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The influence of surface finishes on the energy demand of HVAC systems for existing buildings

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ABSTRACT

In historical centres, the buildings are characterized by pitched roofs, sometimes not insulated, with low thermal inertia and coated in brick tiles with low solar reflection factor. So, the attics show high energy costs for heating and cooling.

This paper analyses the energy saving obtainable by applying innovative surface finishes on interior and exterior surfaces of opaque envelope components of existing buildings. This simple and inexpensive retrofit action determines energy cost reductions for heating and cooling, but also benefits regarding indoor thermal comfort and useful life of buildings, because condensation problems and thermal shock are reduced; moreover, it preserves the architectural and chromatic characteristics of the building envelope.

The analysis is performed by means of a building energy simulation code, considering typical HVAC systems for various Italian and European cities. A technical-economic and environmental investigation is also performed.

Thermal energy needs of buildings for summer cooling can be reduced up to 60% by applying "cool paints" on the external surface of walls and roof, while internal low infrared emissivity coatings can reduce winter thermal requirements up to 12.5%.

Significant primary energy savings for heating and cooling and reductions of greenhouse gas emissions (up to 60%) can be obtained, as well as a payback value of few years in most cases.

1. Introduction

In the last decades, the summer heat waves have increased and similar future weather events will be probably more severe [1]. This leads to an increase of HVAC system use and of their energy requirements.

A significant part of total energy consumption and pollutant gas emissions depends on buildings [2]. In the European Union, 40% of global energy consumption depends on buildings, and this sector is on the increase [3]; moreover, in 2005, 26.6% of the final energy requirements depended on residential sector [4].

Therefore, the European Union is engaged in diminishing energy consumption by 20%, with reference to 1990, within 2020 [5]. To this aim, all member states must increase the energy performance of new buildings and related systems and provide energy retrofit measures for existing buildings [3]. One of the challenges consists in improving the building energy efficiency while keeping a satisfactory indoor microclimate for the occupants [6].

In temperate or hot climates, the use of summer air conditioning is spreading also in residential buildings, causing the increase in peak electric demand and blackouts [7].

Energy saving in buildings is typically achieved by a combination of active and passive techniques. The active ones are based on the utilization of renewable energy sources (mainly solar) [8,9]. Simultaneously, significant savings can be achieved by implementing passive techniques, mainly focused on the appropriate selection of the components of the building envelope [10].

Among the various passive techniques for building envelope, an important option is the optimization of the radiative characteristics of surface finishes. Absorptance is about 40% for external surface finishes with a light colour, whereas about 90% for dark finishes [11].

The Albedo control allows to achieve three important effects by reflecting to the space the shortwave incident radiation: Global Warming mitigation, reduction of urban heat island phenomenon and energy savings in buildings [12].

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The application of cool paints on the building roof can improve also the indoor thermal comfort of the occupants in summer, by decreasing the mean radiant and the operative temperatures of the rooms [13]; moreover, the overall energy needs of the building for space heating and cooling can be greatly reduced [14].

In [15], the authors investigated the performances of green roofs in reducing the cooling energy demands in summer. They also show that cool coatings, mainly in warm European climates, are preferable compared to green roofs, because of the great potential in reducing the heat gains due to the solar radiation and the related energy costs for cooling. Anyway, an optimization procedure is required to identify the best technology depending on the climate [16].

Pisello et al. reported experimental analyses on innovative cool coatings for traditional clay tiles [17]. The results show that the application of this coating reduces the number of hours when the attic operative temperature is greater than 26 °C by about 18% in summer, while the worsening in winter is negligible.

In California and Florida, the American Society for Testing and Materials (ASTM) introduced, for roofs and almost horizontal building surfaces, the solar reflectance index (SRI), which combines far-infrared emissivity and solar reflectance. In temperate and hot climates, the use of coatings with high SRI reduces the energy demand for summer cooling by 10–60% [18]. Cool roofs (roofs with coatings characterized by high infrared emissivity and solar reflectance) are widely promoted in the U.S.

In Europe, materials with colour similar to those of historical and traditional buildings are frequently used for existing buildings, so the solar reflectance is partially sacrificed. Nowadays, tiles treated superficially with "cool colour" finishes are also considered; this kind of finishes has the same spectral response of terracotta tiles in the visible range (43% of the solar radiation), but reflects much more radiation in the near infrared spectral band (between about 700 nm and 2500 nm), which characterizes more than 52% of the solar radiation. Therefore, these cool paints show much greater solar reflectance compared to traditional materials, but the same colour [19].

