Improving energy efficiency in existing school building: the case study of Lecco

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Highlights

The paper analyse a school buildings stock of Lecco Municipality defining a methodology for cost-benefit analysis for different renovation scenarios. The method represent replicable guidelines useful to the Public Administration in terms of financial planning and intervention priority. The analysis estimated an overall cost for the building stock renovation equal to € 62,971,530,0 with an investment per student equal to € 5,060,0.

Abstract

Existing school buildings energy retrofit is one of the most sensitive current issues concerning the Italian public property. The presented research analyse 38 school buildings of Lecco Municipality with different educational level, age of construction and typological design. The methodology developed allows dividing the sampled schools in homogeneous clusters, each one represented by a reference building, used as base case for cost/benefit analysis. The present work investigates optimal energy retrofit strategies to be implemented from both an economic and an energy efficiency point of view.

Keywords

School building stock analysis, Energy efficiency, Retrofitting planning

1. INTRODUCTION

The EU and national energy efficiency strategies recognize the built environment sector as one of the most promising sector in order to reach the CO₂ emission reduction target. This issue is particularly current in Italy where the largest portion of the building stock was built between 1950 and 1980, with technology that did not take into account energy efficient measures. In this scenario the 48.275 educational building, holding about 8 million students (15% of the Italian population) [1] do not represent and exception with more than 65% of schools built before the 1973, so before the entry into force the Laws 373/1976 [2] and 64/1974 [3]. The energy efficiency of the Italian school buildings is low with an estimated energy use for heating between 110 and 130 kWh/m²a with a mean electricity use equal to 50 kWh/m²a. More than 90% of
the building has been erected, in fact, before the Law 10/91 [4]. Moreover, the international standard, in terms of energy efficiency in buildings [5], state the need to define strategies able to reach the Zero Energy Building target [6,7] for new construction and deep renovated. In this respect, the school building would represent an instance of successful sustainable architecture and would stand as a prime example of how the dual goal of preserving our cultural heritage, while promoting sustainable architecture, can be achieved [8]. The presented work deal with an actual issue analysed in several international studies as a following demonstrate. Last year, in Austria the work of Stocker et al. [9] proposed a study about heating energy performance focusing on 8 different primary schools affected by particular climate conditions. The aim of their work regards cost-optimal building performance: they show that the best scenario is between a heating energy demand of 50 to 60 kWh/m² reach with different renovation strategies depending on building age and technology construction. Similarly, Santamouris et al. [10] carried out energy audits on 238 Greek schools, characterized by an annual average total energy consumption amounting to 93 kWh/m² anno. They prove that it is possible easily reduce the energy consumption by 20% with various energy-conservation strategies. The study of Trachte and De Herde [11], starting from the consideration that a lack of comfort has negative consequences on pupils’ concentration and learning, shows different energy efficient strategies for non-residential building. In addition, Dimoudi and Kostenala [12] focused on potential energy saving of school buildings in the climatic zone of Greece. They demonstrated, through simulation studies, that it is possible to reduce the heating consumption of about 30% improving the insulation level. Sesana et al. developed and test a Methodology for Energy Efficient Building Refurbishment (MEEBR) on two case studies [13] proposing different technological solution for historical buildings. Another study was carried out by Desideri and Proietti [14] in order to calculate the energy consumption and the possible intervention to save energy in a school building stock located in Perugia, central Italy. The theme of improvement of energy performance in school building is assessed also by Dall’ O’ and Sarto [15]; starting from a study on 49 schools building located in the Lombardy region of Italy, they analysed cost-effectiveness building performance based on different energy retrofit scenarios. Their studies show that the excessive improvement of heating energy performance is not always the best economically advantageous solution. The energy renovation measure for existing building has been investigate also by Masera et al. [16] showing a set of innovative technologies for inner and outer envelope renovation. Arambula et al. [17], with the aim of exploring a clustering method applied
to a sample of 60 school buildings in the province of Treviso, Italy. Similarly, Santamouris et al. [18], developing a clustering technique, selected 10 school buildings, which were representative of a sample of 320 schools in Greece. They analyse in detail the energy efficiency and the performance of the reference buildings proposing several scenarios in order to improve the building energy efficiency. Through the achievement of a building categorization, the presented work aims to define an analysis method expeditive and repeatable for different group of buildings. The research sample consists of 38 school buildings belonging to Lecco municipality, in the Northern Italy. The final goal pursued is therefore to achieve a complete knowledge on the renovation strategies to be undertaken, on their costs and benefits obtainable on each building, in order to carry out the most effective urban resources renovation planning. In detail the paper deals with the followings topics:

- Classification of the study sample through a mapping tool;
- Definition of the energy retrofit strategies, from both economy and performance point of view;
- Development of a clustering analysis method, speditive and repeatable;
- Determination of references buildings for each cluster;
- Assessment of the most economically advantageous strategy for each cluster.

