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ABSTRACT

Energy efficiency can be an interesting field for alternative investments. The main question is: Are these investments worthwhile? This article presents a new approach to evaluate the risks and achievable returns of energy efficiency investments via the example of lighting devices: To the author's knowledge, cost equivalents have not been used to compare alternative solutions in the field of energy efficiency investments. The selection of optimal technology always depends on the intensity of use and on the expected rate of return. The primacy of compact fluorescent tubes is indisputable from a financial perspective. With the LED and Compact fluorescent lamps compared to incandescent light bulbs, depending on the daily use, an annual average 24-74% cost saving can be achieved. In case of spot lighting, LED light sources have been better than those observed in the case of illumination of a particular area, and in almost each tested case they held second place with only a minor lag in comparison with the compact fluorescent tubes.

KEYWORDS

Energy Efficiency, Green Investment, Cost Equivalent, NPV, LED

I. INTRODUCTION

Alternative investments are receiving more interest, as the financial and economic crisis has destroyed long-living investment fundamentals, and market participants are on the search for less risky though profitable investment opportunities outside equity markets. One interesting field is the opportunity in energy efficiency investments. While environmentalists, environmental economists and supporters of sustainable development have long disputed that these investments are inevitable, their spread have not yet reached the critical mass. There is a long debate in the economic literature about whether these investments really do have significant positive returns and net present value, and if so, why are not they more widespread. Supposed obstacles against these investments include a lack of required information, and lack of ability to correctly assess them. In the analysis via the example of lighting devices a new approach (the use of cost equivalents) is proposed as a means to evaluate the risks and achievable returns of energy efficiency investments. The main question is: Are these investments worthwhile? One should not only focus on the achievable returns, but also on the arising risks, which are not always fully covered by the producer's warranty.

The article is structured as follows:

1. Summary of Literature
2. Analysis of energy efficiency investments via the example of lighting devices
3. Presentation of individual light sources
4. Comparison of individual light sources
5. Comparison of individual light sources in case of spot lighting
6. Summary

II. SUMMARY OF LITERATURE

In the summary of literature articles are presented which focus on the returns/net present value of energy efficiency investments and the anticipated obstacles that hinder their realization.

Brounen et al (2012) states that about one-fifth of global energy consumption is caused by residential dwellings via heating, cooling and lighting. Energy efficiency in this sector is receiving more interest from scientists and policy makers addressing fossil fuel depletion and sustainable energy supply worldwide. In their article, the authors have examined Dutch households' awareness and behaviour in connection with their residential energy expenditures.

Results are surprising, as of the 1721 respondents just 56 percent in case of gas, and 47 percent in case of electricity were aware of their monthly energy bills. The authors called the ability to evaluate energy efficiency investments correctly - where one has to make a trade-off between long-term savings from energy efficiency and the upfront investment required to reach this development - "energy literacy". They found that this factor is low among Dutch households, since only 60 percent of the sample was able to evaluate investment decisions in energy efficiency correctly. This was tested via a question, where respondents had to choose between two heating systems with both having a 15 years lifespan: one which has a cheap purchase price with higher energy consumption and thus higher operating costs, and the other which is more expensive to purchase, but has lower energy consumption and lower operating costs. The data indicates that 40% of the consumers are unable to make rational decisions even if they are well informed.

Alcott and Greenstone (2011) make a summary of the existing literature in the field of energy efficiency, and line up several articles proving that there are various occasions where energy efficiency investments have significantly positive net present values (McKinsey & Co. (2009), Brown et al. (2001)), ergo the gains of these investments are greater than the required costs, even when including the time value of money in the calculations. In contrast, Alcott and Greenstone (2011) also summon articles which are using experimental observations suggesting that there are unobserved costs and risks which reduce the possible gains through energy efficiency investments and thus in several cases remarkably lower the ex ante calculated returns, and in some occasions even make the net present value negative ex post (Anderson and Newell (2004), Blasnik (2010), Schweitzer (2005)). Some of the named obstacles facing the otherwise profitable energy efficiency investments were the following, according to Anderson and Newell's analysis based on the energy audits for small- and medium sized enterprises provided by the U.S. Department of Energy: "lack of staff for analysis/implementation,", "risk of inconvenience to personnel", "suspected risk of problem with equipment". Metcalf and Hassett (1999) estimated the distribution of returns from attic insulation in the U.S. population using nationally representative panel data. The estimated median and mean returns on investment were approximately 10 percent, and one-quarter of households had returns greater than 13.5 percent. Alcott and Greenstone made the conclusion that the unobserved costs, and the credibility of various analyses make it difficult to assess the net returns of the energy efficiency investments, they believe there are investment inefficiencies, but their magnitude is relatively small from policy makers' viewpoint. They also highlight the heterogeneity of investment inefficiencies across the population, which requires targeted policies.

Sandberg and Söderstrom (2003) investigated the required decision supports for energy efficiency investments through in-depth interviews with company representatives. Access to correct information, better follow-up activities, and transparent, understandable calculations are considered to be important.

