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Portfolio energy analysis and condition assessment: case study of public schools of the Lugano municipality

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Abstract. Buildings significantly contribute to the overall energy balance, so an accurate approach for condition assessment, energy performance benchmarking and retrofit scenario selection is necessary. The aim of this research is to analyse the energy performance and the overall condition of public buildings in the Ticino Canton; this paper focuses on 31 school buildings of the Lugano Municipality. The analysis has been conducted using a combination of tools (PETRA, BIM, GIS) and aims at defining retrofit scenarios and providing public managers with a precise picture of their portfolio. This portfolio investigation allows for an appropriate building operation and management strategy.

1. Introduction

In November 2015, the Municipality of Lugano, in accordance with the objectives of the new Federal Energy Strategy 2050 and supported by SUPSI ISAAC (Institute for Applied Sustainability to the Built Environment), decided to investigate the energy conditions of the school building stock. Following this vision and aiming at valorising their school building portfolio, a change in the general asset management approach became necessary. In order to preserve the building stock and reach the energetic standard required, the maintenance of building components and systems should be planned within different steps during the lifetime of each element. The maintenance operations need to be included within an investment programme rather than an occasional expenditure. This need has been the starting point of a wider research that allowed analysing several public buildings in Ticino; this paper shows the results related to 31 schools, primary schools and kindergarten, analysed in Lugano.

1.1. State of the art and Innovation

As largely investigated in the past decade, the operation of buildings over their entire life span contributes to a large portion of the worldwide total energy consumption [1-3]. Furthermore, buildings are responsible for approximately 36% of CO_2 gas emission in the EU [4]. Therefore, optimised retrofit strategies are essential in order to consistently reduce the ecological footprint and simultaneously improve the energy performance of buildings [5, 10]. In fact, many governments and international organisations, e.g. United States [6, 7], UK [8] and Commercial Building Disclosure in Australia [9], have put an immense financial effort towards efficient retrofit technologies to increase energy efficiency in existing buildings. Although the economic effort led to the development of a large body of different retrofit technologies, the current rate of retrofit on existing building stocks is only 2.2% per year [5, 11].

Until a few years ago, building retrofit analysis in Switzerland was primarily linked to best practices and expert heuristics [10]. Recently, several studies led by the ETH Zürich [10], the EPFL and the municipality of Geneva and supported by model-driven technologies (BIM – Building Information Modelling, BEM – Building Energy Modelling), developed new approaches able to accurately simulate retrofit scenarios [10].

1.2. Context

SUPSI developed between 2010 and 2013 the PETRAtool platform in collaboration with external partners such as EPFL, ESTIA SA, PK SA and EPQR Renovation. Besides offering a diagnosis of the functional, safety and energy condition of an existing building, the PETRA further provides a robust retrofit tool extensively used for building stock analyses in Ticino [12]. The analyses conducted on the Lugano school building stock have been used to improve existing procedures, by implementing new instruments and tools in the process: namely the integration of GIS (Geographic Information System) and BIM into PETRA, thus to improve data management and the overall quality of the output.

The mandate received on November 2015 foresees an analysis of the current state of conservation of the school building portfolio as well as the identification of both criticalities and strengths of the investigated assets, paying particular attention to the energy aspects. Furthermore, in accordance with the building stock's current state of conservation and the client's vision, effective retrofit scenarios, which consider the financial benefit and a strategic vision of the municipality as well as the environmental sustainability, have been implemented.

Based on the case study of public schools of the Lugano municipality, this research aims at showing the current multistep workflow adopted to analyse assets' energetic data. The workflow involves a three-step process: (1) First, technical inspections are carried out for each building according to a unique and systematic method, characterised by a set of common methodological criteria. The data are stored within the online software PETRAtool, which allows extracting the technical, energetic and financial aspects of each asset. (2) Then, LOD200 BIM models of the main buildings are generated, thus to automatically compute envelope quantities as well as to evaluate the building space usage efficiency. (3) Finally, the entire building information is integrated within territorial GIS maps, which allow for a powerful and straightforward small- and large-scale asset overview. Hence, the identification of the best alternatives in the decision-making process for municipal facilities is strongly facilitated.

