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Engaging domestic users on demand response for heating cost reduction with a recommendation tool: Case study in Belgrade

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Abstract

The European Union has established a legislative framework that aims to enable consumers and businesses to take information-based decisions to save energy and money. Additionally, the increase of Distributed Energy Resources (both on generation and consumption) requires additional efforts to maintain the reliability and stability of the electric grid and the need of flexibility from residential buildings. The present study introduces a domestic decision support tool for reducing heating costs. This app provides detailed recommendations to end-users based on the day-ahead hourly weather forecast, electric and district heating tariffs predictions, heating demand, and heating systems dynamic performance. The tool was tested in 6 dwellings of a neighborhood of Belgrade during the last months of 2021 heating season (March–May). Energetic results suggest that 40% of participants followed the given recommendations and changed their heating pattern. Additionally, survey results show that end-users found the lack of information and knowledge as the main barrier to actively participate in the energy market, also preferring to have automatic control in their heating system. Authors conclude that recommendation tools are key elements in user-engagement, but they should be supported by additional information and training.

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Keywords: Demand response; Heating electrification; Recommendation tools; User-engagement

1. Introduction

The European Union (EU) has established a legislative framework for the promotion of energy efficient and carbon-neutral building stock by 2050. Such framework aims to enable consumers and businesses to take informed choices to save energy and money [1]. That said, as stated in [2], the energy system is still driven from suppliers

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perspective, and residential and small tertiary sectors have limited options and benefits to track their energy consumption or actively participate in the market.

Additionally, the energy generation and its use are being transformed. The former is becoming more decentralized with the large-scale integration of distributed renewable energy sources. The latter, particularly in the building sector, is becoming more energy-efficient and evolving from a fossil-based to an electricity-based consumption. As such, many authors have illustrated that Greenhouse Gas emissions are reduced when electric technologies are used, as long as the renewable energies have relevance in the electric mix [3–5].

All this requires additional efforts to maintain the reliability and stability of the grid along with the consolidation of users' engagement. Hence, the development of new tools is needed to ensure a correct operation of the grid while end-users participate in Demand Response (DR) programs, saving costs without compromising their comfort. Under this context, EU funded HOLISDER [6], in which framework the present work is included, aimed to develop a set of components and tools to enable DR in building and small-tertiary sectors, empowering end-users.

Several studies can be found in the literature where the benefits of user engagement tools are analyzed. In [7], how users engage with smart home tools and its influence were investigated. Authors conclude that, while smart home tools could add flexibility to District Heating (DH) systems, those tools are rarely used as intended by occupants since they do not comply everyday practices. [8] simulate different scenarios to discuss the effect of weather conditions and user behavior to reduce heat pumps power peak of residential district.

It should be noted that most studies are based on simulation analysis [9], and those that are based on real applications either analyze end-user participation in a qualitative manner (focus groups, surveys, ...) [10], or results are shown from the grid's perspective [11].

In consideration of all the above, in the present work the model presented in [12] was adapted to fit the particularities of a Serbian neighborhood, enabling end-users to benefit from participation on implicit DR schemes. In particular, the model gives day-ahead recommendations to select the cheapest heating system in an hourly basis. Users receive these recommendations every day through an app. The model was tested in real-life environment during 2021 heating season. Furthermore, energetic results are shown in addition to end-users' feedback.

2. Materials and methods

The proposed model was tested in six dwellings of the Stepa Stepanović neighborhood. This neighborhood belongs to the Vozdovac system, one of the several heating networks that form the DH system of the city of Belgrade (Serbia). The selected apartments are representative of usual dwellings in Belgrade. Heating for both space heating and Domestic Hot Water (DHW) is supplied by the thermal network. Additionally, occupants have installed reversible air source Heat Pumps (HP) to cover the cooling demand of summer period. The distributed energy of the DH is produced in the Vozdovac gas natural heating plant. Regarding the Stepa Stepanović subnetwork, it also includes the energy required to cover the heat demand of 52 residential buildings, a kindergarten, and a primary school. A more detailed description of the technical features of the Vozdovac system and the Stepa Stepanović neighborhood can be found in [13].

