ABSTRACT

In the last twenty years, maintenance of buildings has grown in importance, especially in the European countries, due to the generalized aging of the real estate park and the necessity to preserve the built patrimony in terms of efficiency and productivity. As result, the cost maintenance is reaching and overcoming the investment cost related to new constructions: this implies the development of new professional competences and a new political vision of maintenance. It requires a global approach for the real estate maintenance.

In this context, the University of Applied Sciences of Southern Switzerland has been mandated by the Government of Canton Tessin (Switzerland) to develop a methodology for building management, which has as its objective the elaboration of a new maintenance plan for its school building pool. The EPIQR program (Energy Performance Indoor Quality and Retrofit) and its related methodology served as a basis for the analysis. The method enables a fast but sufficiently accurate evaluation of the deterioration state of a building, and provides a cost estimation to bring it back to its original condition. Energy aspects can easily be taken into account with the elaboration of scenarios. Although the EPIQR program had been developed for buildings designed for habitation, its use was extended to school buildings.

Forty-two buildings were analysed in 2003, representing 38% of the 108 school buildings of Canton Tessin. The analysis of all the data showed that the flat roof was the element most subject to maintenance operations. The paper presents the results concerning the different roof typologies. Service life as well as life cost were established for the most significant roof typologies. The implications for the maintenance of the school building park are discussed. It highlights the necessity for scheduled maintenance based on structured information which has to be carefully collected from the past life of each building.

A roof retrofit is also an opportunity to improve roof insulation and integrate a photovoltaic power plant. Such an innovative solution has been devised and is presented as a roof retrofit possibility.

KEYWORDS
Durability, service life, life cost, deterioration, maintenance, flat roof
1 INTRODUCTION

The government of Canton Tessin holds and administers building assets which consists of more than 500 administrative and school buildings, for an estimated global value of about 1 billion euro. The real estate assets are located both in alpine and in sub-tropical climate zones in heavily urbanized and rural regions. In this area climate is characterized by sudden changes in temperature, heavy rainfall, long periods of drought and high summer temperatures. Therefore, under such climatic conditions, the tendency towards deterioration in buildings, especially in the envelope, increases. Moreover, in a situation where resources are limited, investment in maintenance tends to be ad hoc and only for urgent cases. In this context, the University of Applied Sciences of Southern Switzerland has been mandated by the Government of Canton Tessin to develop a methodology for building management, which has as its objective the elaboration of a new maintenance plan for its school building pool.

Assessment is based on visual inspection, condition appraisal and diagnosis of as many as 50 different elements, like for example: external infrastructures, roofs, floors, façades, structural elements, technical plants. The analysis of the deterioration and the building dimension coefficients form the basis for an estimation of the building renovation costs. This allows the manager of the facility to plan the financial requirements over a period of years, thus enabling him to discard the unpleasant process of breakdown intervention and to pass over to a programmed or preventive maintenance system.

Research consisted in visiting 42 buildings and diagnosing 50 construction elements per building. From the survey it emerged that the flat roof, apart from being one of the elements most under stress is also that showing the greatest differences in deterioration, some materials resisting a long time whereas others have a life-span of only a few years.

This article reports the results of the analysis regarding the life-span of flat roofs attained from the sample of school buildings examined and states the consequences for maintenance strategies and costs. Finally, a concrete example is presented where an opportunity was taken during a maintenance operation for an innovative refit where the restoration of a flat roof involved the integration of a thin layer of photovoltaic material in the waterproofing membrane.

2 METHOD

2.1 Research Method

The analysis of school facilities was carried out by means of EPIQR (Energy Performance and Indoor Environmental Quality Retrofit), which is a methodology developed within the framework of JOULE - a European research program, supported by the European Commission, DG XII for Science, Research and Development - that involved various organizations and experts from seven European countries (DK, F, D, GR, CH, NL and UK). This new method was developed to assist architects, engineers and other professionals who are involved in refurbishment or retrofitting (upgrading) work on apartment buildings [Flourentzos et al. 2000].

