# Energy Service Companies for Office Lighting: Characterization and Economic Potential

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**Abstract.** Artificial lighting is responsible for between 20 to 45% of the total electricity demand in office buildings. The energy efficiency of lighting systems can be improved by replacing existing installations with the best available technology and by implementing lighting control systems. The deployment of these technical solutions should be based on a sound business model. Traditionally, lighting systems are sold as products, but a promising alternative is offered by Energy Service Companies (ESCOs), whereby energy efficiency projects are developed, installed and financed over a period of several years. This article argues that ESCO-offerings should be regarded as a special case of PSS, and provides a novel characterization method for ESCOs for office lighting, that allows to unambiguously describe existing ESCO types. The outline and results of a quantitative analysis of the economic potential of an ESCO for office lighting are presented and interpreted.

**Keywords:** ESCO, Cost, Simulation, PSS.

## 1 Introduction

Artificial lighting is responsible for between 20 to 45% of the total electricity demand in commercial buildings [1, 2]. A reduction of at least 50% is deemed feasible [1], and can be realized through the implementation of a diverse set of measures, including on the one hand the replacement of lighting systems (luminaires, lamps and ballasts) by the best available technology, and on the other hand the implementation of lighting control systems (e.g. application of daylight harvesting, occupancy or time control). In promoting these energy-efficiency improvements, there is a need for a viable business model. Traditionally, lighting systems and lighting control systems are sold as products, in a production-based economic model. The prevalence of this business model limits the uptake of the best available technology, especially for existing installations, since customers often have no knowledge about the potential improvements and lack access to the required capital. A promising alternative is offered by a performance-based rationale [3], whereby lighting systems and lighting control systems are sold under energy performance contracts [4]. A key role is foreseen for so called Energy Service Companies (ESCOs), companies typically engaged in developing, installing and financing performance-based projects, centered around the improvement of the energy efficiency of facilities [5]. In the case of office buildings, an ESCO will implement energy efficiency improvements (e.g. lighting renovation and

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lighting control), assume (part of) the performance, energy price variation and financing risks during a certain fixed or variable contract period and will obtain revenue based on the actual energy savings realized during that period.

In the specialized literature, several definitions and classifications of ESCOs are provided [5-8]. They have drawn criticism for their lack of consistency and clarity in describing different ESCO types [9]. In essence, the term 'ESCO' refers to a type of business model, a business model being a 'representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network' [10]. Business models can be characterized by specifying the different building blocks that constitute them. Examples are the popular business model canvas of Osterwalder [11], with nine building blocks, and the representation proposed in reference [12], whereby business models for investment goods are represented in a structure with four domains and twelve building blocks. But in order to highlight the core characteristics of a certain ESCO, a comprehensive description of all of these building blocks is not required. Based on a review of the available descriptions of ESCO models (e.g. in references [6], [7] and [8]), the following main characterizing features of an ESCO were determined:

- The *value offering* of the ESCO (i.e. which products and services it offers)
- The *revenue mechanism(s)* of the ESCO (i.e. according to which logic it generates revenues from its offering)
- The way *risks* are assigned between the involved stakeholders (the main stakeholders involving the ESCO, the end user, plus potentially an external financing organization and other intermediaries)

Since the value offering of an ESCO is essentially an integration of products and services, whereby the focus is on value-in-use and not so much on exchange value, it is evident that the value offering of an ESCO can be seen as a *special case of a Product-Service System (PSS)*, specifically applied within the energy sector. Therefore, the representation method and typology developed in reference [13] can be applied for the specific case of ESCOs.

This article proposes a novel way of characterizing ESCOs for office lighting, based on a description of the three main building blocks identified above. This is elaborated in Section 2. In Section 3, insight is provided on the economic potential of an ESCO business model for office lighting through an extensive Monte Carlo simulation of a lighting system's life cycle costs. The focus of this study is on lighting applications in Belgian offices. In Section 4, the main conclusions are stated.

## 2 ESCO Business Model Characterization

In this section, a new way for characterizing ESCO models for office lighting is provided, based on a description of the value offering (Subsection 2.1), revenue mechanism (Subsection 2.2) and the distribution of the main risks within the ESCO model (Subsection 2.3).

