Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 126 (201709) 171–178

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

Cost optimal analysis of lighting retrofit scenarios in educational buildings in Italy

Marina Bonomolo[a]*, Cristina Baglivo[b], Giacomo Bianco[b], Paolo Maria Congedo[b], Marco Beccali[a]

[a]*Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici—Università di Palermo, Viale delle Scienze Ed. 9, 90128 Palermo, Italy*

[b] *Dipartimento di Ingegneria dell'Innovazione, Università of Salento – 73100 Lecce, Italy*

Abstract

The European Energy Performance of Buildings Directive (EPBD) recast proposes, a comparative methodology to calculate cost-optimal levels of minimum energy performance requirements for buildings. This paper presents a method able to select the best retrofit action for lighting system, selectively analysing the daylight conditions and applying the cost-optimal methodology for different scenarios proposed for two existing educational buildings located in Italy. With the aim to improve both energy efficient and visual comfort conditions, the retrofit scenarios include lighting solutions with different combinations. They consider the replacement of lamps with more efficient lighting sources and the application of lighting control.

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: Retrofit actions, lighting system, cost-optimal analysis, payback time

* Corresponding author. Tel.: +393202223939.
E-mail address: marina.bonomolo@deim.unipa.it

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.137

1. Introduction

The educational buildings sector represents one of the most intensive part of energy consumption. In Italy the existing stock was built before 1980 and most of the buildings are obsolete. Thus, the retrofit of them can be relevant because of the poor energy performance of the stock, as well as for its high social value [1]. On the other hand, many studies demonstrated that retrofit actions can be very expensive and, if not well designed, their actual performances, both in terms of comfort and energy, could be lower than the expected ones [2]. An accurate predictive analysis of different possibilities of intervention and strategies is necessary to achieve good energy and comfort performances. Kesten Erhart et al. [3] presented a study developed within an initiative, financed by the Innovation and Quality Fund of Baden-Württemberg (Germany), that supports the development of universities as living laboratories to demonstrate and implement sustainability (Ministry of Higher Education, Research and the Arts, 2014). In particular, they investigated efficient ventilation and lighting solutions for the retrofitting of campus buildings, with a particular emphasis on a lecture hall.

As well-known, lighting systems accounts for approx. 19% (~3000 TWh) of the global electric energy consumption. For this reason, the retrofit action for lighting system can be a good strategy to achieve significant energy savings. In fact, also in this field, in many countries about 75% of the lighting installations are considered to be out of date (older than 25 years). With the aim of improving the lighting refurbishment process in non-residential buildings, in order to unleash energy saving potentials while at the same time improving lighting quality, a big team of experts are working on SHC Task 50. The main activities are developing a sound overview of the lighting retrofit market, planning trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs, increasing robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically, increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders, demonstrating state-of-the-art lighting retrofits and developing as a joint activity an electronic interactive source book including design inspirations, design advice, decision tools and design tools. Many studies have been carried out based on method developed within this task. Dubois et al. [4] presented some results from a large monitoring campaign performed in 22 buildings around the world as part of International Energy Agency (IEA) Task 50 "Advanced lighting solutions for retrofitting buildings", addressing in particular the work of Subtask D, which aims to demonstrate sound lighting retrofit solutions in a selection of representative, typical Case Studies. A method to select the best retrofit action in terms of energy savings achievable and not too long payback time, is the cost-optimal methodology. It is a useful tool to address the evaluations of financial, energy and environmental issues. Through the balance between energy consumption and costs, it is possible to choose the best performing solutions, exploiting many variables and selecting different best configurations. Baglivo et al. presented the results of the application of a methodology to identify cost-optimal levels in new residential buildings located in a warm climate [5]. Chen et al. [6] proposed a cost-benefit evaluation method for building intelligent systems, using life cycle net present value (NPV) of all the costs and benefits, including tangible and intangible, as an index to evaluate the performance of the building intelligent systems. Some research focused on the economic analysis for retrofit of lighting system. n-Ho Yang, Eun-Ji Nam [7] did an economic analysis of the daylight-linked automatic on/off lighting control system installed for the purpose of energy savings in office buildings. Beccali et. al [8] demonstrated the importance to analyze different scenarios in order to select the best ones.