2. METHODOLOGY

2.1. SCHOOL BUILDING STATUS ANALYSIS

The building survey results allow to divided the school building typology with different geometrical typology [19]: merged block (47%), linear block (40%), which are the most recurrent, a stepped block (8%) and internal court block (5%). In relation to the buildings age, the analysis shows that the 69% was completed before 1974, which is the year when the anti-seismic regulations came into force, while no new school buildings were erected from 1990 to this day. It should also be noted that there is a percentage of older buildings (16%), built between the second half of the nineteenth century and the first decades of the twentieth century, often bound by restrictions from the local Superintendence authority. The results relating to the maintenance carried out to improve the school building energy performance (windows replacement, new plant installation and presence or absence of insulation in vertical or horizontal closures) show that 26% of the sample has not undergone any type of interventions since its construction, while 50% has only had one major intervention, which in most cases consisted of windows replacement. However,

su due edifici universitari proponendo diverse soluzioni tecnologiche per la riqualificazione di edifici scolastici. Un altro studio condotto da Desideri e Proietti [14] ha analizzato il consumo energetico di diversi edifici scolastici in Perugia, in centro Italia, evidenziando le possibili strategie di intervento. Il miglioramento delle prestazioni energetiche dell’edilizia scolastica è stato valutato anche da Dall’O e Surto [15]; a partire da studi condotti su 49 scuole localizzate in Lombardia, hanno analizzato i costi-benefici per diversi scenari di retrof. Essi hanno dimostrato che un eccessivo miglioramento delle prestazioni energetiche per il riscaldamento non è sempre la soluzione economica più vantaggiosa. Le diverse possibili soluzioni per l’efficienza energetica degli edifici sono state studiate anche da Masera e altri [16] mostrando soluzioni innovative sia per interventi interni che esterni alla muratura. Arambula e altri [17], ha esplorato i vantaggi dell’applicazione di metodi di raggruppamento, in cluster omogenei, applicato ad un campione di 60 scuole nella provincia di Treviso. Similmente, Santamouris e altri [18], ha sviluppato una tecnica di suddivisione in cluster selezionando 10 edifici scolastici come campione rappresentativo di 320 scuole in Grecia. Il lavoro è stato condotto attraverso l’uso di edifici di riferimento sui quali analizzare i diversi scenari di riqualificazione energetica. Attraverso l’utilizzo di cluster rappresentativi di diversi campioni di edifici, il presente lavoro mira a definire un metodo di analisi speditive e replicabile per diversi contesti. Nello specifico il campione di analisti è costituito da un gruppo di 38 edifici scolastici di proprietà del Comune Lecco. L’obiettivo generale consiste nell’acquisizione di una conoscenza completa dello stato degli edifici scolastici e nell’analisi, attraverso il parametro costo-beneficio, della potenzialità di miglioramento ottenibile per ogni edificio al fine di una efficace pianificazione di risorse economiche. Nel dettaglio il presente lavoro affronta i temi seguenti:

- Classificazione del campione di studio attraverso uno strumento di mappatura;
- Definizione delle strategie di retrofit energetico, sia dal punto di vista delle prestazioni che della spesa;
- Sviluppo di un metodo di analisi per clusters speditive e ripetibile;
- Definizione di edifici di riferimento rappresentativi dei diversi raggruppamenti;
- Valutazione della strategia economicamente più vantaggiosa per ogni cluster.