### 2.1 Value Offering of an ESCO for Office Lighting

ESCOs offer an integrated combination of products and services that delivers value in use, specifically in the energy sector. In the specific case of lighting systems for office buildings, the ESCO offering contains a specific set of *product and service components*. The possible components are represented in Figure 1. A further partitioning of these components is still possible, e.g. the lighting system can be divided into luminaires, lamps and ballasts.

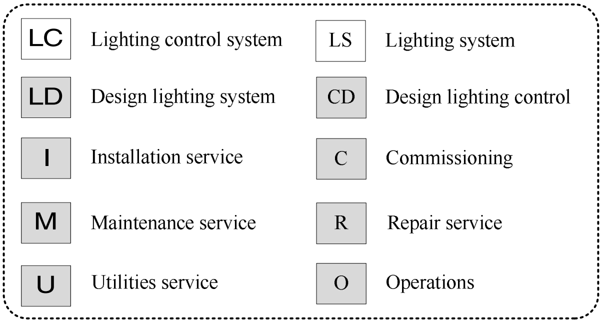



**Fig. 1.** Product and Service components that can be part of the offering of an ESCO for office lighting (products components: white, service components: gray)

Thus, the offering of an ESCO for office lighting will always be a combination of (some of) the product and service components defined above. In combining these products and services, some of them can be integrated in an 'integrated offering' (visually, this is represented by joining the rectangles). This means that they will always be sold together and have a common revenue generation mechanism. As such, the complete offering of an ESCO can have a combination of different revenue mechanism, one for each integrated combination of products and services. The possible types of revenue mechanisms are presented in the next subsection.

### 2.2 Revenue Mechanisms

Different *types of revenue mechanisms* can be discerned (cfr. [13]), based on the degree of performance orientation:

1. An *input-based (IB)* revenue mechanism means that revenue is transferred from the customer to the provider according to the inputs delivered to effectuate the function of a product or service. In case of a product, this means that the property rights of the products (e.g. lamps, luminaires, sensors, …) are transferred to the customer and revenue for these products is generated at the moment of property transfer. For a service, this means that revenue is generated per intervention, based on the resources necessary to deliver the service, such as labor hours or materials.

2. An *availability-based (AB)* revenue mechanism means that revenue is transferred from the customer to the provider based on the time period during which the product or service are available for the customer, independent of how much they are actually being consumed during that period. For a product this means for example a monthly rental or leasing fee and for a service this means a fixed monthly sum to be paid for which the provider promises to deliver the service to the customer whenever necessary.
3. A *usage-based (UB)* revenue mechanism means that revenue is generated only during the actual usage of the product or service. Usage can be expressed in time units (in the case of office lighting: the number of hours that there is a lighting demand).
4. A *performance-based (PB)* revenue mechanism means that revenue is generated based on the functional performance of the product or service. Functional performance can be related to the main customer demands that the product or service aims to fulfill. The main customer demands for a lighting system are twofold: it should *provide visual comfort* and the user should be able to *control the usage costs*. In between these demands and the product and service elements of Figure 1, the functions of these elements can be expressed on different levels of abstraction [13]. On the lowest level of abstraction, the functions are expressed in terms of parameters of a specific solution (e.g. 'Generate luminous flux', expressed in lumen). On a higher level of abstraction, the functions are expressed in terms of effect on the environment (e.g. 'Provide illuminance of a task area', expressed in lux), and on the highest level of abstraction the function is directly expressed in terms of the subjective demand that is to be fulfilled ('Provide visual comfort'). Thus, three subtypes of performance based revenue mechanisms can be discerned [11]:

   - Solution-oriented performance based *(PB-SO)* revenue mechanism
   - Effect-oriented performance based *(PB-EO)* revenue mechanism
   - Demand fulfillment-oriented performance based *(PB-DO)* revenue mechanism