Hausman (1979) estimated a discrete choice model using 65 observations of consumer choices between air conditioner models, which vary in upfront cost and energy efficiency rating. The author found that the real implied discount rate is around 20 percent and it varies inversely with income.

Brounen and Kok (2011) represent that the asymmetric information of the consumers can be reduced by providing the essential data on energy efficiency and consumption for example via energy labels of dwellings.

III. ANALYSIS OF ENERGY EFFICIENCY INVESTMENTS VIA THE EXAMPLE OF LIGHTING DEVICES

While asymmetric information, and the distortions derived from it can be handled via regulation and energy labels, the information assessment problem is another topic. In my analysis via the example of lighting devices I suggest a basic approach to evaluating the risks and achievable returns of energy efficiency investments.

In residential dwellings, offices, factories, and common buildings the most widely realizable green investment from the smallest investment amount is the change of the lighting devices to a more efficient technology.

One of the most spread light source is the E27 screwed socket, 60 Watt incandescent light bulb. To construct the financial analysis as a first step all costs appearing during the use of the incandescent light bulb have been taken into account. The next step is the same calculations for its more energy efficient alternatives. The subjects of the analysis beside the incandescent light bulbs, were its equivalents, which provided comparably same amount of light: the halogen light bulb, the compact fluorescent light and the LED light source.

In the analysis, prices form the Hungarian domestic market have been used and converted to USD with an exchange rate of $220 USD/HUF. To calculate the costs of the operation a gross 47 HUF ($0.2136 USD) per kWh residential electricity price has been used for the entire lifecycle of the equipment. We face a 30-year lifespan for the LED light sources in the case of an average daily usage of 1-hour. For quite a long time the price of the electricity has been uncertain. The trends until today make price elevation more probable then price fall. The assumption of constant electrical prices seems to be the best estimation due to the huge uncertainty. Although it has to be mentioned, that in the case of price elevation the cost benefits of the energy saving light sources will rise compared to the less energy efficient ones. Expenses have been calculated on a monthly basis taking into consideration all the arising hours of monthly operations, the electricity prices, as well as the upfront costs. In case of procurement expenses, the assumption has been made that the prices of the equipment will not change in the future and that the replacement of the light sources are made at the end of that month in which the operation hours do not exceed the theoretical lifespan.

The alternative light sources have different upfront and operation costs, and highly different lifetimes. To accurately compare the alternative light sources' total cost over their lifecycle, one should compute the yearly cost-equivalents. The simplest method to compute this value is to calculate the present value of all accruing costs for the lifespan of the light source (1) and then to divide it with the appropriate annuity-factor (2). With this operation we distribute the present value of total costs to the particular years so that every year has the same amount. Ergo the yearly cost-equivalents (3) will give the annual yearly expenses on an average in present value for the analyzed devices. This way the expenses of the alternative technologies can be compared to each other properly, and cost savings can be determined relative to the incandescent light bulb which has been considered the starting point. It is important to note, that in reality the costs are not divided evenly among the years. The bigger the procurement costs are, the bigger savings of electricity expenses are needed via energy efficiency during the lifespan of the light equipment, to achieve the initial extra investment's pay-off while taking money's time value into account.

$$\text{(1) Present Value of Lightsource's Operation} = \frac{\text{Cost}_t}{(1+r)^t}$$

$$\text{(2) Annuity Factor}_t = \frac{1}{r} \cdot \left(1 - \frac{1}{(1+r)^t}\right)$$

$$\text{(3) Yearly cost equialent of Lightsource} = \frac{\text{PV of Lightsource's Operation}}{\text{Annuity Factor}_t}$$

In the first table a fragment of present value cost calculations can be seen beside a daily average 1 hour of operation and 5% alternative rate in the case of an incandescent light bulb and a halogen light bulb. In the Sum of operation hours column, the month in which the light source reaches the end of its lifespan with monthly 30 hour usage can be observed. This shows the month when the equipment needs to be replaced. In this example the incandescent light bulb's replacement is necessary in the 33rd month. On the other hand the halogen light bulb will only end its theoretical operation in the 66th month, which though is not shown in the table due to lack of space. In the 6th and 7th column the present value of the monthly costs can be seen. In the next two columns, are the present value of total costs required for the determination of the discounted payback time. In the case of the halogen light bulb the extra procurement investment's discounted payback time is 18 month. The present value of total costs will be divided with the appropriate annuity-factor to calculate the cost-equivalent (*see table 1*).

IV. PRESENTATION OF INDIVIDUAL LIGHT SOURCES

The 60-Watt incandescent light bulb will be the benchmark and it will be compared with alternative technology light sources which provide as identical amount of light as possible.