2. METODOLOGIA

2.1. ANALISI DEL PATRIMONIO SCOLASTICO

Dal censimento e catalogazione del patrimonio scolastico pubblico della provincia di Lecco (escluso le università e le scuole materne) si evince la seguente articolazione per tipologie edilizie [19]: la tipologia a blocco accoppiato (47%) e quella a blocco lineare (40%) rappresentano le più diffuse sul territorio pesato in considerazione, seguite dal tipo a...
8% of the buildings underwent such maintenance as to gain, at least on paper, a good energy performance. Regarding the sample energy performances reference was made to data provided by the CEER (Energy Land Registry of Regional Buildings) [20], in order to overcome the lacking knowledge on the subject. Upon consultation made available the low energy performances of the schools buildings in Lecco is apparent: the primary energy demand (EPH) for heating stands at 59.94 kWh/m²·year. It was also possible to obtain the U-value averages of the building constituent elements, which are as follows: basement 0.86 W/m²·K, coverage 1.04 W/m²·K, windows 3.36 W/m²·K. The mean U value of the building envelope is equal to 1.13 W/m²·K.

2.2. ENERGY RENOVATION STRATEGIES DEFINITION

Different renovation measure has been analysed among the major suitable interventions for the building envelope’s performance improvement, such as windows replacement and wall insulation improvement, besides plant system interventions, such as air conditioning replacement or photovoltaic plants installation for on-site renewable energy production.

To establish a unit price for each strategy, firstly it was necessary to identify and quantify the materials involved in each intervention, starting from an essential assumption: the insulation material quantities were assessed based on those needed to achieve the U-value limits as imposed by the Lombardy Region with the 6480 Decree of 30 July 2016, starting from medium energy performance for building element (CEER data). According to the quantities calculated as shown in Table 1, an economic strategies quantification was carried out establishing a unit price parameter per m² or m³. The values were obtained by consulting the “Regione Lombardia, 2011” and “Camera di Commercio di Milano, 2013” price lists, within sections of the completed works.
2.3. BUILDING TYPOLOGY CLASSIFICATION

In order to simplify the sample analysis a typological classification based on objective parameters was considered necessary. Through the adoption of a data, mining technique the sample was divided into homogeneous clusters, which share typological and technological characteristics, as well as fuel consumption and similar energy behaviour. With a view to significantly reduce the number of schools having to specifically submit to energy analysis, it was firstly necessary to define which variables were the most suitable to characterize the sample in the classification construction. Based on the available data, the authors analysed the school buildings characteristics that come into play in energy performance, dividing them between fixed and variable benchmarks in function of the homogeneity within the sample. A benchmark was considered “fixed” if it was homogeneous in at least 80% of the sample (for example opaque and transparent vertical closures types, internal ventilation type); whilst it was considered “variable” if it turned out to be uneven within the reference (Table 2). The following benchmarks were identified:

- **Building types**, which for the study sample of school buildings were found to be: linear block (40%), merged block (47%), a stepped block (8%) and internal court block (5%).
- **Number of floors above ground**, distinguishing the school buildings of the sample in two categories: low buildings with 1-2 floors (50%) and medium-high buildings with 3-4 floors (50%).
- **Ratio between transparent vertical surfaces and the total vertical surfaces**, distinguishing two categories: 18%, average between 13-23%, of glass consideration: the substitution of the infissi, the coibentazione dei diversi subsistemi dell’invólucro, ma anche gli interventi sugli impianti per la climatizzazione e la produzione di energia elettrica da fonti rinnovabili. Il prezzo unitario di ogni strategia di intervento in rapporto alla tipologia di isolante o di impianto prescelti (i più diffusi sul mercato) è stato quantificato al m² o m³ considerando i valori indicati nei prezziari della Regione Lombardia 2011 e della Camera di Commercio di Milano 2013. Le quantità di materiale isolante sono quelle necessarie a raggiungere, partendo dalle prestazioni energetiche medie per elemento edilizio (dati CEER) i limiti di trasmittanza imposti dalla normativa, vale a dire quelli definiti da Regione Lombardia con il decreto 6480 del 30 luglio 2015.

<table>
<thead>
<tr>
<th>Energy strategies</th>
<th>Materials: quantities and characteristics</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>External insulation</td>
<td>11 cm of XPS ($\lambda=0.035$ W/mK)</td>
<td>€66.88/m²</td>
</tr>
<tr>
<td>Internal insulation</td>
<td>11 cm of glass wool ($\lambda=0.035$ W/mK)</td>
<td>€45.58/m²</td>
</tr>
<tr>
<td>Flat roof insulation</td>
<td>11 cm of XPS ($\lambda=0.035$ W/mK)</td>
<td>€28.59/m²</td>
</tr>
<tr>
<td>Sloped roof insulation</td>
<td>11 cm of XPS ($\lambda=0.036$ W/mK)</td>
<td>€57.18/m²</td>
</tr>
<tr>
<td>Basement insulation</td>
<td>9 cm of XPS ($\lambda=0.035$ W/mK)</td>
<td>€24.38/m²</td>
</tr>
<tr>
<td>Windows replacement</td>
<td>Windows in PVC low-e 4/15/4</td>
<td>€271.2/m²</td>
</tr>
<tr>
<td>New plant installation</td>
<td>Heat pump, UTA, fan coil unit</td>
<td>€59.2/m³</td>
</tr>
<tr>
<td>PV installation</td>
<td>Photovoltaic panels in mc-Si (0.125 kW/p to m²)</td>
<td>€275/m²</td>
</tr>
</tbody>
</table>

