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Potential and optimization of a price-based control strategy for improving energy flexibility in Mediterranean buildings

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Abstract

The present study proposes the implementation and fine-tuning of a rule-based control strategy aiming to improve the energy flexibility of residential buildings in the Mediterranean area. The adopted control reacts to the time-varying electricity price signal, and modulates the set-point for space heating and domestic hot water production accordingly. A parametric study on three control variables of the control algorithm was carried out, in order to choose appropriate values. The analysed outcome consisted mainly in the provided flexibility, the impact on the comfort conditions, and the evolution of the energy use and costs compared to a standard reference case. After tuning the control strategy, a decrease in energy costs of around 22 to 26% was observed, along with an important shifting of heating loads towards low energy price periods. The proposed control additionally caused an increase of energy use of 2 to 4%, without jeopardizing comfort conditions. These results emphasize the potential of residential buildings for energy flexibility in the Mediterranean area.

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Keywords: energy flexibility in buildings; demand-side management; heating control strategy; rule-based control; sensitivity analysis.

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1. Introduction

With the increasing penetration of renewable energy sources (RES), electricity grids are facing new challenges. In particular, the high variability of some of these sources such as solar and wind power can jeopardize the balancing of the networks at every instant.Integrating large shares of variable RES is however necessary in order to achieve the decarbonization of our energy systems agreed upon the Paris agreement to fight climate change [1]. New methods for counteracting the threats of these RES on the stability of the grid are thus needed.

In this regard, Demand-Side Management (DSM) solutions are investigated in different fields, as demonstrated by the numerous tasks developed by the International Energy Agency (IEA) within its DSM programme [2]. The present work applies DSM to make the energy consumption of buildings more flexible and thus more grid-supportive. Buildings represent approximately 33% of the global primary energy use [3], therefore driving theseenergy consumers towards more flexibility represents a large potential [4]. In particular, heating, cooling and Domestic Hot Water (DHW) loads can partly be shifted in time to provide this flexibility, since the heat (or cold) can be retained for a certain period within the thermal mass of the building or in other storage means such as water tanks [5].

Several control strategies exist to manage building flexible loads. Rule-based controls (RBC) consist in relatively simple algorithms aiming for instance to shift loads with fixed schedules, shave energy peaks or reduce the energy costs. More advanced strategies such as Model Predictive Control (MPC) make use of an optimization problem to achieve the best performance over a certain time horizon, projecting the behavior of the systems in the future with weather or occupancy forecasts [6]. MPC presents more difficulties and costs in its implementation due to the prior need of a building model for the controller. A well-tuned or predictive RBC can already achieve substantial results, even though they are not entirely optimized [7].

In the present work, an RBC strategy is utilized: it reacts to the time-varying electricity price signal and adapts the heating set-points accordingly, turning the space heating (SH) and DHW needs into flexible loads, shiftable in time. The first objective of the study consists in adjusting three parameters of the applied method with regards to energy costs, flexibility and comfort.These parameters relate to the definition of the price thresholds, and to the amplitude of the set-point modulation. Once the most satisfying combination is found, the potential of a typical Mediterranean building is evaluated, since energy flexibility has still scarcely been investigated in this climate zone.

Nomenclature

DHW	Domestic Hot Water	RBC	Rule-based control
DSM	Demand-Side Management	RES	Renewable Energy Source
MPC	Model Predictive Control	SH	Space Heating

2. Methods

2.1. Model of the building and its mechanical systems

The chosen case study is a residential flat of 109 m^2within a multi-storey building, situated in Barcelona (Spain) and typical of Catalonia's building habits. For this study, a refurbishment of the building is considered, with an improved insulation of the external walls (12 cm EPS) leading to a U-value of 0.2 W/m^2K. The external windows have a U-value of 2.5 to 5.7 W/m^2K, and only natural ventilation is considered. The dwelling is occupied by a family of two adults and two children, to whom the occupancy schedule has been adapted.

For the production of hot water (SH and DHW), an air-to-water heat pump is implemented (nominal power of 4.3 kW and COP of 3.0 for leaving water at 55°C and outside air temperature at 7°C [8]). For DHW, the heated water is stored in a tank of 250 liters, normally kept at 60°C, and withdrawn according to the standard tapping programme M [9]. For space heating, the heated water is circulated in a circuit of eight radiators, controlled by a central thermostat placed in the living room. More details about the modelling hypothesis can be found in [10,11].