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The reduction of energy demand from the existing stock of schools buildings. An Italian case study

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Abstract:
The paper will focus on the existing school stock buildings recovery in order to reduce the energy demand. The research has been developed with the aim of spreading a sustainable retrofit for the existing school buildings in Italy, where, the constant dependency on fossil fuels, oil and methane gas is still high in school sector. At a national level, Italy has adopted the European Directive 2002/91 with the Dlgs. 192/2005, that has been integrated and modified over the years. So, in 2009 the energy certification of buildings was made compulsory, also for the school buildings where the display energy certificates must be prominently displayed.
The European Union established these regulation through the Energy Performance Building 2002/91/CE and EU Directive 2010/31. These aim to diffuse local and national regulations to guarantee high the efficient buildings, using appropriate policies which consider local climate conditions. From 31st December 2018, we must start building zero energy public buildings, this means that for the same date we should have zero-energy school buildings.
The research analyze the actual legislative Italian situation and describes an expressive case study of a sustainable recovery of a building school situated in the Lucca city that is partner in the project TEENERGY, founded by EU Commission in the MED Program, that have as principal objectives to create a transnational network among Public Authorities, Universities, technical bodies and schools, in order to implement a concept design action based on technological solutions for passive cooling, natural lighting and ventilation and use of renewable energies.
The Strategic Plan of Schools, developed by Lucca Province as Public Authority, aims to found the way towards an appropriate energy efficient retrofitting of school buildings in the specific Mediterranean area.

Keywords:
Energy Audit, Sustainable Schools, Energy Saving, Refurbishment Strategy

1 Introduction

The Sustainable Strategic Plan of Schools, developed by Lucca Province, is a planning tool developed to meet the school building energy issues in South Europe and in Italy.

The school buildings in the South Europe and in Italy have been built in the sixties / seventy and now are in bad conditions with very high energy consumptions. Italy has old laws for the school building sector (L. n. 430, 23 December 1991, and L. n. 23, 11 January 1996) and is necessary to do actions to energy, functional and structural retrofitting, through planned actions of refurbishment that can be controlled, from Public Administrations, for energy and economic aspects. The typical school buildings, in Italy, have a heating requirement of 100 kWh/m^2 year. The total energy consumption for the Italian school building sector is 1 million of TEP for year: the 70% for heating; the 30% for electricity consumptions. The secondary school is the 27% of the total energy consumption in the building sector.

With the European Directive 2002/91 CE also the school buildings become place where is possible to test and verify innovative technologies(in the building envelope and in heating and cooling plants) for energy saving. In Italy the EU Directive is incorporated with the Dlgs 192/2005, that obliges to respect energy consumption limits more restrictive in the public buildings, in cases of new construction or retrofitting, than other types of buildings.

The Lucca Province, in the absence of adequate national legislation in Italy, has so decided to start experimental actions to improve energy performance of the school buildings, so to decrease the management costs.

The analysis of the school buildings and the development of the Strategic Plan maintenance of schools have been launched under the European research project Teenergy Schools. Teenergy Schools has developed an Action Plan and a common Strategy based on the experimentation of: energy saving techniques, integration of innovative materials and renewable energies (passive cooling) for reducing costs and consumption. Moreover, the project has set out a good practice benchmark based on data from an Energy Survey in the Mediterranean which provides representative values and compares secondary schools' actual energy performance.

The energy analysis has been made on 12 school buildings during the Teenergy Project, through energy audit and thermographic analysis, and after this first phase has been extended to other 17 schools (for a total of 29 buildings). In the phase of survey and collection data we have analyzed: the energy performance of the buildings; the functional standards; the presence of architectural barriers; the structural and seismic behaviour; the fire safety.

The research has allowed us to analyze in detail the energy consumptions of school buildings of the Province of Lucca and to make, on the basis of European legislation, an instrument for the assessment of energy and economic retrofitting actions.

2 Research Methodology

The research to develop the Strategic Plan of School has been conducted by analyzing existing buildings that were divided into climatic zones:

- Media Valle Building's; land, temperate clime;
- Valle del Serchio Building's; mountain, cold clime;
- Versilia Building's; costal marine area, hot clime.