2. Scientific Methodology

Technical inspections have been carried out for each building, together with an analysis of documentation provided by the municipality and the data of energy consumptions of the previous years. The surveyor is guided through the assessment by the PETRatool checklist (web- or paper-based), which allows to evaluate, for each envelope and system component, degradation (4 levels, from good to bad condition), area and priority, and to store pictures taken. In addition to this, the survey includes an overall assessment of fire safety, accessibility, electric and thermal systems condition, thus to highlight potential risks or missing/not updated documents. The result of the survey is not only the current state of degradation, but also a list of operations needed to restore or improve the asset condition. The methodology is based on an innovative approach enabled by the creation of a LOD200 BIM model of the main buildings, thus to automatically calculate envelope quantities and surfaces and to evaluate the building space usage efficiency. Energy efficiency is considered through the energy balance performed according to the SIA 380/1, and the spatial analysis is carried out according to SIA 416. The energy balance of each school has been compared with the related real energy consumptions, in order to calibrate the energy model, to check for problems or inefficient behaviours and to define precise retrofit scenarios. Several scenarios have been defined following an order of priority to improve both the envelope and the system, thus to achieve a better energy label or the Minergie certification [13], which in Canton Ticino is mandatory for public buildings (art. 11 of the RUEn [14]). Eventually, the analysis has been developed at portfolio level, aiming at suggesting a strategy for buildings' retrofit but also for a better operation and management process. The technical properties of the buildings as well as the BIM models are integrated within territorial GIS maps in order to provide the municipality with a proper and complete overview of their portfolio.

3. Approach

3.1. PETRAtool

The analysis of the building stock is a process that requires time. The software PETRAtool simplifies the process, allowing to organise data in a database, evaluate the thermal balance and define retrofit scenarios. The analysis of the 31 schools is performed through three different steps:

- **Buildings diagnosis and state of conservation.** The diagnosis of 31 buildings is conducted first through surveys. The description and the classification of each building element provides an overview of the building stock analysed according to the degradation rate and the work complexity. Furthermore, data regarding the safety in use are collected. The software PETRAtool helps to define the abovementioned building element classification and store it within an internal database.
- **Energy balance evaluation.** The energy balance of the schools of the Lugano municipality is calculated with the software PETRAtool according to the SIA 380/1. For each building component, the software requires as input dimensional and thermal data elaborated through surveys by an expert. In addition, data about HVAC systems, such as power, energy source and efficiency, need to be implemented.
- **Retrofit scenario and cost assessment.** The retrofit scenarios have been developed for only 10 schools according to the criteria of feasibility, real necessities and strategic role in terms of return of investment and comfort. By selecting specific retrofit interventions for building components and devices, the software PETRAtool permits to calculate new energetic scenarios, offering as output the heat balance of the retrofitted building, an estimation of the expenditure and the cost effectiveness of the intervention. Three different strategies have been considered for the analyses: scheduled intervention (already in progress); suggested intervention (with most favourable quality / price ratio); and Minergie® (Figure 3).

3.2. BIM

The analysis with the PETRAtool platform has been consolidated through the years, so it has been decided to integrate some innovation in the process, in order to establish the basis for future upgrades of the platform itself. The BIM models have been created only for the most complex and interesting buildings (in terms of retrofit), whilst the remaining have been analysed with the traditional process.
The BIM models have been created with a low level of geometrical detail (namely LOD200 according to the D 0270 [15]) but with a higher level of information, thus to proceed with the degradation, service life, energy analysis and retrofit planning (an example can be seen in Figure 1). The BIM models have been created starting from CAD drawings provided by the client, whose dimensions have been checked thanks to short surveys; a detailed dimensional survey has not been performed.