Incandescent light bulb

The E27-socket, 60-Watt incandescent light bulb, in accordance with its name, uses 60 Watts of electric power per hour. Light is produced when the electric current passes through and a Wolfram fibre glows, a process by which the great majority of the electricity used is converted into heat, and only 5 - 10% into light. The 60-Watt incandescent light bulb features 630-710 lumen light output[1], thus the utilization of light is 10-12 lumen/Watt.

Figure 1: E27-socket, 60-Watt incandescent light bulb[2]

1 http://www.argep.hu/trend/60WI/60W-izzo.html

2 http://commons.wikimedia.org/wiki/File:Gluehlampe_01_KMJ.jpg

Sum of operation hours	Monthly operation hours	Month	Incandescent 60W costs	Halogen 42W costs	Edison 60W present value of monthly costs	Halogen 42W present value of monthly costs	Incandescent 60W present value of total cost	Halogen 42W value of total cost
		0	0.32	2.27	0.32	2.27	0.32	2.27
30	30	1	0.38	0.27	0.38	0.27	0.70	2.54
60	30	2	0.38	0.27	0.38	0.27	1.08	2.81
90	30	3	0.38	0.27	0.38	0.27	1.46	3.07
120	30	4	0.38	0.27	0.38	0.26	1.84	3.34
150	30	5	0.38	0.27	0.38	0.26	2.22	3.60
180	30	6	0.38	0.27	0.38	0.26	2.59	3.87
210	30	7	0.38	0.27	0.37	0.26	2.97	4.13
240	30	8	0.38	0.27	0.37	0.26	3.34	4.39
270	30	9	0.38	0.27	0.37	0.26	3.71	4.65
300	30	10	0.38	0.27	0.37	0.26	4.08	4.91
330	30	11	0.38	0.27	0.37	0.26	4.45	5.16
360	30	12	0.38	0.27	0.37	0.26	4.81	5.42
390	30	13	0.38	0.27	0.36	0.26	5.18	5.67
420	30	14	0.38	0.27	0.36	0.25	5.54	5.93
450	30	15	0.38	0.27	0.36	0.25	5.90	6.18
480	30	16	0.38	0.27	0.36	0.25	6.26	6.43
510	30	17	0.38	0.27	0.36	0.25	6.62	6.69
540	30	18	0.38	0.27	0.36	0.25	6.98	6.94
570	30	19	0.38	0.27	0.36	0.25	7.34	7.18
600	30	20	0.38	0.27	0.35	0.25	7.69	7.43
630	30	21	0.38	0.27	0.35	0.25	8.04	7.68
660	30	22	0.38	0.27	0.35	0.25	8.39	7.93
690	30	23	0.38	0.27	0.35	0.25	8.74	8.17
720	30	24	0.38	0.27	0.35	0.24	9.09	8.42
750	30	25	0.38	0.27	0.35	0.24	9.44	8.66
780	30	26	0.38	0.27	0.35	0.24	9.79	8.90
810	30	27	0.38	0.27	0.34	0.24	10.13	9.14
840	30	28	0.38	0.27	0.34	0.24	10.47	9.36
870	30	29	0.38	0.27	0.34	0.24	10.82	9.62
900	30	30	0.38	0.27	0.34	0.24	11.16	9.86
930	30	31	0.38	0.27	0.34	0.24	11.50	10.10
960	30	32	0.38	0.27	0.34	0.24	11.83	10.33
990	30	33	0.70	0.27	0.61	0.24	12.45	10.57

Table 1: Comparing incandescent light bulb to Halogen light bulb for 1 hour operation on a daily average ($ USD)

A 60-Watt incandescent light bulb can be purchased for gross price $0.32 USD, and its life-span is 1,000 hours of operation. Calculating with gross power price of $0.2136 USD/kW and the 60-Watt consumption means a cost of $0.0128 USD per hour. Beside a daily 1-hour use and 7% of alternative rate of return, taking into consideration the procurement cost as well, the annual equivalent cost can be determined, which can be considered as the average annual cost of operation, or, in case of financing via lease, the annual lease fee. In this case the operation of the bulb costs an average of $4.89 USD per year.

Halogen bulb

The halogen bulb can be considered as an improvement of the incandescent bulb. In this type of bulb there is a small quantity of halogen in the surrounding medium of the filament, and as a result it induces a halogen circuit between the Wolfram fibre and the halogen allowing the filament to operate more effectively at higher temperatures. In comparison with the incandescent bulb a 30% energy saving can be achieved. The 42-Watt, E27-socket halogen bulb lumen features 550-630 lumen light output[3], thus the utilization of light is 13-15 lumen/Watt.

Figure 2: E27-socket 42-Watt halogen bulb[4]

A 42-Watt halogen bulb can be purchased for gross price $2.27 USD, and its life-span is 2,000 hours of operation. The 42-Watt consumption means a cost of $0.00896 USD per hour for the user. Beside a daily 1-hour use and 7% of alternative rate of return, taking into consideration the upfront cost as well, the average annual cost of operation is $3.84 USD per year.

