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Energy audit of schools by means of cluster analysis

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ABSTRACT

More than 30 % of the Italian schools have very low energy efficiency due to aging or poor quality of construction. The current European policy on energy saving, with the Commission Delegated Regulation (EU) 244/2012, recommends a cost-optimal analysis of retrofit improvements, starting from some *reference buildings*. One relevant issue is the definition of a set of reference buildings effectively representative of the considered stock. A possible solution could be found using data mining techniques, such as the *K-means* clustering method, which allows the division of a large sample into more homogeneous and small groups. This work adopts the cluster analysis to find out a few school buildings representative of a sample of about 60 schools in the province of Treviso, North-East of Italy, thus reducing the number of buildings to be analyzed in detail to optimize the energy retrofit measures. Real consumption data of the scholastic year 2011–2012 were correlated to buildings characteristics through regression and the parameters with the highest correlation with energy consumption levels used in cluster analysis to group schools. This method has supported the definition of representative architectural types and the identification of a small number of parameters determinant to assess the energy consumption for air heating and hot water production.

1. Introduction

According to the latest report about school buildings of the Italian Association for the Environment Safeguard, in Italy 42 000 schools are currently in operation and about 60 % of them were built before 1974 [1]. Despite nearly 50 % of the schools have undergone emergency repairs in the last 5 years, more than 30 % requires urgent maintenance not only due to aging reasons but also because of the poor quality of the recent constructions.

The current interest in school buildings, not only in Italy but also in Europe, is primarily related to two aspects: the high level of energy consumption of this sector, and the inadequate level of comfort (both thermal and air quality). Numerous studies have been carried out to determine both the real dimension of the problem and to propose technically and economically feasible solutions, while the governments have established tougher regulations and standards that new and retrofitted constructions have to comply with. The main problems in schools, as pointed out by many authors, deal with not only the building envelope and system features, but with the management as well.

Some years ago, Antonini et al. [2] carried out a survey on a sample of 50 schools in the North-East Region of Veneto, Italy. Schools were assessed as for the energy performance, through analytical calculation methods, and for the environmental quality, through experimental detections. It was found that schools in Veneto use annually between 250 kWh m^{-2} and 350 kWh m^{-2} (290 kWh m^{-2} in average) including hot water for the gymnasiums and the canteens. About one third of this use is attributable to heat losses through the building envelope. With respect to the heating systems, in addition to the oversized heat generators found in almost all the buildings of the sample, the same analysis identified problems, only detectable through in situ measurements, related to an incorrect positioning of the internal thermostatic probes or of the heating elements or to a general bad management of the heating system. Similarly, Filippín [3], starting from a study on 15 Argentinian schools, reported a number of issues of management and control related to the maintenance, the appropriate positioning of thermostats, the identification of critical areas, the monitoring of abnormal loads and the training of staff and students in the proper use of the facilities.

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Nomenclature

Symbols

A	area (m^2)
C	referred to cluster or centroid
EP	normalized energy performance ($Wh\,m^{-3}\,K^{-1}\,h^{-1}$)
F	F-test statistic (–)
H	capacity of the heating system (kW)
h	hour (h)
HDD	heating degree days (K d)
HDH	heating degree hours (K h)
K	number of partitions for *K-means* algorithm
Q	heating demand (Wh)
R^2	index of determination (–)
S	dissipating surface (m^2)
T	temperature (°C)
U	thermal transmittance ($W\,m^{-2}\,K^{-1}$)
V	conditioned volume (m^3)
VIF	variance inflation factor (–)

Subscripts

0	initial
adj	adjusted
env, *gl*	referred to transparent envelope
env, *o*	referred to opaque envelope
ext	external
f	referred to floor
f–g	floor in thermal contact with the ground
int	internal
k	referred to the k^{th} cluster
occ	occupancy
r	referred to the roof
vw	vertical walls exposed to the external environment
win	referred to the windows