The different types of revenue mechanisms for the specific case of office lighting are indicated in Figure 2, organized according to the two main customer demands. The reason why there is no demand-fulfillment oriented revenue model for the 'control costs' demand is that this would have to be expressed in terms of the subjective appreciation of costs, which is not a practical concept. All the other options are (theoretical) possibilities that indicate on which basis lighting (control) systems could be sold. From Figure 2 it becomes clear that, apart from the business models that are traditionally regarded as ESCO models (on the right hand side, related to the customer demand 'control costs'), different theoretical ESCO models also exist on the left hand side of the figure, related to the customer demand 'provide visual comfort'. Since the revenue models on the right hand side are more prevalent for existing ESCOs, in the remainder of this article they will be the main focus.

| | | VISUAL COMFORT | CONTROL COSTS |
|---|---|---|---|
| PERFORMANCE-BASED | DEMAND-FULFILLMENT ORIENTED | Per promised level of VISUAL COMFORT | X |
| | EFFECT-ORIENTED | Per LUX [lm/m²] | Per € SAVED [€] |
| | SOLUTION-ORIENTED | Per LUMEN [lm] | Per kWh SAVED [kWh] |
| USAGE-BASED | | Per LIGHTING HOUR [hr] | |
| AVAILABILITY-BASED | | Per MONTH [month] | |

**Fig. 2.** Types of revenue mechanisms for office lighting ESCO's, corresponding to the two main customer demands related to a lighting system (provide visual comfort and control costs)

### 2.3 Risk Allocation within the ESCO

The way the main risks are distributed is an essential characteristic of an ESCO model. There are three main risks involved:

- The *risk of variation of the energy price.* Since ESCO contracts are running over a period of several years, and the variation of the energy price over these years is uncertain, this risk will exist in every possible ESCO model. In case a PB-EO revenue mechanism is chosen, whereby the ESCO is paid a fixed percentage of the actual monetary savings in energy cost until the end of the contract period, the risk is shared between the customer and the ESCO. In case the PB-SO revenue mechanism is chosen, whereby the ESCO is paid a fixed sum per saved kWh of energy, this risk is completely allocated to the customer.
- The *performance risk.* This risk is related to the system's ability to achieve the stated savings. In most ESCO models, this risk is primarily assigned to the ESCO itself, since this gives the ESCO the right incentives to optimize the performance of the system delivered.
- The *credit risk.* This is the financial risk related to the possibility to recover invested funds. It depends on which party does the investments in the equipment. Credit risk depends on the salvage value of a system being offered that is being used as a lien for acquiring the necessary financing. In case the customer would terminate the activities in the building where the lighting (control) systems are being employed and would fail to commit to the contract agreements, it is difficult – if not impossible – to take the lighting components out of this building and put them into service elsewhere, since the labor costs for removing and re-installing the equipment are prohibitive. This is different for equipment that is more mobile (e.g. a mobile construction machine, such as a bulldozer or portable compressor, that can in most cases easily be transported and put into operation elsewhere). Therefore, the credit risk will be considerable in the case of office lighting (control) systems.

Apart from these risks, another important characteristic is the contract term in which the ESCO operates. It can be fixed or variable [7, 14]. In general, if the contract term is longer, the three relevant risks will be considered to be larger. For example, in what is known as a 'First-Out' ESCO model, whereby the ESCO invests in the energy saving technology and is paid the full energy savings benefits until an agreed sum is acquired [15], the contract term is shorter than in case the ESCO gets for example 60% of the real cost savings for a fixed contract period (this last model being known in literature as the 'Shared Savings' ESCO model [15]), and the three risks for the ESCO will be larger for the latter model.

## 2.4 Characterization of ESCO Models: 2 Examples

ESCO models can be characterized by the features discussed in the previous subsections. Since going through all the main ESCO types is not feasible within the scope of this paper, two ESCO types are described in detail, for the specific situation of office lighting: the *Shared Savings type* and the *Guaranteed Savings type*. The value offering and corresponding revenue models of both types are visualized in Figure 3.

