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LED Lighting for Indoor Sports Facilities: Can Its Use Be Considered as Sustainable Solution from a Techno-Economic Standpoint?

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Abstract: In this paper, the authors propose a techno-economic comparative analysis between different lighting solutions, using, respectively, floodlight with metal halide lamps, luminaires with fluorescent lamps and LED floodlights. The comparison is aimed to identify general criteria for assessing the techno-economic sustainability of the use of LED lighting for indoor sports facilities, since this solution is very often proposed to achieve a reduction of the electrical power for lighting. From a technical standpoint, the analysis takes into particular consideration the aspects related to the satisfaction of lighting requirements, safety and energy efficiency. From an economic standpoint the investment, the operating and the maintenance costs are evaluated. To make comparisons on an economic basis, specific indicators are used. From the obtained results it is possible to highlight as the solution that uses the LED floodlights is characterized by highest energy efficiency. This solution requires a smaller number of luminaires and it has limited maintenance costs compared to the other solutions, but it has high investment costs, which involve reasonable payback times only when the sports facility is used intensively and for competitions of high level.

Keywords: sports facilities; LED lighting; economic analysis; lighting system refurbishment; energy consumption for lighting

1. Introduction

Sports participation fulfills important social functions among children, adolescents and adults [1]. In a large number of countries, the number of sports facilities has grown over the last two decades, both in the public and private domain [2–6].

In Italy, there are about 150,000 sports facilities, according to the census carried out by the Italian National Olympic Committee (CONI) and updated in 2003 by the National Council for Economy and Labor (CNEL), from which emerges the high degree of obsolescence and age of the sports facilities [7,8]. Of Italian sports facilities, 62.5% were built before 1981 and 30% between 1981 and 1990. The main interventions implemented on the sports facilities are, for the most part (over 60%), intended to the refurbishment of the existing assets. In relation to the interventions aimed to improve energy efficiency, the main energy consumptions of the indoor sports facilities are due to the lighting of the playing fields and to domestic hot water production. It is evident that the reduction of the energy consumption for lighting can be achieved through the reduction of the installed power of the lamps and the better distribution of the luminaires [9]. In this case, a detailed study of the lighting systems is very important in order to increase the energetic and economic sustainability of sports facilities [10–16].

Requirements for artificial lighting of sports facilities are introduced in Europe by EN 12193 [17]. In Italy, the CONI takes the same parameters in the national guidelines [18]: "CONI regulations for sports facilities". In sports facilities, the lighting system is commonly realized with one of the following solutions, which are characterized by the use of different types of luminaires [19]: floodlights with metal halide lamps (MH), luminaires with tubular fluorescent lamps (FL) and LED floodlights. The first two solutions are widely used, while the LED solution is poorly diffused because its recent adoption. Nowadays the use of LED is often proposed to achieve an immediate reduction of the electrical installed power, both for the realization of new facilities and for the refurbishment of existing facilities [20–22].

In this paper, the authors propose a techno-economic comparative analysis between the three different lighting solutions, in order to identify general criteria for assessing the techno-economic sustainability of LED lighting solution for the indoor sports facilities. From a technical standpoint, the analysis takes into particular consideration the aspects related to the satisfaction of the lighting requirements, the safety and the energy efficiency. From an economic standpoint the investment, the operating and the maintenance costs are evaluated. To make comparisons on an economic basis, specific indicators are used such as: Net Present Value (NPV) and simple Pay-Back Time (PBT). The discussion is based on the analysis of the results obtained from a case study, however the considerations made by the authors can be easily extended to all sports halls built with an arch structure covered by membrane, as shown in Figure 1, widespread in Italy and Europe.

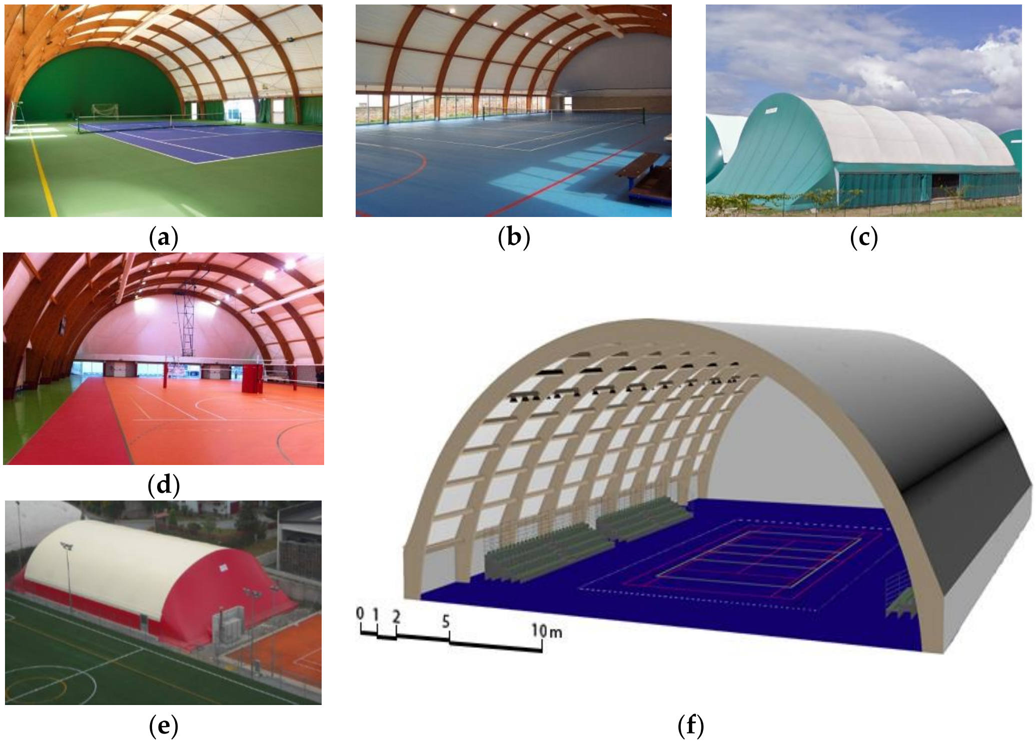

Figure 1. Examples of Italian sports halls, built with an arch structure covered by membrane: (**a**) sports hall in Bologna; (**b**) sports hall in Barbianello (Pavia District); (**c**) sports hall in Ponsacco (Pisa District); (**d**) sports hall in Villafranca (Verona District); (**e**) sports hall in Millesimo (Savona District); (**f**) 3D view of the case study sports hall in Pisa (see also Section 3).