2.1. Case study: Stepa Stepanović neighborhood

As stated before, the present work continues with the authors' previous investigation about the electrification of buildings' energy demand [4], and the potential role of HP on domestic DR participation and enhancement of user engagement in the energy market [12]. As shown in Fig. 1, a set of recommendations are generated and sent to the users' smartphones, in order to minimize heating costs by using the day-ahead hourly weather forecast, electric and DH tariffs predictions, apartments heating demand, and the performance of the heat pump. The methodology for calculating these parameters is described in the following sections.

2.2. Methodology

As stated before, the present work continues with the authors' previous investigation about the electrification of buildings' energy demand [4], and the potential role of HP on domestic DR participation and enhancement of user engagement in the energy market [12]. As shown in Fig. 1, a set of recommendations are generated and sent to the users' smartphones, in order to minimize heating costs by using the day-ahead hourly weather forecast, electric and DH tariffs predictions, apartments heating demand, and the performance of the heat pump. The methodology for calculating these parameters is described in the following sections.

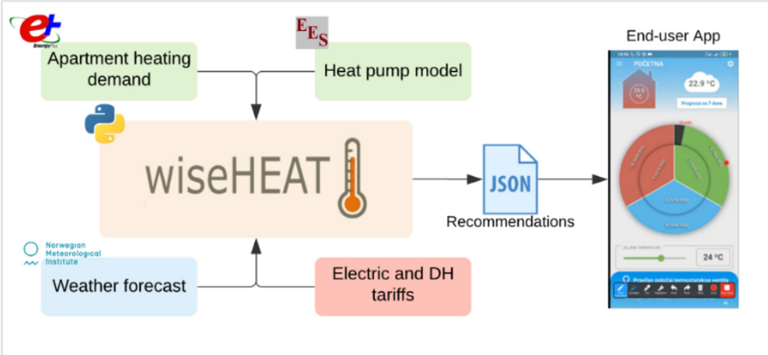

Fig. 1. Overview of the proposed model for the most cost-effective heating system selection.

Table 1. Electric prices for each zone and period.

	Green zone	Blue zone	Red zone
Higher daily tariff	6.196 RSD/kWh	9.294 RSD/kWh	18.588 RSD/kWh
Lower daily tariff	1.549 RSD/kWh	2.323 RSD/kWh	4.647 RSD/kWh

Weather forecast

The day-ahead weather forecast is obtained via API from The Norwegian Meteorological Institute [14]. Specifically, hourly outdoor air temperature is used for the calculation of both heating demand and Coefficient of performance (COP) of the heat pump.

Electric and DH tariffs

- **DH:** The DH is seasonal in Stepa Stepanović neighborhood, starting on October 15th and ending on April 15th. During the heating season, it runs from 06:00 to 22:00 between Monday to Saturday, and from 07:00 to 22:00 on Sundays. Moreover, when the outdoor temperature is higher than 18 °C, the DH turns off. When the outdoor temperature is below 3 °C the heat is also provided during the night. The DH price is constant: 7.57 RDS/kWh.
- **Electricity:** Users electric tariff is split in three zones based on the consumption of the billing period: (i) Green zone up to 350 kWh, (ii) Blue zone between 350 kWh to 1600 kWh, and (iii) Red zone when the electric consumption is over 1600 kWh. Additionally, each zone has two price periods according to the time the energy is consumed: (a) "Higher daily tariff " between 07:00 and 23:00, and (b) "Lower daily tariff" from 23:00 to 07:00 [15]. Prices for each zone and period are summarized in Table 1:

Heating demand

In order to estimate the day-ahead hourly heating demand the simplification proposed by [16] was used (1):

$$Q_T = UA_{efec} \cdot (T_{in} - T_{out}), \tag{1}$$

where the heating load (Q_T) is determined by the overall heating transfer coefficient (UA_{efec}), the indoor temperature (T_{in}), and the outdoor temperature (T_{out}).