This paper presents a study on the application of cost-optimal methodology for different scenarios proposed for a existing school located in Italy. With the aim to improve both energy efficient and visual comfort conditions, the retrofit scenarios include different lighting solutions with different combinations. Several lighting configurations have been evaluated from an economic point of view for the energy retrofit projects.

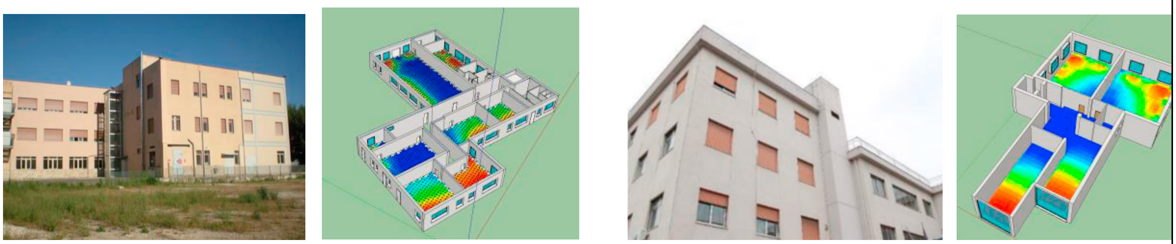
2. Case studies

In order to apply the proposed method, two different case studies have been considered. Both of them are educational buildings and located in south of Italy.

The first one is the Liceo Classico "Antonio Calamo". It is located in Ostuni (40°43'34"N, 17°34'20"E), 17.572901) in Apulia, in a suburb zone. The building has been built in 1960 and has three floors. It is used for about 10 hours during the working days and, occasionally during holydays. It is characterized by a "T" shape plan and it has a terrace.

The floor height is about 3,85 m. The windows are equipped by double-glazing. The existing indoor lighting system is composed mainly by fluorescent lighting sources characterized by different power, luminous flux and shape. The second school, "Istituto Pertini-Fermi", is located in Taranto (40°27'13"N, 17°15'37"E). It was built in 1950 and it has a covered area of 1900 m2. For both cases, the outdoor lighting systems, consisting in metal halide lamps in the first school and sodium vapour and metal halide lamps for the second ones, have not been considered in this study. In Figure 1 some pictures of the schools' objects of this study.

Both the schools have not other buildings present in the external surroundings area.



Liceo Classico "Antonio Calamo" "Istituto Pertini-Fermi"

Fig. 1 Some pictures of the schools and of the models.

3. Methodology

In order to select the best retrofit action, paying attention both to the energy efficiency and visual comfort conditions, a visual comfort analysis has been performed, analysing the illuminance values achieved with the existing system. In particular, for selecting proper lighting the task illuminance values suggested by the Standard EN 12464-1 "Light and lighting-Lighting of workplaces" [9] have been considered. For selecting different scenarios, the daylight contribution for each space of the schools has been taken into account. Daylight analysis has been carried out using the simulation software Daysim [10] to calculate the Daylight Autonomy [11]. It has been calculated for a grid of points at a height of 0.85 m. Given that in this step of study, the possibility to divide in different control groups the luminaires have not been taken into account, the minimum value of daylight autonomy has been considered as whole value for each space.

For both models the following optical characteristics of materials have been considered:

- inner coating of plaster: reflectance 0.80%, rugosity 0.01%, specularity 0.0%;
- floor material: reflectance 0.20%, rugosity 0.03%, specularity 0.02%;
- task plane material: reflectance 0.60%, rugosity 0.02%, specularity 0.05%;
- windows double glazing: transmittance 78%.