2. Lighting Requirements in Sports Facilities

The lighting system in a sports facility should ensure good visual conditions for players, athletes, referees, spectators, and (if present) for TV shots. To achieve adequate lighting conditions is necessary to optimize the perception of visual information during the performance of sports events, maintaining the correct levels of visual performance and provide an acceptable level of visual comfort. The lighting requirements for indoor sports facilities are specified in Europe, in the Technical Standard EN 12193 [17].

In addition to the lighting requirements, it is important also a verification of the photobiological safety and the health effects of the lighting sources, to whose emissions the athletes can be exposed for several hours a day [23–26], in accordance to what should be done for other environments intended for the permanence of people [27–30].

The main parameters influencing the luminous environment, with reference to the artificial lighting for indoor sports facilities, are: horizontal average maintained illuminance, illuminance uniformity, color rendering index of the lamps and discomfort glare. To take into account the various needs of the different levels of play and the different viewing distances, depending on the sports facility capacity, three lighting classes (LC) are defined [17]: LC I (international competitions), LC II (national competitions), LC III (training). The minimum requirements of lighting parameters are variable in function of the considered combination between sport and lighting class. Table 1 shows the geometric dimensions of the playing fields, the values of the horizontal average maintained illuminance (E_m), the minimum value of the illuminance uniformity (U_0) and the minimum value of the color rendering index (Ra), for the three lighting classes and for three sports, which are considered as significant: volleyball, basketball and tennis. The specified lighting requirements should be satisfied at least on the calculation grid, that usually correspond to the playing field.

Table 1. Lighting requirements for indoor sports facilities according to different lighting classes and to different sports [17].

	Lighting Requirements [1]							
	Volleyball-Basketball				**Tennis**			
LC	**E_m (lx)**	**U_0**	**Ra**	**UGR_{lim}**	**E_m (lx)**	**U_0**	**Ra**	**UGR_{lim}**
I	750	0.70	60	22	750	0.70	60	22
II	500	0.70	60	22	500	0.70	60	22
III	200	0.50	20	22	300	0.50	20	22

[1] Playing fields of the following dimensions (width × length): 15 m × 28 m for Volleyball, 15 m × 24 m for Basketball, 18 m × 36 m for Tennis.

From Table 1 it is possible to notice that the values, which have to be satisfied, increase with the lighting class, because a growing perception of visual information is request with the increase of speed of the game actions. The correct perception of fast moving objects generally requires illuminance levels higher than that for fixed objects, typical of indoor workplaces.

In Italy, the National Federal Regulations provide additional information and details [31–33]. Some regulations give minimum values for the horizontal average maintained illuminance, which generally are higher than those reported in Table 1. In some cases, in addition to the identification of the illumination values, the methodologies of verifications and trials of the lighting systems are explained.

3. Case Study Description

The techno-economic analysis on the lighting systems were carried out for a sports hall with a structure of laminated wood arches, covered by a membrane with PVC sheets, in which a polyvalent playing field was inserted, as shown in Figure 1 (Section 1). This type of structure is widespread in Italy for volleyball, basketball and tennis. Considering that the values of the lighting parameters (see Table 1) are referred to the playing field and considering that the sports halls have big volumes with very distant envelope surfaces each other, lighting design is not significantly affected by the reflection of the envelope surfaces. The results obtained from the analysis can therefore be generalized, with good approximation, to all sports halls with construction features similar to the case study.

The structure in laminated wood arches used as case study has the following dimensions: 30 m wide, 45 m long and 13 m height. The sports hall dimensions are such as to allow the carrying out the sports of volleyball, basketball and tennis, and the installation of removable stands for a maximum capacity of 230 spectators. The reflection coefficients (ρ) of the main surfaces of the sport hall are the following: laminated wood arches (1600 m^2) ρ = 52%; sports floor (1300 m^2) ρ = 22%; Internal cover sheet (2562 m^2) ρ = 86%; tribunes (350 m^2) ρ = 70%.

The lighting system is commonly made by using one of three types of luminaires: high-power floodlights with metal halide lamps (MH), luminaires with tubular fluorescent lamps (FL), and LED floodlights (LED). The first two solutions are widely used and usually they are provided "turnkey" together with the lighting design by the luminaires installer, while the LED solution is less used and requires a case by case analysis. In Table 2, the technical data of typical examples of these luminaires are reported, one for each different type. In this work, a complete lighting design was carried out, through the lighting simulation software Dialux 4.12 (DIAL GmbH, Lüdenscheid, Germany, www.dial.de). The aim of the design was to define lighting system configurations able to satisfy the minimum lighting requirements listed in Table 1, according to the Technical Standard EN 12193 [17], using the three different type of luminaires.

Table 2. Main technical features of the considered luminaires (data declared by the manufacturers).

	MH	**FL**	**LED**
Luminaires			
Type of Lamps	Metal Halide	Fluorescent	LED
Numbers of Lamps	1	4	20
Electrical input power (W)	428	340	284
Optical efficiency (%)	71	96	97
Single Lamp Properties			
Electrical nominal power (W)	400	80	14.2
Luminous Flux (klm)	35.0	6.8	1.5
Color Temperature (K)	5500	4000	4000
Color Rendering Index	92	80	80
Lamp survival factor	0.83 *	0.90 **	0.90 ***
Lamp lumen maintenance factor	0.99 *	0.99 **	1.00 ***

* evaluated at 2000 h; ** evaluated at 12,000 h; *** evaluated at 40,000 h.