Compact fluorescent

A compact fluorescent tube filled with low-pressure gas can be screwed into an E27 lamp socket, in which, as a result of the electric current, gas begins to glow. Usually it is filled with mercury vapour that emits UV light and which by generating the light dust on the fluorescent wall produces visible light. In comparison with the incandescent light bulb an 80-percent energy saving can be achieved. The 11-Watt, E27-socket compact fluorescent tube features

3 http://www.landlite.hu/content.php?kategoria=fenyforras&csoport=halogenizzo&alcsoport=ECOHAL
http://bolthely.hu/tungsram/id/01105____Normal_halogen_izzo_HaloGLS_230V__42W_E27__60W_

4 http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/halogen-lampak/halozati-feszueltsegue-halogenek-reflektor-nelkuel/ecoclassic-a-shape/37652/cat/

600-700 lumen light output[5], thus the utilization of light is 55-63 lumen/Watt.

Figure 3: E27-socket 11-Watt compact fluorescent tube[6]

An 11-Watt good quality compact fluorescent tube, whose life-span is therefore 10,000 hours of operation and has high light output, can be purchased for gross price $9.09 USD. The 11-Watt consumption means a cost of $0.00235 USD per hours for the user. Beside a daily 1-hour use and 7% of alternative rate of return, taking into consideration the procurement cost as well, the average annual cost of operation is $1.62 USD per year.

LED light source

The light emitting diode is made of semiconductor material whose electrons, as a result of the electric current, emit light. Due to its technical features one single LED diode can only emit light in a maximum of 120º angle[7], contrary to the otherwise observed 360º-radiation angles of any other light sources. Because of this characteristic LED light sources can primarily be used competitively as point or spot lights. In spite of the above feature LED lighting manufacturers have made significant developments by building more light emitting diodes and placing miniature optical mirrors into a "bulb" in order to gain equal alternative lighting technique in consideration of both the light output and the radiation angle. A 12-Watt, E27 socket LED light source has a radiation angle of 300º, which features an 806 lumen light output[8] and the utilization of light is 67 lumen/Watt.

Figure 4: E27-socket 12-Watt LED light source[9]

For a 12-Watt LED-lamp manufacturers provide 25,000 hours of operation and a maximum 3-year warranty[10]. LED light sources feature a very long

5 http://www.argep.hu/trend/KOMP/Kompakt-fenycsoe-E27-11w.html

6 http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/energiatakarekos-lampak/specialis-energiatakarekos-fenyforrasok/tornado-performance/37161/cat/#filterState=FG_LP_WATTAGE|range%3D5%2C13%3BFG_LP_CAPBASE|E27%3Dtrue%3BFG_LP_COLOR_TEMP|range%3D2700%2C6500

7 http://www.anrodiszlec.hu/article_info.php/articles_id/70

8 http://www.argep.hu/trend/PHIL/Philips-e27-led-12w.html

9 http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/led-vilagitasi-rendszerek/led-fenyforrasok/master-led-lampak/929000182402_eu

10 http://www.lighting.philips.com/main/connect/tools_literature/warranty-policy.wpd

time to remain operative since their components rarely fail to the extent that they could not continue to light up. Instead, as time goes by, the intensity of their brilliance reduces, so in case of LED light sources life-span does not mark hours of operation during which the product is expected to remain operative, but it marks hours of operation where the brilliance falls to 70 % of the initial value[11]. In case of this lamp manufacturers provide 25,000 hours of operation as the time of the 70% reduction in light output. Then light output is 806*0,7= 564 lumen, which is 10% less than the 60-Watt incandescent bulb's light output, yet further continuous operation can be assumed, however a slow deterioration in performance occurs.

Calculating conservatively the assumption will be used that a LED lamp can operate over 18,000 hours of operation without error and then the value of light output is 806*(1-18000/25000*0.3)=632 lumen, which is still comparable with the alternative light sources. The analysed LED-lamp can be purchased for gross price $64.77 USD. The 12-Watt consumption means a cost of $0.00256 USD per hour for the user. Beside a daily 1-hour use and 7% of alternative rate of return, taking into consideration the initial cost as well, the average annual cost of operation is $5.65 USD per year.

V. COMPARISON OF INDIVIDUAL LIGHT SOURCES

To the question "Which is the cheapest source of light?" an unambiguous and correct answer can be given only in case it is clarified, that, calculating on a daily basis, how many hours the light sources expectedly will be used as well as the extent of the alternative rate of return shall also be taken into consideration. The applied present value and rate of return calculation, for simplicity, has been calculated with horizontal yield curve. I considered as base case the 7% of alternative rate of return; however, I carried out calculations for 5%, 6%, 8% and 9%, so that the magnitude of the effect of the expected rate of return could be illustrated. In Table 2 cases depending on daily use of hours have been analysed separately and in a relevant sub-case the lowest operating cost of a given light source has been marked in green, in blue is the next best choice shown, in white is the third and in orange is the fourth case, thus the most expensive choice of a given case.

