On the Thermophysical Performance Optimization of Italian Schools of the 60s: A Case Study in Ostia (RM)

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Abstract

In recent years, energy efficiency and energy saving issues have dominated the field of buildings research. Since new constructions are characterized by an efficient design, the real challenge is to define accurate and effective retrofit interventions for existing buildings. In order to understand the energy behavior of buildings and identify the best viable retrofit solutions, accurate analyses, carried out by means of dynamic simulations and in-situ measurement campaigns, are needed. Furthermore, in Italy compliance of the effects of the proposed interventions with standards is necessary. In this paper, a school built in the 1960s was considered as a case study and its energy performance was investigated. An in-situ measurement campaign was conducted with a thermal imaging camera, a heat flow meter and air temperature probes. Following this, a dynamic model of the school was implemented by means of TRNSYS dynamic code and different retrofit scenarios were evaluated and compared. The aim of this analysis was to quantify the effectiveness of the chosen refurbishment strategies on the energy demands of the investigated school.

1. Introduction

In recent years, there has been a significant increase in energy consumption due, in part, to the economic growth of developing countries. This has led to a greater exploitation of fossil fuels, with a consequent increase in CO_2 emissions and other greenhouse gases.

The reduction of the overall energy demand of buildings is an important environmental objective. The aim to be pursued is to make public and private buildings consistent with the principles of energy efficiency and environmental sustainability (Marrone et al., 2018; Stabile et al., 2019). The importance of defining strategies to increase energy efficiency and reduce energy consumption and greenhouse gas emissions is a priority to which it is necessary to give precise and certain answers. Technical solutions have evolved over the years and for this reason, it is important to understand the energy behavior of buildings through accurate energy analyses (Dalla Mora et al., 2017; Evangelisti et al., 2017; Gori at al., 2016).

The construction sector clearly has a significant role in terms of energy consumption. Encouraging research and promoting retrofit interventions on buildings could act as an engine for the entire sector and contribute to achieving the objectives defined by the European Union. For this reason, effective policies and strict controls must be promoted to guarantee the expected results.

This work is part of the "Sustainability of Schools - SoS" project: an interdisciplinary project funded by Roma Tre University, which involves the Departments of Architecture and Engineering at Roma Tre University, together with the Departments of Economics, Mathematics and Physics, and Sciences. The final goal of the whole project, which involves different disciplinary fields, is to develop and validate

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). (2020). Building simulation applications BSA 2019. bu,press. https://doi.org/10.13124/9788860461766

predictive models of energy efficiency, comfort and health of existing school buildings, with the aim of proposing best practices and procedures for users (Marrone et al., 2018).

The aim of this paper is to study a selected category of educational building and define retrofit interventions in order to reduce energy consumption, support better internal environmental conditions and suggest more sustainable solutions. Preliminary experimental results and simulations are presented in the present paper.

1.1 The Selected Case Study

Prefabrication – introduced in Italy in the 1960s – took advantage of a considerably reduced construction time compared to traditional systems. Due to the economic boom and increase in birth rates in this period, many buildings were constructed, often by assembly of "large panel" prefabricated systems.

Due to the need to respond to the strong demographic growth, Law No. 17 of January 26 1962 allocated funding for developing prefabricated school buildings. Furthermore, the Ministry of Education provided funding for the construction of approximately 340 schools in 35 Italian provinces.

This happened before the implementation of the Technical Standards for School Construction (Ministerial Decree of May 18, 1975), the Norms for Fire Prevention in School Buildings (Ministerial Decree of August 26, 1992) and the provisions on energy saving (Law No. 10 of January 9, 1991). Consequently, the selected case study, along with all the other buildings built in the same period, do not comply with the important laws in all the aforementioned areas.

The strong and frequent impact of thermal bridges, performance losses, condensation phenomena and structural inadequacy of the external prefabricated large-panel walls has become an issue over time. This has led to the need to focus on stratigraphy, joints and technological solutions, in order to ascertain whether it is possible to improve the envelope behavior, in order to reach the performance level currently required.

As can be seen in Fig. 1, the investigated case study is characterized by a modular structure, with encapsulated asbestos cement panels that imply the presence of several thermal bridges. The windows, with a single glass sheet of 4 mm, are relatively old and the in-situ survey revealed that the frames do not close perfectly.

Fig. 1 – External view of the school

2. Methodology

The methodology used consisted of an experimental and numerical framework aimed at both supporting strategies and best practices for an efficient use of an educational building in the Lazio region and evaluating the effectiveness of possible retrofit interventions.