The outdoor temperature is obtained from the weather forecast, and the indoor temperature is set to a constant value of 21 °C during the day and 16 °C during the night-hours, as established by the DH company. Finally, the UAefec is obtained by simulating each apartment's energy performance, for which the construction properties and systems specifications were gathered, using the commercial software DesignBuilder.

Heat pump model

The heat pump model represents a typical air-to-air commercial unit, as previously developed by the authors in [4], which fits with the AC units found in the case study, as:

$$COP = 2.85633 + 0.072432 \cdot T_{out} + 0.000546578 \cdot T_{out}^2. \tag{2}$$

Day-ahead recommendations

Once all the above is established, the wiseHEAT model is run and a set of recommendations are sent to each apartment. These recommendations advise end-users which system to use the following day to cover heating demand based on price, availability, and systems capacity. Overall, the user can get 6 different types of recommendations per each hour:

1. DH: HP is not enough to cover the total heating demand, but the electricity is cheaper.
2. DH: HP is not enough to cover the total heating demand, and the electricity is more expensive.
3. DH: HP is enough to cover the total heating demand but the electricity more expensive.
4. HP: HP is enough to cover the total heating demand and the electricity is cheaper.
5. HP: HP is enough to cover the total heating demand and the DH is not working during this hour.
6. HP: HP is not enough to cover the total heating demand, but the DH is not working during this hour. (Keep in mind that probably you will not reach the temperature set point).

In Fig. 2 an example of the day-ahead recommendations is shown. In this particular case, results for the apartment 16 are shown when the electric tariff is on the Red zone. These are thoroughly described below:

- From 0:00 to 01:00, and 22:00 to 23:00: (i) the outdoor temperature is low, as a result the heating demand is higher than the capacity of the HP (yellow line is above the black line in Fig. 2(b), (ii) the DH is not working during that night blue line in Fig. 2(c); therefore, the user would get the 6th recommendation.
- From 02:00 to 05:00: (i) the temperature gets higher during this time, as a result the heating demand is lower than the HP capacity (yellow line is under the black line in Fig. 2(b), (ii) the district heating is not working during that night; therefore, the user would get the 5th recommendation.
- From 06:00 to 07:00, and 10:00 to 15:00: (i) the heating demand continues being lower than the capacity of the HP (yellow line is under the black line in Fig. 2(b), (ii) the electric price is lower than the DH price (red line is below the blue line in Fig. 2(c); therefore, the user would get the 4th recommendation.
- From 08:00 to 09:00: (i) the heating demand continues being lower than the capacity of the HP (yellow line is under the black line in Fig. 2(b), (ii) the COP is not high enough, as a result the electric price is higher than the DH price (red line is above the blue line in Fig. 2(c); therefore, the user would get the 3rd recommendation.
- From 16:00 to 21:00: (i) the temperature drops drastically, and the heating demand is higher than the capacity of the HP (yellow line is above the black line in Fig. 2(b), (ii) because of the low temperatures the COP is not high enough, as a result the electric price is higher than the DH price (red line is above the blue line in Fig. 2(c); therefore, the user would get the 2nd recommendation.

3. Results and discussion

3.1. Energetic results

In the following section, the energetic results are discussed. As explained in 2.1, six dwellings of the Stepa Stepanović neighborhood were selected for the test. Selected apartments, belonging to different floors of two nearby building blocks, are being monitored since the beginning of March 2020. Specifically, heat meters were installed to measure DH consumption, and several power meters were deployed to monitor the electric consumption of the DHW boiler, HP as well as the rest of equipment.

Table 2 shows the average daily consumption (DH + HP) of the apartments measured during the monitoring campaign, this is, from 01/03/20 to 24/05/21. For this period, it was observed that the DH and HP consumption of one of the apartments was considerably lower compared to the others, with an average daily consumption of less than 5 kWh. Hence, this apartment, Apt 01, was dropped from the study.

Since 15th of March 2021, daily recommendations were given to the users through an app that they were already familiar with. Daily results indicate that 40% of the users have changed their heating pattern following the recommendations they were sent. The rest of the apartments, by contrast, do not show any change in their consumption. It could, therefore, be concluded that they did not follow the given recommendations.

