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Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings

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ABSTRACT

This paper investigates several actions for the energy refurbishment of some buildings of the University Hospital Federico II of Naples. The analysis focuses on a specific lot of 4 buildings, representative of the whole district hospital. For those structures, sustainable energy savings actions are investigated. They regard the installation of: i) roofs thermal insulation; ii) a substation climatic 3-way valve; iii) radiators thermostatic valves; iv) AHU (air handling unit) time-programmable regulation. This paper aims at presenting an investigation methodology, useful for designers and other stakeholders involved in hospital energy refurbishments, based on an integrated approach which combines dynamic energy performance simulations and experimental campaigns. In order to measure all the simulations' missing input parameters, a suitable experimental analysis, including measurements of temperature, humidity, flow rate and density of construction materials, is performed. A thermographic investigation is also performed for investigating the building envelope performance. This analysis showed that significant savings can be achieved especially by adopting radiators thermostatic valves and AHU regulations. Coherently, the installation of a 3-way valve in the substation does not determine significant additional savings when radiators thermostatic valves are already installed. For high-rise buildings, roofs insulation returns only marginal reductions of space heating and cooling demands.

1. Introduction

Healthcare is provided in complex and energy-intensive facilities that range from critical care hospitals to medical office buildings. In general, they account for a remarkable fraction of the energy consumption in the utility buildings sector, due in large part to the very high energy intensity levels of hospitals and other inpatient care facilities. Particularly in hospitals, high energy consumptions are mostly due to their continuous usage patterns and operation which require substantially variable energy demands depending on the specialized services provided [1]. In addition, sophisticated heating, ventilation, and air conditioning systems are necessary to guarantee a careful control of hospitals internal climate. At the same time, high infiltrations and air changes are demanded by strict indoor air quality levels required by surgeries, intensive care units, white rooms, outpatient clinics, etc. [2]. Therefore, in order to guarantee and maintain satisfactory thermal comfort and indoor air quality levels, continuous demands of heating and cooling energy, as well as electricity (for artificial lighting and electrical equipment), yield remarkable energy consumptions, which are relatively higher in comparison with other types of buildings [3]. Hospital construction techniques also play an important role on the energy demands. In this regard, existing hospitals usually consist of large buildings, often known to be among the least energy efficient public buildings, as it is for most European countries [3]. As a result, hospital accounts for the highest energy consumption per unit floor area in the buildings sector and may offer great potentials for energy and cost savings through their refurbishment [4]. From this point of view, technical regulations and directives have been laid down aiming at providing guidelines and promoting measures for the reduction of the energy consumption of hospitals [5]. These measures must be adopted and applied to the hospitals design, construction, retrofit, operations and maintenance, also by integrating advanced energy efficiency technologies and renewable energy sources [6–8].

Nevertheless, the reduction of the energy consumptions must be achieved while preserving or enhancing healthcare delivery. From this point of view, it must be also noted that depending on the design conditions of each hospital function, the related technical system must be properly designed and adjusted in order to meet

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the requirements of each individual environment [5]. In general, energy and cost savings in hospitals can be achieved by implementing different kinds of energy saving measures, which depend on the particular energy flow and/or production system. They range from simple (e.g. switching off all energy-consuming equipment when not required) to significant (e.g. building envelope refurbishment) actions which can be extremely cost-effective. Significant hospitals energy-using systems can be identified by means of comprehensive energy analyses which aim at obtaining a better management of energy resources and the reduction of losses. As a result, depending on the different categories of refurbishments, these measures can be applied to: i) the building envelope, ii) the HVAC systems, iii) the energy conversion and transfer systems.

Many authors have been involved in researches about the efficient use of energy and the potential energy savings in the hospital sector, on the basis of theory and practical case studies and from both technical and regulatory points of view. Recent and comprehensive literature reviews on hospitals energy efficiency and energy saving potentials on their HVAC systems (Ref. [9]), also taking into account thermal comfort with regard to the effects on patients' healing process and the staff's levels of productivity (Ref. [10]), are available in literature. Energy savings measures regard the envelope (e.g. isolation for reducing leakages [11], thermal insulation, etc.) and the heating (e.g. heat exchangers [12]), cooling (e.g. air-cooled chillers with centrifugal compressors), ventilation (e.g. advanced ventilation strategies [13,14]) and power generation (e.g. CHP (combined heating and power) or CCHP [15]) systems. Concerning the ventilation systems, which play a significant role in hospitals from the energy and thermal comfort point of views, common problems are identified, such as: insufficient indoor air exchange, poor control on indoor thermal conditions, inappropriate ventilation system operations and poor technical installations maintenance (Ref. [3]). In this regard, the current literature suggests that achievable energy savings can be obtained by: adopting new ventilation strategies and more efficient technologies [11]; by optimizing the configurations of air distribution hospital rooms [13]; by taking into account adaptive VAV (variable air ventilation) operation [14,16]; by adopting heat recovery units [17] ad energy recovery ventilators [18]. In order to improve the resilience of the existing hospitals, the importance of good practices in the maintenance and repair of existing energy services and the adoption of low cost measures, that do not interfere with the functioning of the hospital, are recommended. As an example, in Ref. [10] the reduction of overheating and occupants dissatisfaction is achieved through the adoption of thermostatic valves. Energy and comfort oriented measures to be implemented in existing hospitals with minimal disruption and at low-costs are investigated through field measurements and observations, as well reported in Ref. [11].