A prefabricated building was selected as case study: a school (see Figs. 1 and 2), in Ostia, near Rome (climatic zone D), representative of a high number of educational facilities built in Italy during the 1960s.

The stratigraphy was established starting from information provided by the technical staff of the school and in-situ surveys. The stratigraphy and the theoretical transmittance value are reported in Table 1. The total thickness of the external walls is about 21 cm (Fig. 3).

Given the impossibility of intervention with destructive diagnostic techniques in order to investigate the actual stratigraphy, it was necessary to move to non-destructive diagnostic investigations. In particular, infrared thermography and the heat-flow meter method were employed.

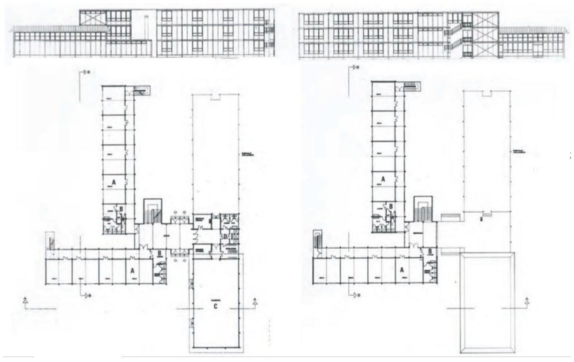

Fig. 2 – School layout and facades

Table 1 – Stratigraphy of the wall

Layer	Thickness [m]	Thermal conductivity [W/mK]	Thermal resistance [m²K/W]
1) int.	-		0.13
plasterboard	0.015	0.200	0.075
2) fiber cement panels	0.008	0.500	0.016
3) Polystyrene granulate and cement	0.040	0.070	0.571
4) Cement-Asbestos	0.100	0.700	0.143
5) Polystyrene granulate and cement	0.040	0.070	0.571
6) fiber cement panels	0.008	0.500	0.016
ext.	-		0.04
	Wall thermal resistance		1.563 m²K/W
	Wall thermal transmittance		0.640 W/m²K

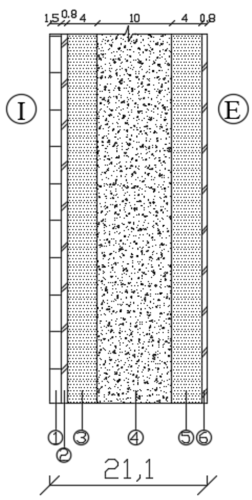

Fig. 3 – Stratigraphy of the wall

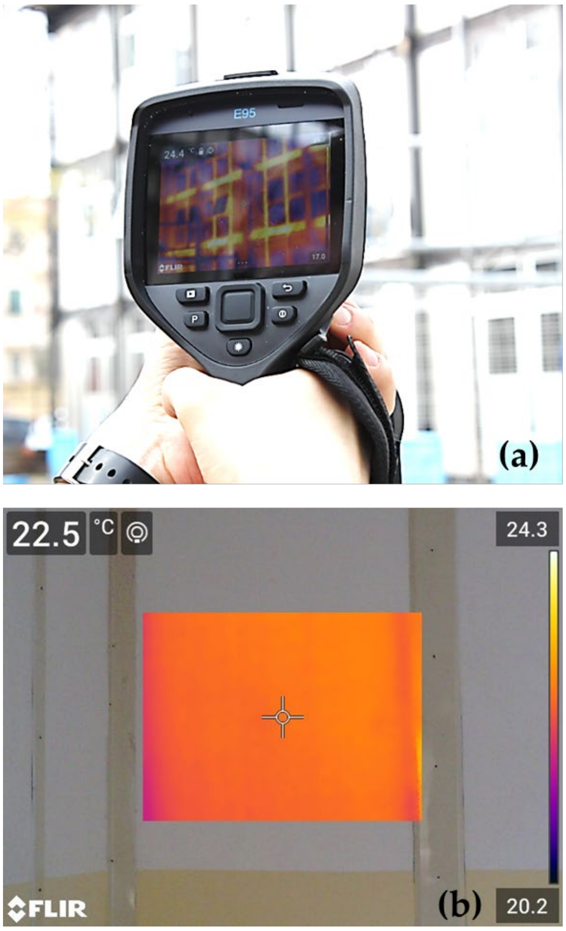

Fig. 4 – External (a) and internal (b) infrared thermography survey

The measurement campaign was conducted in April 2019 by means of a heat-flow meter through which heat fluxes, and indoor and outdoor temperatures were acquired. In addition, a thermographic survey was conducted in order to identify both thermal bridges in the structure and for the proper installation of the heat-flux sensor (see Fig. 4).

