Energy-efficiency in industrial buildings by lighting solutions; A case of Smart Lighting

– Summary of Master thesis in Energy-efficient and Environmental Building Design –

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Background and problem motivation

Nowadays, lighting covers a great portion of the total energy use of a building, almost 21%, while in most of the places, the quality of the existing lighting conditions is usually notably poor. In addition, lighting is responsible for 14% of all electricity demand in EU (CELMA, 2011) and 19% of the latter worldwide (CELMA, 2011). At the same time, the European Union has set ambitious climate and energy targets for sustainable development, widely known as “20-20-20 Energy Efficiency Targets”, with which all countries should comply. (European Commission, 2014).[1] Europe has already developed a wide range of policy instruments in charge to stimulate the uptake of sustainable technologies, including lighting. (European Commission, 2011). One way to achieve this is by the introduction of Smart Lighting technology into buildings of high energy demand. Continuously responding to the desired illuminance levels indoors through various sensors incorporated into each fixture, the energy demand for lighting is notably abridged, leading to a reduction in the total energy use of the building as well.

Purpose and goals

The objective and the purpose of this study has been to examine the energy performance and the lighting conditions of an industrial building, poorly daylit and with electrical installation. The building is located in Greece, a place that offers great quantity of daylight and the possibility to achieve notable energy savings due to lighting and improved building envelope. However, windows that allow daylight penetration inside are not preferred due to the fact that the building hosts spaces with fridges and of constant indoor temperature. Therefore, the main question of this thesis has been whether the introduction of smart lighting technology is more preferable than modern LED in terms of lighting, functionality, energy and cost savings.

The goals of this study are to:

- Reduce the installed power need for lighting.
- Reduce the total energy demand of the building due to lighting and improved building envelope.
- Reduce the CO_2 emissions of the building due to lighting and improved building envelope.
- Comply with international and local energy standards for energy efficiency.
- Introduce the Scandinavian building structure in a warmer climate and test it for possible moisture growth as well as its potential for energy savings.
- Present the economic analysis of the systems to investigate the amount of profitability.

Smart Lighting systems are a prosperous technology. The flexibility a Smart Lighting system offers leads in remarkable energy efficient and cost effective lighting solutions as well as in the mitigation of CO_2 emissions. The vast possibilities that Smart Lighting systems offer are summarized and analyzed below:

- *Control:* over the configuration of the light installation to control, set and modify light levels, create schedule profiles, group fixtures, adjust sensor delay, etc, via the software or manual control.
- *Insight:* via an interactive map in the software to understand where the activity is concentrated and visualize in charts the energy use and cost, the daylight harvesting and the occupancy of the facility at any time of the day, month or year.
- *Reporting:* in charts and on an hourly, daily, monthly or even yearly basis energy use and cost, daylight harvesting and occupancy data using data obtained by integrated sensors into smart fixtures.
- *Ease of use:* access via a simple web-based interface that allows quick familiarization of the users.
- *Security:* Secure access to the software via username and password protection.
- *Scheduling:* creation of different profiles according to the facility’s needs and operation, such as shifts, holidays, etc, to optimize the energy and cost savings achieved.

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[1] Three key objectives for 2020:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency.

- *Maximum energy-efficiency:* excellent combination of LEDs and sensors incorporated into each fixture, as well as insight and continuous overview of the energy and cost savings of the facility.
- *Adaptability to different needs:* control and adjust the lighting installation accordingly to different facilities' or rooms' operation, etc, via different lighting profiles and scheduling systems.

Methodology

The methodology followed in this structure consists of:

- Climate analysis using Autodesk® Ecotect® Analysis.
- Lighting simulations using DIALux, to simulate the lighting conditions in each room.
- Energy simulations using Design Builder, to simulate the energy performance of the building.
- Moisture safety design using WUFI Pro 5, to investigate the possibility of moisture growth in the structural elements.
- Life Cycle Cost (LCC) of the different systems to examine their profitability.