For a daily 1-hour use the best choice is a compact fluorescent tube and the second best one is halogen bulb. The high upfront cost can explain why LED light source "returns" its price only beside an expected 5% of rate of return, and only then is able to outpace the incandescent light bulb and to come up to the podium as the third one. In case of higher interest rates it will be only the fourth one. It can be said that the higher the expected rate of return is the less worth is investing in expensive light sources.

For a daily 2-hour use the best choice is still a compact fluorescent tube. Then, supposing that the alternative rate of return is not higher than 7%, LED lamp comes up to the second place outpacing halogen bulb. However, if the expected rate of return is higher than 7%, halogen bulb comes up to the second place while LED light will be only the third one. Incandescent light bulb, beside a daily 2-hour use, is no longer able to compensate higher operating costs with its lower initial cost, therefore on the examined rate of return levels it has become the last. From a daily 3-hour use to a daily 6-hour use, taking cost effectiveness sequence into consideration, a compact fluorescent tube is the best choice, which is followed by LED light source; then the third best choice is a halogen bulb while incandescent bulb is worse than the latter (*see table 2*).

11 http://www.4shared.com/office/WInj8G9n/Understanding_power_LED_lifeti.html

		Yearly cost equivalent ($ USD)			
Hours of operation	Alternative rate (r)	Incandescent light bulb	Halogen light bulb	Compact fluorescent	LED light source
Daily 1 hour	5%	4.85	3.78	1.48	4.49
	6%	4.87	3.81	1.55	5.06
	7%	4.89	3.84	1.62	5.65
	8%	4.91	3.87	1.70	6.25
	9%	4.94	3.90	1.78	6.87
Daily 2 hours	5%	9.68	7.50	2.66	6.48
	6%	9.73	7.55	2.72	6.96
	7%	9.77	7.60	2.79	7.46
	8%	9.81	7.64	2.86	7.98
	9%	9.86	7.69	2.94	8.52
Daily 3 hours	5%	14.52	11.23	4.16	8.65
	6%	14.58	11.29	4.23	9.10
	7%	14.65	11.35	4.31	9.56
	8%	14.72	11.41	4.39	10.04
	9%	14.78	11.47	4.47	10.53
Daily 4 hours	5%	19.36	14.95	5.05	10.87
	6%	19.44	15.03	5.12	11.30
	7%	19.53	15.11	5.19	11.75
	8%	19.62	15.19	5.27	12.21
	9%	19.70	15.26	5.34	12.68
Daily 5 hours	5%	24.19	18.67	6.26	13.11
	6%	24.30	18.77	6.33	13.54
	7%	24.41	18.86	6.41	13.98
	8%	24.52	18.96	6.49	14.43
	9%	24.62	19.05	6.57	14.89
Daily 6 hours	5%	29.38	24.90	7.46	15.36
	6%	29.51	25.02	7.54	15.79
	7%	29.64	25.13	7.62	16.23
	8%	29.77	25.24	7.71	16.68
	9%	29.90	25.35	7.79	17.14

Table 2: Average yearly cost equivalents of the light sources depending on the average daily operating hours and alternative rate

It can be concluded that together with the increase in the daily hours of operation the relative advantage of the longer lasting light sources also increases in comparison with the short life-span ones. For example, beside a 7% alternative rate of return a daily 3-hour operation of the incandescent bulb is at an annual average of $14.65 USD and then the LED light source is at an annual average of $9.56 USD, consequently incandescent light bulb is nearly 35% more expensive to operate. In case of a 6-hour daily operation the annual cost equivalent of the incandescent bulb is $29.64 USD, while LED's is $16.23 USD, thus the difference increases up to 45%. Similarly, with the increase in the daily hours of operation the difference between a LED light source and a compact fluorescent tube will reduce; and it shall also not be forgotten that a LED light source, after its operating time applied in the analysis, theoretically remains usable between 18,000 and 25,000 hours of operation and can be used instead of lower intensity bulbs.

In financial terms it can be said that money invested in technology with higher upfront cost will return only when it is used/illuminated relatively much. This, of course, does not mean to replace lighting with a more efficient one, then to use it as much as possible in order to regain our investment. One shall not forget that in fact no positive returns are obtained by investing in energy efficiency in the present, but we save ourselves from bigger negative rate of returns, thus from expenses in the future. But this claim is available only when in the new position our behaviour is not changed i.e. lighting is used the same way as it was used before the investment (rebound effect).

In Table 2 an answer is given to the question that which light source at what cost can be best operated, from the aspect of the daily hours of operation and alternative rate of return, thus which one should be chosen when taking cost effectiveness into consideration.

However, before investment decision is taken, the individual is not only interested in the average cost of operation but he also might be interested in the size of the initial investment, in the discounted payback period, in the energy-saving and expected life-span of the light source. Based on the above written information comparison was carried out with the help of Table 3.