In Table 3, the function of the lighting class and for all the considered sports, are specified: the number of the luminaires (N) and the overall electrical power (P) of the lighting system configuration, the value of horizontal average maintained illuminance (E_m) and the illuminance uniformity (U_0), which are, together with the usage time, the parameters mostly influencing the annual energy consumptions for artificial lighting.

From the analysis of the data shown in Table 3 and from the comparison between Tables 1–3, it can be observed that:

- the lighting requirements fixed for the parameters E_m and U_0 are satisfied by all the lighting system configurations (compare Table 1 with Table 3);
- the minimum values required for the parameter Ra are satisfied by all the considered lamps (compare Table 1 with Table 2);
- the lighting system configurations with LED floodlights, if compared to similar configurations that use other luminaires, are characterized by the lowest number of luminaires and the lowest electrical installed power for lighting (see Table 3).

From the simulations results it was also possible to verify that all types of luminaires are able to satisfy, for the main directions of views, the UGR maximum values fixed for the different lighting classes and sports. However, the analysis of the glare in dynamic and very demanding visual conditions, such as those that occur during sport participation, requires advanced and very detailed assessments, which are beyond the scope of this paper.

In order to make the techno-economic evaluations on the lighting systems, the data in Table 3 for Tennis are used, because they are characterized by the maximum number of luminaires and the maximum installed electric power.

Table 3. Lighting system configurations: summary of the results obtained from the simulations.

Sport	LC	Lighting System Configuration [1]											
		MH				FL				LED			
		N (-)	P (kW)	E_m (lx)	U_0 (-)	N (-)	P (kW)	E_m (lx)	U_0 (-)	N (-)	P (kW)	E_m (lx)	U_0 (-)
Volleyball	I	36	15.4	752	0.93	32	10.9	767	0.76	28	8.0	770	0.86
	II	24	10.3	540	0.78	24	8.2	502	0.82	20	5.7	553	0.90
	III	16	6.8	330	0.79	16	5.4	330	0.84	12	3.4	304	0.71
Basketball	I	40	17.1	784	0.83	36	12.2	764	0.78	28	8.0	771	0.83
	II	24	10.3	533	0.79	28	9.5	524	0.83	20	5.7	547	0.90
	III	16	6.8	329	0.81	16	5.4	317	0.86	12	3.4	310	0.77
Tennis	I	40	17.1	755	0.77	40	13.6	752	0.73	28	8.0	751	0.84
	II	24	10.3	540	0.71	28	9.5	505	0.78	20	5.7	529	0.82
	III	16	6.8	311	0.71	16	5.4	300	0.78	12	3.4	309	0.72

[1] For all the system configurations, the following maintenance factors (MF) have been considered, according to the calculation method described in International Commission on illumination (CIE) [34]: MF = 0.7 for MH, MF = 0.8 for FL, MF = 0.8 for LED. For the calculation the following assumptions have been done: clean environment, elapsed time between cleanings of the lamps equal to 0.5 years, technical data about the lamp survival and lamp lumen maintenance factor provided by the manufacturers.

4. Techno-Economic Comparisons between Lighting Systems

The comparisons between the different lighting systems are addressed in this work on techno-economic standpoint. The economic analyses were conducted for a reference period of 20 years. Before introducing the results, it is necessary to provide information on the economic items considered for the calculation. For the three lighting systems were calculated: the initial investment cost (I_0), the operating cost (C_o), and the maintenance cost (C_m). The parameter I_0 is given by the product of the number of installed luminaires (N) and their unit cost. The comparisons were done considering the realization of the lighting system with: its own funds and a bank financing. In the first case, I_0 is placed to the year of realization of the lighting system, while in the second case the mortgage payment is considered in the annual outflows. The mortgage payments were calculated using a fixed rate equal to 3.5% [35]. The parameter C_o is due to the energy consumptions when the lighting system is switched-on and it depends on: the electrical installed power for lighting (P), the usage time and the hourly rate of electrical energy (estimated at 0.18 €/kWh [36] according to the Italian Regulation Authority for Electricity, Gas and Water). The parameter C_m depends on the frequency of the maintenance works for the luminaires, which are necessary in order to guarantee that the lighting requirements are satisfied (see Table 1). This parameter was evaluated as International Commission on illumination (CIE) [34]: $C_m = N_r \cdot C_u$, where N_r is the number of replaced lamps during the scheduled maintenance and C_u is the all-comprehensive unit cost of lamp (that takes into account the supply, installation and disposal costs usually applied in Italy). The frequency of the scheduled maintenance varies in function of the lamp type and it is equal to 1, 6 and 14 years respectively for MH, FL and LED. The determination of this frequency for each lamp is influenced by the lighting requirements, which need to be satisfied, and by the technical data about the lamp survival and lamp lumen maintenance factor provided by the manufacturers (see Table 2). The frequency of the scheduled maintenance of 14 years for LED was determined considering conservatively an accidental failure of 10% of the installed LED floodlights at the 70% of the reference period (20 years) [37]. C_o and C_m are referred to different years, respect to the year of the realization of the lighting system (base year). For this reason, they have to be reported to the base year by discounting procedure. The discounting procedure depends on discount rate (r). The discount rate is defined as the rate at which the investment revenues and costs are discounted in order to calculate its present value. For the realization of the lighting system with its own funds, a discount rate equal to 2% was considered [38], while for the use of a bank financing, the discount rate assumes the same value of the interest rate (3.5%). The discounting of the individual cost parameter was done by using the following equation: $C_d = C_k/(1 + r)^k$, where C_d (€) is the discounted cash flow, C_k (€) is the cash flow expected in the k year and r is the discount rate.