Energy plus weather data files have been used for considering climatic conditions of the two locations. Simulations have been carried out considering an average of 9 daily hours of occupancy. For each school 8 different scenarios (combination of retrofit actions in selected rooms) have been proposed and analysed (table 1). The scenarios have been selected with a criteria based on Daylight Autonomy calculated for each room. Two kinds of retrofit actions have been considered: the replacement of the existing lighting sources (L.R.) and the installation of ON-OFF automated lighting control systems (C.S.I.). The first scenario (0) considers the replacement of the existing fluorescent lamps (18W, 36W e 58W) with LED fixtures (10W, 16W e 24W) in every room of the schools. This action is the main retrofit intervention included in previous studies made for these schools by local authorities which have commissioned to external professionals a global lighting design [12]. For the scenario 1 only the replacement of the luminaires have been analysed, but only in the rooms where the minimum value of DA is <30% and where high values of illuminance are required for the task (e.g. laboratories). Given that the schools are used for the most part during the daytime, in these spaces the luminaires would be turned on for a larger number of hours. Thus, the energy saving would be higher, replacing the existing luminaires with the more efficient ones. The scenario 2, in addition to the retrofit action considered in scenario 1, includes the replacement of the existing lighting sources and the installation of a control lighting system in the spaces where a minimum value >20% of DA has been calculated. Scenarios 3, 4, 5, 6 and 7 include the same retrofit actions of scenario 2, but selecting for the installation of the automated system only the spaces where a minimum values of DA is >30%, for scenario 3, >40%, for scenario 4, >50%, for scenario 5, >60%, for scenario 6, >70%, for scenario 7.

Table 1. The analysed scenarios and the selection criteria based on DA minimum value.

Scenario	0	1	2	3	4	5	6	7
L.R.	All rooms	<30%	<30%	<30%	<30%	<30%	<30%	<30%
C.S.I.	\	\	>20%	>30%	>40%	>50%	>60%	>70%

Legend: L.R. : Lamp and fixture replacement; C.S.I.: Control system installation

4. Cost optimal analysis

4.1. Case 1: Liceo Classico "Antonio Calamo"

Once defined the measures for each scenario, the cost-optimal analysis has been carried out. Table 2 points out the calculated costs, the energy consumption ante and post, the energy savings and economic indices of investment, i.e. the Net Present Value (NPV) and the Total Return Swap (TRS).

Table 2 – Financial analysis.

Scenario	0	1	2	3	4	5	6	7
Total cost [euro]	32357,60	14590,00	37829,04	36767,60	26691,60	20712,52	18589,64	16784,72
Yearly consumption of the lighting system - Ante intervention [kWh/y]	18182,64	8823,36	18636,24	18182,64	13949,04	11454,24	10547,04	9730,60
Yearly consumption of the lighting system –Post intervention [kWh/y]	8389,92	4230,24	8446,30	8174,14	6010,17	4925,15	4605,82	4397,16
Savings attributed to the intervention [%]	53,86	52,06	54,68	55,04	56,91	57,00	56,33	54,81
Savings after the intervention [kWh/y]	9792,72	4593,12	10189,94	10008,50	7938,87	6529,09	5941,22	5333,44
Unit cost of the energy [euro/kWh]	0,18	0,18	0,18	0,18	0,18	0,18	0,18	0,18
Annual Savings [euro/y]	1762,69	826,76	1834,19	1801,53	1429,00	1175,24	1069,42	960,02
Period of intervention [y]	25,00	25,00	25,00	25,00	25,00	25,00	25,00	25,00
NPV [y]	4473,81	3084,81	465,82	858,79	3309,77	4094,87	4051,90	3617,61
Total Return Swap (TRS) [y]	17,99	16,92	20,23	20,01	18,22	17,11	16,82	16,86
Total Return (TR) [y]	22,00	20,00	25,00	25,00	22,00	21,00	20,00	20,00

The selection of the best action may be done basing on the NPV for an up to 25 years of cash flows and on the payback time. In particular, the results outline a TR for the scenario 1-7 equal to 20; 25; 25; 22; 21; 20 e 20 years, involving the amortization of the total cost within the considered time.

Figure 2-9 show the NPV trend for each scenario, highlighting the inversion of the trend after the 20th year for the scenario1, 6 and 7 after the 21nd year for the scenario 5; after the 22nd year for the scenario 4 and after the 25nd year for the scenario 2 and 3.