With the aim to identify the morphological and construction features, and thus the strategies of energy retrofitting we have divided the buildings for age groups:

- Buildings built before 1945;
- Buildings built between 1945 and 1981;
- Buildings built after 1981.

The research has been divided into four key actions:

- Preliminary analysis, with thermographic analysis and energy audits for each building;
- Energetic simulation to verify the energy retrofitting strategy;
- Cost – benefits analysis
- Drafting of a spreadsheet to estimate the cost of the retrofitting actions and place it in an time schedule of management.

Figure1: Thermography has been a fundamental instrument in the diagnosis phase: heat losses can be localized easily

The strategies for the energy retrofitting that we have analyzed are:

- Wall insulation with thermal insulation coating or inside insulation to bring the heat transmission value (U_{wall}) to the limit required by energy Italian law;
- Replacement of windows with thermal break windows that provide to bring the heat transmission value (U_{window}) to the limit required by energy Italian law;
- Envelope insulation, with insulation wall's, insulation roof's and replacement windows;

- Heating system retrofitting, with replacement of the existing boiler with a condensing boiler and installation of underfloor heating and heating system control;
- Envelope and heating system retrofitting.

We have verify in each building, for a type class room, the daylight luminance with the software Relux, in order to evaluate the energy saving that is possible achieve by the replacement of existing lamps with smart lamps and an electronic control system of artificial light.

The research objective is to identify the best action, about costs – benefits analysis, to give at the public administration a tool that allows to plan future energy retrofitting and economic actions.

In this paper we describe only the results of retrofitting actions on the envelope and heating plant system.

2.1 Energy Simulations

We have did energy simulations with the software Thermus, made by ACCA Software for each building and for each strategies of energy retrofitting. Thermus is a software that evaluates the energy requirements of buildings as indicated by the Italian legislation and UNITS 11300 technical standards . With this energy software we have calculated:

- The thermal transmittance of the of the external envelope surfaces, opaque and transparent (U_{wall} e $U_{windows}$, kWh/m^2K)
- The requirement of primary energy for heating (E_{pi}, kWh/m^3)
- The water heating primary energy requirement (E_{acs}, kWh/m^3)
- The total primary energy requirement (E_{Gl}, kWh/m^3)
- The CO_2 Emission ($E_{m,u,}$ kg/m^3 year)
- The Building Energy Class

The data collected during the audit and simulation stages were processed using the spreadsheet BENDS, developed by Turin Polytechnic in European research DATAMINE and that allows to compare energy data from the schools of the Province of Lucca with those of other European schools.

2.2 The spreadsheet cost-benefits of retrofitting actions

We have also designed a spreadsheet that allows the public administration to assess the cost of energy retrofitting actions to:

- Energy efficiency
- Architectural barriers removal
- The renovation of the interior and exterior
- The structural and seismic adjustment

Each action is evaluated through individual actions that can be made on the school building, so is possible to calculate the prices of energy retrofit actions that crossed with the results of energy simulations (especially the share of energy saving) and the data of heating energy consumptions, made it possible to quantify the payback on investment.

In this first phase of analysis we haven't assessed in the payback period VAN and TIR, focusing more on evaluation of energy consumptions of the school buildings.

The spreadsheet is easily manageable by end users and allows at Public Administration to quantify the cost of the retrofit actions on each school building compared to energy improvements. The goal is to develop a Strategic Plan that allows to achieve measurable environmental benefits (energy consumption reduction, CO_2 emissions reduction).