In order to consider the different usages of the lighting system, according to the different lighting classes, multiple scenarios have been defined. Each scenario is characterized by a total annual usage time of the lighting system equal to 2000 h [39] divided into smaller fractions of time, for which the lighting system is used to satisfy different lighting classes. The assumed scenarios are defined in Table 4, where the total usage time and the usage times for each lighting class are indicated.

Table 4. Definition of the lighting scenarios in function of the usage times of the sports hall.

Scenario	Annual Usage Time for Each LC (h)			
	LC I	**LC II**	**LC III**	**Total**
1	2000	-	-	2000
2	-	-	2000	
3		200	1800	
4	200	1800	-	
5	200	-	1800	
6	70	130	1800	

In order to evaluate the sustainability of the different lighting systems, the data contained in Table 3 were used. In the following sections, two techno-economic evaluations are discussed: the first (Section 4.1) is referred to the realization of the lighting systems in a sports hall of new construction, the second (Section 4.2) is referred to the refurbishment of the lighting system in an existing sports hall.

4.1. Energy and Economic Analysis of the Realization of the Lighting System in a Sports Hall of New Construction

When the lighting system in a sports hall of new construction has to be realized, the total management cost of the lighting system (C_T) can be estimated as $C_T = I_0 + C_o + C_m$. In this paper, I_0, C_o, and C_m were calculated for all the defined scenarios and considering the three different type of luminaires (MH, FL, LED, see Table 2).

Table 5 shows the calculation results for the scenarios 1, 2 and 3 and using a discount rate equal to 2%. The calculation results for scenarios 4, 5 and 6 are not reported because they are very similar to those of scenario 3. In the sixth column of Table 5, the values of the normalized management cost $C_{m,n}$ are reported. They were obtained dividing the values of C_m by the number of years between two consecutive scheduled maintenances. The values of $C_{m,n}$ are useful in order to have an immediate comparison between the maintenance costs of the different systems, but in order to correctly applied the discounting procedure the values of C_m were considered in the calculation. The last column of Table 5 reports the values of the primary energy consumption in tons of equivalent oil (toe). For the calculation of tons of equivalent oil, the Italian Regulation Authority for Electricity Gas and Water [40,41] gives the value of the conversion factor for the electrical energy into primary energy, estimated in 0.187×10^{-3} toe/kWh.

Considering the values shown in Table 5, the trends of C_T in function of time is shown in Figure 2 for the scenario 1. From the trends of C_T it can be observed that the lighting system with MH, despite having the lower cost of initial investment (I_0 = 13.4 k€), reach at the twentieth year the higher value of C_T (209.6 k€, higher than 2.33 times the lighting system with LED and 1.75 times lighting system with FL). This behavior is caused by the high operating cost, due to high energy consumption, and the high maintenance cost.

Table 5. Calculation results: evaluated technical and economical parameters in function of the Scenario for different luminaires.

Scenario	Luminaire	I_0 (€)	C_o (€/year)	C_m *	$C_{m,n}$ (€/year)	toe (toe/year)
1	MH	13,371	6115	3757	3757	6.2
	FL	22,166	4482	3240	540	4.6
	LED	36,892	2911	3689	264	2.9
2	MH	5348	2508	1503	1503	2.6
	FL	8865	1992	1296	216	2.0
	LED	15,811	1248	1581	113	1.3
3	MH	13,371	2726	1503	1503	3.1
	FL	22,166	2168	1296	216	2.2
	LED	36,892	1360	2635	188	1.5

* FL: €/6 years; MH: €/year; LED: €/10 years.

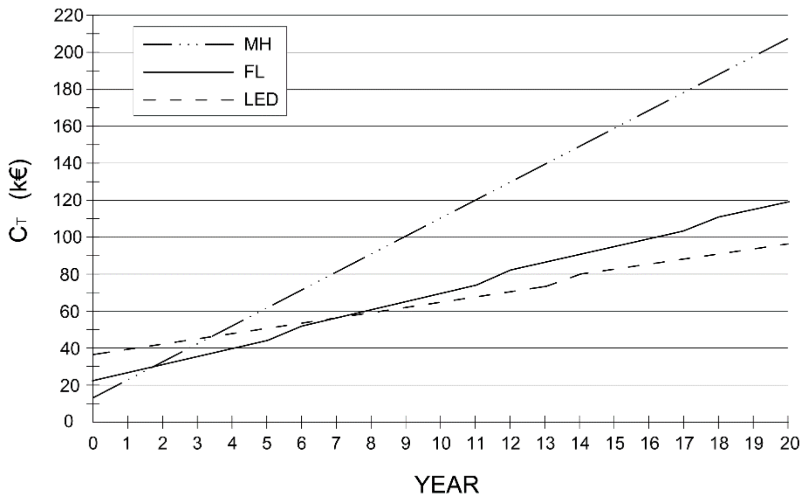

Figure 2. Trend of C_T discounted values in function of time, for lighting systems with different luminaires: results of scenario 1.

The lighting system with LED is characterized by the maximum value of the initial cost (I_0 = 36.9 k€) and the related trend of C_T has a weak inclination from the horizontal axis, due to the reduced operating and maintenance costs. For this reason, the total management cost is the lowest among all (C_T = 97.5 k€). The lighting system with FL has an intermediate trend and reach, at the twentieth year, a total management cost higher than the lighting solution with LED. With reference to the total management cost of the solution with MH, the lighting system with LED allows a simple payback time (PBT) of the higher initial investment cost, equal to 3.5 years, while the lighting system with FL allows a PBT of 1.7 years (see Figure 2).

In Figure 3, for an immediate comparison of the obtained results, C_T values reached at twentieth year are reported for different scenarios, both in the case of realization of the lighting system by own funds and in the case of bank financing.