The improvements suggested for the facility in this study mainly concern the lighting installation and the building structure. As the study focus laid on a newly-built construction, three lighting scenarios were examined and compared:

a. Simple lighting technology (fluorescent and metal halide lamp technology corresponding to the "existing lighting conditions").
b. LED technology (fixture and lamp technology of high luminous efficacy corresponding to energy efficient lighting design).
c. Smart lighting technology (LED technology combined with numerous sensors embodied in each fixture). The intelligence of the system contains daylight harvesting, motion, occupancy and temperature sensors in combination with dimming control.

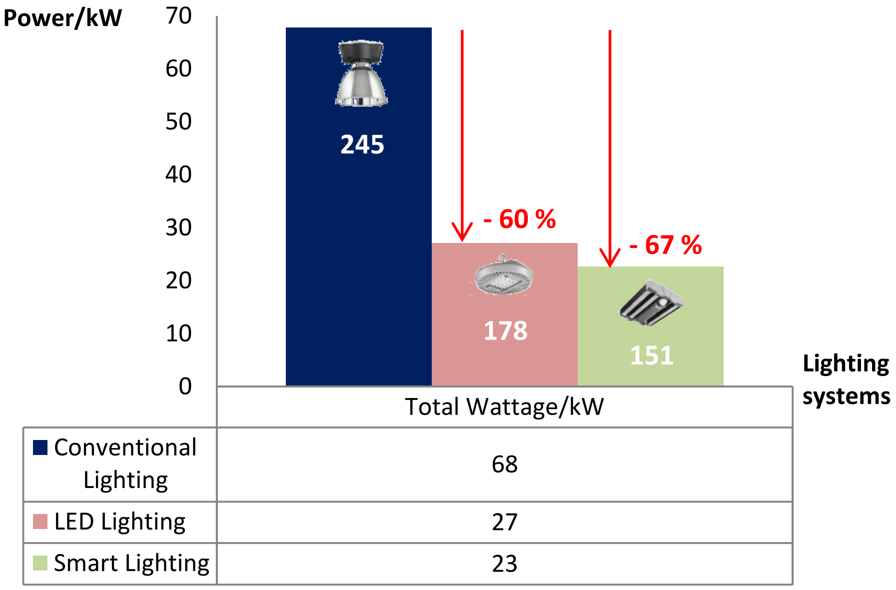
Finally, two scenarios concerning energy demand were examined:

a. Existing conditions, which refer to simple lighting technology combined with poorly insulated building structure, and
b. Improvements, which refer to smart lighting technology combined with improved construction elements.

Main results

1. Lighting analysis

Figure 1 presents the reduction in the installed lighting power for the different lighting scenarios without applying any sensors or dimming control yet. The reduction in the total installed power when LED technology is applied reaches up to 60% in comparison to conventional lighting technology. Yet, the reduction in the total power need is remarkable when smart lighting is introduced, up to 67% compared to simple lighting technology. An additional reduction of 17% can be achieved compared to LED technology.



	Total Wattage/kW
■ Conventional Lighting	68
■ LED Lighting	27
■ Smart Lighting	23

Figure 1: *Comparison among the three different lighting scenarios.*

The reduction of the total energy demand for lighting can be further improved reaching up to 90.3% compared to simple lighting and up to 69.1% compared to LED lighting. This is possible by applying occupancy, motion and daylight harvesting sensors, the operation hours and finally, by installing the necessary software to control and monitor the electrical lighting installation, as the smart lighting principles imply. It is highly important to mention that the comparison amongst the three different scenarios presumes the maximum light output of the fixtures regardless the impairment due to ambient temperature. Generally, the rule is that maximum light output is achieved at a certain temperature range for each lighting system and deviations from that temperature cause degradation of the total luminous output. Thus, this rule suggests that if the number of fixtures for the two first lighting scenarios is kept as described above in Figure 1, the desired illuminance levels for these rooms of specific use will not be achieved and the area could be characterized as notably underlit.

