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Innovative control logics for a rational utilization of electric loads and air-conditioning systems in a residential building

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ABSTRACT

The paper focuses on the evaluation of the impact on residential buildings of innovative control logics defined for a rational utilization of the electric loads and air-conditioning systems. The control logics are implementable thanks to a Decision Support and Energy Management Systems developed by the same authors and easily installable in new and still-existing houses.

The paper shows how a significant reduction of the primary energy consumption can be obtained by controlling the air-conditioning units together with the other electric loads of the house.

After having explained how the control logics operate, a simulation tool is described, developed for a preliminary evaluation of their effects on the energy consumptions of residential buildings in the design stage. An application of the simulation tool on a typical house, considering different scenarios and varying the climatic conditions and the energy performance class of the envelope, is presented.

Finally, a measurement campaign on two real existing houses, equipped with the Decision Support and Energy Management System, is described, and the effects of the control logics are assessed.

1. Introduction

In accordance with the European Standard EN 15232 [1], it is well known how buildings energy performance can be influenced by the presence of Building Automation Control (BAC) Systems an Technical Building Management (TBM) systems [2–4].

Also the Energy Performance of Building Directive (EPBD) 2010/31/EU [5] in line with Directive 2009/72/EC [6], promotes the adoption of BAC and intelligent metering systems recognizing their potentiality of reducing primary energy consumptions.

Moreover, in the last few years many research studies have been devoted to Demand Side Management (DSM) policies [7–13] implemented in order to achieve an intelligent and interactive management of domestic devices and air-conditioning systems obtaining, in this way, higher performances during normal operation. DSM is assessed as an integral part of the smart grid and one of the most important methods of energy saving also thanks to new Information and Communication Technology (ICT) infrastructures that allow faster and more efficient communications between users and public utilities.

Recognizing the importance of this topic, the authors have proposed some innovative control logics that, implemented in a Decision Support and Energy Management System (DSEMS) for residential applications, can be applied to the operation of the electric and thermal loads of a house for attaining the optimization of the energy consumption.

Thanks to these control logics, the direct benefits for customers may be various, involving energetic, economic and comfort issues (more flexibility, different user profiles according to the environment, elimination of overload black-out due to the simultaneous use of more devices).

The utilization of the DESMS leads also to benefits for the distribution system operator (DSO): power losses reduction, possibility to defer the strengthening interventions of the existing networks and to improve the employment of production units, reduction of Green House Gases (GHG) emissions, etc. Moreover, the load control can become a precious reserve in emergency situations.

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The control logics have been implemented also in the simulation tool "TiDomus" developed by the authors in Visual Basic (VB) environment, carried out for assessing their effects while considering buildings with different characteristics and equipment. Then, the same control logics have been implemented in two prototypes of DSEMS installed in two real houses in order to carry out experimental tests.

The present study is part of National Research Project SIRRCE (System for the resIdential eneRgy optimization with summeR air Conditioning intEgration) supported by the Italian Ministry for the Economic Development.

The aim of this paper is to illustrate the main results of the SIRRCE project, presenting the control logics, the simulation tool, the DSEMS and the measurement campaign done on two real houses in order to check the real operation of the DSEMS.

The structure of the paper is as follows. In Sections 2 and 3 the control logics and the functioning of the real DSEMS are, respectively, described.

In Sections 4 and 5 TiDomus is, respectively, presented and applied to a test case in different scenarios. Finally, in Section 6 the results of a measurement campaign on two real houses are shown while in Section 7 conclusions are given.

2. Innovative control logics

Many authors have proposed logics and strategies for the control and the management of electric and thermal loads in residential and not residential buildings. In [14] the authors propose electrical loads management in emergency conditions, when main power sources are limited or totally absent, for residential and commercial buildings.

In [15–17] four rule-based control logics and an artificial neural network (ANN)-based control logic are developed for the integrated control of openings and cooling systems in buildings with double skin envelopes during summer. In [18] a fuzzy logic control system to keep the illumination level at 350 lux in a room is presented. In [19] a lighting control algorithm is developed with the goal of achieving energy efficiency and health aspects of occupants in office buildings in Dubai. In [20] an energy management strategy based on the rules of the electricity bill for a commercial building in a supermarket application is presented. Also in [20] the authors establish some objectives as load shedding in order to reduce the electricity bill and the CO_2 emissions of commercial building, using photovoltaic (PV) and storage systems.

In [21] the authors analyze the influence of DSM strategies on the performance of a thermally activated building system (TABS) applied in a commercial building with the goal of estimating the potential of TABS for load shifting requested by the electricity grid.

Finally, in [22] two different hydraulic configurations of heat pump with thermal energy storage and four different control strategies are analyzed.

Most of the above-mentioned papers deal with specific loads and, in particular, no one deals with the problem of the control of single air-conditioning units for residential buildings.

The proposed control logics have been designed in order to face this issue and in the same time to provide management strategies for all the electric and thermal loads usually present in a house. The control logics are implemented in a DSEMS for residential applications and the user may select and change one or more control logic in every moment according to its preferences. Selecting a given control logic among the six proposed, the end-user can attain well-defined effects on its electrical and thermal load.

The proposed logics are:

- Comfort;
- Economy;

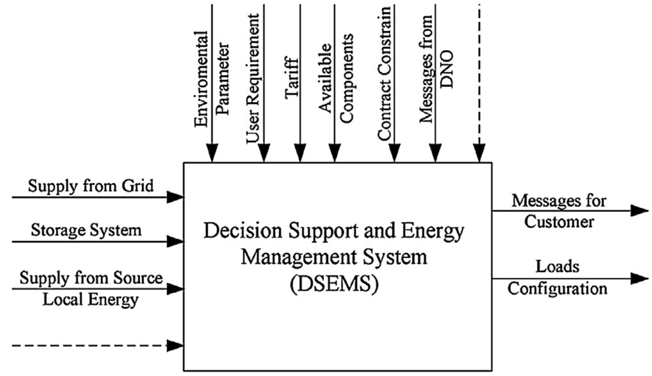

Fig. 1. Input and output of the DSEMS.

- Emergency;
- Energy;
- Power;
- Thermal storage.

The DSEMS is also able to receive control signals from the DSO by activating a NET-Service (NetS) function. Therefore, NetS function is not a proper control logic and is only selected when the end-user wants the DSEMS to receive external signals. By activating the NetS function, some selected electric and thermal loads can be controlled by the DSO in order to achieve precise benefits for the grid, while the end-user will receive a premium or a discount of the electricity price for the service it offers to the DSO.

The DSEMS, whose inputs and outputs are represented in Fig. 1, has been described in detail in [23,24], presenting also the utilized designing and testing methods.

The state machine that manages the activation of the control logics consists of seven super-states. Each super-state handles a different control logic (and the NetS function) and contains precise sub-states and functions.

Even if the SIRRCE project was born with the aim of concentrating on summer air-conditioning, the DSEMS implements the following actions in both summer and winter seasons:

- indoor climate control during the economic tariff range: when the power consumption exceeds the contractual power limit, the temperature set point of the air-conditioning system is gradually changed in order to reduce the energy absorption;
- climate control during the expensive tariff range: the DSEMS varies the temperature set point of the split in order to reduce the energy absorption.

In the following it is described how each control logic operates.

2.1. Comfort

The Comfort function is selected in order to assure:

- the energy supply to all types of loads;
- the preservation of the maximum comfort in the house in terms both of indoor temperature and of electrical load usage.

Controllable and shiftable loads are managed by the DSEMS in order to avoid they exceed the maximum available active power, limited by contract, thus improving the continuity of supply for the end-user.