From the Figure 3 it is possible to notice that the lighting system with MH, in all the analyzed cases and for all the considered scenarios, has the highest values of C_T and therefore a low economic sustainability. More difficult is the comparison between the lighting systems with LED and FL. Despite the clear differences in energy consumptions (see Table 5), the C_T values, reached at twentieth year, of these two lighting systems does not present, for all the scenarios, economical differences with significant relevance, because the lighting system with LED has the lower operating and maintenance costs, but also an higher initial investment cost.

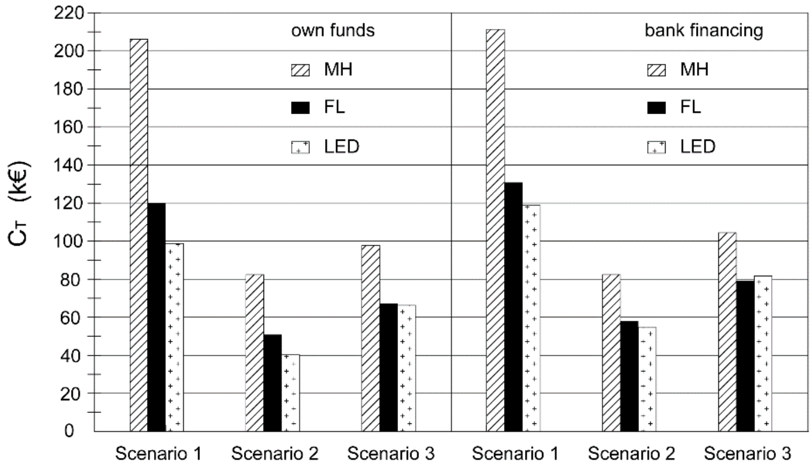

Figure 3. Comparison between the C_T values, reached at twentieth year.

It is important to point out that the greater difference between the values of C_T for lighting systems with MH and with LED is reached in the Scenario 1, which provides for the maximum use of the lighting systems. Obviously, increasing the exploitation of the artificial lighting (in terms of the product between the number of luminaires switched-on and the usage time), the lower operating and maintenance costs have a more significant influence on the value of C_T. Higher is the use of the sports hall and more attractive is the use of a lighting system with LED.

4.2. Economic Analysis of the Refurbishment of the Lighting System in an Existing Sports Hall

In this section, the refurbishment of the lighting system in an existing sports hall is analyzed. Therefore, in addition to the initial investment, the operating and the maintenance costs, the benefits that can be achieved through the refurbishment of the system are taken into consideration from the economic point of view. The expected benefits were assessed in terms economic benefit for the electrical energy saving (B_o) during the analyzed period and for the different maintenance associated with the different type of lamps (B_m). For each evaluation, there are both the incoming and outgoing cash flows and it is possible to calculate the payback time (PBT) and the net present value (NPV) [38]. The intervention of refurbishment is sustainable when NPV has positive values during the analyzed period. The following were considered: refurbishment of MH with LED (MH-LED), refurbishment of FL with LED (FL-LED), refurbishment of MH with FL (MH-FL).

The evaluations are carried out on the lighting systems able to meet the minimum lighting requirements fixed by the technical standards (see Table 1). The economic analysis has carried out considering the 6 operating scenarios (see Section 4, Table 4) and a reference period equal to 20 years. Table 6 shows the results obtained for the considered economic parameters for each scenario.

In Figure 4, the trend of NPV in function of the time is shown, in the case of the refurbishment of MH with LED, realized with an investment by own funds. The economic benefit, linked to the refurbishment, is higher as much as the value of NPV is higher. The time for which NPV = 0 corresponds to the PBT. In the specific case, it is possible to note that the PBT varies from a minimum of 6 years (scenario 1) to a maximum of 16.5 years (scenario 6). The refurbishment of MH with LED is always profitable for each analyzed scenario, because the NPV value always assumes a positive value at twentieth year.

Table 6. Calculation results: evaluated technical and economical parameters in function of the Scenario for different luminaires.

Scenario	Luminaires	I_0 (€)	C_o (€/year)	C_m *	$C_{m,n}$ (€/year)	B_o (€/year)	B_m **
1	MH-LED	36,892	2911	3689	264	6132	3757
	FL-LED	36,892	2911	3689	264	4494	3240
	MH-FL	22,164	4494	3240	540	6132	3757
2	MH-LED	15,811	1248	1581	113	2515	1503
	FL-LED	15,811	1248	1581	113	1997	1296
	MH-FL	8865	1997	1296	216	2515	1503
3	MH-LED	26,352	1335	2635	188	2656	1503
	FL-LED	26,352	1335	2635	188	2134	1296
	MH-FL	15,515	2134	1296	216	2656	1503
4	MH-LED	36,892	2169	3689	264	4149	2630
	FL-LED	36,892	2169	3689	264	3483	2268
	MH-FL	22,164	3483	2268	378	4149	2630
5	MH-LED	36,892	1418	3689	264	2877	2630
	FL-LED	36,892	1418	3689	264	2247	1296
	MH-FL	22,164	2247	1296	216	2877	2630
6	MH-LED	36,892	1360	3689	264	2733	1503
	FL-LED	36,892	1360	3689	264	2174	1296
	MH-FL	22,164	2174	1296	216	2733	1503

* MH-LED: €/10 year; FL-LED: €/10 years; MH-FL: €/6 year; ** MH-LED: €/year; FL-LED: €/6 years; MH-FL: €/year.