Thermal transmittance values were measured by following the ISO 9869-1 (2014). In accordance with this Standard, measurements were carried out for 8 days, with an acquisition time step equal to 10 min.

The heat-flow meter was applied to a north-west facing wall, in order to avoid direct solar radiation as much as possible.

A calibrated dynamic model was created by means of the TRNSYS simulation code. The geometrical characteristics of the building were reproduced through TRNSYS-build (Type 56) and a thermal transmittance measurement was used to generate a correct wall model.

Physical environmental phenomena were set in TRNSYS-studio, reproducing the outdoor environmental conditions by using Type 54, inside which actual average air temperatures, relative humidity and wind velocity were introduced in order to generate realistic climatic data. Solar radiation measurements were not performed, and data were obtained by Type 109. The heating energy demand was increased by 20% in order to consider the influence of thermal bridges. Regarding internal boundary conditions, internal gains were represented by people, characterized by sensible heat of 65 W and latent heat of 55 W; an infiltration rate for each thermal zone equal to 0.6 1/h was set.

In order to attempt to provide effective retrofit solutions, external thermal coats made of XPS and characterized by different thicknesses were tested. In addition, windows with a higher thermal performance (thermal transmittance value equal to 1.300 W/m²K and g-value equal to 29.8%) were tested in the simulation.

The calibration procedure, based on a comparison between simulated and actual indoor air temperatures, was achieved by calculating the Mean Bias Error (*MBE*) and the Coefficient of Variation of Root Mean Square Error (*CV(RMSE)*).

The retrofit intervention mentioned above was tested in order to verify the reductions in monthly heating energy needs.

3. Results and Discussion

From the results obtained through the heat-flow meter measurement campaign, it was assessed that the building envelope is characterized by a thermal transmittance value equal to 0.522 W/m²K. As shown in Fig. 1, the building facades are characterized by panels joined together, creating a discontinuous structure characterized by many thermal bridges. Moreover, the windows are quite old, and do not ensure high thermal insulation levels. Due to these problems, energy refurbishment measures are needed in order to enhance the thermal behavior and the indoor thermal comfort.

Comparing the experimental thermal transmittance (equal to 0.522 W/m²K) with the theoretical transmittance (equal to 0.640 W/m²K), it is possible to observe a percentage difference equal to -18.43%, matching the ISO9869-1 criterion (Evangelisti et al., 2019).

Starting from the experimental data, a dynamic simulation, through the well-known dynamic code TRNSYS (2018), was carried out in order to verify the effectiveness of different retrofit scenarios.

Due to the intended use of the building, simulations aimed at assessing the energy needs of the building were performed only during the winter. A comparison between energy needs for heating after the retrofit interventions with those related to the current conditions was considered. Attention was also paid to the spring months, in which indoor temperatures become higher than the winter ones, due to the poor inertial properties of the building. In particular, the analysis focused on two periods: from 15th of April to the end of June; and from September to October. During these months, the heating system is switched off.

3.1 Retrofit Scenarios

Two retrofit scenarios were simulated: an external insulation improvement (using XPS) and the replacement of the windows, using solar control glass.

As mentioned above, the building is characterized by a light structure, with high internal thermal gains represented by students in the classrooms. Consequently, the first test involved the addition of an insulation layer on the external side of the walls. During this analysis, three different thicknesses of XPS were tested (5 cm, 10 cm and 16 cm). This approach leaded to reduced heating energy needs but with an average reduction value of less than 8%. Detailed results are listed in Table 2.

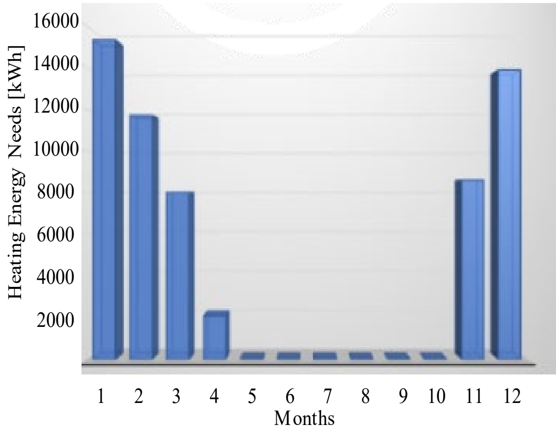

Fig. 4 – Heating energy needs of the actual conditions

Table 2 – Monthly heating energy needs and average percentage differences obtained by applying XPS

Month	Actual conditions [kWh]	XPS 5cm [kWh]	XPS 10cm [kWh]	XPS 16cm [kWh]	Average percentage difference [%]
J	15293	14702	14505	14391	-4.97%
F	11685	11202	11043	10952	-5.30%
M	8009	7624	7496	7424	-6.17%
A	2095	1967	1925	1902	-7.81%
M	0	0	0	0	-
J	0	0	0	0	-
J	0	0	0	0	-
A	0	0	0	0	-
S	0	0	0	0	-
O	0	0	0	0	-
N	8597	8205	8079	8008	-5.81%
D	13859	13306	13118	13011	-5.15%

The results indicate that this type of intervention cannot be considered as particularly effective.

