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Transforming "The National Autonomous University of Mexico (UNAM)" Into a Lighthouse-Project of Sustainability.

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Abstract

UNAM is the oldest and one of the most prestigious universities in the Americas. The main campus of the university is home of about 300 000 students and covers an area of about 4 square-kilometres in the south of Mexico City. UNAM is also one of the biggest electricity consumers in Mexico-City. More than 70 Million kWh electricity are consumed yearly, producing about 49 000 tons of CO_2 emission. Within the paper we will show that this could be changed with a high financial and educational profit.
As UNAM has no heating and only a few cooling systems, lighting is by far the biggest use of electricity. The existing lighting system is extremely inefficient while providing unsatisfactory illumination in some places. The UNEP Centre on Sustainable Production and Consumption (CSCP) together with Büro Ö-quadrat devised a project which demonstrates how UNAM can benefit from an upgrade to a highly efficient lighting system. What makes the project unique is that the results are not based on theoretical calculations but were corroborated by implementation results of a highly efficient lighting system in four different areas (a foyer, classrooms, a library and a workshop) and the measurement of the electricity savings. Within these four areas the average electricity saving was 84% and the combined pay-back time was 2.7 years. Based on the empirical results and an analysis of 10 UNAM-buildings a master plan was developed for the entire university campus. Here the objective was to establish the broad strategic principles for a successful lighting system upgrade, as well as the necessary budget and savings that could be achieved. The results demonstrate that an initial investment of US$ 14 million would result in electricity costs savings of US$ 68 million over the 20 year lifetime of the upgraded lighting system. About thirty per cent of the electricity consumed in UNAM today could be saved with a high profit on investment.

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In a second step we show that most of the remaining electricity consumption could be produced by solar energy. The Feed-in Tariff system in Germany has led to a high capacity of PV-production and lowered the cost for PV-systems: In May 2013 a 40 kW PV system, including all parts for the mounting, can be bought in Europe for a price of about 800 Euro/kW. Assuming that on 2% of the UNAM-area PV-systems would be installed, these systems could produce about 23 GWh with lower costs compared to the electricity price UNAM has to pay.
Combining the investment for efficient lighting and PV-systems, about 60% (or about 29 000 tons) of the CO2-emissions of UNAM could be saved with a high rate of return.
Best of all: What would be a more convincing way to educate 60 000 students every year about sustainability than a practical example of highly efficient lighting system and powered by solar energy? UNAM could be a light house for many other universities and schools.

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Keywords: efficient lighting; PV at UNAM; Sustainable University; Profitable Investment, Climate Protection

1. Introduction

UNAM is the oldest and one of the most prestigious universities in the Americas. The main campus of the university is home of about 300 000 students and covers an area of about 6 square-kilometers in the south of Mexico City. UNAM is also one of the biggest electricity consumers in Mexico-City. More than 70 Million kWh electricity are consumed yearly, producing about 49 000 tons of CO_2 emission.
As UNAM has no heating and only a few cooling systems, lighting is by far the biggest use of electricity. The existing lighting system is extremely inefficient while providing unsatisfactory illumination in many classrooms places. The UNEP Centre on Sustainable Production and Consumption (CSCP) together with Büro Ö-quadrat devised a project which demonstrates how UNAM can benefit from an upgrade to a highly efficient lighting system.
We have carried out a very successful demonstration project. Based on the findings of this demonstration project, a master-plan was build which systematically analyzes the potential for lighting –renovation. With a refurbishment of the lighting system alone a reduction of electricity consumption of 19 Million Kilowatt-hours per year can be reached. [1] In addition to the enormous energy saving potential, UNAM also offers vast potential for the integration or renewable sources. If only on 2% of the area of UNAM PV-systems would be installed, about 23 Million of Kilowatt-hours could be produced per year.
Combining the two investments for efficient lighting and PV-systems, about 60% or 29 000 tons of CO2-emissions of UNAM could be saved with a high rate of return.
Additionally the better light would lead to a rise of the user comfort and to an educational profit.

