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Energy retrofit of the Krsan Castle: From sustainable to responsible design—A case study

Paolo Blecich[a,*], Marko Franković[b], Živa Kristl[c]

[a] Faculty of Engineering, University of Rijeka, Vukovarska 58, HR-51000 Rijeka, Croatia
[b] Faculty of Civil Engineering, University of Rijeka, Radmile Matejcic 3, HR 51000 Rijeka, Croatia
[c] Biro-Arcus, Borsetova 19, SI-1000 Ljubljana, Slovenia

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ABSTRACT

This paper studies the effects of energy efficiency measures on energy demand in the Krsan Castle, which is a cultural heritage complex in Istria (Croatia). The heating and cooling energy demand is calculated by means of a dynamic building energy model based on hourly weather data. The largest individual reductions are obtained with thermal insulation for the heating demand, and with external window shading and natural night ventilation for the cooling demand. Energy reductions of up to 80%, relatively to the existing state, can be achieved by energy retrofit projects which include thermal insulation, energy efficient windows, improved airtightness, mechanical ventilation with heat recovery and passive cooling techniques. The economic analysis revealed that payback periods between 10 and 16 years can be achieved by this kind of energy retrofit projects.

1. Introduction

The energy retrofit of existing buildings will be a major challenge of the EU building sector in the forthcoming years. The energy retrofit of cultural heritage buildings is particularly demanding because these buildings are subject to special regulations that narrow the choice of applicable energy efficiency measures. The energy retrofit of cultural heritage buildings encompasses two very distinct areas: culture and sustainability. Responsible and careful planning is required for the preservation of cultural heritage buildings to coincide with the application of energy efficiency measures. Indeed, the esthetical and architectural character of these buildings could be unacceptably altered by energy efficiency measures. Generally, energy efficiency interventions and renewable energy systems are not allowed, unless they are invisible to every extent and purpose and comply with rigid conservation requirements. Nevertheless, this is an emerging research field as cultural heritage buildings offer substantial energy saving potentials.

As pointed out by Polo López and Frontini [1], retrofit projects aiming to improve the energy performance of cultural heritage buildings need to weigh different aspects. The implementation of features such as high performance HVAC systems, solar collectors and photovoltaic modules can be controversial on heritage buildings. One of the problems that inhibits the use of these technologies is also the reversibility of interventions. This is why, as pointed by Milone et al. [2], the allowed energy efficiency measures are not necessarily also the best ones for the energy retrofit of historical buildings. Maahsen-Milan and Fabbri [3] drew attention to the problem of technical plant installation impact, which is a big challenge in restoration and retrofit projects, especially due to the rapid development of HVAC solutions. Recently, several successful energy retrofit projects of cultural heritage buildings have been presented. For example: the retrofit of the Bernardas' Convent in Lisbon [4], the renovation of an UNESCO heritage settlement into a spread hotel in southern Italy [5], the transformation of an old army barracks into a museum [6] and the opening of a museum inside a historical building [7]. The key issue in all of these projects was to find a balance between conservation regulations and energy efficiency interventions. Systematic guidelines for the energy retrofit and efficient energy management of cultural heritage buildings in Italy were recently proposed by de Santoli [8].

In Croatia, the installation of energy efficient interventions and renewable energy systems in heritage buildings is restricted by regulations for the cultural preservation [9]. The retrofit of cultural heritage buildings is supervised by the Office for protection of cultural heritage [10].

* Corresponding author.
E-mail address: paolo.blecich@riteh.hr (P. Blecich).

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Fig. 1. Aerial view of the Krsan Castle [18].

Kulmer et al. [11] conclude that the heritage building stock in Croatia needs a clear, long-term governmental policy program and a general strategy for preservation. For these buildings to be financially sustainable, they should undergo energy retrofit while maintaining their original appearance and functions, while supporting public needs. At present, cultural heritage buildings in Croatia are excluded from national and EU directives concerning the energy performance of buildings. Croatian heritage buildings are approached individually in renovation plans, without a general framework. Mazzarella [12] states that national cultural heritage authorities can encourage the EU policy to come out with a better definition of what is expected from the energy retrofit in historic buildings.