This visualization can be interpreted as follows. For the Shared Savings type, the investment in materials (i.e. LC and LS) are performed by the ESCO and not arranged by the customer, as is the case in a Guaranteed Savings type. This is indicated on the left hand side of Figure 3: for the Shared Savings type the product components are integrated with the service components and all are sold according to a common performance-based revenue mechanism (i.e. an effect-oriented model (PB-EO), such as defined in Subsection 2.2 and Figure 2). For the Guaranteed Savings type only most of the service components are integrated in a solution-oriented revenue mechanism (price per kWh saved above a certain threshold). Ambiguity exists in the literature on ESCOs on whether the ESCO receives a fixed payment per saved kWh above the threshold or whether the ESCO receives the actual cost savings above the kWh threshold. In this article, the Guaranteed Savings type is restricted to the first interpretation.

The comparison in risks and contract terms between both models is given in Table 1. The main difference lies in the allocation of the credit risk. Since the contract period is longer for the Guaranteed Savings type, the performance risk for the ESCO is larger (stated as 'high', 'medium' or 'low'). According to the interpretation of Guaranteed Savings chosen in this article, the energy risk is completely for the customer's account and mainly for the ESCO in the Shared Savings model.

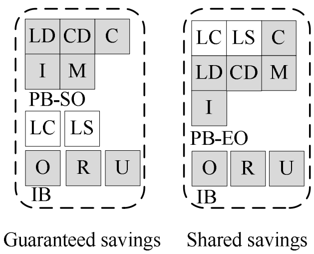
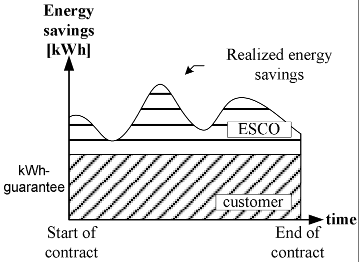
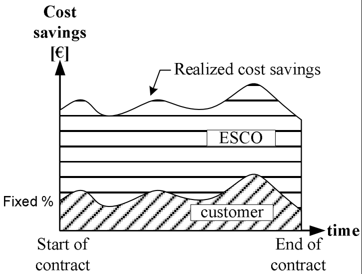



**Fig. 3.** Visualization of the value offerings and revenue models of a Guaranteed Savings and a Shared Savings ESCO type, whereby the abbreviations of Subsections 2.1 and 2.2 are used

**Table 1.** Comparison of a Guaranteed Savings and Shared Savings ESCO model

| ESCO type | Visualization | Contract term | Risk allocation |
|---|---|---|---|
| Guaranteed Savings |  | Fixed<br>(5-15 years) | Credit: ESCO<br>Performance (for ESCO): high<br>Energy price: customer |
| Shared Savings |  | Fixed<br>(1-10 years) | Credit: customer<br>Performance (for ESCO): medium<br>Energy price: mainly ESCO |

The other ESCO types that occur in practice can also be described by the characterization method introduced in this section, which allows for a comprehensive and unambiguous description of ESCOs. This contributes to a better understanding of the specific characteristics of ESCO types.

## 3 Quantitative Analysis of the Economic Potential of an ESCO for Office Lighting

The economic potential of an ESCO business model for office lighting has been analyzed, based on a comprehensive Life Cycle Cost simulation model. The basic research goal was to establish the conditions under which an ESCO could be profitable in replacing existing lighting systems by state-of-the-art luminaire, lamp and ballast technology and/or by implementing advanced lighting control strategies. Several base scenarios and improvement scenarios were identified, and the cost improvement potential has been quantified of certain improvement scenarios over a certain base case. Furthermore, a sensitivity analysis has been performed on the results, in order to define the key success factors for ESCO profitability. In Subsection 3.1, the outline of the method is described. Subsection 3.2 summarizes the results obtained within this study.