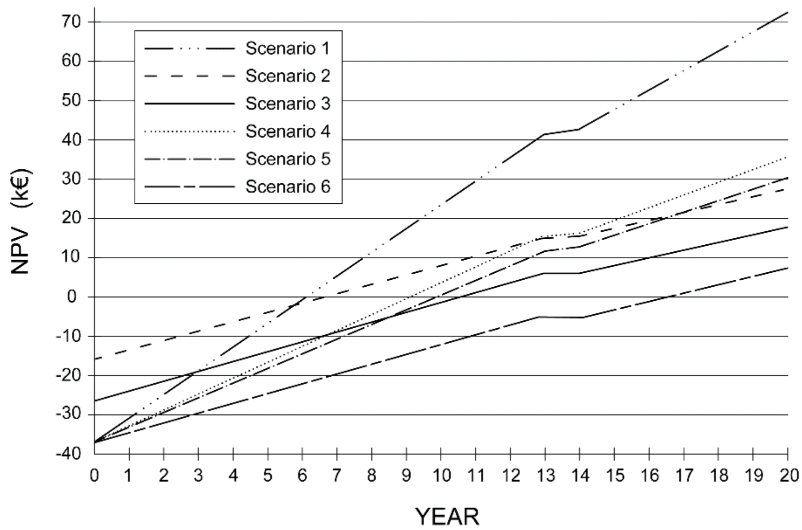

Figure 4. Evaluation of MH Floodlights replacement with LED Floodlights: trends of NPV in function of the time (investment by own founds, r = 2%).

In Figure 5, for in an immediate comparison of the obtained results, NPV values reached at twentieth year are reported for the different scenarios. In Figure 5, it can be observed that the replacement of MH with LED can always be economically viable. The maximum benefit is achieved for the scenario 1, when the sports hall and the lighting system are exploited intensively (see Section 4). For this scenario the reduced installed power of the LED, combined with their long life time, allows a significant reduction of the operating and maintenance costs, permitting to recover the initial investment cost in a short time and ensuring high benefits in economic terms (see also Figure 4, scenario 1). In contrast, the replacement of FL with LED does not reach, for any scenario, positive NPV values, therefore it is not a recommended solution from an economic point of view. If a discount rate of 4% (instead 2%) is considered, the same trends are obtained.

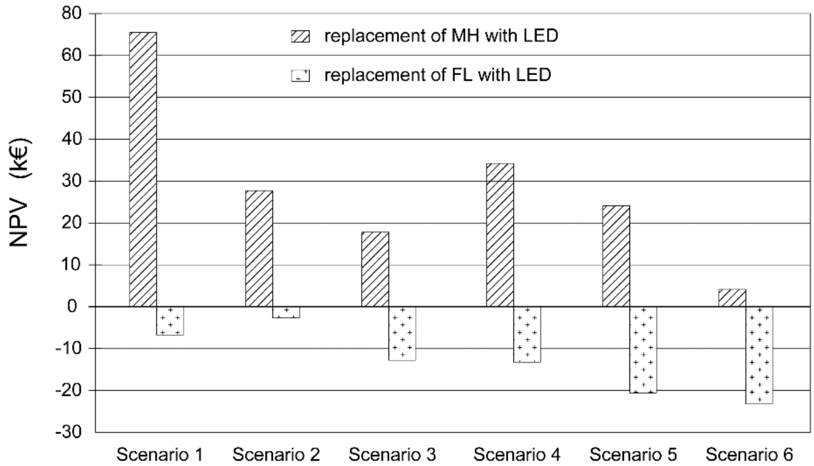

Figure 5. NPV values for MH floodlights and FL luminaires replacement with LED floodlight (investment by own founds, r = 2%).

In Figure 6, NPV values reached in the twentieth year are reported for the replacement of MH floodlights with LED floodlights and with FL luminaires. From the observation of the Figure 6, it can be noticed that the replacement of MH floodlights with LED floodlights, despite a sharp drop in energy consumption, shows situations (see Scenario 6) for which NPV slightly exceeds the null value. The replacement of MH floodlights with FL luminaires, which are characterized by positive values of NPV for all the analyzed scenarios, shows NPV values higher than those obtained for the refurbishment with LED floodlights.

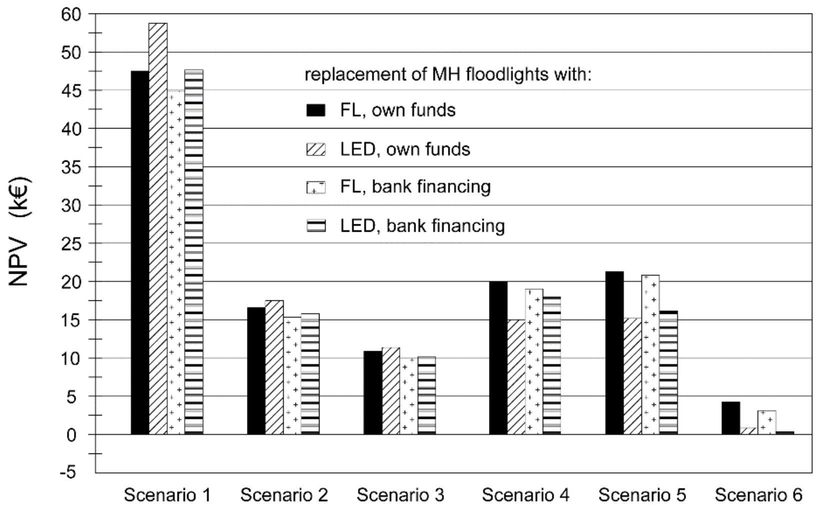

Figure 6. NPV values obtained for different MH floodlights replacement.

5. Conclusive Remarks

The recent European directives on energy efficiency and the resulting national regulations are leading to a gradual reduction of global energy consumption in buildings. The energy consumption for lighting is becoming increasingly important, especially in sports facilities. In recent years, the trend is to replace the traditional lighting luminaires with LED, which have a constant evolution of lighting features.