2. Efficient Lighting

The study we refer in this paper was done in the year 2009. The basis of the study was a refurbishment project at different UNAM buildings. What made the project unique is that it is based not only on theoretical calculations but on the experience gained with four separate modernization programmes which have been realized and documented.†

† http://www.oe2.de/fileadmin/user_upload/download/UNAM_engl.pdf

For each of the four model areas the situation before and after the refurbishment was analysed. The load and energy consumption of the old and new system were measured. The costs of the refurbishment and maintenance cost have been calculated accurately. Based on the data of the four model areas and a developed master-plan for the whole UNAM-area a cost benefit analysis has been developed.
We will first give an example for one of the four areas before we refer the results of the four areas and the results of the master plan.

2.1 Refurbishment at Classroom, Laboratory

Pre-upgrade situation

The laboratories at the Institute of Engineering were built several decades ago and have shed roofing to provide glare-free daylight (Figure 1)

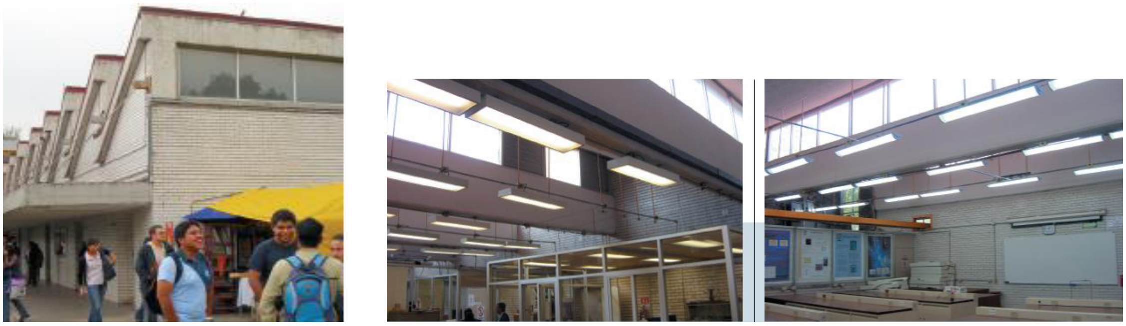

Figure 1: laboratory at the Institute of Engineering a) from outside, b) before and c) after refurbishment[1]

The analysis came to the result, that

- Luminaire efficiency is very low and only about 40 percent and
- the artificial light is not adjusted according to incident daylight,
- Presence detectors have not been installed. The lights stay on even when a laboratory is not in use. This is partly because the light switch is situated at the other end of the building.

In the next step different solutions for a more efficient lighting have been worked out and discussed and the most efficient has been selected.
The following package of measures was installed:
High efficient luminaires with a luminaire efficiency of 75 per cent and including T5 technology with dimmable electronic ballasts, day-light sensor and occupancy sensors were installed.
These changes provide the amount of light needed relative to incident daylight. The more incident daylight available, the less artificial light is produced. Once the required amount of lighting is reached, the room is lighted exclusively using natural daylight. The new lights were also wired to presence detectors, so that they are only switched on when laboratories are in use.

Outcome

- These measures would reduce electricity consumption in laboratories by 72 percent.
- The better light would lead to a rise of the user comfort and to an educational profit.
- Annual savings would amount to 4 500 kWh

- The simple payback period is 5.4 years (based on an electricity price of 16 US-Cent/kWh‡)

Table 1: Situation before and after upgrade [1]

	Pre-Upgrade	Post-Upgrade
Lighting	2 x 32 Watt (T8)	1 x 28 Watt (T5)
Ballasts	Conventional	Dimmable, electronic
Circuit power	60 Watt	33 Watt
Luminous efficiency	40%	75%
Daylight-controlled	No	Yes
Presence detectors	No	Yes
Illuminance level	374 Lux	438 Lux
Electricity saved	_	72%

2.2 *Outcome for the four model areas*

In table 2 the outcome of all four model areas is shown. The results have been quite different, depending on the quality of the old lighting system, the daily duration of using artificial light, the possibility of using daylight, the lighting level before and after modernization.