2. *Cost analysis*

The energy analysis of the different lighting scenarios is followed by a cost analysis that takes into consideration the following parameters; the initial cost of investment, the annual maintenance costs and the annual energy costs for lighting. The electricity cost per kWh reaches up to 0.11€/kWh while the interest rate for the electricity is assumed to be 5%. Figure 2 reveals the total cost of ownership (TCO) for a time period of 10 years for all the three lighting scenarios investigated. The superiority of smart lighting technology (blue curve) over the simple one (red curve) is evident, even though the initial cost of the latter is notably lower. This occurs because of high maintenance costs and energy use for the simple lighting technology that raise the total costs significantly. The green curve stands for the LED lighting technology the characteristics of which are the abridged energy use and the increased initial cost of investment compared to simple lighting. Yet, when compared to the smart system, the latter is still the most energy- and cost-efficient system over the 10-year period, despite the higher initial cost, as it presents the lowest TCO amongst the three different lighting scenarios.

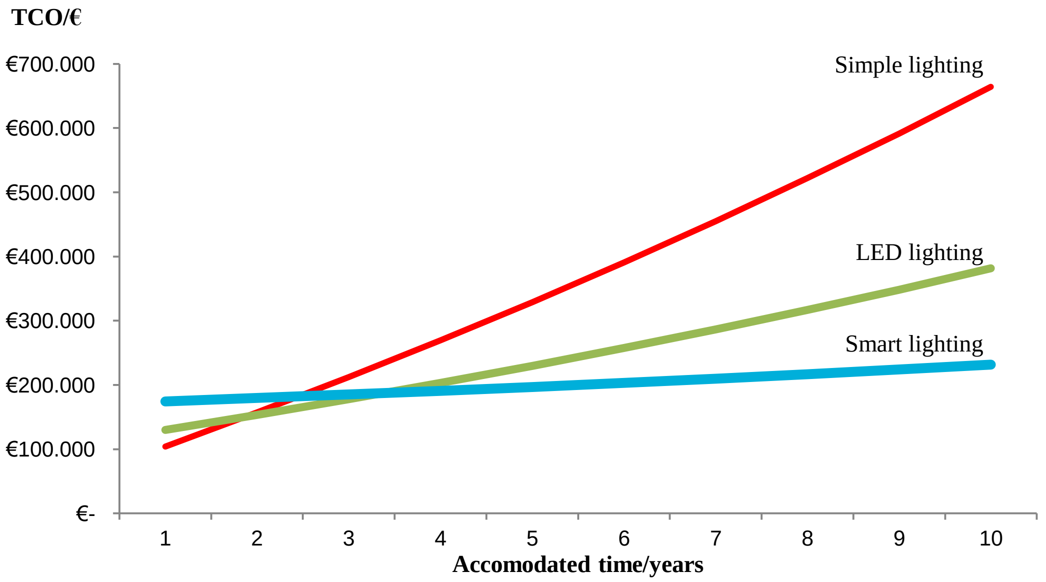


Figure 2: *10-year total cost of ownership (TCO) for the different lighting scenarios.*

Potential reduction in the power demand in lighting also affect the energy demand of a cooling machine. No heat storage is assumed to occur during the night; thus, the total power is equal to the maximum power for lighting for each lighting scenario. The cost analysis for a cooling machine due to lower power need in lighting yields significant cost savings of 41% compared to simple lighting and of 7% compared to LED lighting technology, when smart lighting systems are introduced to the facility.

Again, Figure 3 shows that despite the high initial cost of investment, the payback period for each lighting system drops to 2 years when comparing smart lighting technology to the simple one, whereas when comparing it to the LED one, it drops to less than 3.5 years.