In this study, the authors analyze, from the techno-economic standpoint, different lighting solutions for the realization of new lighting systems and for the refurbishment of existing lighting systems in sports facilities, in order to guide the design choices. Different energy and economic analysis were carried out, considering the initial investments, the operating costs, the maintenance costs and the primary energy consumptions.

By techno-economic evaluations could be observed that the use of LED floodlights allows an immediate reduction of the primary energy consumptions for lighting.

In the case of the realization of the lighting system in a sports hall of new construction, the use of LED floodlights allows percentage reductions of the primary energy consumption till to 52% and to 32% if compared respectively to the use of MH floodlights and FL luminaires. The use of LED floodlights usually requires a smaller number of luminaires and it is characterized by limited maintenance cost compared to the other solutions, but it is characterized also by high investment cost, which involve reasonable payback times only when the sports facility is used intensively and for competitions of high level. Indeed, increasing the exploitation of the artificial lighting (in terms of the product between the number of luminaires switched-on and the usage time), the lower operating and maintenance costs of the LED have a more significant influence on the total management cost.

In the case of refurbishment of the lighting system in an existing sports hall, the replacement of MH floodlights with LED floodlights, despite a sharp drop in energy consumption, shows situations for which the net present value (NPV) slightly exceeds the null value. The replacement of MH floodlights with FL luminaires, which is characterized by positive values of NPV for all the analyzed scenarios, shows NPV values higher than those obtained for the refurbishment with LED floodlights.

In any case, the choice of the light sources and of the luminaires should always be preceded by detailed lighting evaluations (i.e., illuminance levels, glare phenomena, photobiological safety, health effects, etc.), in order to verify that all the lighting requirements, fixed by the technical standards, are satisfied.

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References

1. Prins, R.G.; Mohnen, S.M.; van Lenthe, F.J.; Brug, J.; Oenema, A. Are neighbourhood social capital and availability of sports facilities related to sports participation among Dutch adolescents? *Int. J. Behav. Nutr. Phys. Activ.* **2012**, *9*. [CrossRef] [PubMed]
2. Fried, G. *Managing Sport Facilities*, 3rd ed.; Human Kinetics: Champaign, IL, USA, 2015; pp. 1–440.
3. Kozma, G.; Pénzes, J.; Molnár, E. Spatial development of sports facilities in Hungarian cities of county rank. *Bull. Geogr. Socio-econ. Ser.* **2016**, *31*, 37–44.
4. Barghchi, M.; Bt Omar, D.; Aman, M.S.; Ling, H.L.O.; Marzukhi, M.A. Sports facilities development: A case study of Malaysia. In Proceedings of the ISBEIA—IEEE Symposium on Business, Engineering and Industrial Applications, Langkawi, Malaysia, 25–28 September 2011; pp. 426–430.
5. Rafossa, K.; Troelsenb, J. Sports facilities for all? The financing, distribution and use of sports facilities in Scandinavian countries. *Sport Soc. Cult. Commer. Media Politics* **2010**, *13*, 643–656. [CrossRef]
6. Harger, K.; Humphreys, B.R.; Ross, A. Do New Sports Facilities Attract New Businesses? *J. Sports Econ.* **2016**, *17*, 483–500. [CrossRef]
7. ISTAT; CONI; ICS. *Census of Sports Facilities in 1989*; ISTAT: Rome, Italy, 1991.
8. National Council for Economy and Labour. *The Situation of Sports Facilities in Italy to 2003*; National Council for Economy and Labour: Rome, Italy, 2005.
9. Fantozzi, F.; Leccese, F.; Salvadori, G.; Rocca, M.; Capranelli, I. Opportunities for Energy Savings with Interventions on the Lighting Systems of Historical Buildings (The Case of "Palazzo Medici" in Pisa, Italy). In Proceedings of the 17th IEEE International Conference on Environment and Electrical Engineering, Florence, Italy, 6–8 June 2016; pp. 1076–1081.
10. Artuso, P.; Santangeli, A. Energy solutions for sports facilities. *Intern. J. Hydrog. Energy* **2008**, *33*, 3182–3187. [CrossRef]

