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Evolutive Housing System: Refurbishment with new technologies and unsteady simulations of energy performance

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ABSTRACT

The aim of the present paper is to evaluate the energy performance in unsteady-state conditions of an Evolutive House. The original design was presented by two important architects, Renzo Piano and Peter Rice, in 1978. The house has two large glass walls in the east and west façades. Experimental investigation and numerical analysis were carried out in a prototype of the house realized in Perugia. The air temperature, the surface temperature of floors, the global solar radiation, the relative humidity were measured. Simulations were performed using both Energy Plus and TRNSYS software. Simulation models were tested and validated with experimental data considering a new weather database compiled for Perugia. The analysis compares different scenarios in terms of energy demand, such as the substitution of the glazing and the use of innovative packaged solutions. Innovative glazing systems filled with silica aerogel were investigated as a solution for energy saving in buildings. Results show that an important energy saving was obtained for all the proposed glazings (about 60–70%). The simulation codes' results are in good agreement, but some differences are due to the different approach in the evaluation of the solar irradiance on tilted surfaces and to the transient heat conduction model.

1. Introduction

Buildings which need to be refurbished are a very significant part of the building heritage in European countries: in Europe about 80% of all residential buildings were in fact built before 1980. The building studied in the present paper was built in 1978, based on a project of Renzo Piano and Peter Rice [1] and it has large glazing areas in the façades. After 35 years from its construction the building is still very modern; in fact nowadays many buildings have large glass windows to provide a physical and visual connection to outside: windows are important for creating a comfortable indoor environment, but the energy demand is greater than the one for buildings with conventional façades, especially in summer time [2]. In both residential and commercial buildings, most of the energy used is required for space heating and cooling (about 40% of energy consumption): windows represent the most contribution in building envelope energy losses, that is approximately 60% in commercial buildings and 20% in residential ones [3,4].

The case study is a not conventional house because it has a window-wall ratio of about 37%: it has two large glass walls in the east and west façades, but the existing glazing system is not well insulated ($U = 2.3\,\mathrm{W/m^2\,K}$). It is an example of earthquake-proof building and it is composed of prefabricated concrete elements. The prototype built near Perugia in 1978 today is not inhabited. The peculiarity of the Evolutive Housing System is the changeability of the internal spaces, thanks to a simple mechanism of the glazing façade that is able to run along a rail. The internal sliding glass wall can be moved to increase the occupied space. The building was meant to be inexpensive and easy to assemble and modify [1].

The aim of the present paper is the energy demand analysis of the building and the evaluation of the influence of different design options: the simulations were carried out with two codes (Energy Plus and TRNSYS), varying the type of glazing and considering also innovative glazing solutions with aerogel in interspace. Aerogel is one of the most promising materials for use in highly energy-efficient windows: in addition to the low thermal conductivity (down to 0.010 W/(mK) in evacuated conditions), a high solar energy and daylight transmittance is achieved [5]. Optical, thermal and acoustic properties of innovative glazing solutions with aerogel have been investigated at the University of Perugia since 2003, with both experimental campaigns and simulation codes [6,7].

Two experimental campaigns were carried out in February–April 2013, in order to monitor the internal thermal conditions of the building and the most important characteristics of the envelope. A new weather file representative of the real climatic conditions during the experimental campaign was implemented, in order to compare the simulation results and the experimental data and to validate the model. The different approaches of the two

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Nomenclature

DGG:	Double Glazing with Granular aerogel
DGM:	Double Glazing with Monolithic aerogel
ED:	Energy Demand (kWh)
E+:	Energy Plus
I_{cl}:	Clothing thermal insulation (clo)
M:	Metabolic rate (met)
PMV	Predicted mean vote (–)
PPD:	Predicted percentage of dissatisfied ()
T:	Temperature (°C)
TEG:	Triple Existing Glazing
TGA:	Triple Glazing with Argon in interspace
TR:	TRNSYS
U:	Thermal transmittance ($W/(m^2\,K)$)
W:	Global solar radiation (W/m^2)
τ:	Transmittance (–)

Subscripts

i:	Indoor
o:	Outdoor
g:	Ground
w:	Wall
v:	Visible

simulation codes were compared, considering both the Direct Root Finding method (TRNSYS) and the State-Space method (Energy Plus) [8].

Results obtained by these codes in terms of energy savings are very similar (the differences between TRNSYS and Energy Plus vary in 6–12% range). A significant reduction in energy consumption should be obtained by varying the type of window, especially when considering the heating period.

The unsteady state models implemented in the software are very powerful tools in building design: many different solutions can be investigated and the most appropriate design options can be selected thanks to the simulation results [9–12]. Thanks to the use of these programs also the influence of the glazing surface on the thermal comfort conditions can be evaluated [13–20].