EPIQR is typically used for an overall assessment and diagnosis of the existing condition of residential buildings (deterioration state), the evaluation of various refurbishment and retrofit scenarios, and cost of induced works, in the preliminary stages of a project. The entire building is divided into 50 elements such as windows, façade, structure, roof, heating and cooling systems, electrical installations etc. Each element can be subdivided in different types. As a result of the building inspection the level of deterioration of each element is determined. This is done by selecting a deterioration code “a, b, c, or d” defined in the method. The "a" code means that the element is in good condition, while the "d" code means that the element has deteriorated and needs replacement or extensive repair. b and c are intermediate states. These codes
have been defined accurately for all elements and can be observed during a building survey on the basis of the building model described in EPIQR.

Another current research project [Medimmo 2002-2004], supported by the Swiss innovation promotion agency (CTI) is developing an extension of the EPIQR method on administrative and school buildings. The results of the above research are obtained with a draft version of the new software tool referred to as EPIQR+.

2.2 The sample analysed

The buildings used for school activities in Canton Tessin total 108. The combined surface area is ca. 380,000 m² and the total volume is ca. 1,333,000 m³. The average volume per building is around 16,000 m³.

The real estate pool has not had a steady increase: almost 60% of the buildings were constructed in a relatively short space of time between 1970 and 1979. Our study has shown that this building surge has resulted in a significant increase in maintenance work over a short space of time.

The analysis was carried out on a representative sample of 42 school buildings (38% of the cantonal school pool). A reading of the results indicates that problems regarding deterioration or deficiencies were concentrated in the thermal insulation of the facades (65% of the sample), the roof (57%), the windows (44%) of the concrete façade [Teruzzi et al.2003 a,b] and the waterproofing of the flat roof (39%). The final element is of particular interest in that despite partial repairs and rebuilding it continues to present problems and can cause serious collateral damage.

3 RESULTS

3.1 Roofing typologies

Four typologies were present in the 72,800 m² of roofing studied (Fig. 1). Presented in order of appearance on the market they are: bituminized cloth consisting of 2 or 3 layers (23% of total surface area), synthetic membranes (55% of surface area), compact roofs (19% of surface area) and reverse roofs (3% of surface area).

![Figure 1. Distribution of the four typologies in the sample studied.](image)

3.2 Damage typologies

The damages found relate to the type of construction. In compact and reverse roofs no damage was found. In roofs using bituminized cloth damage was found in 13.5% of its surface area (2,200 m²). With the synthetic membrane technique 27% of the surface area was classed as either code c (significant but potentially reparable damage) or code d (significant damage requiring complete substitution of material). These definitions derive directly from the working method chosen and allow us to classify the elements studied.

TT6-235, Durability of flat roofs: practical experience on service life and consequences on the maintenance strategy, Bernasconi-Cadoni-Chianese-Kaehr-Pahud-Salvadori
The synthetic membrane technique became popular during the 1970s at a time when there was a sharp increase in school building construction in Tessin. The high percentage of damage found must be carefully considered in light of the possible repercussions on maintenance both technically and financially.

3.2.1 Condition of flat roofs with synthetic membranes

The 21.5% of the surface of the roofs examined (corresponding to 8,500 m²) needed to be substituted as the damage was severe and beyond repair. Another 5.6% (2,200 m²) was badly damaged and almost beyond repair. When a synthetic membrane breaks, water penetrates below the surface, soaks the insulation below (unless it is an extruding foam) and spreads over the supporting surface since the insulation is not glued but laid (Fig 2). The damage caused to the building is therefore always significant especially as the damage is usually noticed only after a certain delay.