The payback period for the capital investment was between 1.3 years and just over 12 years. The extremely short payback period for the Centro de Ciencias de la Atmosfera foyer is due to the very long running time of the pre-upgrade lighting system. Despite the availability of daylight, artificial light was constantly used. The significantly more efficient lights and a daylight-controlled system reduced consumption to an absolute minimum.

Table 2: Investment and annual cost-savings achieved in UNAM model modernization project [1]

Area	Invest-ment US$	Electricity savings kWh/year	Electricity savings Percent	Cost-savings US$/Year	Pay-back period years
Laboratory (classroom)	4 400	4 458	72	811	5.4
Rivero Borell Library	2 900	1 402	59	235	12.3
Foyer Centro de Ciencias de la Atmos.	4 900	20 746	92	3 893	1.3
Workshop/Laboratory	1 700	1 625	85	290	5.9
Total	**13 900**	**28 231**	**84**	**5229**	**2.7**

The longer payback time for the library can be attributed to several factors:

- The existing T8 tubes were already fitted with electronic ballasts, so that compared with the old system, the energy saved with the new, more efficient technology is lower than in other cases.
- The lighting control system only applies to the twelve luminaires that were replaced, meaning that the cost of investing in the light control system is spread over a relatively ‘small’ saving.
- The illumination level was increased by about 60 per cent.

‡ In the year 2009

The average payback period for all four rooms in the model modernization project (total investment divided by the overall annual electricity saving in the four areas) is just under three years. While this appears to contradict the individual results, it can be explained in that the foyer was the biggest area and was also where the greatest savings were achieved, which made this result the dominant factor in the average results for all four areas.

2.3 Approach and outcome of the master plan for efficient lighting at UNAM

Providing efficient lighting for a room or a building is a highly complex matter and involves far more than simply replacing old light bulbs with new ones. An efficient lighting plan has multiple components and because they are interdependent, each step must be implemented in accordance with an integrated approach. For example, daylight-controlled lighting requires the use of dimmable, electronic ballasts. By using available technology, electricity consumption can be cut by 90 per cent reduction while providing the same degree of light.

When developing the master plan, it was assumed that this systematic approach would be taken when replacing the lighting system.

1. Desired degree of light: The desired and required degree of light must be ascertained and measured in lumen per square meter. The task at hand is to find out how much light is needed to perform certain tasks in different areas of a room.
2. Light reflection: The next step involves designing a room so as to provide the best possible conditions for light to be reflected and incident light to be used. The brighter the walls, ceilings and floors, the more light can be reflected.
3. Efficient technology: The third step takes in the choice of efficient lights, reflectors, tubes, bulbs and ballasts to enable the desired degree of light to be achieved with minimum use of energy.
4. Incident daylight: In step four, all available technology is installed to allow use of incident daylight, for example by means of light-directing sunshades. Use of daylight sensors should minimise the need for additional, artificial light.
5. Presence detectors: Presence detectors can ensure that lighting is only activated when a room is actually in use.

In drawing up the master plan, a dozen UNAM buildings were analyzed and lighting use patterns monitored in each of the buildings. Four typical lighting situations were identified:

- Lighting in foyers and corridors, both those on the outside and those towards the middle of the building (without incident daylight)
- Libraries
- Seminar rooms in which lectures and tests are held
- The offices of the university departments and the administration.

For each lighting situation, an efficient lighting system was designed and both the investment costs and the savings in electricity costs were calculated.

In the next step the modernization schedule was defined. It was assumed that the modernisation work begins in those areas where savings were greater relative to the amount of money invested. This meant almost all foyers and corridors in the UNAM buildings. The payback period is just under two years.

- In the first year, the lighting in all foyers and corridors are replaced.

- In year two, work is started on a quarter of the libraries. Over the four-year period some 100 of UNAM's 130 libraries receive new lighting.
- In year four, the seminar rooms are tackled with work stretching over four years.
- In the sixth and seventh years, new lighting is installed in all offices.

Outcome

a) Financial Benefits

The total investment from the first to the seventh year amounts to US$ 13.9 million. The total savings on energy and maintenance costs which accrued over the lifecycle of the new lighting systems (20 years) amount to US$ 68 million. The figure 2 shows investment and energy costs and maintenance savings over time. Through the systematic approach and the strategy to start investment in the highly profitable areas, only about 3 million US$ are necessary for the investment, because the savings from the first years cover part of the following investment costs.