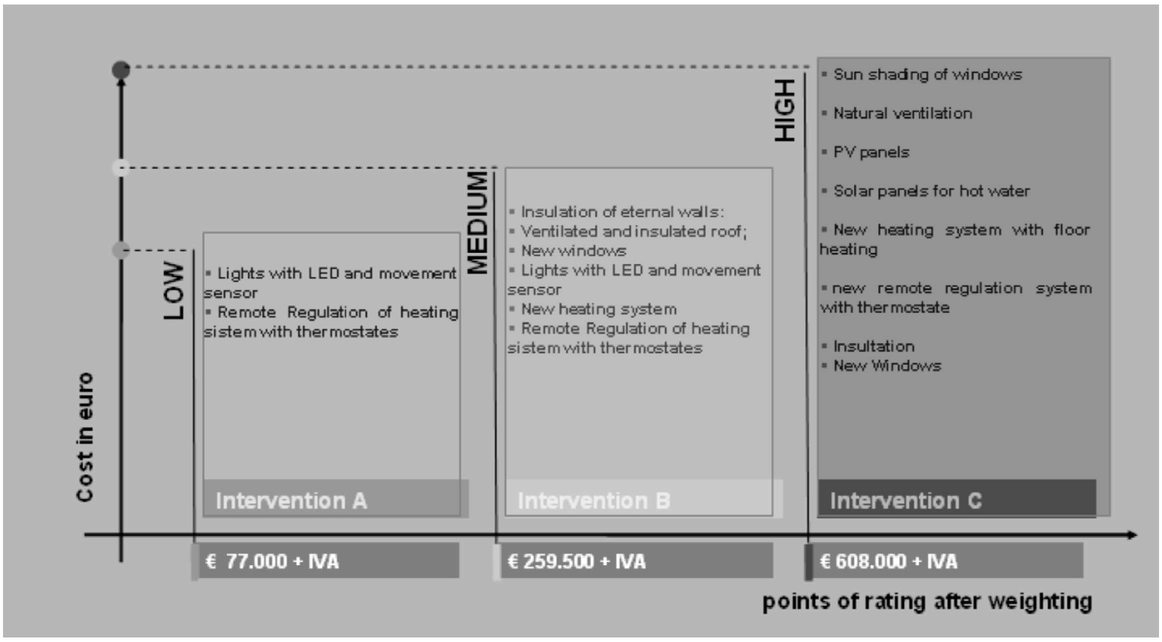

Figure 2: The three-scales scenario permits a ranking that takes into account energy performances of the proposed retrofitting solution, indoor comfort and economical aspects:

3.1 Building characteristics

The schools built before 1945 are often located in buildings built for other uses and changed into schools in the early 1900's. In Lucca, for example, the Secondary Schools Passaglia and Macchiavelli are located in two historical building built in the nineteenth century as convents and residence. Those buildings have bearing walls with thermal transmittance value of 1,02 W/m^{2}K, the windows have big glass surfaces with wood frames and single glazes and are the major cause of heat loss (U: 4,83 W/m^{2}K). The pitched roofs are not insulated (U: 2,0 W/m^{2}K), also the ground floor slabs are not insulated and border on the basement (U: 1,56 W/m^{2}K). The heating system consists of steel boilers and radiators, there is no building management system. The building envelope has a poor energy performance, in excess more than twice those provided by law, and the schools have an energy needs of about 56.62 KWh/m^3 year.