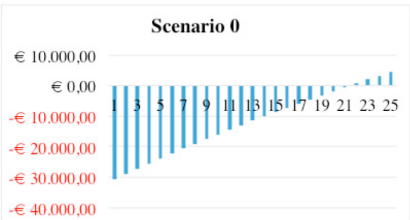


Fig. 2 – Scenario 0

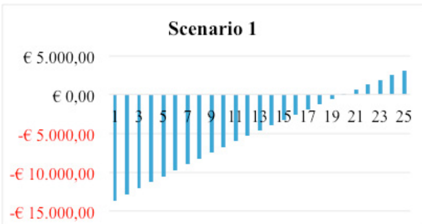


Fig. 3 – Scenario 1

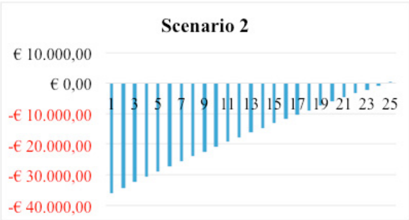


Fig. 4 – Scenario 2

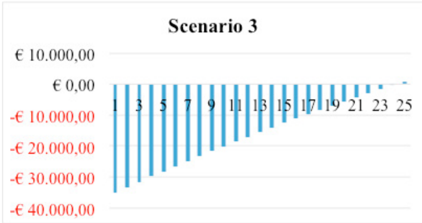


Fig. 5 - Scenario 3

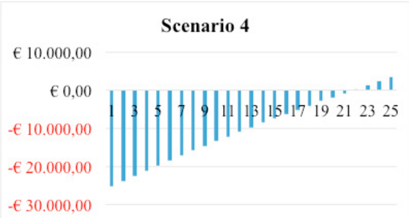


Fig. 6 – Scenario 4

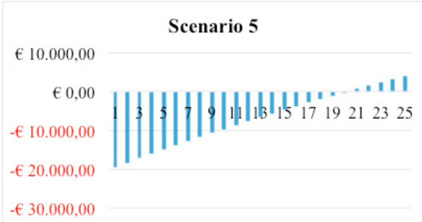


Fig. 7 – Scenario 5

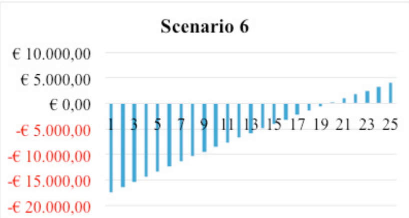


Fig. 8 – Scenario 6

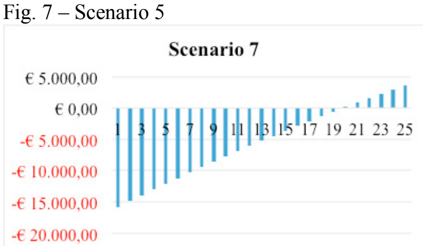


Fig. 9 - Scenario 7

4.2. Case 2: Istituto Pertini-Fermi

As the previous case, the financial parameters have been reported in Table 3 for each scenario.

Table 3 – Financial analysis.

Scenario	0	1	2	3	4	5	6	7
Total cost [euro]	92072,00	38078,00	98826,28	85660,32	83603,76	78139,36	67436,56	47869,52
Yearly consumption of the lighting system - Ante intervention [kWh/y]	43777,44	18648,00	40763,52	35552,16	35007,84	33042,24	29232,00	22458,24
Yearly consumption of the lighting system –Post intervention [kWh/y]	20076,00	8907,36	18081,04	14798,72	14348,75	13384,69	11819,47	9707,51
Savings attributed to the intervention [%]	54,14	52,23	55,64	58,37	59,01	59,49	59,57	56,78
Savings after the intervention [kWh/y]	23701,44	9740,64	22682,48	20753,44	20659,09	19657,55	17412,53	12750,73
Unit cost of the energy [euro/kWh]	0,18	0,18	0,18	0,18	0,18	0,18	0,18	0,18
Annual Savings [euro/y]	4266,26	1753,32	4082,85	3735,62	3718,64	3538,36	3134,26	2295,13
Period of intervention [y]	25,00	25,00	25,00	25,00	25,00	25,00	25,00	25,00
NPV [y]	-3997,46	-1438,47	-14505,84	-8446,94	-6737,98	-4963,50	-2531,91	-140,08
Total Return Swap (TRS) [y]	21,40	21,29	24,00	22,71	22,27	21,86	21,27	20,54
Total Return (TR) [y]	–	–	–	–	–	–	–	–

For each scenario, the TR values are higher than the considered time (25 years), leading to the consideration that the proposed measures are not convenient from an economic point of view, Figures 10-17.