*Table 1. List of the energy conservation measures.*
surface (58%), which includes most of the buildings with traditional fixtures; 29%, average between 24-34%, of glass surface (42%), including most of the buildings with large ribbon windows.

The building type benchmark can thus be referred to the S/V parameter (the ratio between envelope surface and volume defining the primary energy demand - EPH) used primarily in energy study fields and in accordance with prescribed regulations. Between the buildings within the clusters, a correlation is then obtained which does not depend directly on their geometric dimensions, but on the relationships among them. Different cluster types were generated by their interpolation, which in the study sample case were found to be 9, as stated in Table 2.

### 2.4. THE REFERENCE BUILDING AND ITS VALIDATION

In order to quantify the benefit in terms of primary energy demand reduction (EPH), obtained through the application of every single energy strategy, the authors proposed an approach based on using a new analytical tool: the reference building [21]. It is a fictitious building set up using elements from each cluster. To prove the reference building the cluster 5 is used to verify the method. Subsequently their energy demand was calculated and the same was done for the other buildings belonging to them: our assumptions are true when EPH and S/V values obtained prove comparable. Several dynamic building energy simulation by means of the Green Building Studio® software plug-in for Autodesk® Revit® BIM platform were carried out in order to evaluate the energy consumption of each building. We simulated the building energy behaviour according to the design benchmarks, which were considered the

<table>
<thead>
<tr>
<th>Clusters (N)</th>
<th>Linear block</th>
<th>Mergered block at C or L</th>
<th>Internal court block</th>
<th>Stepped block</th>
<th>Nº floors</th>
<th>% glass surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 (10)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>1/2</td>
<td>Average 18% (13-23%)</td>
</tr>
<tr>
<td>C2 (4)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>3/4</td>
<td>Average 29% (24-34%)</td>
</tr>
<tr>
<td>C3 (2)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4 (3)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5 (8)</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>C6 (1)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C7 (5)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C8 (2)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C9 (3)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. The reference buildings definition and classification.**
same for the all samples. The obtained data verified the assumption: the EPH values are comparable with each other, the error range ranging between 1 to 13% (Table 3). The research method identified nine representative building named “Cluster”.

3. RESULTS AND DISCUSSION

3.1. GENERAL RESULTS

Energy consumption simulations were carried out for each reference buildings, relating both to the current state and to each energy strategy applied individually. The values of primary energy demand (EPH) determined for each energy strategy were compared with the value obtained for the current state, in order to quantify the energy savings generated by every intervention and their value expressed as a percentage. The cost/benefit parameter was then defined, expressed in €/kWh year, as the ratio between the amount of savings on the total annual energy consumption and the overall intervention cost, determined by multiplying its extension by the unit costs. As regards the quantification of the cost/benefit parameter, in the case of the internal insulation strategy applied to the vertical surfaces for buildings subject to architectural restrictions, a correction had to be made, in order to take into account the thermal bridge incidence generated by the use of this intervention.

In accordance with the provisions specified in Decree 6480 of 30 July and applying the analytical method to a case study (primary school E. De Amicis), this incidence was found to be 20% of the envelope thermal performance. This value was thus used to increase the cost/benefit consequent result. The simulations results point out, for all clusters, the cost/benefit values achieved for each energy strategy. By their comparison, it was possible to identify the...
most promising strategy between those proposed. Firstly it can be noted how, in all cluster typologies, the strategy that involves the best benefit in terms of reduction of EPH, variable between 30 - 40%, appears to be the new plant installation – S4 (Figure 2).