LED lighting requires the highest investment being seven times more expensive than compact fluorescent tube costs, which fact can only partly be compensated by its longer life-span. Regarding the discounted payback period, independent of the expected rate of return and no matter how many hours of operation have been done, halogen bulb is always in the first place since the 30% energy-saving is achieved with a relatively low initial investment. Compact fluorescent tube is in the second place and LED light is the third due to the reasons mentioned above.

In Table 3 from the values of the cost equivalents beside the 7% rate of return and certain hours of operation, when incandescent light bulb is replaced with other technologies the average annual cost-saving can be calculated, which can be considered as the rate of return of technology changing. In case of a daily 1-hour of operation a 66.8% saving is obtained if incandescent bulb is converted to a compact fluorescent tube. In case of changing for a halogen-bulb the cost advantage is 21.5%, while the application of LED lighting is not recommended in this case justifying with the cost side because its operation cost is higher by an annual 15.4% than that of the incandescent bulb's.

In case of a daily 2-hour of operation the cost advantage of the compact fluorescent tube is 71.4%, the LED's 23.6% and the halogen bulb's is 22.3%. The sequence, in accordance with Table 1, does not change if the hours of operation remain between 3 and 6 hours per day, only the cost advantage ratio of energy-efficient and long-life light sources increases.

Hours of operation		Halogen light bulb	Compact fluoresent	Led light source
Daily 1 hour	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	1.50	2.58	NA
	Lifespan	5.56	27.78	33.33
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	1.05	3.27	-0.75
	Cost saving compared to incandescent light bulb percent (r=7%)	21.5%	66.8%	-15.4%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%
Daily 2 hours	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	0.75	1.25	12.67
	Lifespan	2.78	13.89	16.67
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	2.18	6.98	2.31
	Cost saving compared to incandescent light bulb percent (r=7%)	22.3%	71.4%	23.6%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%
Daily 3 hours	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	0.50	0.83	7.17
	Lifespan	1.85	9.26	11.11
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	3.30	11.73	5.09
	Cost saving compared to incandescent light bulb percent (r=7%)	22.51%	73.1%	34.7%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%
Daily 4 hours	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	0.42	0.67	5.08
	Lifespan	1.39	6.34	8.33
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	4.42	14.34	7.78
	Cost saving compared to incandescent light bulb percent (r=7%)	22.6%	73.4%	39.8%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%
Daily 5 hours	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	0.33	0.50	3.92
	Lifespan	1.11	5.56	6.67
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	5.55	18.00	10.43
	Cost saving compared to incandescent light bulb percent (r=7%)	22.7%	73.7%	42.7%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%
Daily 6 hours	Investment need in USD	2.27	9.09	64.77
	Discounted payback time in years (r=7%)	0.33	0.42	3.25
	Lifespan	0.93	4.63	5.56
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	4.52	22.02	13.41
	Cost saving compared to incandescent light bulb percent (r=7%)	15.2%	74.3%	45.2%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	80.0%

Table 3: Comparing the indicators of the different light sources relative to the incandescent light bulb

Although the risk of transition to another light source is elusive, since in case of new technologies we do not have enough experiences concerning failures, yet the discounted payback period is a good guidance. The halogen bulb with its 2,000-hour of operation exceeds the incandescent bulb's with 1,000-hour of operation, and its discounted payback period, beside a daily 1-hour use, is not more than 1.5 years, so the chance of circumvention of our extra investment due to a failure is negligible. In case of a compact fluorescent tube and LED lighting for the better quality products manufacturers provide a 3-year warranty

After reviewing the Table we can see that in case of a daily 1-hour of operation, which is considered as the least "safe" the discounted payback period of the compact fluorescent tube is 2.6 years, so the potential financial risk arising from failure is borne by either the manufacturer or the merchant instead of us. In case of LED lighting the 3-year warranty, in most cases, does not seem to be satisfactory in terms of secure return. In case of a 6-hour use the discounted payback period is 3.25 years, so if we do not want to bear any adverse financial implications of failures, investment into LED lighting should only be done when it is intended to be used over 6 hours per day. The manufacturer's warranty conditions shall also be taken into consideration when calculation is made. In case of the analysed LED lamp the manufacturer provides the 3-year warranty only if the annual hours of operation do not exceed an annual 4,000 hours, which means a daily 11-hour average use.

It is important to mention that the mercury in the compact fluorescent tubes cannot be specified as an environmental friendly solution, and at the end of its life compact fluorescent tubes become hazardous waste whose management is a serious challenge. Accordingly, in case the importance of environmental considerations is as much essential as financial interests for the investor, it might be worth rethinking that depending on the hours of operation whether LED lighting, on the second place because of its cost, or halogen bulb should be chosen.