Fig. 3 depicts the daily consumption of both DH (red line) and HP (blue line) of two apartments. These consumptions have been normalized using daily Heating Degree Days (HDD) [17]. Normalized data reduces

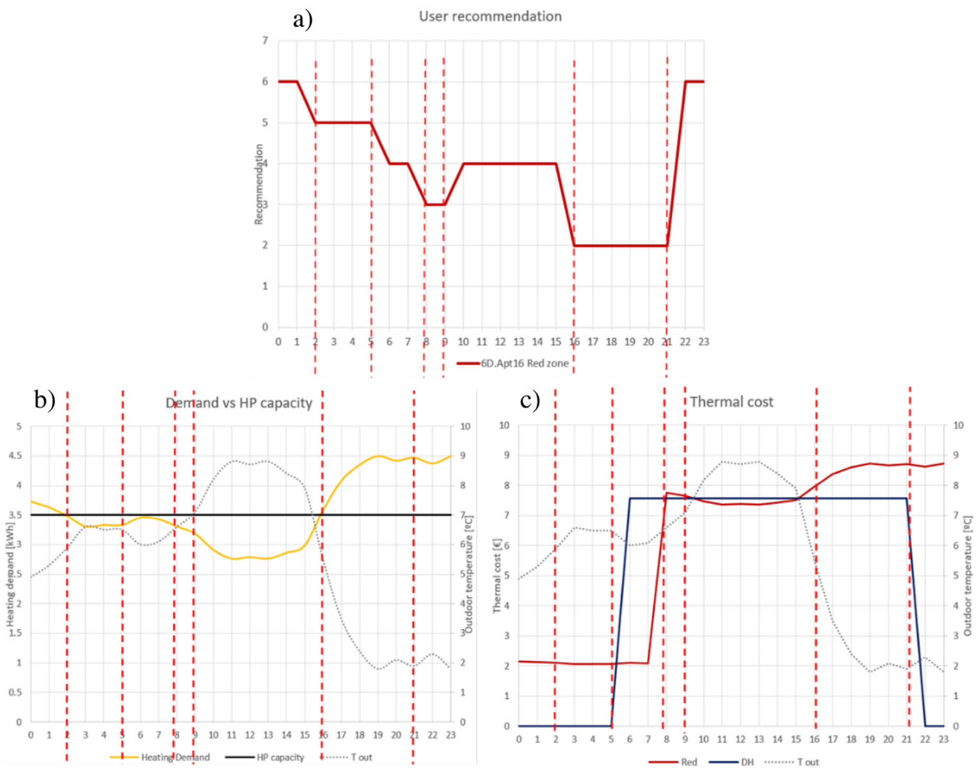

Fig. 2. Day-ahead recommendation example for one of the apartments in the Red zone electric price. Fig. 2(a): Given recommendations. Fig. 2(b) Hourly heating demand and HP's capacity. Fig. 2(c): Hourly heating cost for both DH and HP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2. Average daily consumption (DH + HP) of the apartments (measured from 01/03/20 to 24/05/21).

	Apt 1	Apt 2	Apt 3	Apt 4	Apt 5	Apt 6
Average consumption [kWh]	3.40	13.79	12.65	20.84	12.80	24.52

the effect of weather variations due to the variability of temperatures, and it allows to accurately compare the consumptions before and after the study. Fig. 3(a) illustrates one of the apartments that has not altered its pattern. One could note that there is no difference between the consumption profile before and during the recommendations were given and after it (the area highlighted in yellow). On the contrary, in Fig. 3(b) an apartment where the recommendations were adopted is shown. The highlighted area of the figure proves that users applied the recommendations since they started using the HP to cover their heating demand more often than before.

3.2. Feedback from end-users

Since the study started 15th of March, there has not been enough time to properly analyzed users' engagement. Therefore, a survey was sent to the occupants to better understand, among other facts, their knowledge about energy efficiency and DR, possible barrier for not participating in DR programs and the types of tools they would prefer.