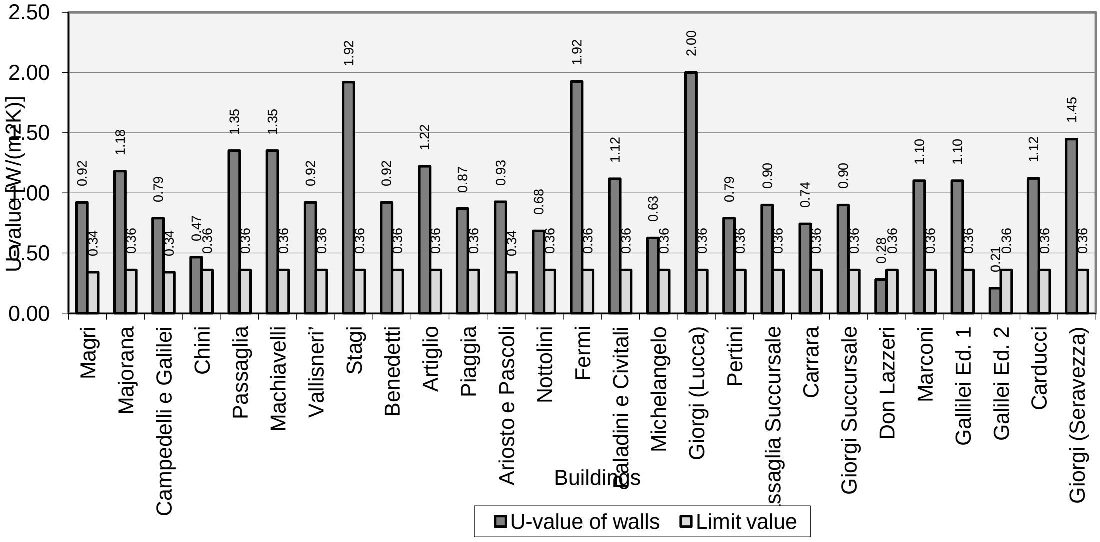

Table 1. U-value of walls

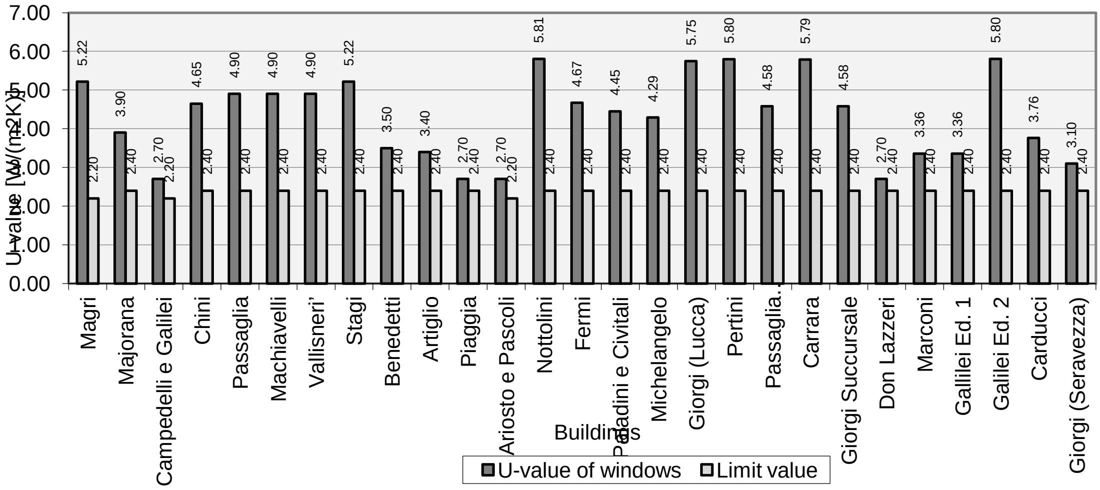

Table 2. U-value of windows

The schools built between 1945 and 1981, are located in buildings built with scholastic function, located outside the historic centre and feature the following technological solutions: reinforced concrete structure; walls uninsulated made of bricks with thickness of 25,00 to 30,00 cm and plaster (U: 1,10 W/m^{2}K); the roofs, uninsulated (U: 1,4 W/m^{2}K), are pitched or flat, as well as the ground floor slabs (U: 1,57 W/m^{2}K); the windows have aluminum or wood frames and single gazed (U: 4,14 W/m^{2}K). The building envelope has a poor energy performance and the schools have an energy needs of about 57,74 KWh/m^3 year.

The schools built after 1981 are locate in new urban areas, outside the historic centre. This buildings has been built after the first Italian law on energy saving in building: the

Dlgs. 373/76, and show a better energy performance compared at the schools built in the previous years. In these schools: the structure is in reinforced concrete; the walls made of double layer of bricks and air gap of 5,00 cm, with the external surface finished with plaster or facing brick (U: 0,37 W/m^2K); the windows have aluminum frames and single gazed (U: 4,51 W/m^2K); the roofs are flat and made with hollow block floor - thickness of 25,00 cm - with a concrete screed -thickness of 5,00 cm -and exterior finish made with a single layer bituminous waterproofing (U: 1,63 W/m^2K); ground floor slabs are uninsulated and border on the basement (U: 1,68 W/m^2K). The buildings have an energy needs of about 47,51 KWh/m^3 year.