VI. COMPARISON OF INDIVIDUAL LIGHT SOURCES IN CASE OF SPOT LIGHTING

Figure 5: Spot lighting in case of a variety of technologies (from left to right: incandescent, halogen, compact fluorescent tube, LED lighting)

If we do not need a space be illuminated at an angle of 360º but just intend to highlight a particular area then the so-called spot lamps are recommended. In the previous chapter analysed E27-socket light sources have suitable versions for spot lighting and their light scatter is at an angle of 30-35º. LED lamps, due to their structure, are more effective for this scope of task. A LED light source, in this case, a 7-Watt-power spot light has been chosen[12], which, because of the loss in brilliance and similarly to the first example, will be used for 18,000 hours of operation when its level of brilliance will have been reduced to the incandescent bulb's brilliance level (*see figure 5*[13]).

In comparison with the base case there is a conspicuous change in the rise of LED lighting. Considering the tested daily hours of operation its performance is better than that of the incandescent bulb's, and compared to a halogen bulb it drops behind only in case of a daily 1-hour use and if the alternative rate of return is at least 8% or higher, but in all other cases its implementation is better. In addition the relative advantage of the compact fluorescent tube contra LED lighting is reduced; however, the compact fluorescent tube technology wins in terms of cost. (*see table 4*)

The cost advantage of energy-efficient technologies is more spectacular in this case than in the previous ones. The biggest change can be observed in the return period. LED light source's return is available in case of every tested hour of operation. Considering the 3-year period of warranty, in case of a daily 4-hour of operation LED lighting can be applied without any financial risk because this time its return period is 2.75 years. The changeover on the podium's first two stages in the order of energy-saving shall be emphasised in favour of LED lighting. (*see table 5*)

VII. SUMMARY

In the analysis financial indicators, techniques, and considerations were presented to help the reasonable comparison of the initial extra investments, with cost savings arising later through energy efficiency via the example of lighting technique. Each case of application of alternative technologies can be rationally evaluated, and one can conclude whether an energy efficiency investment is worthwhile or not depending on the conditions of the case. The selection of optimal technology always depends on the intensity of use and on the expected rate of return (assuming that procurement and operating cost remain unalterable). To invest into technologies with higher procurement cost is feasible only when the benefits of future cost saving can be used, thus they can be used in appropriate intensity. Regarding new technologies, presently no adequate experience is available; therefore the investor can avoid financial risk arising from failure when time limitations of the manufacturer's warranty period are taken into account, and a particular technology is chosen only in case its discounted return period is within the warranty period.

In the case of 360 degree illumination of a particular area the primacy of compact fluorescent tubes is indisputable from financial perspective. In case of a daily use up to 2 hours and beside an alternative rate not exceeding 7% the second best alternative are LED light sources, and the best choice are Compact fluorescent tubes. With the

12 http://www.creoven.de/a-2142/?ReferrerID=13

13 http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/izzolampak/fenyvetoek-nr-r-par-e-a-p-pc-forma/reflector-diam-63-mm/37419/cat/

http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/halogen-lampak/halozati-feszueltsegue-halogenek-reflektorral/ecoclassic-reflector/925636044201_eu/

http://www.ecat.lighting.philips.hu/l/reflector/66176/cat/

http://www.ecat.lighting.philips.hu/l/professzionalis-fenyforrasok/led-vilagitasi-rendszerek/led-fenyforrasok/master-ledspot-par/929000174502_eu/

		Yearly cost equivalent ($ USD)			
Hours of operation	Alternative rate (r)	Incandescent light bulb	Halogen light bulb	Compact fluorescent	LED light source
Daily 1 hour	5%	5.46	4.45	1.42	3.24
	6%	5.49	4.50	1.48	3.67
	7%	5.52	4.55	1.55	4.11
	8%	5.56	4.60	1.62	4.57
	9%	5.59	4.65	1.69	5.04
Daily 2 hours	5%	10.86	8.76	2.56	4.48
	6%	10.92	8.83	2.63	4.95
	7%	10.98	8.90	2.69	5.32
	8%	11.04	8.97	2.75	5.71
	9%	11.09	9.03	2.82	6.12
Daily 3 hours	5%	16.27	13.07	4.02	6.06
	6%	16.35	13.16	4.10	6.40
	7%	16.44	13.25	4.17	6.75
	8%	16.52	13.33	4.24	7.11
	9%	16.60	13.42	4.31	7.48
Daily 4 hours	5%	21.68	17.38	4.89	7.58
	6%	21.78	17.49	4.96	7.91
	7%	21.89	17.60	5.02	8.24
	8%	22.00	17.70	5.09	8.59
	9%	22.10	17.81	5.16	8.94
Daily 5 hours	5%	27.09	21.69	6.06	9.11
	6%	27.22	21.82	6.14	9.43
	7%	27.35	21.94	6.21	9.77
	8%	27.48	22.07	6.28	10.11
	9%	27.61	22.20	6.35	10.45
Daily 6 hours	5%	34.57	32.02	7.23	10.65
	6%	34.73	32.17	7.31	10.98
	7%	34.88	32.31	7.39	11.31
	8%	35.04	32.46	7.46	11.64
	9%	35.19	32.60	7.54	11.98