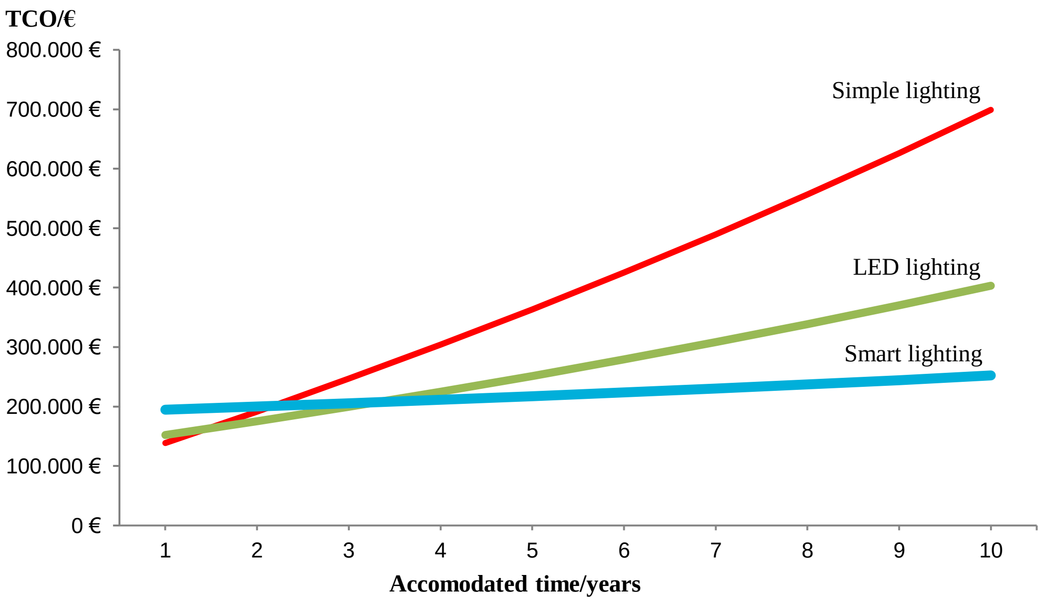


Figure 3: 10-year total cost of ownership for smart lighting technology with the cooling machine cost reduction included.

3. *Energy analysis*

The results of a short parametric analysis concerning energy demand in the facility are presented in Figure 4:

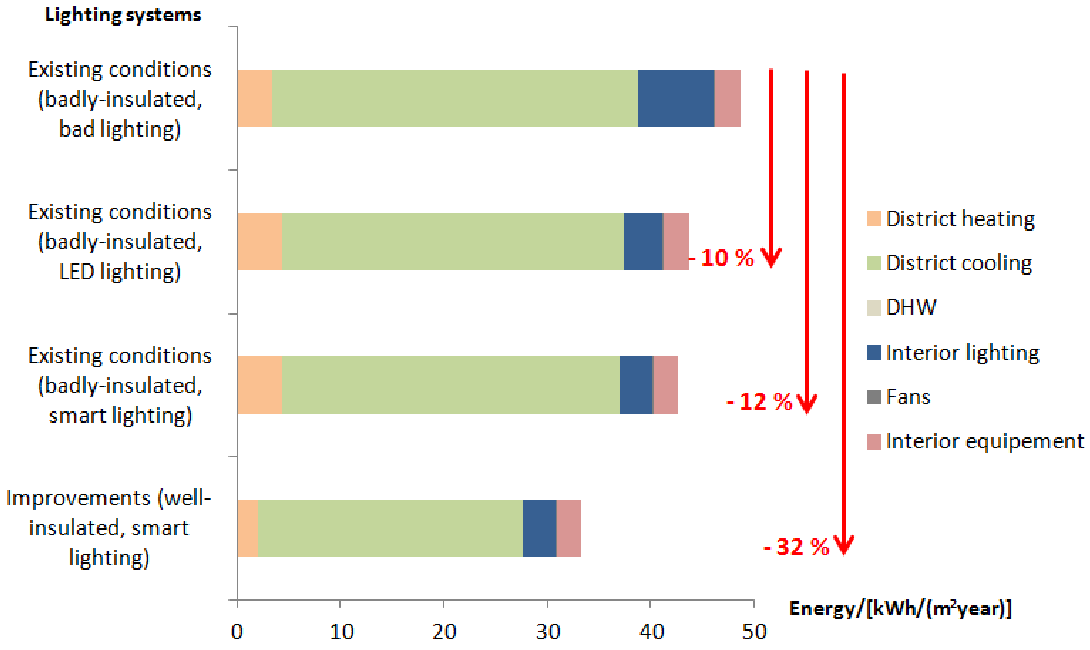


Figure 4: *Energy demand.*

As far as the energy savings is concerned, simply by replacing the conventional lighting with LED lighting, the total energy demand is reduced by 10%. Heating demand is slightly increased, mostly in warm rooms, whereas cooling demand is notably reduced, as LED technology emits less heat that is unnecessary in cold rooms. As expected, the load corresponding to the interior lighting is almost half, when comparing to existing conditions.

An additional reduction of 2% compared to the first improvement may occur with the introduction of smart lighting technology, which is the second improvement. Note that at this point, the principles of smart systems have not been included into the calculation yet and the energy demand for lighting refers only to the installed power for lighting. Braver energy savings are to be expected when these are applied. Generally, energy demand for cooling, heating and interior lighting follow the pattern explained above.

Changing the structure is of great significance. The energy simulations in Design Builder reveal the potential to reduce the annual energy demand of the building by 32%. Note that the aforementioned reduction comprises of reduction in lighting, cooling and heating demand; heavy machinery operating in the factory was not taken in consideration in the energy simulations as it is impossible to correctly estimate its full extent.

More specifically, the reduction in the cooling load reaches up to 27% whereas the heating load is limited by 42%. The reduction in the cooling load appears notably lower than the reduction in the heating load. This is because the building is originally well insulated in general, except from the spaces that do not serve as cold rooms or refrigerators where the insulation layer is thinner by 33% resulting in greater energy losses from these areas.

Figure 5 compares the insulation cost against the energy cost for existing conditions and improvements:

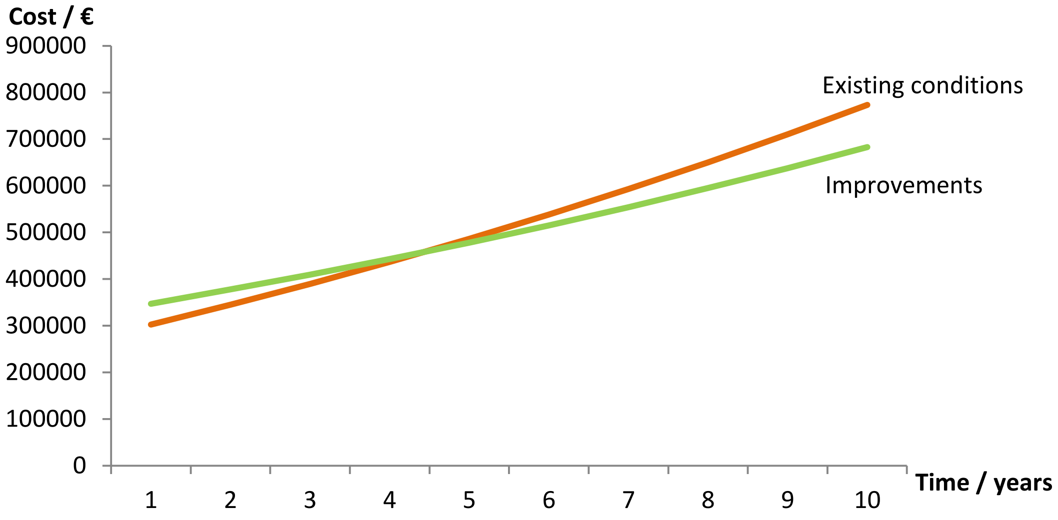


Figure 5: *Insulation cost versus energy cost for existing conditions and improvements.*