A BIM template has been created, thus to automate some time-consuming activities, such as the calculation of the bill of quantities, of the surfaces and the creation of schemes of the plans to evaluate space efficiency. Buildings have been modelled using Autodesk Revit and some Dynamo scripts to automatically fill-in attributes like orientation and CRB classification (eCCC-E system [16]), useful for cost assessment of the retrofit scenarios. Each model took approximately one working day to be created, once the template has been fully tested. Eventually, models created can be considered an investment, as they are now used as the basis for the development of a new BIM-based maintenance management system, starting from the characteristics and the database of the PETRAtool, thus to keep the knowledge of the +300 buildings analysed in the Ticino canton.

3.3. GIS

The third step of the investigation process consisted in collecting all the data obtained thanks to the PETRAtool and BIM methods and integrating them into an easy-to-read map. Thanks to the incorporation of ArcScene within the classic geographic maps occurred with the advent of the ArcGIS PRO version, it became possible to simultaneously visualise and interact with multilayer information and 3D building models. The process of importing a BIM model and its attributes within GIS maps involves a two-step process: first, the geographic coordinates of the base and survey points are anchored to a specific envelope corner. Then, the *rvt and a *prj files, containing the information for the used coordinate system, are simultaneously imported into GIS for the correct positioning of the model. This process allows to interact with both the 3D geometries as well as the most important energy properties of each building, thus to provide a fluent management of the entire portfolio.

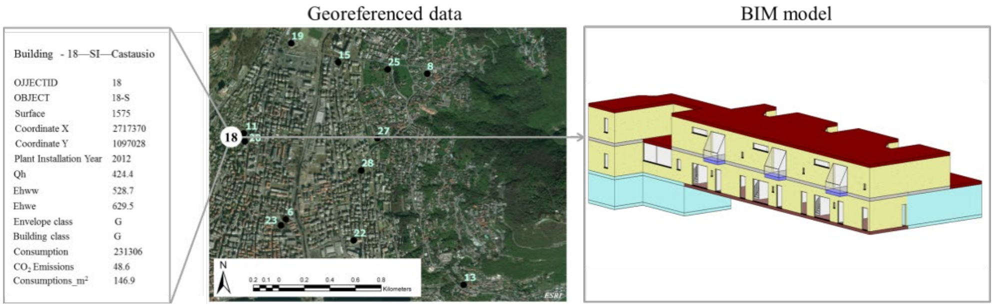

Figure 1. Integration of a BIM model and building properties within territorial map in ArcGIS

4. Results

Figure 2 shows the thermal demand distribution and total amount for the investigated assets. The average Q_h resulted to be equal to 109 kWh/m^2, which is comparable to the average of Ticino school buildings (123 kWh/m^2 – calculated in another project "MapTel" [17] considering 126 schools).