2. Methodology

2.1. The case study

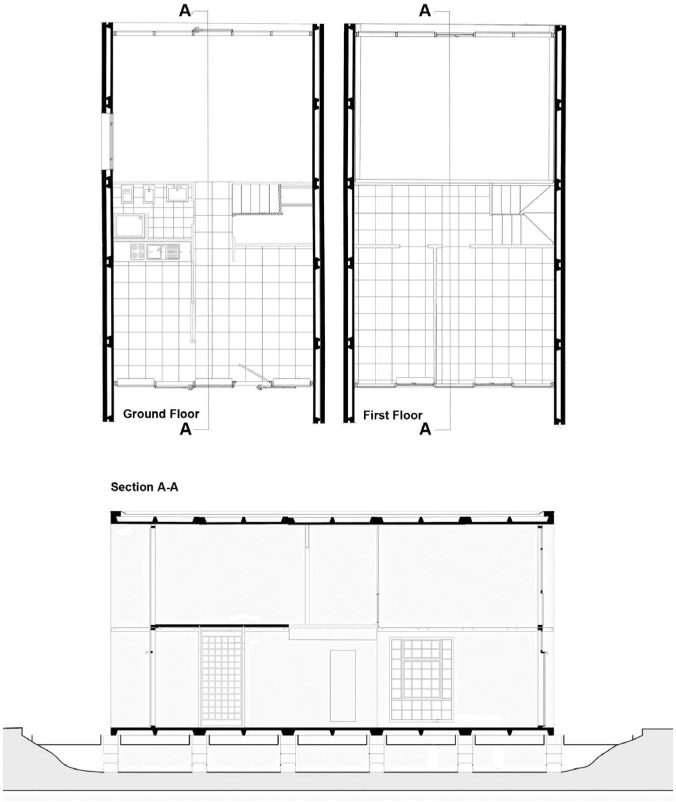

Fig. 2. Plans and section of the building.

The case study is the prototype of an Evolutive House. The building was originally design in 70s as an example of earthquake-proof buildings. It consists of two floors: the living zone is placed in the first one (a kitchen, a bathroom, a junk room and a living room 6 m high). Stairs allow the access to the first floor: a landing and two bedrooms are upstairs (see Fig. 1).

The entrance of the building is placed in the south-east façade; the living zone presents a large glass wall in the north-west façade, for a total area of about 37 m^2. Fig. 2 shows the plans and a section of the building. The total building area is 96.24 m^2, the living zone is 72 m^2. The volume of the total conditioned area is about 330 m^3. The windows have a triple glazing system (from the external side to the internal one: glass layer 3 mm, air 7 mm, glass layer 3 mm, air 6 mm, glass layer 3 mm), for a total thickness of about 22 mm, and an estimated thermal transmittance of about 2.3 W/m^2 K, calculated according to ISO 10077-2 [21,22].

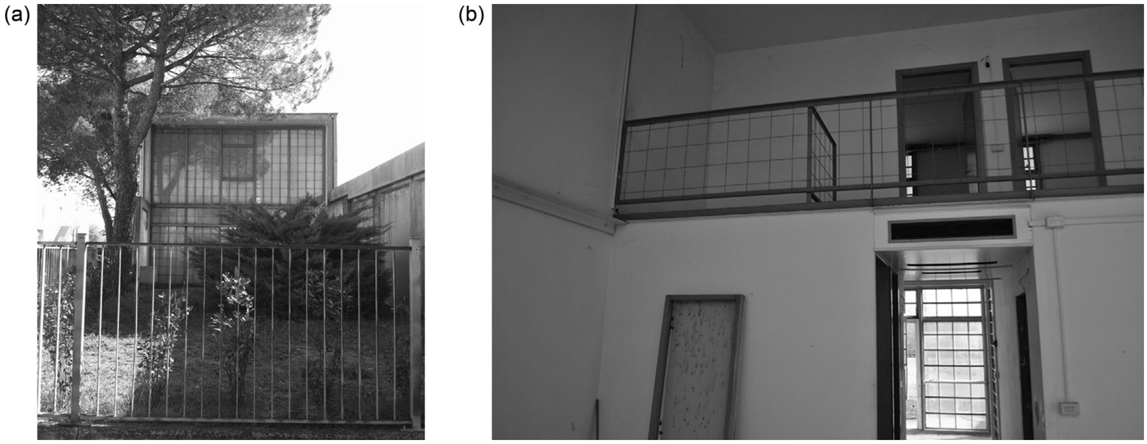

Fig. 1. External view of the Evolutive House (a) and internal view of the landing and the bedrooms (b).