![Figure 2. Distribution of the four deterioration codes on flat roofs with synthetic membranes.](image)

The damage reported is essentially due to material shrinkage. Up to the 1980s, the waterproofing membrane was made of PVC. Because of the damage provoked by this phenomenon – which is illustrated in the pictures in Fig. 3 where it is possible to observe how the shrinkage of the membrane has caused tension around the fixing points – the manufacturers took steps to substitute the material and the cover is now made of flexible polyolefin membranes.

![Figure 3. Examples of damage found on roofs with synthetic membranes.](image)

Considering the flaws of this type of covering and its popularity – thanks to the large amount produced in the 70s as it was relatively cheap, easy to lay and easy on the eye – a study of the average life span of roofs with synthetic membranes was deemed necessary.

Assuming that the refurbishment of a roof occurs when the end of the life span has been reached, and with the date of construction and the date of the work on its repair to hand, it is possible to calculate the life spans of various roofs. Taking into account only roofs with synthetic membranes, for which there was sufficient data, it was possible to calculate the average life span as being

\[ T = 23.8 \pm 5.5 \text{ years} \]

The graph in Fig 4 shows an accumulated statistic, that is, the ordinate of the single dots indicates the number of buildings with a life span lower or the same as that reported in abscissa. The continuous TT6-235, Durability of flat roofs: practical experience on service life and consequences on the maintenance strategy, Bernasconi-Cadoni-Chianese-Kaehr-Pahud-Salvadori
curve represents, in integrated form, the Gauss-distribution corresponding to the $s$ and $\mu$ values obtained from the experimental data and then normalized. It can be observed that the curve follows the dots obtained from the study in a satisfactory way. Applying this kind of distribution, out of 100 buildings with first generation synthetic membranes, 16 would not exceed a life span of 18 years.

The bibliography at our disposal, based on data from owners of large real estate assets (Confederation, UBS), generally indicates 30 years as being the upper limit for the average life span of a flat roof [Meyer et al.1995], thus confirming the validity of our study.

3.3 Consequences for maintenance strategy

The consequences of the damage resulting from this type of covering for the maintenance of the buildings have been and will be important. In this specific case, one aspect not to be underestimated is the concentration of maintenance work within a very short space of time. As can be observed in Fig 5, where the number of schools (solid line) and the number of c and d deterioration codes (bar) are reported as a function of the year of construction of a building, many cases of serious deterioration are to be found in buildings constructed between 1970 and 1979. The problem found on the roofs, which must be remedied quickly, has also certainly contributed towards this result causing what can be termed as a “maintenance peak”.

Figure 4. Life span vs. number of buildings.

Figure 5. Number of buildings and c and d codes as a function of the year of construction.
On the basis of collected data it has been possible to evaluate the specific cost of the roof refurbishment (125 SFr/m²). The total surface of roofs (four typologies) that needs to be renovated is about 13'000 m² only for the analyzed sample (42 buildings) that means a cost of about 1.6 million of Swiss Franc (~ 1 M€).

Assuming that the sample is sufficiently representative of the entire population of data, the maintenance costs for the roofs is extrapolated to all school buildings [Table 1].

<table>
<thead>
<tr>
<th>N. roofs</th>
<th>Surfaces</th>
<th>Damaged roofs</th>
<th>Estimated costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofs of the analyzed sample</td>
<td>42</td>
<td>72’800</td>
<td>12’937</td>
</tr>
<tr>
<td>Roofs of all school buildings</td>
<td>108</td>
<td>191’523</td>
<td>34’474</td>
</tr>
</tbody>
</table>

Table 1 – Estimated cost of maintenance related to the roofs of all school buildings.

This cost prevision is a very useful instrument for decision maker. In fact an adequate strategy can be developed in function of the needs of buildings and the financial availability.

This situation has some interesting repercussions on the technical front: on the one hand only those materials of proven endurance should be selected, whilst on the other hand the concentrated work load could allow speedy adaptation to current technical standards (opportunity maintenance). Moreover, from the energy point of view, the opportunity should be taken to carry out work aimed at reducing thermal loss through the roof so as to reduce– within the limits of economic sustainability – the energy requirements of these buildings as much one can. Where possible, renewable energy production technology could be integrated during refurbishment.