Table 4: Average yearly cost equivalents of the spot light sources depending on the average daily operating hours and alternative rate

Hours of operation		Halogen light bulb	Compact fluoresent	Led light source
Daily 1 hour	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	2.75	1.83	17.08
	Lifespan	5.56	27.78	33.33
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	0.97	3.27	1.41
	Cost saving compared to incandescent light bulb percent (r=7%)	17.6%	72.0%	25.5%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%
Daily 2 hours	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	1.33	0.92	6.25
	Lifespan	2.78	13.89	16.67
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	2.08	8.29	5.66
	Cost saving compared to incandescent light bulb percent (r=7%)	19.0%	75.5%	51.5%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%
Daily 3 hours	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	0.92	0.58	3.83
	Lifespan	1.85	9.26	11.11
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	3.19	13.82	9.69
	Cost saving compared to incandescent light bulb percent (r=7%)	19.4%	76.8%	58.9%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%
Daily 4 hours	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	0.50	0.50	2.75
	Lifespan	1.39	6.94	8.33
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	4.30	16.87	13.65
	Cost saving compared to incandescent light bulb percent (r=7%)	19.6%	77.1%	62.3%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%
Daily 5 hours	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	0.50	0.42	2.17
	Lifespan	1.11	5.56	6.67
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	5.40	21.14	17.58
	Cost saving compared to incandescent light bulb percent (r=7%)	19.8%	77.3%	64.3%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%
Daily 6 hours	Investment need in USD	5.45	8.18	49.09
	Discounted payback time in years (r=7%)	0.42	0.33	1.83
	Lifespan	0.93	4.63	5.56
	Cost saving compared to incandescent light bulb in USD/year (r=7%)	2.57	27.50	23.58
	Cost saving compared to incandescent light bulb percent (r=7%)	7.4%	78.8%	67.6%
	Energy saving compared to incandescent light bulb	30.0%	81.7%	88.3%

Table 5: Comparing the indicators of the different spot light sources relative to the incandescent light bulb

LED and Compact fluorescent lamps compared to incandescent bulbs, depending on the daily use, an annual average 24-74% cost saving can be achieved.

In case of spot lighting LED light sources have been better than those observed in the case of illumination of a particular area, and in almost each tested case they were included on the second place and there is only a minor lag in comparison with the compact fluorescent tubes. The available cost saving in case of compact fluorescent tubes and LED lamps, depending on the daily hours of operation is 26-79% compared to the incandescent light bulb.

REFERENCES

[1] Alcott, H. and Greenstone, M. "Is There an Energy Efficiency Gap?", Journal of Economic Perspectives, 26(1), (2012), 3–28.

[2] Anderson, S. T. and Newell. R. G. "Information Programs for Technology Adoption: The Case of Energy-Efficiency Audits" Resource and Energy Economics, 26(1), (2004), 27–50.

[3] Blasnik, M. "Energy Models vs. Reality." Presentation. Southface Lecture Series. (2010) January 26.

[4] Brounen, D. and Kok, N. "On the Economics of Energy Labels in the Housing Market", Journal of Environmental Economics and Management, 62, (2011), 166-179.

[5] Brounen, D., Kok, N. and Quigley J. M. "Residential Energy Literacy and Conservation", The European Centre for Corporate Engagement (2012)

[6] Brown, M. A., Levine M. D., Short W., Koomey J. G. "Scenarios for a Clean Energy Future" Energy Policy, 29 (14), (2001), 1179-1196.

[7] Metcalf, G. and Hassett, K. "Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data." Review of Economics and Statistics 81 (3), (1999), 516–28.

[8] McKinsey & Co. "Unlocking Energy Efficiency in the U.S. Economy" (2009) http://www.mckinsey.com/clientservice/electricpowernaturalgas/downloads/US_energy_efficiency_full_report.pdf.

[9] Schweitzer, M. "Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005." Prepared for U.S. Department of Energy. Working Paper ORNL/CON-493, (2004)

[10] Sandberg, P. and Söderstrom, M. "Industrial energy efficiency: the need for investment decision support from a manager perspective" Energy Policy, 31 (15), (2003), 1623-1634.

[11] Decanio, S. „The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments" Energy Policy, 26 (5), (1998), 441-454.

[12] Csutora M. and de Palma, R. „Using EMA to Benchmark Environmental Costs", In: Schaltegger, S., Bennett, B., Burritt, R. L., Jasch C. (edit.) Environmental Management Accounting for Cleaner Production. Dordrecht: Springer, (2009), 143-164.

[13] Emergence Technological Consultants, LLC: Conversion to Energy Efficient LED Lighting – Understanding LED Lifetime Analysis, White Paper

[14] Wald, M. L. „The energy challenge – Efficiency, not just alternatives, is promoted as an energy" The New York Times, (2007)

[15] Simpson D.G. „Photometry" Department of Physical Sciences and Engineering, Prince George's Community College, (2010)