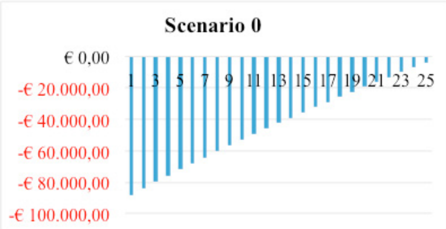


Fig. 10 – Scenario 0

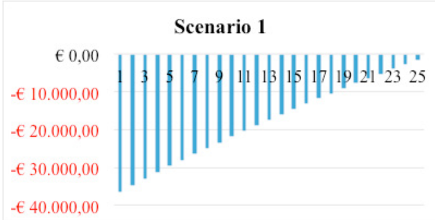


Fig. 11 – Scenario 1

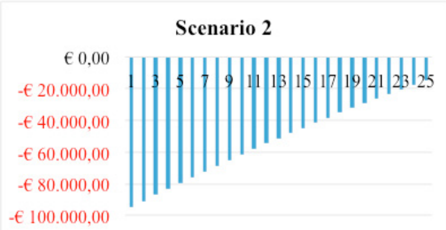


Fig. 12 – Scenario 2

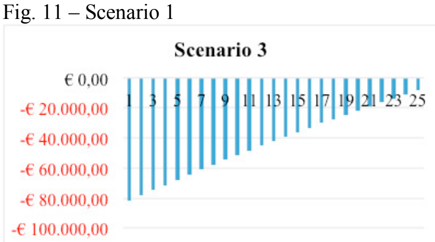


Fig. 13 - Scenario 3

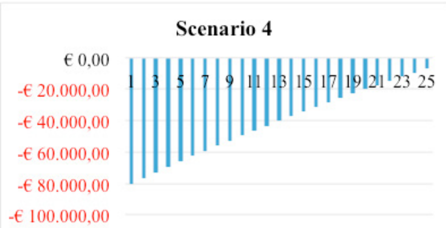


Fig. 14 – Scenario 4

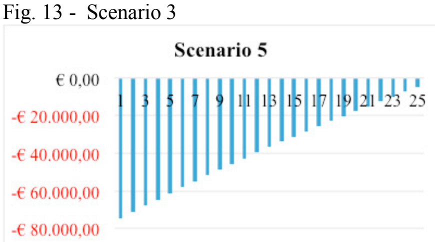


Fig. 15 – Scenario 5

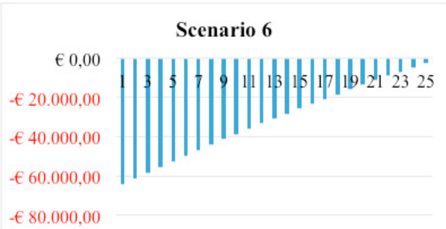


Fig. 16 – Scenario 6

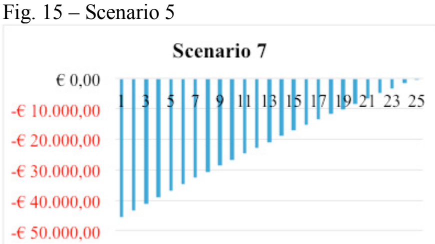


Fig. 17 - Scenario 7

4.3. Discussion

Graphs in figure 18 show the comparison between energy savings and the comparison of the cost calculated for each scenario for the two schools.