There is no accurate data about the energy consumption in Croatian heritage buildings, but some conclusions can be drawn from the available sources. According to the latest reports [13], Croatia has about two million of occupied households in residential buildings. About 36% of the household stock is located in the coastal region which has a Mediterranean climate, and 64% is located in the continental region which has a temperate continental climate. About 80% of the total number of households were built before 1990 when regulations for energy performance of buildings were loose. These buildings can have an annual heating energy consumption of more than 300 kWh/m^2 [13].

This paper analyses the effects of energy efficiency measures on the energy demand of the Krsan Castle, which is a cultural heritage complex in Istria (Croatia). A comparative analysis of various interventions is performed with respect to energy efficiency, invasiveness and visual appearance. Even though the study is carried out for the meteorological conditions present in Istria, which has a Mediterranean climate (Northern Adriatic Sea), the energy retrofit approach presented is also valid for similar projects in Croatia. Each cultural heritage building is a particular case, but they share some common features in Croatia: massive stone walls, small window openings, wooden floor constructions, damaged or non-existent roofs.

Similar studies have been recently carried out by Sahin et al. [14] for the Basmane Semt Merkezi building in Izmir (Turkey), Alongi et al. [15] for the Castle of Zena near Milano (Italy) and by Franco et al. [16] for the Albergo dei Poveri in Genova (Italy). They used dynamic building simulations for assessing the actual energy demand and the potential energy reduction through various energy efficiency measures. The present study expands the analysis by including the effects of passive architectural interventions (thermal mass and natural night ventilation) on the building energy demand.

2. Study setup

2.1. Building description

The Krsan Castle is situated in Istria, Croatia (latitude N 45°10′16″, longitude 14°08′11″), 6 km inland from the Adriatic Sea. It originates from the Middle Ages and was first mentioned in 1274. During the following centuries the castle underwent many changes. Today, the castle ruins include a dominating tower with a courtyard [17]. Several buildings are present at the site, as shown in Fig. 1, which will accommodate tourist residences in the future. The buildings are partially ruined, but the missing elements can be perceived from the remaining structure. The walls consist mainly of 0.5 m thick stone masonry (U = 1.5 W/m^{2}K). The windows are single glazed with wooden frames (U = 5.0 W/m^{2}K). The floor construction is wooden (U = 1.1 W/m^{2}K). The ceiling constructions are made of wood and stone vaults. The roofs have wooden construction with tiles but no thermal insulation (U = 1.8 W/m^{2}K). The doors are wooden (U = 3.0 W/m^{2}K). Thermal bridging effects are taken into account increasing the corresponding U-value of the building element by 10%.

2.2. Methodology

In the first part of the study, several energy efficiency measures and their impact on heating and cooling energy demand are analysed individually and with respect to the existing state. The installation of thermal insulation and its effect is analysed for two different thicknesses (cases #1 and #2). Thermal insulation should be mounted from the inside if there is risk to alter the original building appearance. Although not constituting an energy efficiency measure, the reduced thermal mass is analysed separately (case #3), as a consequence of mounting thermal insulation from the inside. After energy retrofit, it is assumed that the energy efficient windows have a U-value of 1.5 W/m^{2}K and a solar transmittance of 0.70 (case #4). Also, the building airtightness is improved to 0.3 ach (case #5). Installation of a mechanical ventilation system with heat recovery (MVHR) would ensure addition energy savings (case #6). The two remaining energy efficiency measures, natural night ventilation (case #7) and external window shading (case #8), should prevent overheating in the summer period. None of the energy efficient measures may be allowed to alter the visual appearance of the Krsan Castle complex. Thermal insulation and MVHR air ducts have to be installed from inside the walls. Newly installed energy efficient windows and shutters have to faithfully resemble the old ones, in terms of appearance and performance.