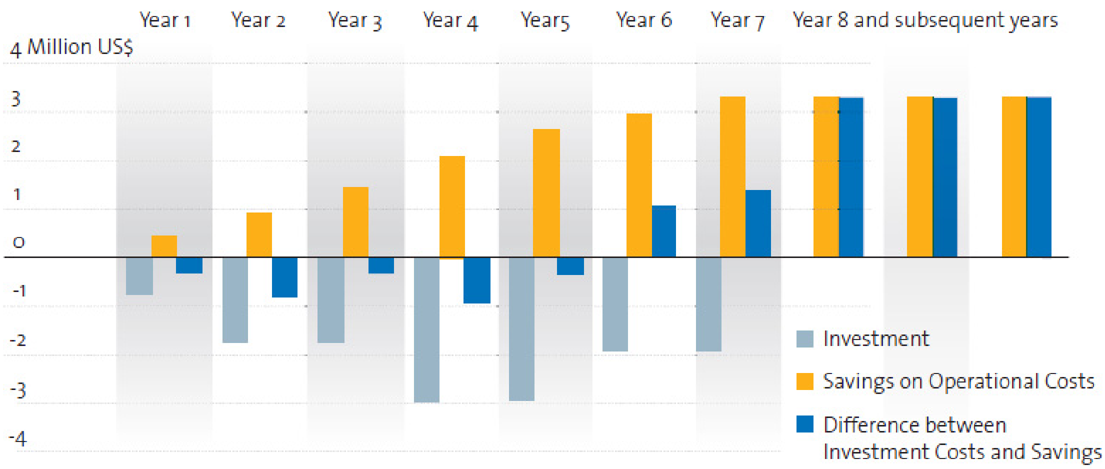

Figure 2: Investment costs of the new lighting system, energy and maintenance cost savings and the remaining difference between investment-cost and savings. [1]

The master plan shows that with a systematic approach and a low upfront investment (only 3 million US$ are needed to start the master plan) great savings in energy and operational costs can be achieved. Assuming a price rise in the electricity sector of 3% per year, the internal rate of return of the investment within the master plan would be 51%. That means, that an investment with very low risk will promise a high profit rate over a long timeframe.

b) Environmental Benefits

The total electricity saved per year is estimated at 19 million kWh. The resulting reduction in carbon emissions will be about 13,300 tons of CO_2 per year or about 266,000 tons over the lifecycle of the lighting system. With other words: a highly profitable investment goes hand in hand with a big reduction in CO_2 and climate protection.

c) Other Benefits

There is no doubt: Better lighting in classrooms and libraries leads to better learning results. The economic advantage of this effect cannot be calculated but it might be a multiple of the investment into new lighting technology. Last but not least: The new UNAM lighting concept could become a lighthouse project for other universities in Mexico and around the world, adding to the cultural influence of Mexico.

2.4 New technology

The study we examine was carried out in 2009. Since then, lighting technology has further developed. Especially the LED lighting technology has made big progress. Today good LED-lamps are comparable to those high efficient T5 lamps we installed. In some areas of application, especially where very directional light is needed, the LED-technology might be even more efficient (for example security lights, street lights, spot lights). Additionally it can be expected, that the new technology has lower maintenance costs. On the other hand, the prices for high efficient LED luminaires are still higher compared to the approved T5 technology. Of course the new LED technology has to be taken into consideration by planning a high efficient lighting system for UNAM.

3. Development in the PV-sector

With the Renewable Energy Law in Germany, which was introduced in the year 2000, a new time age came up. In Germany the market for PV-systems developed at a tremendous pace and in consequence of higher production capacities for PV-systems the price decreased and led to further installations. At the beginning of May 2013 about 34,000 MW of PV-systems have been installed in Germany – more or less one third of the global capacity.

The subsidies for the PV technology led to a technology revolution and made solar energy competitive to fossil fuel power plants in many regions.