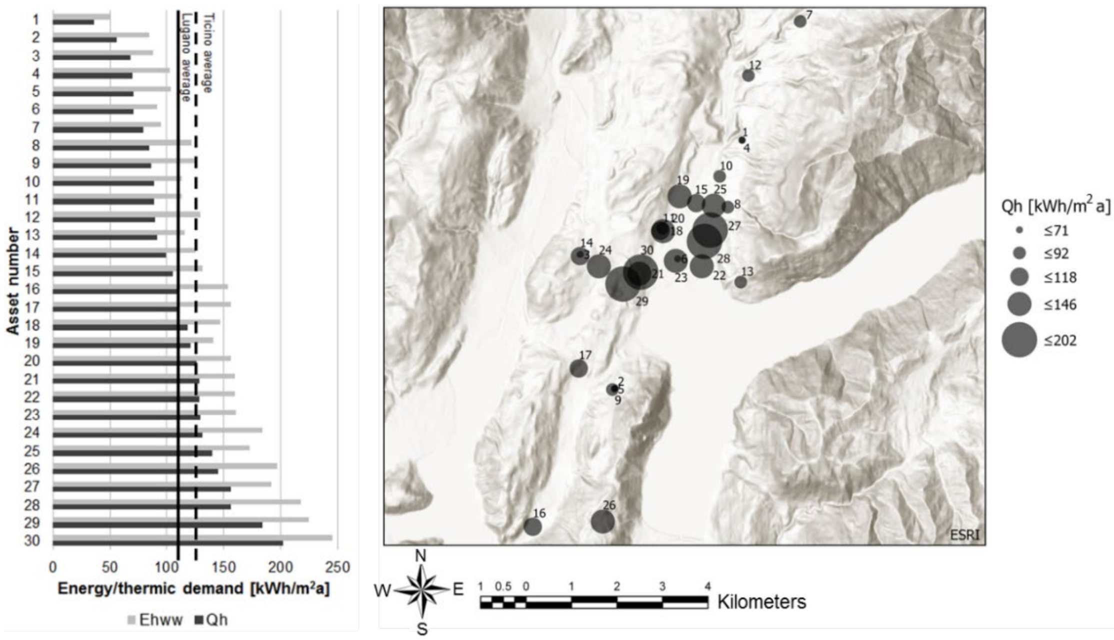

Figure 2. Thermal energy need Q_h of the 31 investigated buildings listed in ascending order (left) and plotted in an ESRI map (right). The Lugano and Ticino average are also illustrated

The spatial distribution of the Q_h shows that in the city centre, where the buildings and heating systems are in average older, the energy demand for heating and hot water is larger with respect to the

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suburban areas. Figure 3 shows the outcomes of the retrofit investigation conducted on the 10 key assets of the Lugano's school portfolio.

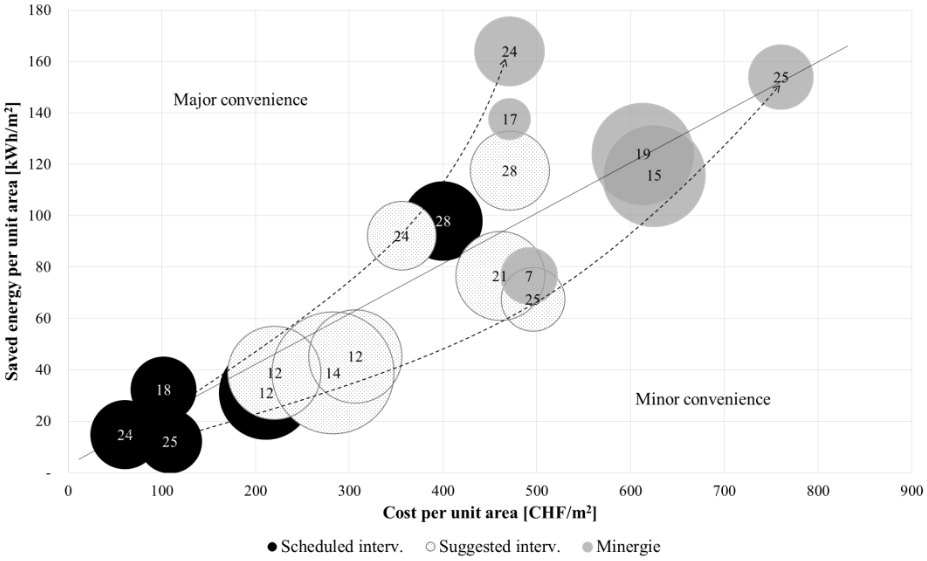

Figure 3. Comparison of different scenarios. The size of the bubble reflects the heated usable area Ae (m^2) according to SIA 380/1 . Buildings above the black central line show a greater convenience

The position of each bubble within the plot, besides providing the cost and the energy saved per unit area, is correlated to the type of energetic intervention. Generally, the scheduled interventions lie on the lower left corner, the suggested interventions in the centre of the figure, while the Minergie® interventions are located on the upper-right corner. The more the circle deviates to the left and upwards with respect to the median line, the more convenient is the implementation of the intervention. In fact, the ratio between savings and costs per unit area increases. The opposite criteria is valid for circles that tend to the right quadrant. Based on the available economic possibility of the municipality and the actual needs of each individual asset, the best suited individual approach displayed in Figure 3 should be selected.