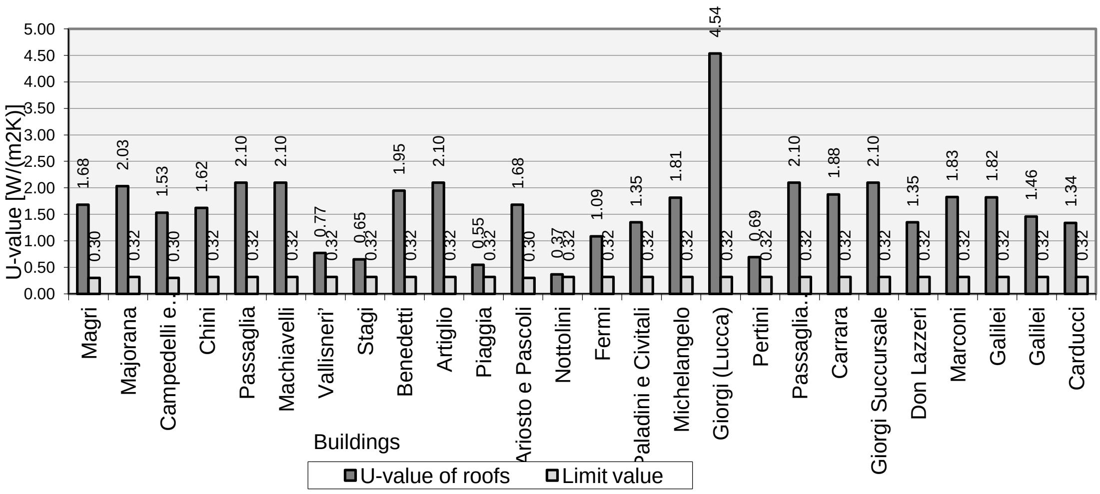

Table 3. U-value of roofs

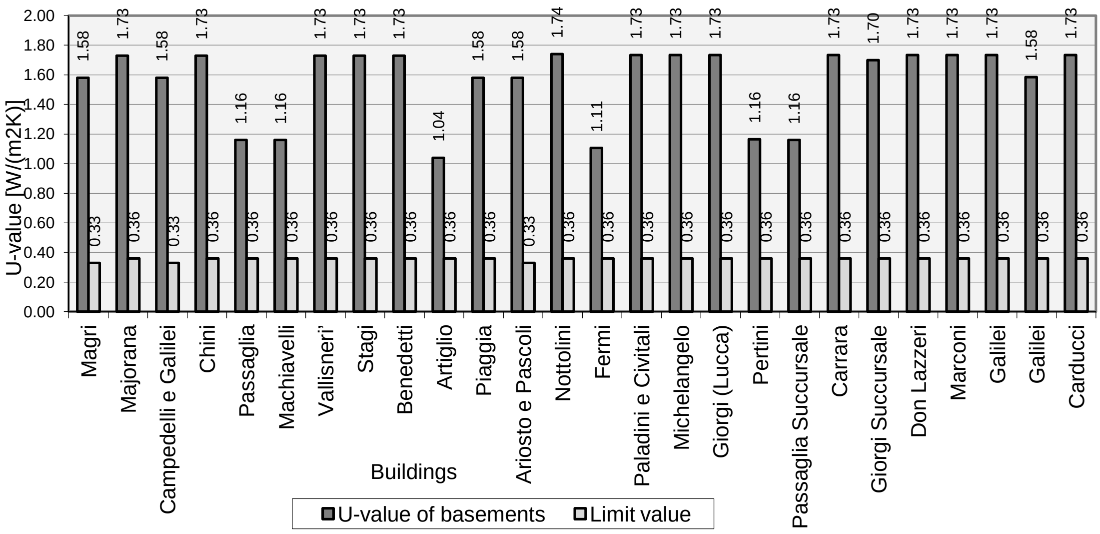

Table 4. U-value of basements

All school buildings have a heating system plant made with steel boilers (single-stage), power ranging from 600 to 1000kW, connected to cast iron radiators or, in the building built after 1960, to air-fan. The boiler didn't produce hot water, and only in a few buildings, in the bathrooms, there are electric boilers, with power of 1,5 kW, that produce hot water.

The thermographic analysis shows as the building envelope is the major cause of energy losses, because is not insulated and the radiators are located on the external walls; also the pipes are not insulated and are the cause the most problems of inefficiency of the heating system.