### 3.1 Method Description

The modeling approach used is a Monte Carlo simulation of the Life Cycle Cost (LCC), whereby the uncertainty and variability in the input parameters was modeled by using appropriate statistical distributions and thus obtaining the output distribution of the Life Cycle Cost. The general structure of the method is depicted in the flowchart of Figure 4. The model generates cellular offices (< 40 m²) and open plan offices (> 40 m²) with variable size and usage patterns. The design of the lighting system is based on the lumen method (e.g. described in [16]), whereby a luminaire layout is calculated from a required illuminance level of task areas according to the European standard EN12464, assuming a depreciation of the lighting system over its maintenance cycle (represented by a maintenance factor) and a lighting efficiency represented by a utilization factor, which is determined by the European standard EN13032. The maintenance factor and utilization factor assume information about the selected *luminaire-lamp-ballast (LLB) combination*. In this research a pool of 26 LLB combinations, representative for the lighting systems installed in European offices, and 6 best available technology (BAT) LLB combinations are adopted from a study on the Belgian office lighting market [17]. The design of the lighting control system is based on European standard EN15193, whereby the formulas in that standard are applied to

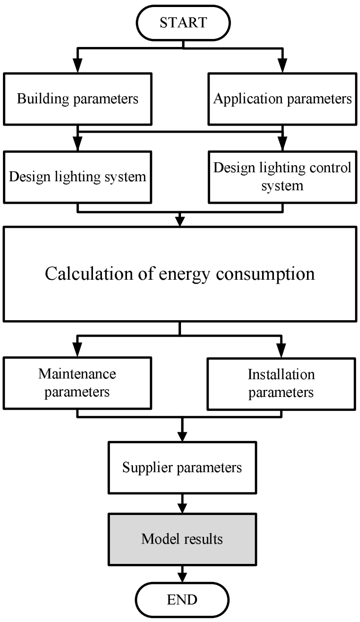



**Fig. 4.** General outline of the simulation model

estimate the savings from *dimming to a maintained illuminance* as a function of the maintenance factor, the savings from *occupancy control* and the savings from *daylight control*. The *maintenance parameters* represent periodic group lamp replacements and the *installation parameters* represent the installation times of the components of a lighting system. The *supplier parameters* contain labor costs and discount rates. All input parameters are modeled according to a uniform or PERT distribution and were determined by eliciting expert information from a range of stakeholders (e.g. an electrical installation company, a lighting control systems provider, a lighting technology specialist). The model output is the LCC of the lighting system, expressed as the Net Present Value of the aggregated installation, energy, maintenance and removal costs of luminaires, lamps, ballasts, cabling and lighting control system components over a period of 20 years.

### 3.2 Results and Discussion

Six analyses were performed, as indicated in Table 2.

**Table 2.** Description of the six analyses performed within this study

| Analysis | Description | Goal |
|---|---|---|
| 1 | Base Case | Identification of LLB combination with significant high total LCC (base case scenario) |
| 2 | BAT | Identification of LLB combination with lowest total LCC (best available technology) |
| 3 | Sweep + dimming | Analysis of the potential of a new lighting system with automatic lighting control based on a sweep function and dimming to a constant maintained illuminance w.r.t. the base case scenario |
| 4 | Presence detection + dimming | Analysis of the potential of a new lighting system with automatic lighting control based on automatic presence detection and dimming to a constant maintained illuminance w.r.t. the base case scenario |
| 5 | Daylight + sweep + dimming | Analysis of the potential of a new lighting system with automatic daylight control, sweep function and dimming to constant illuminance w.r.t. the base case scenario |
| 6 | Daylight + presence + dimming | Analysis of the potential of a new lighting system with automatic daylight control, automatic presence control and dimming to constant illuminance w.r.t. the base case scenario |

**Some of the main findings are:**

- *Determination of base case and best available technology (BAT) scenario.* The base case and best available technology scenarios were determined by calculating the Normalized Power Density (NPD) of a lighting system for the different LLB combinations of reference [17]. The NPD is a measure of the efficiency to illuminate a specific task area [18]. This analysis defined 5 out of 26 LLB combinations as energy inefficient, i.e. they represent on average a higher NPD, expressed in

W/m².100 lux. One LLB combination was defined as the best available technology, with a low NPD and a ballast type that allows for the implementation of a lighting control system.