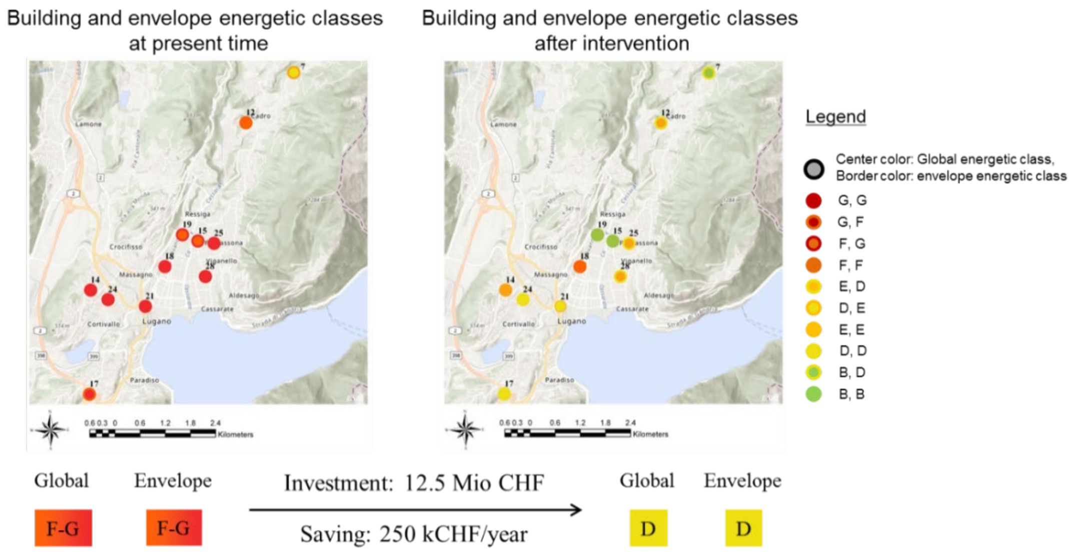

Figure 4. Comparison between building and envelope classes in the current state (left) and after the implementation of the suggested interventions (right). The average global and envelope classes for the 10 assets are further shown

Figure 4 shows the retrofit analysis outcomes for the global and envelope energy efficiency classes of the 10 key assets within the school portfolio. Even though in some cases up to three strategies have been investigates for a single building, for the figure on the right only the most energy-efficient approaches have been plotted and used for the cost-benefit analysis. A 12.5 Mio CHF investment is necessary to shift the energy efficiency from an average of F to D classes. Global annual savings related to thermal energy and electricity of approximately 250k CHF have been computed.

5. Discussion and Conclusion

Thanks to a comparative analysis of the buildings between retrofit costs (CHF/m^2) and the cost of saved energy (CHF/kWh), it was possible to identify the most efficient interventions for the key assets. The results strongly suggest a retrofit for most of the buildings: in fact, these 31 buildings consume more than 9M kWh/year and the potential energy saving is around **70%** in case of a global intervention. However, a merely financial cost-benefit analysis conducted on the key assets shows a 50-year monetary return. Even though the computed return value is larger than the life cycle of the main architectural components, a renovation is widely recommended as the park is rather aged. Furthermore, secondary benefits that cannot be easily monetised, e.g. comfort and strong reduction of the environmental impact, are expected.

The PETRAtool has been the basis for this work, whilst BIM and GIS tools and processes have been used to speed up the analysis process in the beginning and then to store and show the results to the client. Moreover, the data collected are the basis for the development of BIM-based management procedures, thus to improve not only the energy efficiency but also the whole operational cost.

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