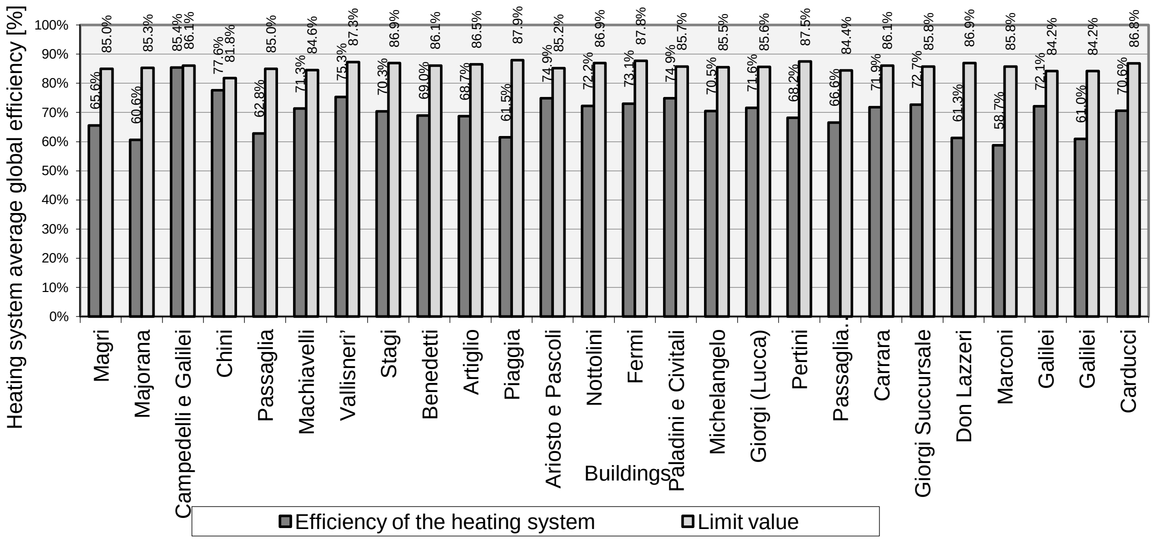

Table 5. Heating system efficiency

3.2 Energy Simulation findings

The energy simulations to retrofit actions described in paragraph 2.1 show that:

- Retrofit of walls or windows do not reduce the building energy requirement. The replacement windows, which is one of the retrofit action done first because is cheap, decrease by only 12% the building energy needs with a long payback time, which can extend beyond 15-20 years. To ensure a real reduction in energy consumptions (about 50%) and improve the energy performance of buildings, is necessary to insulate walls and roof and replace windows in the same time.

- Retrofit of heating system (replacement of steel boilers with condensing boilers; installation of a radiant floor and a room control system) decreases by about 25% energy needs of buildings with a cost of about € 100.000,00, which has a payback time of 35 years. But change the heating system without isolating the building envelope cannot be considered a good retrofitting action, because the thermal bridges of the building envelope causing, anyway, energy losses.

- Retrofit of building envelope and heating system, guarantees to decreases by about 60% energy needs of buildings and to decreases by about 50% CO^2 emissions.