In figure 3 the development of PV capacity in Germany, the whole world and the development of PV system costs are shown.

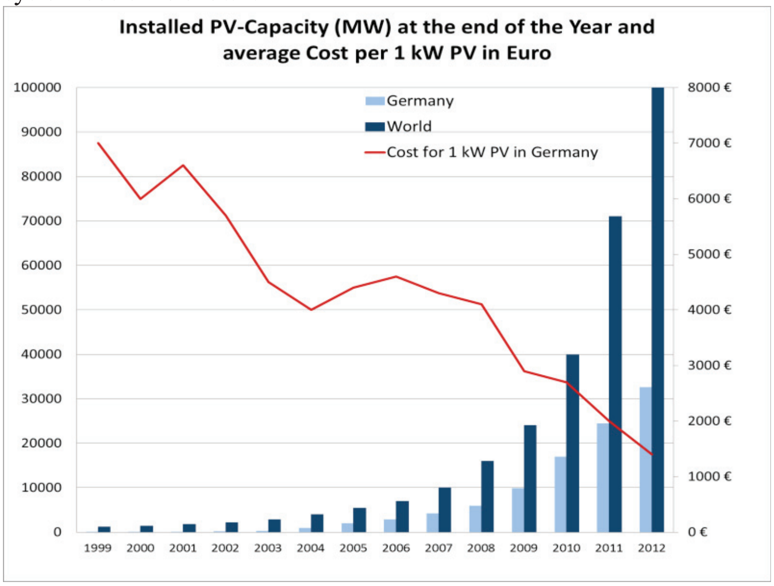

Figure 3: Installed Capacity of PV-systems in Germany and worldwide (left axis), Cost development of PV (Euro per installed kW in Germany) (Source: [2], [3], own calculation)

In spring 2013 the cost of a complete 50 kW-PV-system (including all parts and the materials for installation) are about 40.000 Euro§ (without transport, VAT and without installation). That means that the cost per installed kW will be between 1100 and 1300 Euro.
A 1 kW PV system in Germany has a typical annual production capacity of 900 to 1000 kWh. Assuming capital costs of 8% per year and maintenance costs of 2% of installation cost per year as well as insurance cost of 5 Euro/kW and year, the specific cost per kWh will be 17 Euro-Cent** – including an 8% interest on investment cost. To compare: the average price for electricity of a German household is about 26 Euro-Cent.

Table 3: Cost of a PV-Electricity System in Germany (50 kW system, own calculation)

Investment per kW peak	1200	Euro
Lifetime	20	years
Additional Maintenance and service costs (2%)	24	Euro/kW,year
Insurance	5	Euro/kW,year
Annuity with 8% interest	0.10	
Capital costs (interest and annuity)	122.22	Euro/kW,year
Maintenance, service and insurance	29.00	Euro/kW,year
Total cost/year	151.22	Euro/year
average yearly production	950.00	kWh/year
Total cost/kWh	**0.16**	**Euro/kWh**

4. PV Costs and Potential of PV-system at UNAM

Mexico has very good conditions for the use of solar energy. The average daily radiation is 5 to 6 kWh/m^2 [4]. The output per kW installed PV will be about 1500-1600 kWh/year in the place of UNAM. In the calculation below we assumed that the cost for a PV-System would be 20% higher than in Germany (even so the installation costs in Mexico should be lower because of the lower wages). Compared to Germany the radiation in Mexico City is substantially higher. With an average yearly production of 1550 kWh per kW peak, the specific cost per kWh would be about 15 US-Cent. Compared to the electricity price UNAM has to pay today (ca. 0.17 US$/kWh), the costs of PV-electricity are already lower – including an 8% interest on the invested capital. While the electricity price for UNAM will rise, the cost of electricity includes maintenance and service and the cost will be stable over a twenty year time period.