Results show that end-user had a general knowledge about energy efficiency in buildings, even though most of them were not familiar about energy flexibility. Since the most typical Serbian electric tariff is composed of an accumulative day/night fixed price, as the one explained in Section 2.2, occupants were unknown or they had very little knowledge about electric tariffs used for implicit DR schemes, such as Time-of-Use, Real Time pricing or Critical peak pricing tariffs. When they were asked about which would be the main barrier not to participate in DR

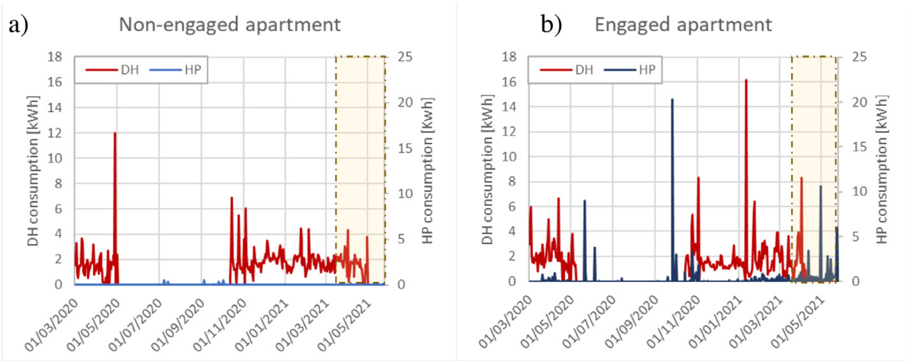

Fig. 3. Daily consumption of DH (red line) and HP (blue line) before (white background) and during the study (highlighted in yellow). Fig. 3(a): Example of a non-engaged user. Fig. 3(b): Example of an engaged user. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

programmers, the majority of them agreed that it would be the lack of clear information and knowledge, followed by the time and effort involved in decision making, and running decided actions. Finally, 70% of the users would prefer that their systems are automatically controlled, with or without the possibility to override the actions, to optimize their use of heating, ventilation, and air-conditioning from a DR perspective. The others would be more comfortable having informative tools that advice and recommend them different actions, so they could be who apply them.

It is worth mentioning that feedback results seem to be in line with energetic results. Feedback results suggest that 30% of the users would prefer to actively participate in DR decisions based on informative tools, while, experimental observations show that 40% of the evaluated users actively followed the recommendations sent via app. As stated in [18], even though informative tools could achieve more cost-effective and sustained saving than automating control, end-users have to be previously involved and engaged in the matter. Therefore, it is important to clearly inform and explain end-user about recommendation tools before implementing them. These would also tackle the main barrier for not participating in DR programs.

4. Conclusion

The present paper presents an innovative model to send day-ahead recommendations through an app. The recommendations suggest end-users to select the optimal heating system, on an hourly basis, to minimize heating costs by using the day-ahead hourly weather forecast, energetic tariff predictions, heating demand, and the performance of the heating systems.

Energetic results suggest that 40% of the participants followed the given recommendations and changed their heating consumption profile, from using District Heating (DH) exclusively to combining it with the use of a Heat Pump (HP) when it was recommended. On the other hand, the rest of the users remain using solely the DH.

In addition, a survey was conducted among the participants. The main outcome shows that end-users believe that the lack of information and knowledge would be the main barrier for not participating in Demand Response (DR) programmes. Finally, up to 70% of the respondents would prefer to have automatic controlling in their HVAC systems, with or without the option to override it, to optimize its use from a DR perspective.

Authors believe that the presented tool would help end-users to actively participate in DR programmes and enhance user-engagement. It is important to mention that these tools should be provided with additional information to ensure end-users' long-term commitment. Thus, a higher use is expected next heating season, once the users are more familiar with the app. In future works, further developments will be done in order to investigate strategies to reduce not just the heating cost, but also the energy consumption or greenhouse gas emissions.

CRediT authorship contribution statement

O. Eguiarte: Investigation, Formal analysis, Validation, Writing – original draft. **P. de Agustín-Camacho:** Supervision, Writing – review & editing. **A. Garrido-Marijuan:** Data curation, Writing – review & editing. **M.**

Vukovic: Data acquisition, Data curation. **L. del Portillo:** Writing – review & editing. **A. Romero-Amorrortu:** Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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