That is due to the type of intervention that plays a key role in school buildings, especially as regards the primary ventilation; indeed the high air changes values imposed by the UNI 103399 legislation result in ventilation losses preponderance within the energy balance. Still in terms of benefit on primary energy demand, if the external insulation strategy – S1 is characterized by a constant value of reduction of EPH in all clusters amounting to approximately 20%, conversely the benefit generated by the strategy of windows replacement – S3 varies according to the percentage of glass surface. In fact, this value swings between 7% in the clusters characterized by classic frames and 15% in those with ribbon windows. Secondly, as regards the analysis of the cost/ benefit benchmarks, we can deduct that the results previously identified may not be equally reflected in terms of best strategy. Actually, if as for primary energy reduction the new plant installation strategy was found to be the most advantageous, in terms of economic investment, it was found to be the least profitable, due to the high cost. The obtained cost/benefit comparison (Figure 2) showed that the best strategy in terms of investment return proved to be the external insulation – S1 for all clusters, particularly for the schools with a low glass surface. In conclusion, for clusters characterized by a high percentage of glass surface the windows replacement intervention – S3 has a performance comparable with that of insulation strategy, especially in the case of restricted buildings with internal insulation applications. The analysis result is corroborated by the fact that for the majority of schools in the study sample, the windows are one of the few elements subject to a requalification of the superficie verticali di edifici vincolati architettonicamente, si è tenuto conto dell’incidenza dei ponti termici generati dall’uso di tale intervento applicando il metodo analitico ad un caso studio (scuola primaria E. De Amicis), tale incidenza è risultata essere del 20% delle prestazioni termiche dell’involucro. Tale valore è stato quindi utilizzato per incrementare il conseguente risultato del costo/beneficio. Le simulazioni effettuate hanno permesso di definire, per tutte le tipologie, i valori di costo/ beneficio in rapporto a ogni strategia energetica. Dal loro confronto si è potuta infine identificare la migliore strategia tra quelle proposte. In primi analisi si nota come, nella totalità dei clusters, l’intervento che comporta il miglior beneficio in termini di riduzione di EPH, che oscilla tra il 30-40%, risulta essere la sostituzione dell’impianto - S4 (Figura 2). Negli edifici o destinazione scolastica esso gioca un ruolo fondamentale, soprattutto per quanto riguarda la ventilazione primaria a causa degli elevati valori di ricambio d’aria imposti dalla norma UNI 10339 che comportano come preponderanti le dispersioni per ventilazione all’interno del bilancio energetico. Sempre in termini di beneficio si è potuto identificare la migliore strategia tra quelle proposte. In primi analisi si nota come, nella totalità dei clusters, l’intervento che comporta il miglior beneficio in termini di riduzione di EPH, che oscilla tra il 30-40%, risulta essere la sostituzione dell’impianto - S4 (Figura 2). Negli edifici o destinazione scolastica esso gioca un ruolo fondamentale, soprattutto per quanto riguarda la ventilazione primaria a causa degli elevati valori di ricambio d’aria imposti dalla norma UNI 10339 che comportano come preponderanti le dispersioni per ventilazione all’interno del bilancio energetico. Sempre in termini di beneficio si è potuto identificare la migliore strategia tra quelle proposte.
in time. Indeed, for this reason the benefit produced by their replacement is lower. It is to be noted that the cost/benefit scenario, which has allowed identifying the most economically profitable strategy, is directly related to the nature and cost of materials used in the interventions. An example may be given by the use of innovative materials such as thermo-reflective insulations, which would increase the investment per m² between 30-35% higher respect the use of traditional insulation materials. In this case, there would be a different scenario (Figure 3) where, for clusters characterized by a high glass surface percentage, the windows replacement – S3 would emerge as the most profitable.

![Figure 3. Best strategy for cost-benefit scenario 2.](image)

### 3.2. THE CASE STUDY

After the scheduling and the analysis phase, a detailed case study has been analysed in order to show the application of the method and the impact of the renovation techniques on cost and energy saving. The case study, selected from the set of the 38 analysed building, is represented by the primary school “A. De Amicis”, located in the south area of the Lecco Municipality, the buildings host 9 class with more than 180 pupils.
The building has been designed in 1932 by the Arch. Giorgio Ezio Lavene and Ing. Gabrio Brandoni. The construction phase started in 1933 and took 3 years. The building is characterized by a merged block at C: the central building hosts the administrative and professor offices, whereas the two parallel block accommodate the teaching rooms. From the technological point of view, the building is characterized by brick walls (thickness of 40 cm), concrete-brick ceiling and wooden frame with single glass for the windows. Considering the age of construction any energy efficiency measures was implemented in the building, which is why the actual primary energy consumption is high and equal to 240,6 kWh/m²/y (in detail: 513.605,0 kWh of thermal energy, 73% of the total, and 19.564,0 kWh of electrical energy, 26% of the total) (Figure 4). Following the process discussed in the previous sections different energy conservation measures has been considered to improve the energy efficiency of the building. 