In Mediterranean climates the use of flat white roofs is quite frequent, but in historical centres the buildings are characterized by pitched roofs, sometimes not insulated, with low thermal inertia and coated in brick tiles with low solar reflectance ρ_s (minor than 0.3–0.4). Therefore, these attics show high energy costs for heating and cooling.

In the present paper, the energy requirements of an attic of an existing building, with typical HVAC systems, are evaluated. Then, after the application of innovative internal and external finishes on roof and walls of the attic, a yearly energy, economic and environmental analysis is performed. The proposed energy retrofit measures are characterized by low cost and simple installation; moreover, they preserve the architectural and chromatic characteristics of the building. The study refers to various Italian and European cities with different climates, i.e. Palermo, Seville, Rome, Milan, Paris, London, Berlin and Stockholm. The obtained results, at least in terms of energy impact, could be related also to non-European locations with climates similar to those of the considered European cities.

The main aim of this paper is the improvement of energy efficiency of existing attics, without sacrificing the little living spaces and available heights (as occurs when considering internal insulation panels).

External and internal innovative coatings on existing building envelopes are applied, so obtaining optimal radiative characteristics, i.e. high ρ_s and infrared emissivity ε_{inf} for outside finishes, low ε_{inf} for internal surfaces.

The attics are modelled with different characteristics depending on the climate. All the energy analyses are performed by using a dynamic building simulation software [20] based on EnergyPlus. The payback period and CO_2 emissions are also evaluated.

The importance of the surface finishes has been already shown in previous articles, but the energy effects related to the described retrofitting measures have not been completely analysed, mainly regarding the yearly primary energy requirements and the combination of internal and external surface finishes. Moreover, this type of investigation is missing when referred to pitched roofs instead of flat roofs.

2. Research approach and case study

As said, the research activity is carried out by using a dynamic building simulation software [20] based on EnergyPlus as calculation engine. EnergyPlus was validated by means of measured data in Europe [21]; moreover, extensive validation procedures for different locations and buildings are available. Currently, three major types of tests are conducted: analytical tests; comparative tests; release and executable tests. EnergyPlus testing reports are available for many of these test suites, for example for building envelope [22] and HVAC equipment [23]. In [24], EnergyPlus was also compared to other simulation codes, and the detected deviation of the obtained results was almost always lower than 10%.

The analysis of the present work is conducted on a building representative of the typical residential buildings built in the period 1920–1960 in some European towns, above all in historical centres [25]. The main geometrical and thermal–physical characteristics of the case study attic are reported in Fig. 1 and Tables 1 and 2. It can be noted that the Swedish reference building shows much better *U*-values compared to other cases.

For the considered European cities, an attic with the same dimensional characteristics is modelled, but with different characteristics regarding *U*-values of the building envelope components, efficiencies and operating hours of the HVAC systems and main climatic characteristics (Tables 2 and 3) [26]. For all the cases, the energy, economic and environmental analysis of the attic is carried out.

For each case, four retrofit measures are analysed: depending mainly on the climatic conditions, each of these actions results advantageous or not from energy, economic and/or environmental point of view. The four retrofit actions are the following:

(1) red tile cool paint on traditional tiles of the pitched roof;
(2) red tile paint on pitched roof and innovative white plaster on outside surface of uncoated walls;
(3) low emissivity plaster (with ceramic nanospheres) on internal surface of roof and walls;
(4) red tile cool paint on pitched roof and low emissivity plaster on internal surfaces.

The main radiative parameters of the innovative and traditional surface finishes are described in Section 3.

The main characteristics and operating hours of the HVAC systems are shown in Tables 2 and 3. These traditional systems, as occurs in urban residential attics, are constituted by simple autonomous systems: radiators served by a typical hot water boiler for heating; split systems for cooling. Regarding the heating season, a seasonal global efficiency (η_{gl}) equal to 0.66 has been used, considering Eq. (1):

$$\eta_{gl} = \eta_g \cdot \eta_d \cdot \eta_r \cdot \eta_e \quad (1)$$

where

- η_g is the generation (or production) efficiency, equal to 0.88 for a traditional non-condensing hot water boiler;