3.4 Opportunity maintenance: an example

When there is important maintenance work to be done, it is possible, in the case of flat roofs, to exploit these large surfaces for energy production. In fact, the thermal and mechanical features as well as the reliability of the new flexible polyolefin synthetic membranes are similar to those of the flexible amorphous-silicon photovoltaic solar modules [Chianese et al. 2003].

In a pilot project [D. Chianese et al., 2004] a flat roof was covered with a single ply roofing system based on Sarnafil T flexible polyolefin (FPO) membranes laminated together with flexible 15.4kW a-Si (amorphous silicon) triple-junction OEM 22-L-T UNI-SOLAR solar modules. The installation was integrated into the 960mq flat roof of the Centro Professionale di Trevano (CPT), situated near the University of Applied Sciences of Southern Switzerland. The power plant, which is shown in the picture of Fig.6, went into operation in December 2003.
The modules are laminated on the membrane which is directly placed on the roof. The membrane is joined to the roof structure by means of hot air welding and then mechanically fastened. The thermal insulation of the roof is 15 to 18 cm thick, and the single elements have an inclination of 3° thus allowing the rain water to flow off. The thermal insulation does not allow ventilation of the modules as usually required by crystalline silicon PV modules. This leads to a heating of the modules and consequently to changes in the electrical operating PV parameters.

In the past, an improvement in the energy yield could be observed due to the thermal insulation of one string of an a-Si (single-junction) installation situated on the roof of the LEEE-TISO laboratory.

With this pilot installation it will be possible to analyze the behaviour and the energy yield of the 15.4kWp triple-junction thin-film amorphous silicon PV system, and verify in which way the better thermal behaviour of a-Si technologies can compensate for losses due to the quasi-horizontal roof integration. First results show an energy production higher (+15 %) than the one expected for the first eleven months of exposure.

4 CONCLUSIONS

By means of EPIQR method (Energy Performance Indoor Quality and Retrofit) 42 school buildings, selected out from a total of 108 buildings, have been analyzed inspecting and judging more than 50 different elements for their deterioration.

In this paper two main results have been shown. The first one is related to the analysis of the selected buildings combined with their age. In the close future an important number of maintenance actions may occur in a short period of time. This is the consequence of various factors, like the age, the choice of materials, the past maintenance.

A second important result consists in the role of the flat roofs in the deterioration of the analyzed buildings. From the collected data it was possible to evaluated the cost for their future maintenance to about 4.3 mio SFr. The analysis has put into evidence a major problem for the flat roof with synthetic membrane, for which it was possible to evaluated a mean life time of 24 years.

In the elaboration of the maintenance strategy it should be considered the possibility to improve the quality and the energy performance during a maintenance intervention. A pilot project has been TT6-235, Durability of flat roofs: practical experience on service life and consequences on the maintenance strategy, Bernasconi-Cadoni-Chianese-Kaehr-Pahud-Salvadori.
described as an example. It is a flat roof covered with a synthetic membrane in which flexible solar modules have been laminated for photovoltaic energy production (15.4 kW).

5 ACKNOWLEDGMENTS

We would like to thank The Department of Education Culture and Sport and the Department of Finance of the Canton of Tessin for their financial support. We would like to extend our thanks to the Logistics Office of the Canton of Tessin for their precious cooperation during the whole length of the research project.

6 REFERENCES

Medimmo. 2002-2004, Méthode de diagnostic et d’aide à la décision pour la rénovation des bâtiments et la gestion de parcs immobiliers CTI n. 5972.1 KTS
Meyer, P., Büchler, M., Christen, K.1995, Vieillisement des éléments de construction et coût d’entretien, Office fédéral des question conjoncturelles, Bern,