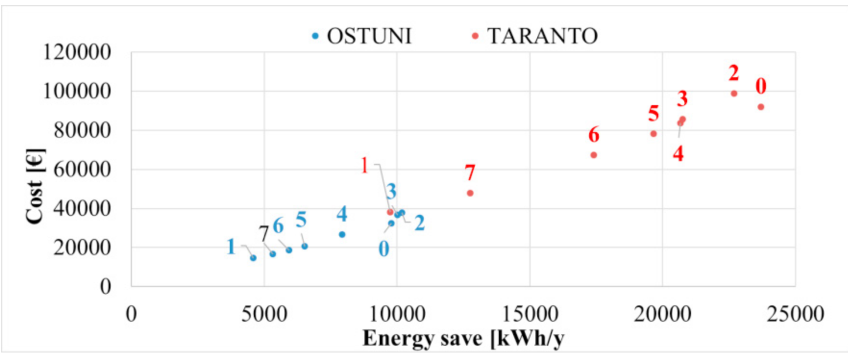


Fig. 18. Comparison between energy savings and costs calculated for each scenario.

Looking at the analysis carried out for the school "Pertini-Fermi", if we analyse also another set of scenarios having as a threshold value for lamp substitution < 10%, it is possible to plot the NPV and the DA threshold curves (figure 19). It can be noted that the right selection of areas leads to optimize this financial indices (maximum NPV). Moreover, a too wide or a too restricted retrofit penalizes the economic performance. This example is useful to highlight how the DA can be utilized as a factor for performing cost optimal analyses.

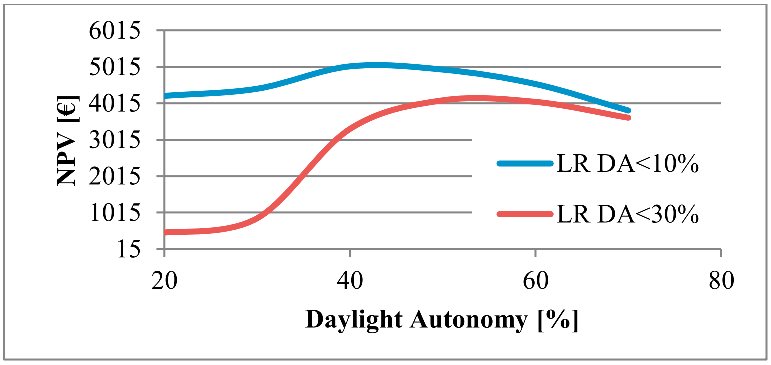


Fig. 19. NPV vs Daylight Autonomy values used to build scenarios.

Unfortunately, in the second school the financial analysis has highlighted very poor results in terms of economics while the trend of NPV is almost the same.

5. Conclusion

Retrofitting of lighting systems can be a sustainable action for buildings. Anyway, it can be very expensive and a detailed preliminary analysis of the costs it is necessary to achieve high performances not only in terms of comfort and energy but also from the economic point of view.

This paper presents a method that allows to select the best retrofit action for lighting system, analysing the daylight contribution for different scenarios proposed for two existing educational buildings located in Italy. These, have been selected as cases studies and analysed. Using the simulation software Daysim, daylight conditions for both schools have been simulated and the results have been studied in order to choose among the possible retrofit actions for lighting system. In particular, for each space of the schools the Daylight Autonomy index has been calculated. Based on this daylight index values, four different scenarios have been proposed and for each one an economic analysis have been carried out. The scenario 0, the replacement of the luminaires has been analysed for all rooms of the schools, without taking into account the DA minimum values. The scenario 1 considers the replacement of the existing fluorescent lamps with LED only in rooms where the minimum value of DA is <30%. The meaning is to avoid massive replacing of lamps and focus the intervention only in areas were artificial lighting has the major probability to be utilized. The scenario 2, in addition to the retrofit action considered in scenario 1, includes the replacement of the existing lighting sources and the installation of a control lighting system in the spaces where a minimum value of DA >20% has been calculated. Scenarios 3, 4, 5, 6 and 7 include the same retrofit actions of scenario 2, but selecting for the installation of the automated system the spaces where the minimum value of DA is >20%, >30%, >40%, >50%, >60% and >70% respectively. Also in these case the rationale is to consider only the rooms were the best energy performances could be expected. All scenarios have been calculated considering a period of intervention of 25 years. Regarding the school “Liceo Classico Antonio Calamo”, the highest total intervention cost is related to the scenario 2, because the considered “range” of the DA (>30%) for the selecting the application area of the C.S.I. action is larger. Consequently, also the yearly consumption and the savings after the intervention are the highest. Moreover, looking at the payback times, Scenarios 0 and 4 are the less convenient, being the calculated TR of 25.00 years. Furthermore, looking at the TRS, results show that scenario 6 is the far more cost-effective, even if the application of scenarios 1 and 7 that have the same TR.

