strategies for the exploitation of the thermal flexibility of the network, a monitoring tool needs to provide all the information that these strategies will require in order to build efficient and robust models. The proposed tool has a remote control monitoring subsystem that receives measurements and transmits data from smart heat meters to the decision-making tool. Such a remote control monitoring subsystem should be connected directly to smart heat meters of the DHN thermal substations. As an example, Balafas et al. [20] developed a low-cost system (approximately 100 Euros), composed by an Arduino MKR WiFi 1010 microcontroller coupled with an Arduino MKR 485 shield, as shown in Figure 2.3. The microcontroller handles all communication and control aspects in this system. A Modbus RTU module can be installed in the smart heat meter (in this case a Kamstrup MULTICAL 603).



Figure 2.3: Monitoring subsystem for thermal substations

The main parameters that the proposed monitoring tool needs to typically measure and transmit (usually once per hour) are the following:

- The energy consumed from the primary source in the form of transferred heat
- The hourly water volume of the primary source
- The temperature of the primary source supply pipe
- The temperature of the primary source return pipe
- The temperature of the secondary source supply pipe
- The temperature of the secondary source return pipe

From the aforementioned parameters, other important parameters can be also calculated, e.g., the primary loop mass supply, the secondary loop mass supply, and the effectiveness of the heat exchanger.

2.3 Controlling aspect

2.3.1 Controllers in substations — an overview

The controlling aspect of this tool refers to the context of the simulation tools that are contained through the controllers of the substations, as well as the controlling strategies those controllers use. More specifically, each substation contains simulation models in respect of its thermal behavior, which will be described in subsection 2.3.2. Those models are responsible for using the information about the available load to simulate the operation of the consumer's substation for a certain time period. The controlling strategies (subsection 2.3.3) are used during the simulations. The simulation results that emerge are used by the controller of each substation to evaluate the adequacy of the thermal load provided by the thermal load producer. This evaluation is gathered across all the consumers and transmitted back to the thermal load producer as feedback (Figure 2.4).

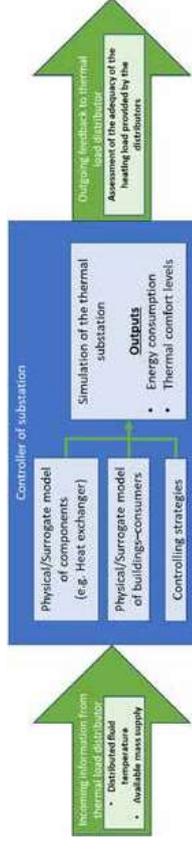


Figure 2.4: Overview of the decision-making tool concept

2.3.2 Simulation models of the controllers

Currently, the available choices on the simulation models are the physical models and the surrogate models. While the physical models are characterized by great simulation accuracy, they are more complex and thus computationally costly [21]. Moreover, most existing simulation software that utilizes physical models requires total knowledge of the real system to be simulated.

Surrogate models [22] are a simplified alternative to physical simulation models that also possess satisfactory accuracy. Due to their low computational requirements and consequently, their ability to be easily calibrated using real site data (using machine learning techniques), they are extensively used in recent literature [23–26]. Therefore, these models are very popular in thermal systems that require the implementation of controlling strategies. From the above, it can be seen that the implementation of surrogate modeling in the support tool would greatly benefit both its installation and operation costs.

2.3.3 Controlling strategies

As already mentioned, the exploitation of the thermal flexibility of the network is achieved through the implementation of smart controlling strategies. Practically speaking, controlling strategies are implemented through changing the mass supply, as well as the temperature of the hot fluid provided to the consumers. In other words, the controlling strategies are implemented through the daily thermal load scheduling, and therefore, they are a core part of the decision-making tool. The proposed decision support system utilizes two of the most popular controlling strategies: preheating and peak-shaving.

3. APPLICATION ON THERMAL LOAD MANAGEMENT

3.1 Demand-side management

3.1.1 Evaluation of thermal flexibility of consumers

3.1.1.1 Single consumer case

As already mentioned in Figure 2.1, since there is a bidirectional communication between thermal distributors and consumers, ultimately the thermal flexibility assessment serves as feedback for the thermal distributors. Therefore, the evaluation methodology of substation thermal flexibility with the implementation of the main controlling strategies have been examined in the work of [27].

In that study, an integrated approach is proposed, for estimating maximum flexibility potential in DHNs, during peak shaving events or power supply cutoffs that may occur in a thermal grid. As an case study that implements the proposed methodology, this paper examines and quantifies the maximum thermal flexibility potential of a DHN substation, providing heating loads to a consumer, namely an office building, under various building weight

categories and thermal comfort zones of the occupant, as well as two different controlling strategy cases (preheating and peak-shaving).