§ http://www.photon-solar.de/index.php?seite=pvkomplettanlagen-paket12, download on 15.6.2013
** The feed-in tariff for a PV-system connected to the grid between 1.4. 2012 and 1.5.2012 was 18.5 Euro-Cent (capacity until 40 kW), the feed-in tariff connected from 1.6.2013 to 1.7.2013 is 14.56 Euro-Cent. [5]

Table 4: Cost of a PV-Electricity System in Mexico (50 kW system, own calculation)

		Germany	**Mexico**	
		Euro	**Euro**	**US$**
Investment per kWpeak		1200	1440	1872
Lifetime	Years	20	20	20
Maintenance and service		2%	2%	2%
Maintenance and service	Euro/kW,year	24	28.8	37.44
Insurance	Euro/kW,year	5	5	6.50
Annuity with 8% interest		0.102	0.102	0.102
Capital costs (interest and annuity)	Euro/kW,year	122.22	146.67	190.67
Maintenance, service and insurance	Euro/kW,year	29.00	33.80	43.94
Total cost/year	Euro/year	151.22	180.47	234.61
average yearly production/kW	kWh/year	950	1550	1550
Total cost/kWh		**0,16**	**0,12**	**0,15**

The main campus of UNAM covers about 7.3 km^2. If only 2 % of the area would be used for the installment of PV-Systems (primarily on building roofs), about 14 600 kWpeak could be installed. The expected electricity production from these installments would be about 22.6 Mio kWh or about one third of the total electricity consumption of UNAM.

Table 5: Potential of PV-Electricity if 2% of the UNAM area would be used for PV installations (own calculation)

Area UNAM	km^2	7.3
Used for PV-systems		2,00%
Used for PV-systems	m^2	146 000
Installed capacity per square meter	kW/m^2	0.1
Installed capacity total	kW	14 600
Annual electricity production per kW peak	kWh/kW	1 550
Total electricity production per year	kWh/year	22 630 000
Investment	Euro/kW	1 440
Total investment	Million US$	27.3

5. Efficient Lighting and PV at UNAM

As shown, the use of efficient lighting and PV-solar energy can reduce the electricity consumption of UNAM by about 60% (see table 6). And the best thing: it can be done in a profitable way. The simple payback time of the two technologies is about 5.8 years. This figure does not include the maintenance costs and the cost of capital. But it also includes the assumption that the price for the purchased electricity would be constant at 0.17 US$, which is rather optimistic.

Table 6: Investment and benefit of efficient lighting and PV-systems at UNAM (own calculation)

		Efficient lighting	PV	Total
Electricity saving/electricity production	MWh/year	19000	22630	41630
Savings/production compared to todays consumption	%	27%	32%	59%
Total Investment	Million US$	13.9	27.3	41.2
Avoided cost of electricity purchase	Million US$	3.2	3.8	7.1
Avoided CO2-emssions	Tons CO2/year	13 300	15 841	29 141
Simple payback time	Year	4,3	7,1	5,8

Together these two technologies have the potential to reduce the electricity-consumption and the CO2-Emissions of UNAM by about 60%.

6. Conclusion

Although the calculations presented in this paper may vary by 10 or 20 percent either way, the logic and economic success of the approach is undoubted. There is next to no risk of entering into a bad investment if the lighting system is refurbished in the described way. At the PV side there might be the situation that the first systems would be more expensive and that they would not cover their cost within the first 10 years. To start small with a small-scale PV system would however minimize this risk. But developing the market and gaining experience, the technology would be profitable for UNAM.
Climate protection does not need to be expensive and brings long-term profits and additional advantages – not measurable in money-units. The described investment would be an important step to a sustainable university. But of course it has to be embedded in (or combined with) a better education for sustainability.

References

[1] Büro Ö-quadrat/UNEP-CSCP: Better Lighting saves Money. Pilot Project on Efficient Lighting at the National Autonomous University of Mexico (UNAM), Freiburg/Wuppertal 2009

[2] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Erneuerbaren in Deutschland im Jahr 2012, Februar 2013

[3] Renewable Energy Policy Network 21: Renewables 2013. Global Status Report, June 2013

[4] McIntosh, J.: Tarifentwicklung und Anreize für PV in Mexiko, Vortrag Berlin 2013

[3] Bundesnetzagentur: Bestimmung der Vergütungssätze nach § 32 EEG für die Kalendermonate Mai, Juni 2013