In the second case, the analysis shows that, in general, these kinds of retrofit actions may not be convenient.

The difference of scale of the buildings areas, causes the impropriety of using the same selection strategy for the two

schools.
DA or other lighting index will be considered as measurable variables to look for a cost optimal analysis of several scenarios.
It is interesting to note that where the retrofit action has a good potential in terms of energy saving, the DA can be utilized as a factor for the optimization of the economic performances related to different grades of implementation.
In a further work, the application of further different strategies will be analysed and compared. Furthermore, cost-optimal analysis for other retrofit actions for lighting system (e.g. dimming control system) will be calculated and included in the proposed scenarios study.

References

[1] Zinzi, Michele, Agnoli, Stefano, Battistini, Giovanni, Bernabini, Gualtiero. "Deep energy retrofit of the TM Plauto School in Italy—A five years experience". *Energy and Buildings* 126 (2016): 239-251.

[2] Ciulla, Giuseppina, Beccali, Marco, Lo Brano, Valerio, Galatioto, Alessandra, Bonomolo, Marina. "Artificial neural network decision support tool for assessment of the energy performance and the refurbishment actions for the non-residential building stock in Southern Italy". *Energy*, in press

[3] Erhart Kersten, Dilay, Schmitt, H. Maximilian,A., Guerlich, Daniel, Bonomolo, Marina, Eicker, Ursula. "Retrofitting Existing University Campus Buildings to Improve Sustainability and Energy performance". In information: PLEA 2016 Conference, 32nd International Conference on Passive and Low Energy Architecture: Cities, Buildings, People: Towards Regenerative Environments, Publication Date: Jul 2016.

[4] Dubois, Marie Clause, Gentile, Niko, Amorim, Claudia Naves David, Osterhaus, Werner, Stoffer, Sophie, Jakobiak, Roman, Geisler-Moroder, David, Matusiak, Barbara, Martens, Fredrik. "Performance Evaluation of Lighting and Daylighting Retrofits: Results from IEA SHC Task 502". *Energy Procedia* 91 (2016):926-937.

[5] Baglivo, Cristina, Congedo, Paolo Maria, D'Agostino, Delia, Zacà, Ilaria. "Cost-optimal analysis and technical comparison between standard and high efficient mono-residential buildings in a warm climate". *Energy* 83 (2015): 560-575.

[6] CHEN, Zheliang; WANG, Fulin; FENG, Qingqing. "Cost-benefit evaluation for building intelligent systems with special consideration on intangible benefits and energy consumption". *Energy and Buildings* 128 (2016): 484-490.

[7] YANG, In-Ho; NAM, Eun-Ji. "Economic analysis of the daylight-linked lighting control system in office buildings". *Solar Energy* 84.8 (2010):1513-1525.

[8] Beccali, Marco, Bonomolo, Marina, Ciulla, Giuseppina, Galatioto, Alessandra, Lo Brano, Valerio. "Improvement of energy efficiency and quality of street lighting in South Italy as an action of Sustainable Energy Action Plans. The case study of Comiso (RG)". *Energy* 92 (2015): 394-408.

[9] EN12464-1:2011. Light and lighting – Lighting of workplaces. Part 1: Indoor work places

[10] http://daysim.ning.com/ (Last view: May 2017)

[11] Reinhart, Christoph F., Mardaljevic, John, Rogers, Zack. "Dynamic daylight performance metrics for sustainable building design." Leukos 3.1 (2006):7-31.

[12] Unione delle Province d'Italia (UPI), "Realizzazione dell'intervento di diagnosi energetica delle strutture pubbliche provinciali ai fini dell'efficientamento energetico", POI 2007e2013 "Energie Rinnovabili e Risparmio Energetico".