11. El-Kadi, A.E.-W.M.A.; Fanny, M.A. Architectural designs and thermal performances of school sports-hall. *Appl. Energy* **2003**, *76*, 289–303. [CrossRef]
12. Trianti-Stourna, E.; Spyropoulou, K.; Theofylaktos, C.; Droutsa, K.; Balaras, C.A.; Santamouris, M.; Asimakopoulos, D.N.; Lazaropoulou, G.; Papanikolaou, N. Energy conservation strategies for sports centers: Part A. Sports Hall. *Energy Build.* **1998**, *27*, 109–122. [CrossRef]
13. Trianti-Stourna, E.; Spyropoulou, K.; Theofylaktos, C.; Droutsa, K.; Balaras, C.A.; Santamouris, M.; Asimakopoulos, D.N.; Lazaropoulou, G.; Papanikolaou, N. Energy conservation strategies for sports centers: Part B. Swimming Pools. *Energy Build.* **1998**, *27*, 123–135. [CrossRef]
14. Beuskera, E.; Stoya, C.; Pollalisb, S.N. Estimation model and benchmarks for heating energy consumption of schools and sport facilities in Germany. *Build. Environ.* **2012**, *49*, 324–335. [CrossRef]
15. Boussabaine, A.H. A comparative approach for modelling the cost of energy in sport facilities. *Facilities* **2001**, *19*, 194–203. [CrossRef]
16. Asdrubali, F.; Baldinelli, G.; Bianchi, F.; Sambuco, S. A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings. *Build. Environ.* **2015**, *86*, 98–108. [CrossRef]
17. European Committee for Standardization. *EN 12193, Light and Lighting—Sports Lighting*; European Committee for Standardization: Brussels, Belgium, 2007.
18. Italian National Olympic Committee. *CONI Regulations for Sports Facilities*; Italian National Olympic Committee: Rome, Italy, 2008; Available online: http://www.coni.it/it/impianti/norme-e-regolamenti.html (accessed on 15 March 2016). (In Italian)
19. Sports Facilities. Light solutions that inspire. Available online: http://www.osram.com/sport (accessed on 18 May 2016).
20. Khan, N.; Abas, N. Comparative study of energy saving light sources. *Renew. Sustain. Energy Rev.* **2011**, *15*, 296–309. [CrossRef]
21. Aman, M.M.; Jasmona, G.B.; Mokhlisa, H.; Bakarb, A.H.A. Analysis of the performance of domestic lighting lamps. *Energy Policy* **2013**, *52*, 482–500. [CrossRef]
22. Gana, C.K.; Sapara, A.F.; Muna, Y.C.; Chongb, K.E. Techno-Economic Analysis of LED Lighting: A Case Study in UTeM's Faculty Building. *Procedia Eng.* **2013**, *53*, 208–216. [CrossRef]
23. Leccese, F.; Vandelanotte, V.; Salvadori, G.; Rocca, M. Blue light hazard and risk group classification of 8 W LED tubes, replacing fluorescent tubes, through optical radiation measurements. *Sustainability* **2015**, *7*, 13454–13468. [CrossRef]
24. Bisegna, F.; Burattini, C.; Li Rosi, O.; Blaso, L.; Fumagalli, S. Non visual effects of light: An overview and an Italian experience. *Energy Procedia* **2015**, *78*, 723–728.
25. Ferlazzo, F.; Piccardi, L.; Burattini, C.; Barbalace, M.; Giannini, A.M.; Bisegna, F. Effects of new light sources on task switching and mental rotation performance. *J. Environ. Psychol.* **2014**, *39*, 92–100. [CrossRef]
26. Leccese, F.; Salvadori, G.; Casini, M.; Bertozzi, M. Lighting of indoor work places: Risk assessment procedure. *WIT Trans. Inform. Commun. Technol.* **2012**, *44*, 89–101.
27. Leccese, F.; Corucci, T.; Salvadori, G.; Rocca, M.; Vandelanotte, V. Evaluation of optical radiation emissions by a measurement campaign on LED sources for general lighting. In Proceedings of the 16 IEEE International Conference on Environment and Electrical Engineering, Rome, Italy, 10–13 June 2015; pp. 689–694.
28. Berlov, D.N.; Baranova, T.I.; Bisegna, F.; Pavlova, L.P.; Aladov, A.V.; Zakgeim, A.L.; Mizerov, M.N.; Chiligina, Y.A. Research perspectives of the influence of lighting modes on changes of human functional state by means of 'smart lighting'. In Proceedings of the 16 IEEE International Conference on Environment and Electrical Engineering, Rome, Italy, 10–13 June 2015; pp. 1426–1430.
29. Leccese, F.; Salvadori, G.; Casini, M.; Bertozzi, M. Analysis and measurements of artificial optical radiation (AOR) emitted by lighting sources found in offices. *Sustainability* **2014**, *6*, 5941–5954. [CrossRef]
30. Bonner, R.; O'Hagan, J.B.; Khazova, M. Assessment of personal exposures to optical radiation in large entertainment venues. *Radiat. Prot. Dosim.* **2012**, *149*, 225–237. [CrossRef] [PubMed]
31. Italian Volleyball Federation. *Game Rules for 2015–2016*; Italian Volleyball Federation: Rome, Italy, 2014; Available online: http://www.federvolley.it/CMS/upload/Regole_di_Gioco_2015_16(3).pdf (accessed on 15 March 2016). (In Italian)
32. Italian Basketball Federation. *Sports Facilities Regulation Where Basketball Is Practiced*; Italian Basketball Federation: Rome, Italy, 2015; Available online: http://www.fip.it/public/statuto/regolamento%20impianti%20sportivi%20ultimo%202015.pdf (accessed on 15 March 2016). (In Italian)

33. Italian Tennis Federation. *Rules of Tennis*; Italian Tennis Federation: Rome, Italy, 2016; Available online: http://www.federtennis.it/PDF/REGOLE%20DI%20TENNIS.pdf (accessed on 15 March 2016). (In Italian)
34. International Commission on illumination (CIE). *CIE 97, Technical Report—Guide on the Maintenance of Indoor Electric Lighting Systems*; CIE: Vienna, Austria, 2005.
35. Il Sole 24 Ore, Observatory rate. Available online: http://mutuionline.24oreborsaonline.ilsole24ore.com (accessed on 15 March 2016).
36. Italian Regulation Authority for Electricity Gas and Water. Economic Conditions for Customers in the Protected Market. Available online: http://www.autorita.energia.it/it/dati/condec.htm (accessed on 15 March 2016). (In Italian).
37. US Department of Energy—Office of energy efficiency and renewable energy. *PNNL-SA-97534, Building Technologies Program—Solid State Lighting Technology Fact Sheet—Lifetime and Reliability*; US Department of Energy: Washington, DC, USA, 2013. Available online: ssl.energy.gov (accessed on 15 June 2016).
38. Dall'O', G. *Operating Instructions for the Energy and Environmental Audits of Buildings*, 1st ed.; Edizioni Ambiente: Milano, Italy, 2011; pp. 299–313.
39. European Committee for Standardization. *EN 15193, Energy Performance of Buildings—Energy Requirements for Lighting*; European Committee for Standardization: Brussels, Belgium, 2007.
40. Italian Regulatory Authority for Electricity Gas and Water. Resolution EEN 3/08 Official Gazette of the Italian Republic. No. 100 of 29 April 2008. Available online: http://www.autorita.energia.it/it/docs/08/003-08een.htm (accessed on 15 March 2016). (In Italian).
41. Ministry of Economic Development. *Circular Energy Manager 14 December 2014 rev.*; Ministry of Economic Development: Rome, Italy, 2014.