The substation operation simulations were conducted using developed Python libraries. Regarding the models, the building model library is based on a simple-hourly model of ISO 13790 [28]. Moreover, the substation components library was based on TRNSYS physical equations [29]. A schematic representation of a DHN substation connected to a single consumer is displayed in Figure 3.1.

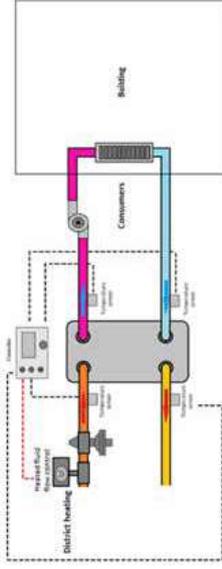


Figure 3.1: Thermal network substation connected to a single consumer

The implementation of controlling strategies and the exploitation of thermal flexibility regarding a single consumer are displayed in Figures 3.2–3.4. It has been found that by implementing the aforementioned controlling strategies, substantial reduction of the provided thermal load power can be achieved (up to 75% from the initial case). However, it is necessary that concrete information about the flexibility of the substation-consumer that is available, meaning the tolerance of the consumer towards deviating from the base thermal schedule. Furthermore, when seeking the maximum flexibility potential of a substation, considering thermal comfort settings along with thermal mass and controlling strategies enables optimized exploitation of the flexibility of the DHN, without compromising the heating demands of the consumers. This methodology can be extended to be used in the proposed decision-making tool, since the evaluation of thermal flexibility is a core mechanism in the algorithmic procedure of the tool, as also seen from Figure 2.2.

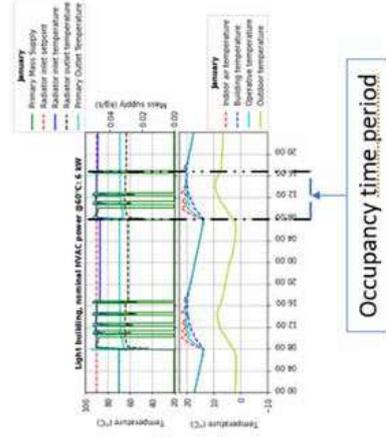


Figure 3.2: Conventional heating schedule scenario

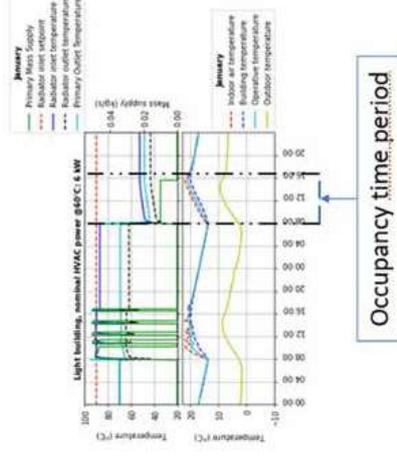


Figure 3.3: Peak-shaved heating schedule scenario

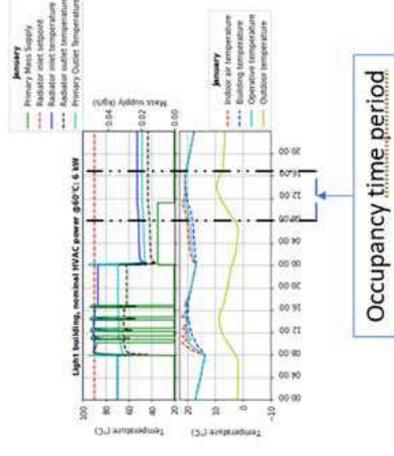


Figure 3.4: Peak-shaving with preheating schedule scenario

3.1.1.2 Multi-consumer case

In the case of the multi-consumers (apartments), a single substation serves multiple customers (Figure 3.5). It should be noted that there might be cases where each consumer has a different flexibility level. While the implementation of the proposed tool still follows the methodology provided by Figures 2.1 and 2.2, having various flexibility levels to consider is a matter that requires further development of the decision-making tool and even the network itself. For example, the initial idea would be that the substation should provide flexibility assessment information regarding the consumer with the least flexibility, or else the thermal comfort of at least one consumer would be compromised. Moreover, another option is to consider the utilization of locally installed thermal storage tanks that would enhance the total thermal flexibility of the said substation.