- *The potential of replacing base case scenarios with BAT.* The potential was determined to replace the lighting systems in a building in one of the 5 base case scenarios with the BAT scenario of Analysis 2, with manual control. The key finding is that the potential is there for open plan offices (potential of on average between 0 and 15 €/m², taking into account a discount rate of 10%) and that the savings in energy and maintenance costs for cellular offices are smaller than the higher investment required. The key success factor determining the profitability of an ESCO model is the room index, which is defined as the ratio of the horizontal and the vertical area of the room. In Figure 5, the sensitivity of the net cost savings of investing in the best available technology in €/m² is shown in function of the room index. As can be seen, for a room index higher than 1.4, the investments in BAT becomes profitable.

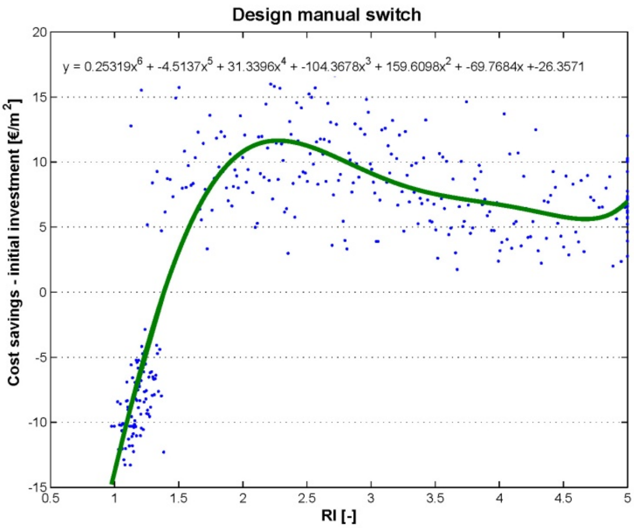



**Fig. 5.** Sensitivity analysis of the net cost savings of changing the base case scenario with the best available technology in function of the room index

- *The potential of automatic lighting control.* The potential was determined for analyses 3 to 6. An upgrade of a base case scenario to a new lighting system with automatic daylight and presence control and dimming to constant illuminance is the most profitable investment in open plan offices with a potential ranging from 5 to 20 €/m² over the lifecycle of the lighting system or a discounted payback period ranging from 10 to 17 years depending on the base case scenario. The investment in cellular offices is not profitable due to the geometry of the offices (i.e. the room index). A sensitivity analysis determined the most important factors for the profitability of an ESCO model that would apply scenario 6 in open plan offices: the room index, the type of luminaire (more specifically its downward light output ratio DLOR [16], which has a major impact on the utilization factor) and to a lesser extent the discount rate and the energy price. This indicates that the performance risk is dominant and that it mainly depends on the choice of the base case. Therefore, an ESCO should carefully consider which buildings it chooses for implementation of an energy saving project. Out of the existing building stock of Belgian offices described in reference [17], it was determined that an investment in energy-efficient lighting systems can be profitable in 10.8% of the Belgian offices. Offices with a room index above 1.4 have a potential of 5-20 €/m² over the lifecycle of the lighting system and a discounted payback period of 10-17 years.

## 4 Conclusions, Limitations and Future Research

This article argues that ESCOs can be considered as the application of the PSS concept in the energy industry. A novel method for characterizing ESCO models, based on a representation method and typology of PSS has been proposed. This allows for a comprehensive and unambiguous representation of the essential characteristics of a certain ESCO type.

Apart from this qualitative description, the outlines of a quantitative study have been proposed wherein the potential of an ESCO for office lighting was determined for the Belgian office market. The analysis of the potential of the investment in energy efficient lighting systems with several lighting control options pointed out that an ESCO should focus on upgrading the lighting systems of open plan offices by installing new energy efficient lighting systems with automated daylight and presence control and dimming to a constant illuminance. It also highlighted that the ESCO should choose with great care the type of lighting systems that are to be replaced, since these parameters are dominant in determining the profitability of the investments.

The main limitation of this study is its high reliance on the description of the base case scenarios of reference [17]. Recommendations for future study are to validate the results of this study with other data concerning the current situation in European offices. This could lead to a new pool of representative luminaires used in offices that can be used as input for the model. Furthermore, the profitability of the different ESCO types (such as the Shared Savings and Guaranteed Savings type) could also be compared more in detail, whereas the profitability potential of an ESCO as presented here is stated independently of the specific type of ESCO applied.

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