Another important data collection, focused in particular on energy consumption, installed power and used fuel, was conducted in the province of Perugia, Central Italy, by Desideri and Proietti [4] on 29 education institutes, distinguished by the type of construction. The specific electric and heat consumptions per unit of volume, per class and student have been calculated. It was noted that the energy needs for heating is about 80 % of the total and, in the hypothetical scenario in which all the examined buildings reduced the consumption to the minimum detected in the sample, the achievable savings in terms of energy per student and energy per cube meter would be 47.6 % and 38 % respectively. Recently, consumption data for space heating of a sample related to 120 school units were collected in the province of Torino, North-West of Italy [5]. The schools were equipped with fuel meters, heat meters and climatic probes allowing the derivation of a performance indicator for the heating consumption, to be used for an initial analysis of the building stock and a preliminary assessment of future budget allocations for the Public Administration. Subsequently, using techniques of multivariate statistical inference on a subgroup of 35 units within the monitored buildings, linear models were developed to correlate the measured consumption with thermo-physical and geometrical characteristics [5,6]. The difficulty of obtaining a complete documentation describing the buildings led to focus on the development of models based on a small number of independent and easily detectable variables, such as the installed power and the floor surface.

Recent studies focused on the identification of the most-effective measures to be applied in the building-system retrofitting. Butala and Novak [7] indicated insulation and replacement of the windows as the most effective, cost-effective and necessary interventions for 20 of 24 Slovenian buildings examined. For the Greek climates characterized by a higher level of heating degree-days, Dimoudi and Kostarela [8] quantified the effect of individual retrofitting interventions to reduce both the needs for heating and cooling in order to increase the indoor comfort of the occupants, assessing the energy savings also in terms of decrease of the pollution agents in the considered environments. The potential savings, after the improvement of the insulation level, were 28.7 % for heating, while more than 99 % in cooling, through the use of simple ceiling fans and especially night ventilation.

When planning the retrofit or assessing the improvement potential of a large stock of existing buildings, a large-scale assessment of the consumption has to be carried out. In this framework different auditing approaches can be adopted to find a benchmark to evaluate the energy performance of the building stock, on one hand, and to assess the performance after retrofitting interventions, on the other hand. Many studies on building stock classification and benchmarking have been carried out, some of them concerning school buildings. A primary goal in these benchmark analyses was to define a stochastic model based on a few variables, either a regressive model [6] or a targeted selection of statistically significant cases [9], suitable to firstly estimate the margins for improvement. Hernandez et al. [10] proposed a method to calculate the energy performance benchmark for a rating system using a calculated energy performance indicator and grading it according to standard EN 15217:2007 [11]. A group of primary schools in Ireland was used as case-study and the main problem they encountered was the lack of historical data, a problem that is also present in Italy.

The European Commission is nowadays promoting the renovation of existing buildings by the implementation of a cost-optimal analysis of different retrofit improvements, starting from a reference building, which has to be representative of a building category [12]. As it can be expected, defining the reference building in a stock of existing ones implies the analysis of a large amount of information to find out how this set can be sub-grouped. In similar cases when the building stock is very large, the application of statistical techniques in order to group buildings with homogeneous characteristics is necessary to focus the investigations on a small number of representatives and possibly extend the results to the others. Gaitani et al. [9], used clustering to identify a few representative buildings on which to carry out detailed considerations of retrofitting, thus anticipating the European directives. Analyzing a sample of 1100 schools, i.e. 33 % of the Greek school building stock, by means of algorithms of clustering and principal components analysis, five typical buildings were selected and described by seven characteristics, such as the heated area, age of the building and heating system, envelope insulation, number of classrooms and students and occupancy profile. In order to reduce the number of variables analyzed, the contribution of each to the final energy performance was calculated individually. The application of clustering in the analysis of existing buildings can be found also in other studies. Indeed, clustering analysis is a powerful data mining technique, used to find correlations and patterns, by which a set of elements is split into several homogeneous groups containing elements that are much more similar to each other and significantly different from those of any other group. Santamouris et al. [13], for example, used clustering techniques to define energy classes based on heating energy consumption of a large sample of schools in Greece. Some other authors applied the cluster analysis for the building stock evaluation, not only to schools but also to the household market [14]. In some studies the regression analysis associated to the clustering has been used. This is the case of Filippín et al. [15], who evaluated the historical heating natural gas consumption during 13 years in 72 apartments belonging to three different multifamily