As shown by the Figure 5 the different scenarios has been analysed comparing the energy saving potential: considering the electrical energy consumption of the schools building the local electricity production can play an important role in terms of energy saving compared to the opaque envelope renovation strategy.

### Renovation strategies

<table>
<thead>
<tr>
<th>Renovation strategies</th>
<th>Energy saving - Primary energy [kWh/m²/y]</th>
<th>Cost [€]</th>
<th>Cost-Benefit [€/kWh/m²/y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opache envelope insulation</td>
<td>105.44</td>
<td>€ 263,196.60</td>
<td>€ 2,496.00</td>
</tr>
<tr>
<td>Windows replacement</td>
<td>33.54</td>
<td>€ 2,694,991.71</td>
<td>€ 7,901.00</td>
</tr>
<tr>
<td>Plant sistem renovation</td>
<td>55.47</td>
<td>€ 290,675.00</td>
<td>€ 5,240.00</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>102.76</td>
<td>€ 693,824.00</td>
<td>€ 6,752.00</td>
</tr>
<tr>
<td>Whole strategies</td>
<td>175.69</td>
<td>€ 1,512,687.31</td>
<td>€ 8,610.00</td>
</tr>
</tbody>
</table>

Table 4: Energy saving, Cost and cost-benefit of the renovation strategies.
Looking at the cost benefit-scenario index, the most suitable strategies still represented by the opaque envelope renovation with a cost-benefit index close to 2,500,0 €/kWh/m²y, three timeless the cost benefit linked to the windows replacement and less than half respect to the cost of the photovoltaic power plant installation.

4. CONCLUSIONS

As argued in the previous section the developed methodology represents an important state school buildings renovation tool, since it provides guidelines applicable and replicable to different contexts from those of the study sample, in view of the method replicability. Through the method developed and applied to Lecco schools, it was possible to define the best energy strategy for each building, setting an extremely useful parameter in planning short-term investments to be allocated to the school buildings. Since the Public Administration does not have the budget to allow the application of all the strategies to each school building, it becomes of paramount importance to know which strategy is the most advantageous from an investment return perspective, in order to plan the interventions priorities over time. Applying firstly a more advantageous renovation strategy in terms of cost/benefit will result in savings leading to the availability, in a shorter time, of more money to be allocated to other strategies, in order to achieve a total retrofit of the building stock in the shortest time. Finally, the breakthrough treatment allowed establishing the overall cost of the investment needed for the building stock renovation that is equal to € 62,971,530.0. The different renovation strategies has been compared using different indicators including the cost/student parameter utile for each building, setting an extremely useful parameter in planning short-term investments to be allocated to the school buildings. Since the Public

5. ACKNOWLEDGMENTS

Authors would like to thank gratefully Sara Girola and Leopolodo Luchini for their contribution.

6. REFERENCES

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4. CONCLUSIONI

Come dimostrato nelle precedenti sezioni la metodologia sviluppata rappresenta un approccio facilmente applicabile e replicabile per l’analisi delle diverse misure di riqualificazione energetica degli edifici scolastici. Attraverso la metodologia descritta e applicata agli edifici scolastici presenti nella Città di Lecco, è stato possibile definire la migliore strategia in termini di costo-beneficio per ogni singolo edificio, parametro questo estremamente utile nella pianificazione degli investimenti futuri e nella definizione delle priorità degli stessi. L’applicazione delle strategie più vantaggiose in termini di costo/beneficio consente una migliore gestione delle risorse economiche disponibili, al fine di ottenere una completa riqualificazione del patrimonio edilizio nel più breve tempo possibile. Il lavoro presentato ha permesso di stimare gli importi totali degli interventi di riqualificazione edilizia, la cui stima ammonta a € 62,971,530.0. I diversi interventi proposti sono stati comparati utilizzando diversi parametri di valutazione tra cui anche il costo/student parametro utile per la classificazione della priorità degli interventi stessi.

5. RINGRAZIAMENTI

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