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Integrated smart system for energy audit: methodology and application

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Abstract

The article describes the design and the application stage of a smart energy audit system, integrated within building, and the methodologies adopted for the detection of malfunctions of the plant. The system is set up as a "black box" consisting of a hardware aimed at logging both energy and environmental parameters and a software for the assessment of building behavior and the management of energy flows. The Energy Signature was chosen as the reference method for the evaluation of the energy performance of building. The system was tested in an existing public office building.

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Keywords: **Energy audit; energy consumption; Energy Signature; logic control; monitoring**

1. Introduction

The high energy consumption of the building sector is a topic discussed and addressed on the tables of all the political and scientific institutions. At the global level, the primary energy consumed by buildings accounts for about 40% and the greenhouse gases emissions for 30% [1]. The awareness of the environmental, economic and social risks related to these emissions were the engine which in recent years has motivated the decision-makers in launching a series of measures to improve building performance [2], [3].

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The European Union is actively involved in the definition of measures aimed at reducing consumption and improving the energy performance of buildings up to the definition of nearly Zero Energy Buildings (and beyond),

with high thermal performance and use of renewable energy sources to meet the energy demand [3]. These concepts are well suited to new buildings, primarily subordinate to design constraints. The situation is rather different if the same requirements are applied to existing buildings, where a further design effort is required in order to consider structural, landscape and environmental constraints which can affect the refurbishment to varying degrees [4].

The European building stock consists for about 70% of residential buildings. The non-residential buildings represent the remaining 30% and constitute a complex and heterogeneous set. The analysis of the time series highlights how more than 50% of European residential buildings were built before the 70th. About 15% of the total was built in the new millennium and just the 4% after 2010 [5]. The Italian situation related to the new buildings shows lower percentage compared to the European average. Finally, the recent international crisis has further reduced the investment in the building stock.

The energy consumption is directly proportional to the age of the buildings [6]. The introduction of energy policies increasingly conservative over the years allows the reduction of buildings energy consumption. Specific studies have highlighted how a systematic procedure of analysis of the state of art and of refurbishment actions can address the national energy policy related to the building sector [7].

Starting from these premises, it is clear how the energy retrofit of the building stock should take a leading role [8] also to achieve the nZEB goals [9]. In Italy, a series of measures to encourage energy retrofits were launched over the years (in terms of tax deductions) stimulating a sector that perhaps more than the others has been affected by the adverse international economic situation. The last available data shows how the actions financed over the years (2007-2015) have produced an overall energy saving of primary energy higher than 13.200 GWh and a CO_2 reduction of about 2.800 kt with a total investment of about 28 billion euro [10]. Although these are encouraging results, they are not enough to achieve the targets. Most of the renovations concerned the replacement of windows, followed by the replacement of the heat generator typically with condensing or high efficiency boilers and the installation of solar panels for Domestic Hot Water (DHW) production. The renovations related to the opaque envelope occupy a marginal position representing about 2% of the total [11], [10]. The choice is often imposed by economic reasons rather than a careful analysis of the overall impact of the intervention.

It is clear how the application of an integrated approach [12], smart devices able to manage the energy and environmental variables [13] and a systematic procedure of energy diagnosis [14] aimed at identifying unusual behavior of the building-plant system and at suggesting the best practices of refurbishment could actively contribute to achieve the set energy requirements for the building sector [15].

The paper describes an automated system for the energy diagnosis of buildings divided into three different levels of analysis: a first level of predictive diagnosis aimed at the analysis of the energy consumption, a second level aimed at the management and optimization of the thermal comfort and a last detailed level aimed at real time monitoring of the energy and comfort variables. A hardware and software architecture for monitoring the energy-environmental variables, for managing the energy flows and for assessing energy retrofit has been realized, tested and optimized in real public buildings. In the present article the focus is on the definition of the methodology of the energy diagnosis for the analysis of consumption and on the optimization and control procedures of energy flows and thermo-hygrometric comfort.

2. Architecture and functionality

2.1. Overview

The system is a multi-level diagnostic tool aimed at investigate a specific feature of the building-plant system. The energy diagnosis in the stricter sense represents the first level of the system.

The need for specific solutions for the monitoring of consumption is satisfied through the use of transducers and smart meters for the measurement and detection of the energy and environmental variables: energy consumption such as electricity, fuel, water and heat, indoor (air temperature, radiant temperature, relative humidity, air velocity, CO_2