The second test involved the installation of windows with solar control glass, characterized by a thermal transmittance value equal to 1.300 W/m²K and a solar factor (g-value) equal to 29.8%. The corresponding results are reported in Table 3.

Observing the data listed in Table 3, it is possible to ascertain that the replacement of the windows is very effective, reducing the annual energy need for heating by approximately 77%, on average.

During the retrofit phase, attention was paid to two aspects. Firstly, an additional external insulation layer results in higher indoor air temperatures during the winter, causing lower heating requirements. However, such higher indoor temperatures during spring and autumn can significantly compromise the comfort of users. This can cause ‘incorrect’ user behaviour, from the point of view of energy use, for example, the opening of windows even though the heating systems are switched on. The thickness of the external XPS layer should therefore be limited, which implies lower costs and better conditions during the warmer months, when the effects of solar radiation start to become significant.

Table 3 – Monthly heating energy needs and average percentage differences obtained by replacing windows

Month	Actual conditions [kWh]	Solar control windows [kWh]	Percentage difference [%]
J	15293	4157	-72.82%
F	11685	2848	-75.63%
M	8009	1512	-81.12%
A	2095	214	-89.79%
M	0	0	-
J	0	0	-
J	0	0	-
A	0	0	-
S	0	0	-
O	0	0	-
N	8597	1629	-81.05%
D	13859	3610	-73.95%

Thermal insulation should not be the only method considered to improve the energy performance of this category of building: the existing walls are characterized by low thermal transmittance and an improvement of the thermal resistance of the envelope is not the only viable and effective solution.

The building is negatively affected by the influence of solar radiation because it is characterized by a light structure, with a not-significant thermal inertia. External environmental conditions are not filtered by the envelope, which is distinguished by low attenuation and phase shift characteristics. This causes incorrect user behaviour, affecting, in turn, the energy consumption of the building.

4. Conclusion

An Italian school built in the 1960s was investigated, from the point of view of energy need, by using an experimental and simulative approach. Dynamic performance was analysed by means of a calibrated model and some retrofit interventions were tested. In particular, an external insulation improvement (using XPS) and the replacement of the windows, using solar control glasses, were considered.

Using XPS, the monthly energy needs for heating did not vary significantly. The average percentage reduction ranges from -7.81% (during April) to -4.97% (during January). In comparison, by substituting the windows a percentage difference ranging from -89.79% (during April) to -72.82 (during January) was achieved. These results suggest that replacement of the windows is the most cost effective intervention to reduce annual energy demand.

However, thermal insulation improvements should not be the method considered to enhance the energy performance of this kind of building, at this latitude. Light structures are affected by poor dynamic thermal performance, and are negatively affected by the influence of solar radiation, with consequent overheating. Subsequently, improving the thermal insulation of the envelope does not represent the most effective solution because it makes it possible to only slightly reduce the energy needs of the building, and implies an increase in internal air temperature values. As a consequence, incorrect user behavior can occur, for example, the opening of windows when heating systems are switched on, affecting, in turn, the energy consumption of the building.

Further measurements will be performed during the winter season and more comprehensive simulations and retrofit scenarios will be studied. Following the preliminary results reported here, movable solar shading devices will be the first additional retrofit solution to be considered. This kind of device may be an effective energy efficiency measure for this building, which is particularly affected by the influence of solar radiation due to its structural characteristics. Shading devices may also affect the indoor lighting, and their installation and the assessment of daylighting will be carefully considered in the next step of the research.

Acknowledgement

This research was carried out as part of the "Sustainibility of Schools - SoS" Research Project, funded by Roma Tre University. The full name of project is "SoS - Sustainability of Schools. Definizione di tecnologie, metodologie e protocolli d'uso per salubrità, benessere e risparmio energetico nei luoghi di formazione" ("SoS - Sustainability of Schools. Definition of technologies, methodologies and protocols of use for health, well-being and energy saving in training places"), published in the 'Extraordinary research development plan, Action 4, for experimental funding action for innovative and interdisciplinary research projects', and recipient of a research grant of 64,000 €.

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