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Impact of low investment strategies for space heating control: Application of thermostatic radiators valves to an old residential building

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ABSTRACT

With an old mean construction age, Italian buildings are considered as long-lasting goods; 75% and 17% of Italian live respectively in buildings built before 1990 and before 1950. The potential energy savings that can be achieved from the refurbishment of existing dwellings are clearly high. To this regard, the European Directive EPBD recast defines a comparative framework to improve buildings energy performance aiming to the nearly zero energy target by 2020. It is thus important to point out energy retrofit actions to be widely applied to the whole existing buildings stock and to be cost optimal.

This paper analyzes the application of space heating control devices such as thermostatic radiators valves (TRVs) on an old existing multi-family building in Turin by means of the EnergyPlus dynamic simulation code. Measured data of the energy supplied by the district heating network were used for calibrating the model. In order to evaluate the impact of the TRVs, simulations were performed with and without TRVs. The application of the dynamic energy simulation to different patterns of TRVs use was proved to bring back significant energy savings from a minimum of 2% up to a maximum of 10%.

1. Introduction

1.1. The retrofit of existing residential buildings

In Europe the building sector contributes largely to the total energy consumption with a 40% influence on the total assessed energy uses [1]. To this regard, many energy efficiency targeted policies and projects have been launched. In particular, the EPBD recast Directive promotes nearly zero energy buildings for the public and the private sectors as a mandatory regulation within 2020 [1]. Nonetheless, by the time this "energy efficient" approach will become the standard best practice for buildings design, energy consumptions will increase even more. Furthermore, concerns about the state of the existing dwelling should be taken seriously. Most of the energy consumptions are attributable to the existing stock because of the buildings age, the construction technologies and the low efficiency of the energy systems that supply the buildings. Moreover, the low replacement rate of old dwellings by new ones amounts to 1–3% per year [2], and especially in Italy residential buildings are often seen as long-term assets. Approximately 75% and 17% of Italians live respectively in buildings built before 1990 and before 1950 [3], confirming the European trend about the old mean building construction age. The amount of energy consumed by the existing dwellings has not been quantified but it is beyond any doubt that great energy savings can be achieved [4]. Moreover, the energy savings that can be obtained with the energy retrofitting of existing dwellings are greater than the ones that can be obtained with the construction of a relatively small proportion of new dwellings. Therefore, the refurbishment of the existing building stock has to be planned and applied in order to have a timely energy reduction.

There again the major focus is nowadays on the design of new buildings with low energy consumptions. Discussions about the choice of demolishing old building and replacing them with new and more efficient ones have raised without any real agreements [5]. Some countries resort frequently and openly to building demolition and re-construction. Indeed other countries like Italy usually avoid demolition due to the cultural heritage of its proper existing building stock. For them, to preserve and to renovate existing buildings is thus the most common and acceptable solution. Due to that, a great amount of Italian energy refurbishment projects, approximately 40% on the overall, regarded buildings built before 1960

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and characterized by low energy performance and without any thermal insulation layer [6]. Moreover, among historical buildings (all buildings built in a different period from the present), approximately 1.8% belong to the Italian Cultural Heritage [7] and are thus subjected to protection by Ministerial Authorities. This means that any retrofit intervention on such buildings should be aimed to the preservation of the materials and goods, as well as to the protection of the buildings cultural values [4].

Nowadays the number of energy retrofit technologies has been increasing in size. Energy efficiency measures (EEMs) can range from actions on the envelope to the system, and on building operation and control. According to a survey on the 2011 Italian 65% tax reduction on existing building energy efficiency projects [6], the most common retrofit measures are windows replacement (59%), replacement of the heating system with a more efficient one (28%) and installation of solar thermal collectors (11%). The improvement of thermal insulation in the building envelope, in both vertical and horizontal components, regards only 3% [6] of the retrofit applications sent for tax reduction. In fact, even if the improvement of the building envelope performance could bring to higher mean energy savings, the mean investment cost is higher than other market available measures. To this regard, the decision on which type of refurbishment should be applied to the building depends on various factors and between them, the most influencing one relapses on the investment profit [2]. It is not an easy task to decide if an energy measure to undertake is worth the investment. Due to that, ad hoc cost optimal levels of energy performance need to be defined for the considered energy efficiency measures in compliance with the EPBD recast requirements [1]. To this regard, analysis on the cost optimal methodology [8], applied to reference building case studies [9] can guide and help in the selection of the most profitable measures.