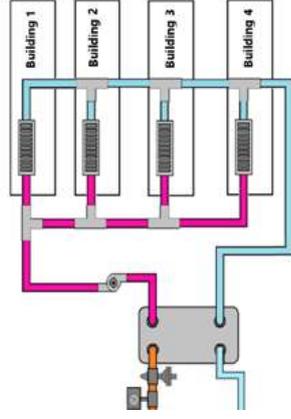


Figure 3.5: Thermal network substation connected to multiple consumers

3.2 Supply-side management

Since the supply-side management is examining the ways that the required thermal energy can be provided, the optimization of it essentially is to find the most environmentally and cost-effective way to provide those thermal loads. Fortunately, the curtailment of maximum heating power in the form of fluid temperature and/or mass supply reduction, as well as the heating storage potential of the network makes the implementation of RES easier to be implemented in the DHNs. Regarding the proposed decision-making tool, the supply-side management manifests at the phases where the thermal load distributor plans the thermal load schedule. By examining once more Figure 2.2, it can be deducted that most of the algorithmic procedure of the tool concerns the demand-side management. Therefore, there are prospects for the algorithmic procedure of the tool to be enriched at the thermal load scheduling steps. This is essential for achieving the bidirectional communication between the thermal load providers and consumers.

4. CONCLUSIONS

This study examines the development of a decision-making tool for the monitoring and controlling of DHNs. It features bidirectional communication between thermal load distributors, in order to optimize the thermal load management of the thermal network.

The contribution potential of this tool is twofold: on the one hand, it can be used to effectively manage the demand-side related heating loads of the consumers, in order to optimize criteria such as thermal power reduction across the network, as well as maximize the thermal comfort of the consumers. The reduction of heating power requirements can be achieved by identifying, enhancing, and exploiting the thermal flexibility of the substations and the consumers that belong to the network. On the other hand, supply-side management optimization can be achieved by exploring the multi-energy system options, namely, having more than one type of thermal load producers in the network available.

At this stage, the proposed tool has been developed mostly from the perspective of demand-side management. In order for the tool to allow the bidirectional communication between thermal load producers and consumers, the decision-making algorithmic procedure of the tool needs to be enriched in thermal load scheduling phases, and essentially establish a supply-side management algorithm that cooperates with the existing one. In addition, the tool also would benefit from the implementation of surrogate modeling methods that allow the customer's controllers to have lower computational requirements, and thus more affordable. Surrogate models also synergize greatly with the monitoring capabilities of the proposed tool, as individual consumer model case training using monitoring is highly effective.

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Evaluation of thermophysical properties of conventional and ventilated facades

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KEYWORDS - indoor conditions, Mediterranean climate, ventilated facades, thermophysical characteristics

ABSTRACT

The need to improve indoor climatic conditions, whilst simultaneously improving a building's energy efficiency, is now of greater importance than ever before, since buildings, and despite the progress made, account for more than 39% of final energy consumption in the European Union. In this context, a series of measures and policies must be implemented in the ongoing decade, to meet to goals set, both with respect to energy efficiency and to indoor environmental quality. The building's shell has a central role in shaping the energy balance of the building, it is determining its thermophysical characteristics. In that sense, it is hardly possible to carry out a study without an in-depth understanding and quantification of the shell's function, focusing on the thermophysical features of the individual materials, the details of the façade's geometry and orientation, but also the effect of exogenous factors, such as shading, exposure to winds, etc. The use of ventilated facades, e.g. systems where the external element [marble or stone plates, ceramic tiles, glass panes, metal, wooden or artificial panels] is fixed to a frame or individual supports and does not come into contact with the bearing structure or the external thermal insulation of the building element, is an approach often chosen particularly in the case of office and commercial buildings. More specifically, the existence of a gap between the coating material and the outer surface of the building shell has multiple advantages over the conventional wall structures, in terms of moisture control, protection of the thermal insulation material, avoidance of overheating as well as sound insulation. Ventilated facades are of particular interest for the refurbishment of buildings; hence it is necessary to further investigate and comparatively evaluate the operation of conventional and ventilated facades. This is the aim of the specific paper, focusing on tertiary sector building.

1 INTRODUCTION

As regards energy consumption at national level, there is a particularly high share of final energy consumption, with percentages reaching 40% for 2016. Residential buildings account for 26 percentage points, while buildings in the tertiary sector account for 14 percentage points. It is particularly interesting to note that these percentages are equivalent to those of the Europe of 28 Members [1]. Taking into account the change in final energy consumption from 1990 to 2016, there is a downward trend for all sectors except transport and services, for the Europe of 28 members [Figure 1] and for Greece [Figure 2]. In particular, for all the Member States of the European Union there has been a steady decrease in the levels of final energy consumption in housing, industry, agriculture and other sectors, while in the transport and services sector there has been an increase in final energy consumption levels [1]. In particular, in the case of Greece, the final energy