The energy and insulation costs are mainly influenced by two reasons; the electricity rate of 5% and the cost of investment for both insulation and the cooling machine. By adding insulation, the initial cost of the structure is bigger. Yet, after a 10-year period, the total cost including the insulation and energy cost is significantly lower than the one of the existing conditions. This occurs because of the magnitude of the energy savings achieved by introducing a better insulated and moisture safe building structure, a more efficient lighting installation and by savings from the initial cost for the cooling machine. The payback period is calculated to 5.5 years and with the replacement of the cooling machine, it is lessened to 2.5 years.

4. CO$_2$ emissions

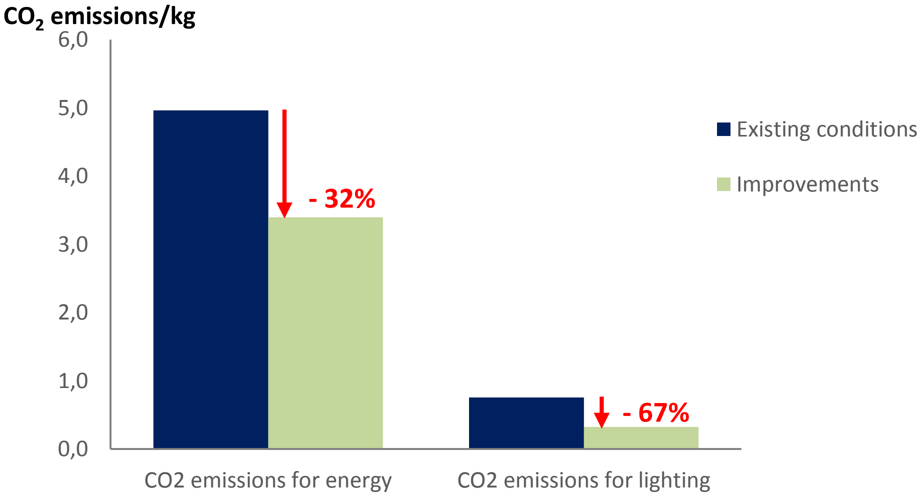


Figure 6: CO$_2$ emissions.

Figure 6 yields that 32% of the CO_2 produced due to higher energy demand can be avoided if more insulation is added. Plus, the CO_2 emissions due to lighting, which is responsible for 15% of the total energy demand, can be reduced further by 67% if Smart Lighting systems are integrated in the building.

Conclusions

The parametric study revealed the great potential of energy and cost savings from the deployment of smart lighting systems, a rather prosperous and continuously developing technology. More specifically, the energy savings accounted to 67% and 17% compared to conventional and LED lighting technology respectively, if only installed power is taken into consideration and without applying any sensors or control systems. This reduction may reach up to 90.3% and 69.1% respectively, if occupancy, motion, daylight harvesting sensors and dimming control are introduced to the system. Hence, the criteria set by the Greek Energy Regulation, ASHRAE's international guidelines and BREEAM (in the office area) were satisfied.

The LCC of the lighting systems revealed that despite the high initial cost of investment, it is worth replacing the lighting technology, the wall structure and the cooling machine as in this way, significant energy and cost savings can be achieved in a 10-year period with a total payback period calculated to 2.5 years. The mitigation of the total energy need also lessens CO_2 emissions and thus, the "20-20-20 Energy Efficiency Targets" are easier to be met.

The operation of the factory could be improved further by the introduction of systems based on renewable energy sources, such as PV panels or wind power, for further reduction on the electricity demand which could contribute to cleaner energy use and less CO_2 emissions in the environment. Yet, the integration of renewable energy systems was not the subject of this study.

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