Moreover, the type of energy efficiency measures that can be selected is quite small for buildings that are considered historical and protected as cultural heritage. It is thus important to point out energy retrofit actions to be widely applied to the whole building stock and to be cost optimal. Thermostatic radiator valves (TRVs) represent a quite common refurbishment measure, which is to be reinforced by law by 2016 in the city of Turin. They have been widely studied, ranging from the study of their adjustment characteristics to their control effectives [10]. Additionally, past studies have demonstrated that TRVs bring an average energy saving from 10% [11] to 50% if considered together with the increase of the envelope thermal insulation [12,13].

1.2. Objective of the study

This study aims, by means of dynamic simulation, to investigate the control effectiveness of TRVs. Additionally cost optimal calculations are used to analyze the feasibility and application of TRVs on an existing building as a low cost energy efficiency measure. The selected case study is an existing multifamily building located in Turin (North Italy). The building, built at the beginning of XIX century, belongs to that category of refined aristocratic buildings characterized by obsolete mechanical systems and without thermally insulated building envelopes, requiring thus heavy retrofit interventions. However, due to its construction age and to its belonging to the cultural heritage patrimony, TRVs represented one of the most eligible EEMs for reducing the energy consumptions. Other kinds of EEMs, which may have higher energy savings, such as those concerning the building envelope could not be taken into consideration for their impact on the building façade, subjected to protection and thus to architectural restraints for its cultural heritage. The energy assessment of the case study was carried out by means of dynamic energy simulation with the EnergyPlus code. Measured data of about two months operation during the winter season, were used for calibrating the energy model. The calibration procedure was carried out based on the total heating energy rate delivered at the building district heating sub-station. The case study was simulated with and without TRVs. The application of TRVs was proved to bring back significant energy savings, around 10% in compliance with results found in literature [11]. A comparison with measured data was also performed. In particular, the results of the present study were also compared to the utility energy bills of another residential existing multi-family building, subjected to the application of TRVs in the last years. The comparison with the utility bills, before and after the application of TRVs, of the other case study brought back results similar to the simulated ones presented within this study.

2. The case study

The case study hereby presented is a multi-family residential building located in the city of Turin, in North Italy. It is an existing historical building (Fig. 1) built at the beginning of XIX century.

The architectural protections and restraints for Cultural Heritage issues, shrinks quite a lot the kind of retrofit measures to be applied to the buildings. Most of them are thus not allowed, even if high energy savings, for their major impact on the building façade (e.g. external increase of thermal insulation cannot be pursued in order to preserve the original historical façade). For this reason, the type of building envelope retrofit measures that could be applied to it, are quite few, including the hereby studied application of TRVs for the space heating control.

Data collection of the building geometry and construction features came from the buildings energy certificate and technical drawings. However, for a full and correct building characterization, additional information were obtained from in situ inspections. In particular, as there were no attic plans, the in situ inspections were strictly necessary and they revealed the attic restoration, following to the issue of the building energy certificate.

The case study is a four-storey building with a total gross volume of 7820 m^3 and a 4 m floor-to-ceiling height. The typical building plan, with a gross floor area of approximately 500 m^2 is composed of three apartments, with an overall number of 12 apartments. The attic does not follow the apartment layout, but is divided into 11 small apartments/studio. The building also has a basement where the district sub-station and the respective apartments cellars are located. Except for the staircase and the basement, all areas are conditioned. Table 1 lists the main geometrical information about the case study.

With regard to the envelope, the building reflects the traditional architecture of its construction age. It is thus composed of bearing brick walls with no insulation and a pitched roof. The transparent elements are single glazing windows with a wood frame. Except for the attic interiors, the building envelope was not refurbished. Consequently, the building does not fulfill with the current Italian regulation, in terms of thermal insulation and energy conservation. As no measured data for the building envelope characterization were available, data from national manuals and standards were adopted [14,15]. In particular the *U*-values of the building envelope main components were defined based on the building construction age, and also modified taking into consideration the envelope decay until the current analysis.

Table 2 lists the main building envelope components *U*-values.

With regard to the heating system, as well as a great part of the urban dwellings in Turin, the case study is served by the district heating network. As mentioned previously, the district heating building sub-station (Fig. 2) is located in the basement and has a heating capacity of 250 kW. The supply side is composed of vertical columns and the terminal units are iron-cast radiators; some