The reduction of hospital energy consumptions can be obtained at different building levels, such as ward/room and at entire hospital building [19]. This can be done by controlling heating and cooling in only one room or thermal zone (e.g. by adopting sensors that regulate the radiator valves), and by reducing the whole building energy consumption (e.g. by adopting a chiller water temperature management depending on the ambient temperature). In order to select proper measures, also applied to different categories of refurbishments, comprehensive analyses performed through the use of appropriate tools are necessary. In literature the adoption of steady-state and dynamic tools for the calculation of hospitals energy consumptions (for preceding refurbishments) is scarcely observed. Simplified steady-state models, often purposely developed, are based on empirical and/or experimental mathematical models. In particular, the adoption of simplified methodologies related to several control techniques able to assess the possibilities for increasing energy efficiency in hospitals were recently presented in Refs. [19,20]. Here, according to the authors, the tool (including such methodologies) enables fast analyses by avoiding complex dynamic modelling. Such tool was tested and calibrated at the new emergency hospital located in Novi Sad, Serbia. Contrarily, the adoption of exhaustive dynamic simulations is particularly advised to find out the hospital weakest points from the energy point of view. This is particularly true in case of energy performance analyses and diagnoses on the whole building envelope – plant system. Nevertheless, due to the difficulties in properly modelling the building-HVAC system for large buildings such as hospitals and to the time consuming simulations, only very few works are available in literature. Some studies are related to single hospital spaces (such as a ward) due to the difficulties in modelling, calibrating, predicting and interpreting results for all the hospital spaces. Large models can also limit the number of possible simulations, since even modest retrofit proposals could imply changes to many parameters. In particular, in order to recommend various refurbishment options, different approaches were utilized. In Refs. [11] and [21], a model, purposely developed by using the IES dynamic thermal simulation model, calibrated against measured temperatures was used in order to simulate the thermal behaviour of a medium-rise ward block of a representative hospital building. A similar analysis also performed by means of IES dynamic thermal simulation model, without the help of measurements, is presented in Ref. [22]. Here, a single new ward of a U.K. hospital is analyzed. Dynamic simulations were also used in order to investigate energy, environmental and economic effects due to the rehabilitation of the building envelope of a hospital located in Naples, Italy [23]. In such paper, the analysis was performed by means of EnergyPlus and its DesignBuilder interface. Here, combined measured/calculated input data for overall thermal transmittances were adopted. The well-known transient system simulation software, TRNSYS, was used for improving the performance of the air conditioning system of a single hospital ward space located in Malaysia [12]. In this study, spot measured data (concerning the mean values of indoor and supply dry bulb temperatures and relative humidity) were collected and compared to those obtained with simulations. TRNSYS tool was also adopted in several studies focused on the improvement of efficiency of energy conversion and transfer systems in hospitals. From this point of view, the evaluation of the energy and economic performance of a solar heating and cooling system serving a hospital located in Crete, Greece was carried out without the help of measured data [24]. A trigeneration plant intended to integrate the existing natural gas fired-boiler central plant serving a hospital located in Parma, North of Italy, was analyzed [15]. Here, while space heating and cooling loads were calculated through dynamic simulation on an hourly basis, the electric load and the heat load for both sanitary hot water and process steam were estimated on an hourly basis from the monitored actual consumptions. A similar approach was used in order to demonstrate the reliability of a purposely developed methodology (applied as a case study) able to predict the performance of an engine trigeneration system [25].

The analysis of the literature about hospital estate shows that:

- outcomes available in literature for hospital facilities are strictly dependent on the investigated loads pattern and cannot be extended to different buildings functions and to different locations [1,9];
- few works coupled dynamic simulations and experimental campaigns (most of them were performed on operating rooms, as in Ref. [3]). Measurements are difficult to perform without interfering with the hospital operation. Note that through measured input data, a proper calibration of the adopted

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