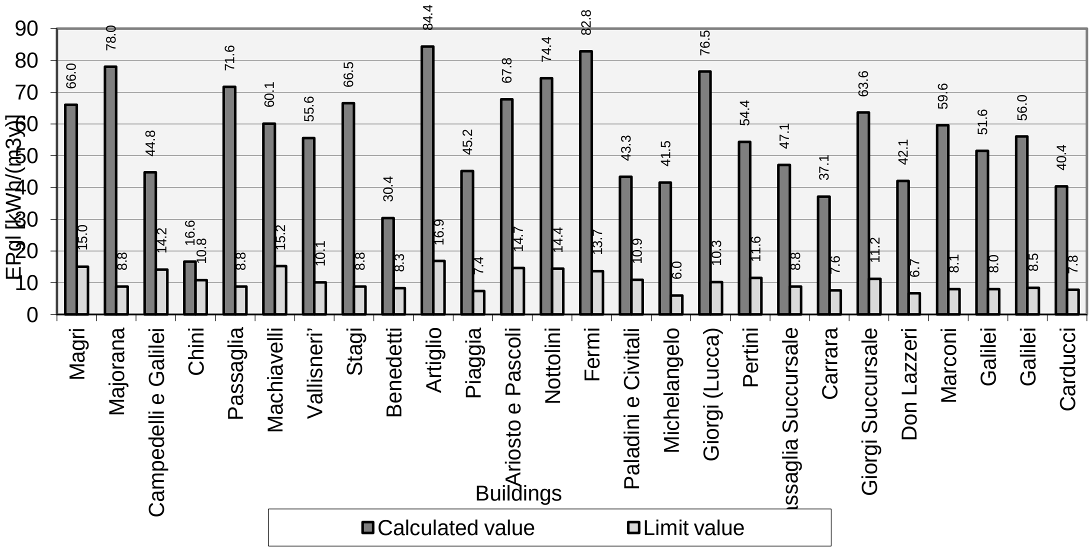

Table 6. Energy Performance Index for space heating and domestic hot water

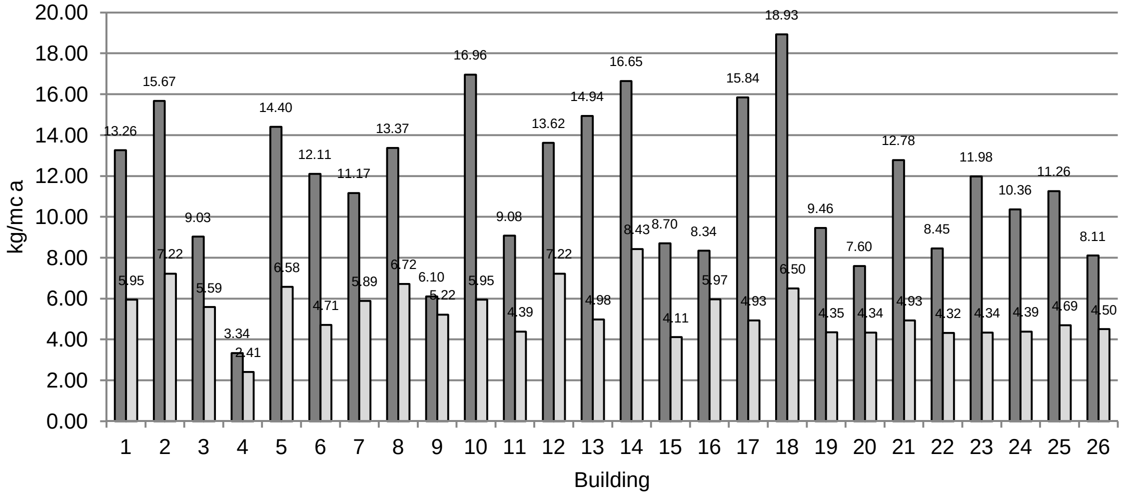

Table 6. CO2

3 Conclusion and Further Research

The energy simulations, made for each building, have show that by a global retrofit on the envelope and heating plant:

- Thermal transmittance of walls, roof, windows, reaches the limit values laid down under the Italian energy law;

- The total primary energy requirements are halved, but does not reach the limit values laid down under the Italian energy law;

- The CO2 emissions are reduced by 50%;

- The building energy class are G or F, but not C that is the limit for the building energy class laid down under the Italian energy law.

The inability to achieve a good energy class is due to the absence, in the schools analyzed, of a mechanical air change system that can control and decrease the energy losses. This data shows as the presence of the ventilation system can be influence the computation of total primary energy requirements. The UNITS 11300, the technical energy laws in Italy, in fact, penalize the public buildings that have not a mechanical ventilation system, but are ventilated only with natural systems. In the future it might be interesting to assess the true incidence of ventilation in the energy needs of school buildings and to propose, only for this buildings, a new model for energy evaluation and certification. The energy simulations and the spreadsheet have allowed the Province of Lucca to begin the planned action for the schools retrofitting, analyzing their economic and environmental impact.

The Province of Lucca wants to carry on with the research started with Teenergy and whit the Strategic plan of schools in a new European research in order to develop a software that to assess the impact of energy retrofitting actions on the energy efficiency for the public buildings located in Mediterranean clime, where the air change is guaranteed only from natural ventilation systems.

4 References

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